



**CNSS**

Clean North Sea Shipping

# FINAL REPORT

**Key findings and Recommendations**



Clea North Sea Shipping  
March 2014

# CONTENTS

<b>INTRODUCTION</b>	4
About the Project	4
Introducing the Partnership	6
Reflections by Lead Beneficiary	9
<b>KEY CHALLENGES</b>	10
A Region under Pressure	10
Rules and Regulation	12
Energy Options	14
Technology	14
Management Systems for Reducing Airborne Emissions	17
<b>CNSS FINDINGS</b>	18
Activities and Network	18
<b>1. Air Quality</b>	20
Recommendations	20
Harbours and Cities	20
Harbour emissions	21
High resolution harbour emissions – the example of Port of Antwerp	25
City scale air quality modelling	29
North Sea	34
Emission factors for sea going ships	34
North Sea emission model	35
North Sea air quality modelling	38
Analysis of Future Prospects regarding Air Emissions from Ships	44
Basis of scenarios	44
Detailed scenario descriptions	44
Model results	46

<b>2. Technology &amp; Fuels</b>	57
Recommendations	57
Clean Shipping Technology	57
Introduction	57
Review of technological solutions	58
Feasibility analysis of technological ideas	59
LNG – Liquefied Natural Gas	62
OPS – Onshore Power Supply	63
<b>3. Environmental performance - Emission Indices</b>	66
Recommendations	66
Environmental Index Schemes for Ships	66
Analysis of ESI	66
The Environmental Ship Index	68
The Clean Shipping Index	72
Comparisons between ESI and CSI	74
Summary of ESI and CSI	76
<b>SUMMARY OF RECOMMENDATIONS</b>	78
Air Quality	80
Technology & Fuels	81
Environmental performance - Emission Indices	82
Cross-thematic Policy & Regulation	82
<b>APPENDICES</b>	84
CNSS References	85
Abbreviations & Definitions	86
List of Figures	88
List of Tables	91

# INTRODUCTION

## About the Project



*The Clean North Sea Shipping (CNSS) project is part of The North Sea Commission Strategy, which contributes to Europe 2020, and focuses on “Increasing Accessibility and Clean transport”. The project addresses challenges caused by air emission and greenhouse gases from ships operating along the North Sea coast and within North Sea ports and harbours.*

*Furthermore, the CNSS project aims to create awareness, share knowledge and convince influential stakeholders, including regional, national and international politicians, ports, shipping companies and cargo owners, to take action.*

*This report summarises the achievements of the CNSS project. It presents key findings and recommendations regarding strategic and operational policy-building for ships in ports, stakeholders and policy makers in the North Sea region.*

*The project started in 2010 with a budget of 4.13 million Euros, and will close In March 2014.*

*Message from Tom-Christer Nilsen,  
County Mayor of Hordaland County  
Council and Vice-President of  
North Sea Commission*

Transport of passengers and goods, both within the EU and between Europe and other parts of the world, is rapidly increasing.

There are many challenges facing the transport industry – congestion, air pollution, climate emissions, energy demand, and safety issues amongst others. These challenges must be addressed in the context of the need for extended mobility, future legislation and international standards. Our job is to develop and secure a sustainable and environmentally friendly transport sector.

A modal shift of transportation from land to sea will obviously give some benefits regarding reduction of air pollution. However such a shift does not solve all problems. The shipping industry will have to improve its performance in order to align with common environmental goals.

Results and findings from the Clean North Sea Shipping project indicate the following:

- The proposed postponement of the NO<sub>x</sub> limitation for new build ships from 2016 to 2021 (Marpol Annex VI, Regulations for the prevention of air pollution from ships) will lead to a higher concentration of NO<sub>x</sub> in the North Sea area of between 11% and 15%.
- The development of onshore power supply and LNG bunkering facilities is lagging behind when considering the increasing numbers of ships supporting such energy sources.
- Today's incentive schemes and related environmental indices must be improved and should be implemented on a large scale in order to support the development of clean harbours.

It is vital to implement measures to address these challenges.

The North Sea Commission along with regional authorities around the North Sea have emphasised the need to support the transport sector, other stakeholders and policy makers in facilitating an urgent and demanding change of direction. The findings and recommendations of the CNSS project are regarded as an important contribution to the discussions and processes ahead of us.

## Introducing the Partnership

CNSS involves 15 partners / beneficiaries from six countries around the North Sea. The partnership reflects a large diversity of the maritime transport sector and therefore secures and involves relevant public and private stakeholders:

- Ports ( major and smaller ones)
- Regions and cities on national and EU level
- Energy suppliers
- Universities / Research centres with a specific focus on maritime affairs.
- Shipping certification association

## The Partners

**Hordaland County Council**  
[www.hordaland.no](http://www.hordaland.no)



**DCMR Environmental  
Protection Agency**  
[www.dcmr.nl](http://www.dcmr.nl)



**Free and Hanseatic  
City of Hamburg,  
Ministry of Urban  
Development  
and Environment**  
[www.bsu.hamburg.de](http://www.bsu.hamburg.de)



**Harlingen Seaport**  
[www.harlingenseaport.nl](http://www.harlingenseaport.nl)



**Port of Antwerp**  
[www.portofantwerp.be](http://www.portofantwerp.be)



**Groningen Seaports**  
[www.groningen-seaports.com](http://www.groningen-seaports.com)



**Newcastle University**  
[www.ncl.ac.uk](http://www.ncl.ac.uk)



**City of Bergen**  
[www.bergen.kommune.no](http://www.bergen.kommune.no)



**BKK**  
[www.bkk.no](http://www.bkk.no)



**Port of Bergen Authority**  
[www.bergenhavn.no](http://www.bergenhavn.no)



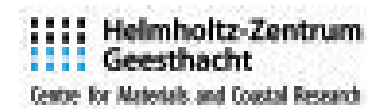
**Shell Gasnor AS**  
[www.gasnor.no](http://www.gasnor.no)



**Swedish Maritime  
Technology Forum**  
[www.smtf.se](http://www.smtf.se)



**Institute of  
Coastal Research  
Helmholtz-Zentrum  
Geesthacht**  
[www.hzg.de](http://www.hzg.de)



**Telemark Fylkeskommune**  
[www.telemark.no/international](http://www.telemark.no/international)



**DNV GL**  
[www.dnvgl.com](http://www.dnvgl.com)





Supporting Partners

Organisation	Website
EXMAR Ship management	www.exmar.be
Federal Maritime & Hydrographic Agency, Berlin	www.bsh.de
State Chancellery Schleswig-Holstein	www.schleswig-holstein.de
Federal Ministry of Transport, Berlin	www.bmvbs.de
Hamburg University of Technology	www.tuhh.de
Maritime Cluster Schleswig-Holstein	www.maritimes-cluster.de
See Hafen Kiel (DE)	www.portofkiel.com
Göteborg Energi	www.goteborgenergi.se
Region Västra Götaland	www.vgregion.se
Göteborgsregionens kommunalförbund	www.grkom.se
Maritimt Forum Bergensregionen	www.maritimt-forum.no
Norwegian Coastal Administration	www.kystverket.no
Norwegian Maritime Directorate	www.sjofartsdir.no
North Sea Commission	www.northseacommission.info



Photo: Bergen Reiselivslag - visitBergen.com - Jan M. Lillebø

Reflections by Lead Beneficiary

Public authorities all over Europe express a major concern regarding pollution from a fast growing transport sector and the dramatic impact it has on people’s health and on the environment. The EU has made it clear that we urgently need to deal with these problems, and that measures must be put into action to improve transport sustainability and reduce oil dependency. Ships are the largest single emission source for sulphur oxide, particulate material, and nitrogen oxide in the transport sector. As a consequence ports suffer from air pollution owing to the arrival /departure of ships, and to emissions during their stay at berth.

These facts were main motivation for putting together a relevant partnership and to develop a project idea where the overall objective was to present documented recommendations on how to address the above challenges described.

It takes devotion, determination, and a competent and complementary partnership to successfully run an ambitious project where research, scenario building, analysis, subprojects and operational evaluations are involved. It is a shared opinion within the project that the achievements from “Clean North Sea Shipping” go

beyond what we originally expected. It is our hope that the findings and recommendations from CNSS will be useful inputs to stakeholders and policymakers in future work.

As Lead Beneficiary we want to express gratitude to all partners for their considerable and professional contributions to the large number of scientific papers, reports, videos and newsletters that have been produced. We also thank them for sharing knowledge and experience with us all in the Project Assemblies, Steering Committee and Management Committee meetings.

Both short and full-length versions of results and recommendations will be printed and made available at the final conference. In addition, our homepages **www.cnss.no** and **www.cleantech.cnss.no** will be updated, with links to all documents and videos.

Project administration

- Lars Tveit, Chair of Steering Committee, Hordaland County Council
- Even Husby, Project Manager, Hordaland County Council
- Nils Egil Vetlesand, Financial Manager, Hordaland County Council
- Anne-Grethe Stenhjem, Financial Officer, Hordaland County Council
- Kate Clarke, Project Advisor, Hordaland County Council
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Dr Alan J Murphy, School of Marine Science & Technology, Newcastle University

WP leader – “Reduction & Handling of Emissions”,  
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# KEY CHALLENGES

## A Region under Pressure



*The North Sea region faces many challenges including the protection of its people and the environment, while keeping up with a competitive economic market in a globalised world in which populations are growing and the demand for goods and services is increasing. Ship based transportation provides a relatively environmental friendly method of distribution for manufacturers, with lower associated production and handling costs than other methods of transport. Furthermore, already having a low environmental impact (per ton/km) the potential for further improvement is huge. There is also the potential to substantially increase the amount of goods transported on sea.*

*The North Sea is one of the densest areas of ship traffic in the world. Every day, around 900 ships are out in the Greater North Sea area. Ship traffic in the region has increased significantly in recent years, with cargo turnover in some North Sea ports increasing by more than 50% since 2000. The actual numbers of ships arriving at busy ports such as Rotterdam and Hamburg have not changed much, however there has been a significant shift in ship sizes, with the number of smaller ships reduced by half but the number of bigger ships more than doubled.*

*This demand for shipping is driven by population growth and globalisation, with increasing import and exports a common theme in the developed world. An inevitable consequence of the growth of shipping activity is an increase in emissions of pollutants to air, leading to a net increase in exhaust emissions from ships. The environmental threats of shipping have been recognised and regulations have been tightened in recent years however the demand for shipping outweighs current mitigation efforts, hence stricter policies for emissions of certain pollutants are being introduced.*

Rules and Regulation

Ship emissions can impact on air quality in coastal regions and further inland. Ship's commonly use heavy oil based fuels with high Sulphur contents, and hence have a tendency to emit Sulphur Dioxide (SO<sub>2</sub>) along with other pollutants such as Nitrous Oxides (NO<sub>x</sub>), Particulate Matter (PM), Carbon Dioxide (CO<sub>2</sub>) and other Greenhouse Gases (GHGs).

Emissions from ships are controlled under a set of regulations governed by the International Maritime Organisation (IMO). In the North Sea region, emissions are regulated by EU directives set out in alignment with the regulations of the IMO. Much of the IMO's legislative guidelines have been derived from the MARPOL convention in 1973, and subsequent amendments and addendums:

MARPOL 73/78

*International Convention of 1973 for the prevention of Marine Pollution from Ships (amended 1978). MARPOL 73/78 contains general policies and special regulations across six annexes controlling the avoidance of pollution by ships. The contents of MARPOL must be adopted into national law in each country worldwide.*

In the North Sea region there are regulations in place to control emissions of NO<sub>x</sub>, SO<sub>x</sub> and GHGs from ships, while PM is covered under SO<sub>x</sub>. Emissions of NO<sub>x</sub> and SO<sub>x</sub> were addressed in MARPOL Annex VI, where the following NO<sub>x</sub> guidelines were set:

NO <sub>x</sub>			
	Diesel engines installed on ships	Speed (n) in rpm	Max. allowable NO <sub>x</sub> emissions (g/kWh)
Tier I	From 1 January 2000 to 1 January 2011	< 130	17
		130 ≤ n < 2000	45*n <sup>-0.2</sup>
		n ≥ 2000	9.8
Tier II	After 1 January 2011	< 130	14.4
		130 ≤ n < 2000	44*n <sup>-0.23</sup>
		n ≥ 2000	7.7
Tier III	After 1 January 2016 when operating in ECA	< 130	3.4
		130 ≤ n < 2000	9*n <sup>-0.2</sup>
		n ≥ 2000	2

Table 1 NO<sub>x</sub> regulations

The limits for NO<sub>x</sub> are dependent on engine age and speed. The rules are stricter for newer ships, and it is expected that after 2016 NO<sub>x</sub> emissions should reduce drastically for ships travelling in emission control areas (ECAs). Tier III (Table 1) limits only apply in ECAs. At present, the North Sea is not considered a NECA (Nitrogen Emission Control Area).

SO <sub>x</sub>		
Date	Sulphur limit in fuel (% m/m)	
	SECA	Global
2000	1.5	4.5
2010	1	
2012	0.1	3.5
2015		0.5
2020a		
a - alternative date 2025, to be decided by review in 2018		

Table 2 SO<sub>x</sub> regulations

In accordance with MARPOL Annex VI guidelines for SO<sub>x</sub>, Sulphur content in fuel should not exceed 3.5% globally (Table 2), while in designated SECAs (Sulphur Emission Control Areas) – including the North Sea – the Sulphur limit is 1%. The limits are set to change in 2015 and again in 2020 or 2025. Fuel suppliers are legally required to provide documentary evidence of sulphur content.

GHGs are controlled by the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships. The EEDI is obligatory for all new constructed ships from July 2011, and is considered as an important technical measure by the IMO. It assumes a minimum energy efficiency level for different types of ships, known as the 'baseline EEDI'. EEDI came into force at the beginning of 2013, and the baseline EEDI is set to be reduced every 5 years for each different ship type. It is thought that through continuing innovation and technical ship development, EEDI will help drive energy efficiency in ships to a higher level.

THE SEEMP is an operational measure designed to reduce emissions further. Each individual ship will be provided with a SEEMP, outlining measures which must be carried out on board to improve energy efficiency. It provides a management process on the principles of:

- Strategy
- Execution
- Monitoring the execution
- Evaluation
- Advancement of energy efficiency measures.

SEEMP will also help optimise operating procedures.

The European Union covers about 89,000km of coastline, and hundreds of seaports. The EU is actively representative in IMO regulations however it also commissions its own European regulations in line with these. Important EU regulations include:

**Directive 95/21/EC concerning the enforcement of port state control:** aims to enforce international standards for ship safety, prevent pollution and

regulate ship board living and working conditions by unifying the inspection practice and 'blacklisting' unsafe vessels, and thus withdrawing substandard ships. The directive has intensified the control of ships and contributed to compliance of IMO (MARPOL convention) standards.

**Directive 2005/33/EC – an amendment to Directive 1999/32/EC regarding the sulphur content of marine fuels:** aims to improve air quality by reducing the sulphur content of marine fuels. The directive goes beyond the regulations of the IMO by introducing stricter limits for ships in ports, requiring a maximum level of 0.1% S to be met (currently 1% S for IMO).The regulation only applies to ships with a berth time of 2 hours or more at a given port.

**Directive 2006/339/EC on the promotion of shore-side electricity for use by ships at berth in community ports:** aims to promote the use of shore-side electricity by offering the possibility of tax concessions to ship owners who use this technology.

Currently, the EU has excluded shipping from the EU CO<sub>2</sub> Emissions Trading Directive however discussions for inclusion have taken place. If the IMO does not adopt regulations to reduce CO<sub>2</sub> emissions, it is expected that the EU will involve shipping in the EU Emissions Trading Directive.

The potential impact of regulation (both IMO and EU) on emissions from ships is clearly visible. Sulphur emissions limits have decreased dramatically in recent years and will continue to do so into the future in an attempt to make shipping more environmentally friendly (refer to Table 2).

There is also a clear downward trend in limit values for NO<sub>x</sub> emissions according to IMO guidelines (refer to Table 1). The emissions guidelines currently in place are expected to drastically reduce the impact of shipping on the environment.



## Energy Options

In order to meet the increasingly strict guidelines outlined by the IMO and the EU, the maritime industry must look to new technologies using alternative energy sources to power ships. A number of technology options have been put forward as an alternative or to work alongside diesel based marine fuels. Ships powered by Liquefied Natural Gas (LNG), fuel cells using LNG, hydrogen and methanol, and high voltage onshore connection systems (OPS) are at the forefront of development of alternative energy options. Methanol is likely to be a very interesting alternative in future. However, in this project we have focused on LNG which we consider to be the most realistic alternative fuel in the near future.

## LNG

LNG as an alternative fuel can reduce both air pollutants ( $\text{NO}_x$  and  $\text{SO}_x$ ) and GHG emissions, with significant reductions achieved.  $\text{CO}_2$  emissions from an LNG engine are lower due to having a higher hydrogen-to-carbon ration than conventional fuels. Studies carried out by DNV (2010) suggest reductions in GHG emissions of up to 25% compared to conventional engines; in addition, LNG does not contain sulphur resulting in almost no  $\text{SO}_x$  emissions and low PM emissions. The IMO (2009) suggests that 60% reductions in  $\text{NO}_x$  emissions can be achieved by using LNG. LNG engines can be of mono-fuel type or of a dual-fuel type, the latter making it possible to switch between LNG and conventional fuel.

LNG has already been in use for 50 years by steam turbine propelled tanker ships. Nowadays the LNG technology is also available for four-stroke engines and is being developed for two-stroke engines, and is generally applied to new build ships. For existing ships substantial modifications are needed and sufficient storage capacity for the fuel is required. For the same energy content, around 1.8 times more (storage) volume is needed compared to diesel, making it hard for existing ships to switch. Other aspects which limit the use of LNG are the availability of the fuel in ports and the perception of safety.

The capital costs of an LNG propelled ship are 10-15%

higher than that of a conventional ship, however at the moment the price of LNG fuel is significantly lower compared to conventional fuels, which provides an incentive to switch. Over the past 20 years, LNG has proven to be 45% cheaper than MGO and 22% cheaper than HFO with a scrubber. Maintenance costs are expected to be 50% lower. (For more information and references please see Clean Technology website: <http://cleantech.cnss.no>)

## OPS

Ships require a substantial amount of power to operate whilst docked at port. The propulsion engines may be switched off, but the auxiliary engines are often used to generate electrical power for cargo operations and hoteling needs (refrigeration, lights, pumps and other equipment), which cause significant emissions in harbour areas. High voltage power installations are often available at ports and quaysides close to residential or industrial areas which offer a genuine alternative to burning fuel oil through use of auxiliary engines.

Emissions of  $\text{SO}_2$ ,  $\text{NO}_x$  and PM can be cut by 90% or more. By switching from fuel oil to gas as an energy source or sustainably generated wind power,  $\text{CO}_2$  emissions can be curbed depending on the energy source.

## Technology

In order to mitigate exhaust emissions from ships, marine technologists have focussed their efforts in developing technologies to reduce both GHGs and other prominent exhaust gas species in shipping such as PM,  $\text{NO}_x$ , and  $\text{SO}_x$ . In addition to mitigating technologies, another approach to reduce harmful emissions is to optimise the way in which ships are operated, requiring accurate prediction of emissions for all operating conditions and ship types.

Reducing energy loss is an important factor in mitigating emissions of GHGs in shipping. A significant part of the energy content of fuel is lost during combustion, with only 28% of energy from fuel contributing towards propulsion thrust. Fuel consumption can therefore be reduced by avoiding

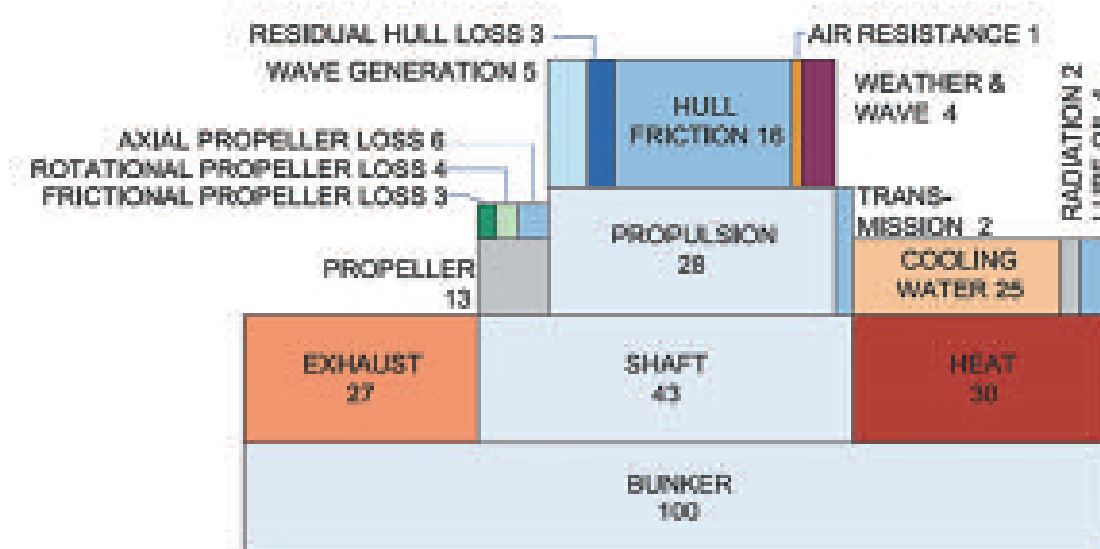
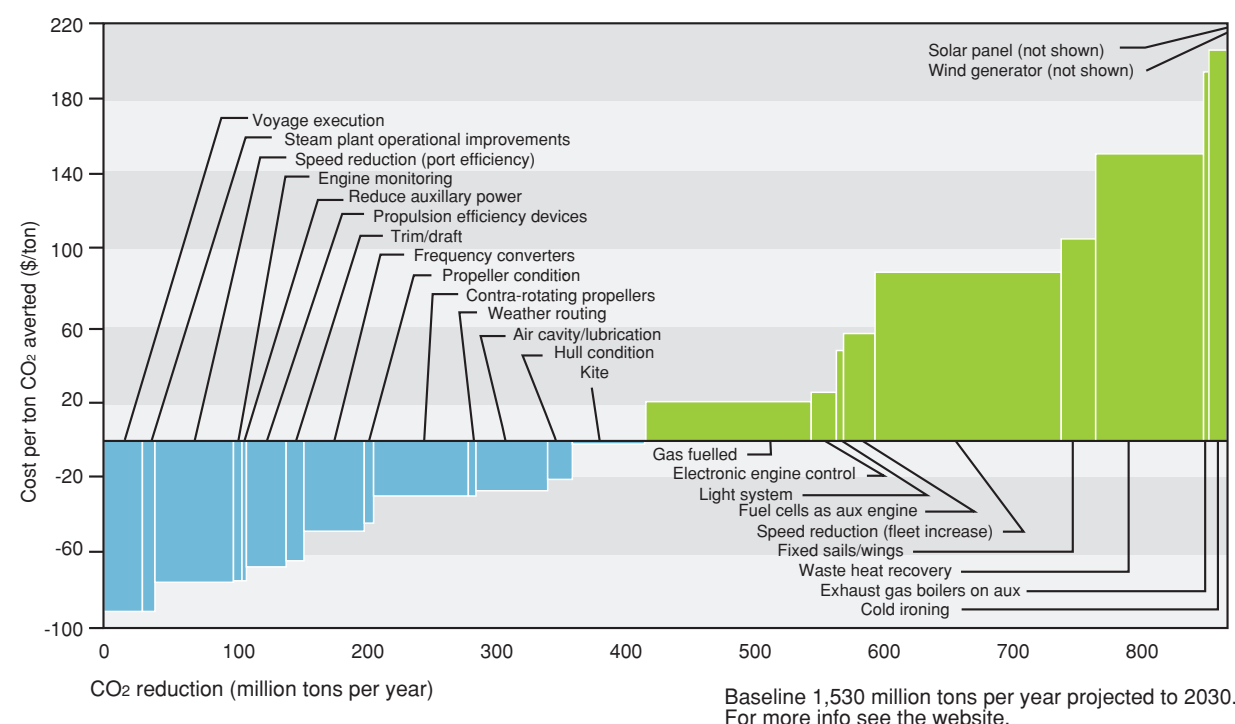


Figure 1 Energy losses from a ship (Source: Second IMO Greenhouse Gas Study 2009 pp. 166)

energy losses in a ships operation (see Figure 1). A number of measures to reduce a ship's emissions of GHGs are shown (Figure 2). The figure highlights a number of technical and operational measures which

can be implemented to reduce GHGs based on their cost effectiveness. Half of the measures can be achieved without net costs, while the most effective emission reducing methodologies are LNG, speed



Baseline 1,530 million tons per year projected to 2030. For more info see the website.

Figure 2 Overview of potential measures, GHG reduction and costs Source: 2010 DNV Pathways to low carbon shipping Abatement potential towards 2030 (for further info see website: [www.cleantech.cnss.no](http://www.cleantech.cnss.no))

Different technical measures can be applied to reduce air pollutants and help improve air quality. Table 3 is an overview of technologies for reducing SO<sub>x</sub>, NO<sub>x</sub> and PM, showing their reduction potential.

Category	Technology aimed to reduce NO <sub>x</sub>	NO <sub>x</sub>	SO <sub>x</sub>	CO <sub>2</sub>	PM
Water addition	Direct water injection	Max. 60%		+0-2%	Max. 50%
	Exhaust gas recirculation	20-85%			
	Humid air motors	20-80%			
	Combustion air saturation system	30-60%			
	Water in fuel (e.g. 20% emulsion)	20%			40-60%
Engine modification	Internal engine modification				
	- side valves	20%			Probably reduced
	- advanced measures	30-40%			Probably reduced
After treatment	Selective catalytic reduction				
	(SCR)	90-99%			25-40%
	SO <sub>x</sub>				
	Scrubber		90-95%		80-85%
(Alternative) fuels	Low Sulphur fuel				
	2,7% S to 0,5% S		80%		20%
	Both NO <sub>x</sub> and SO <sub>x</sub>				
	LNG	60%	90-100%	0-25%	72%
	Onshore Power Supply (OPS) – in harbour only	90%	90%	Depends on energy source	90%

Table 3 Technologies for reducing SO<sub>x</sub>, NO<sub>x</sub> and CO<sub>2</sub> (for further info and sources please see website: [www.cleantech.cnss.no](http://www.cleantech.cnss.no))

Not every technology is fully developed and ready to be applied to ships on a large scale. Some technologies are expensive to install at present and/or face practical barriers. More information as well as costs and maturity can be found on the CNSS Clean

Tech website: [www.cleantech.cnss.no](http://www.cleantech.cnss.no) and in the Technology & Fuels – Review of technological solutions section of this document

Management Systems for Reducing Airborne Emissions

The principal mechanism for reducing exhaust gas emissions from ships is through IMO regulation, more specifically MARPOL Annex VI. In addition to this, the IMO has introduced the concept of efficiency indices in the form of the EEOI and EEDI in order to encourage a reduction in emissions of GHG's. However strategies such as these have limited scope as they do not require actual measurements of emissions from ships. An emerging approach to exert control and ultimately reduce emissions from ships is through the use of indexing schemes, which assess the impact of harmful emissions within the framework of current and future legislation. At present most indexing schemes are voluntary and none are widespread internationally as a mandatory regulation, while some have been developed to address a single pollutant and others incorporate a wider range of environmental indicators.

The Environmental Ship Index (ESI) - designed as part of the World Port Climate Initiative (WPCI) to help assess and reduce the environmental impact of airborne emissions from ships in port areas - is one of the more widespread indexing schemes to be used at numerous ports in the North Sea region. The index is intended for use by ports to reward ships when they participate in ESI. It is used to promote clean ships, but can also be used by ship owners to promote their own services by boasting a good score, and can act as a framework for stakeholders in improving their environmental performance. ESI provides both a total

score and a score for each of the constituent parts making up the index. Participating in ESI is entirely voluntary, but the WPCI hope that:

“The global port community will assume its role in improving the maritime and port environment”

ESI provides a numerical representation of the environmental performance of ships in the following areas: NO<sub>x</sub>; SO<sub>x</sub>; and CO<sub>2</sub>, while a bonus is given for the presence of OPS (Onshore Power Supply) on board.

An alternative scheme, the Clean Shipping Index (CSI), currently operates in Swedish ports and hence is limited to a subset of ships trading with Sweden. The index consists of a questionnaire of 20 questions designed to assess a ships environmental performance. It was devised as an outcome of the ‘Clean Shipping Project’ with the intention of improving the visibility of ‘clean ships’ to ship operators and cargo owners.

The CSI scoring system assesses exhaust gases (SO<sub>x</sub> and PM; NO<sub>x</sub>; and CO<sub>2</sub>), along with other environmental problems such as chemicals, refrigerants, treatment of ballast water and other issues associated with shipping. Each of the indices are designed to recognise ‘greener’ ships, and act as an incentive for ships to take a greater interest in their environmental impact.



# CNSS FINDINGS

## Activities and Network



*The CNSS project has throughout the project period looked into a range of different aspects relevant to the reduction of emissions from shipping. The work has been organised by means of three key work packages, “Policy and strategy development” (WP3), “Clean Shipping Technology” (WP4) and “Implementation: Reduction and handling of emissions” (WP5).*

*The following sections specifically and the document as a whole represent a summary of the findings and recommendations of the project. For further details, please consult the CNSS website (<http://www.cnss.no>) as well as the attached list of references (see appendices).*

*The work has been carried out by means of work groups within the CNSS partnership, supported by external consultants where deemed necessary. The success of the project relies on the good cooperative spirit between the partners in general. In particular, new and novel information has been developed within air emission from shipping, scenarios for further development of air emission in the North Sea area and emission indices for green shipping.*

# 1. Air Quality

## Recommendations

### Harbours and cities

- CNSS recommends that authorities and ports use size dependent fuel use functions for different ship types for calculating emissions from ships at berth (method developed by CNSS). The share of boilers in the total fuel used depends on ship type and must be taken into account.
- It is recommended that harbours estimate emissions from ships in port, including manoeuvring and at berth using the proposed freely available CNSS model. This will help improve reliability and comparability between different harbours, and test the effectiveness of different incentive schemes.
- For assessing the impact of shipping on air quality in cities it is recommended that authorities use models of an appropriate level of sophistication such as computational fluid dynamics (CFD) models. Applying these models requires skilled personnel and highly sophisticated input data on emissions and meteorological conditions.

### North Sea

- It is recommended that load dependent emission factors be used and that further development of emissions factors continues, especially for those emissions for which estimation is still uncertain (e.g. NO<sub>x</sub>, CO, SO, HC & PM) and engine types other than Diesel engines [using all types of fuel] should also be considered i.e. gas turbines.
- It is recommended that more data on actual emission production on board ship be collected and made generally available through promotion of monitoring campaigns, reporting of monitored data. This will allow further improvement of emissions factors and improve verification of emission production models.

- It is recommended that AIS data with the maximum available coverage at the North Sea, and the maximum available detail in port areas, be used as the basis for models of ship movement and traffic density. This will ensure that the most realistic geographic and temporal distribution of emissions from sea going ships is captured which will help to develop and improve the accuracy of emission scenarios in the North Sea region. This can also be extended to other regions.
- In order to achieve emission estimates as realistic as possible it is recommended to use emission factors that consider measurement based functional relationships between the ships' activities and their technical specifications. It may be worth considering even external factors like wind and currents if it can be excluded that those increase the uncertainty of the emission estimates. The open source emission model developed within CNSS considers engine load, engine power, fuel type and propulsion type for estimating pollutant emissions.
- It is recommended that advanced three-dimensional chemistry transport model systems be used for regional modelling of air quality because of the complex chemistry. For example, the main contribution to PM concentrations on shore from shipping is due to particle formation from gaseous SO<sub>2</sub> and NO<sub>x</sub> emissions, produced offshore.

## Harbours and Cities

*Ships emit considerable amounts of pollutants, not only when sailing, but also during their stay at berth. This is of particular importance for harbour cities because ship emissions can contribute a lot to regional air pollution and result in some of the EU standards (for PM and NO<sub>2</sub>) not being met.*

### Harbour emissions

It is difficult to estimate emissions from ships in harbours from only the technical specifications of the ships because their activities are not well known. CNSS conducted an on-board survey of almost 200 ships in 5 different harbours in the North Sea region in order to get more information about the fuel use in auxiliary engines and boilers. This survey contained questions about the ship's specifications, the engines on board, the type and amount of fuel used and the time the engines were run while the ship was at berth. It was also asked if the fuel was burned in boilers to produce steam or in generators to produce electricity. The data was then grouped by ship category and ship size. These

parameters are most frequently available from port authorities in their arrival and departure lists and can therefore later be used to estimate the ship emissions in a certain harbour without further knowledge about the individual ship characteristics.

In total, 195 ships were visited in 5 different harbours, namely Antwerp, Bergen, Bremerhaven, Hamburg and Rotterdam (see Table 4). These ships were of different type and size, because it was known from a previous study (Hulskotte and Denier van der Gon, 2010) that the fuel use of ships at berth depends on these categories. The largest group was container ships (65), followed by tankers (51, split into oil and chemical/gas tankers), Ro-Ro cargo (21), tugs and supply ships (20), general cargo (15) and bulk carriers (13). The number of passenger or cruise ships was very low (4) because the survey was done in the winter when very few cruise ships approach the North Sea harbours.

The data was checked for reliability before it was used for the calculation of fuel use of ships in harbours. It turned out that a number of surveys had to be discarded because of contradictory information in the answers of the ship's personnel. Detailed information about this can be found in the CNSS report "Survey

Ship type	Antwerp	Bergen	Bremerhaven	Hamburg	Rotterdam	Grand Total
Bulk carrier				10	3	13
Chem.+Gas tanker	1			6	16	23
Container ship	7		4	37	17	65
General Dry Cargo	5			9	1	15
Oil tanker, crude				1	27	28
Passenger		2			2	4
Reefer	2			3	1	6
Ro-Ro Cargo / Vehicle		3	5	9	4	21
Tug / Supply		20				20
Grand Total	15	25	9	75	71	195

Table 4 Number and type of ship visited in 5 harbours in the North Sea region

The evaluation of the survey resulted in functional relationships between ship size and fuel use per hour at berth for each ship type. For most ship types the number of ships that were surveyed was still small (around 20 ships), therefore a linear regression was the main method to derive this functional relationship. Container ships could best be represented by a power law that better represents the small ships. For cruise ships, the data base was too small, therefore typical numbers for the energy demand per passenger and a relation between number of passengers and ship size were used to derive a comparable function for this ship type.

Table 5 shows the average ratio of fuel consumption (FC) per hour and the size of the ship (in gross tons (GT) divided by 1000). Additionally, the results of a linear regression with slope (S) and intercept (I) of the linear function are given:

$$FC=S \times \left(\frac{GT}{1000}\right) + I$$

For containers, the best fit was reached using a power law of the type:

$$FC=S \times \left(\frac{GT}{1000}\right)^p$$

Cruise ships have been treated in a separate way. Today's cruise ships on average have about 30 passengers per 1000 GT ship size. According to a study from DNV GL (2008), for each passenger 5.4 kW of power is needed per hour, which results in a fuel consumption of 32.4 kg/(1000 GT h) if 200 g fuel is needed to produce 1 kWh.

Ship type	Fuel/size ratio	Linear function S*GT/1000 + I
Container	6.0	I=134; S=4.3
General cargo and Ro-Ro	6.1	I=18; S=5.6
Bulk carrier	3.1	I=7; S=3.1
Crude oil tankers	21.1	I=140; S=18.6
Chem. and gas tankers	14.5	I=34; S=13.8
Reefers	19.6	I=41; S=18.8
Ro-Pax	8.9	I=91; S=7.6
Tug and supply	15.6	I=10; S=14.6
Power law		
Container		S=0.41; p=0.83
Derived from literature		
Cruise ships	32.4	I=0; S=32.4

Table 5 Parameters for the calculation of the hourly fuel consumption (FC) of ships at berth. Ratio and slope in (kg/(GT\*h/1000)), I in kg/h

Another important parameter that needs to be considered when the emissions of ships at berth are to be calculated is the way in which the power is produced. In many applications on board ships, steam is needed, e.g. to drive pumps or to produce heat. This is done in boilers while electricity is produced in the engines. Boilers have much lower emissions of NO<sub>x</sub>, CO, hydrocarbons and particles (PM) per kWh that is generated. Therefore, the share of energy that is produced in boilers compared to that produced in auxiliary engines is important information (which was also collected in the surveys). In Table 6 the share of boiler use for the different ship types is compared to results from a previous study (Hulskotte and Denier van der Gon, 2010). In some cases significant deviations between the studies were found. This emphasizes the fact that these numbers are uncertain and very difficult to determine. A recommendation is given which value should be used from the author's point of view in emission calculations.

Ship type	Prev. study (HD)	This work	Recommendation
Crude oil tankers	63%	80%	80%
Chemical/gas tankers	73%	32%	50%
Bulk carriers	36%	10%	10%
Container ships	54%	29%	30%
GDC/Ro-Ro cargo	33%	11%	10%
Ro-Pax ships	32%	0%	30%
Reefers	21%	6%	10%
Tug/supply	1%	0%	0%

Table 6 Fraction of energy produced by boilers on board of different ship types. Comparison of values from a previous study (HD2010) and this survey and recommendation for emission calculations.

The results of the survey have been combined with arrival and departure data from different harbours in the North Sea area to calculate the fuel consumption of ships at berth. These values were divided into fuel consumption by auxiliary engines and boilers. Combined with emission factors for the most important species NO<sub>x</sub>, SO<sub>2</sub>, CO, CO<sub>2</sub>, hydrocarbons (VOC), and PM, (see Table 7) the total emissions of ships at berth were calculated. The emission factors were derived from test bed measurements of about 250 different engines that were evaluated by DNV GL within the CNSS project.

Substance	MGO <sup>1</sup>		MDO <sup>2</sup>	
	Boiler	AE <sup>3</sup>	Boiler	AE <sup>3</sup>
VOC	0.27	0.91	0.27	0.91
SO <sub>2</sub>	0.4	0.4	4.0	4.0
NO <sub>x</sub>	0.55	11.0	0.55	11.0
CO	0.15	1.16	0.15	1.16
CO <sub>2</sub>	635	635	635	635
PM <sub>10</sub>	0.14	0.42	0.37	1.1

Table 7 Emission factors for different fuels depending on engine type/machine, (g/kWh)

<sup>1</sup> Marine Gas Oil (MGO), 0.1% S in fuel  
<sup>2</sup> Marine Diesel Oil (MDO), 1% S in fuel  
<sup>3</sup> Auxiliary Engine

The emissions from two different harbours are shown here as an example. Hamburg is the largest harbour in Germany, competing with Antwerp for second position in the list of biggest harbours in Europe after Rotterdam. It is very much dominated by container ships. In 2010, more than 10,000 arrivals and departures were counted in Hamburg.

Bergen in Norway is much smaller in terms of cargo, however almost 8,000 ship movements have been registered in the data base of the port of Bergen for 2010. In contrast to Hamburg, Bergen has a lot of offshore and supply ships as well as cruise ships which visit the city mainly in summer.

Table 8 shows the emissions from ships at berth for the year 2010 in Hamburg and Bergen. Although the number of ship movements in Bergen is only about 25 % lower than in Hamburg, the emissions of most substances are about a factor of 4 lower. The main reason for this is the smaller size of the ships in Bergen. While Hamburg is visited by more than 300 cargo ships bigger than 100,000 GT, just 17 cruise ships bigger than this arrive at Bergen. Just one cargo ship in Bergen was bigger than 30,000 GT.

Substance	Hamburg	Bergen
NO <sub>x</sub>	1238	308
SO <sub>2</sub>	69	15
CO	136	33
CO <sub>2</sub>	109000	23900
PM	55	13
Hydrocarbons	116	28

Table 8 Emissions from ships at berth in 2010

Figure 3 displays the share of the NO<sub>x</sub> emissions between different ship types in the port of Bergen; Figure 4 does the same for the port of Hamburg. In Bergen the ship types responsible for the largest part of the emissions are cruise ships and offshore ships. Cargo ships, including container ships, tankers and bulk carriers cause fewer emissions than cruise ships alone. The main reason for this is that cruise ships are the biggest ships in the port of Bergen having the highest energy demand. Offshore ships are important emitters because they spend a substantial length of time in the harbour. This is connected with some uncertainties in the estimation of the emissions because it is not known if the fuel consumption is constant over time or reduced if the ship stays longer than a day.

In Hamburg, container ships are responsible for the

largest part of the emissions. This is not surprising, because their share in the number of arrivals and departures is about 50%. Keeping this in mind, their share in the total emissions is lower than expected, while bulk ships and Ro-Ro/vehicle carriers emit more than their share in the number of arrivals. This is because bulk ships are relatively big and therefore have high emissions relative to the number of arrivals. The emissions of the Ro-Ro/vehicles category are likely to be overestimated because the relationship between fuel use and size has been derived for ships bigger than 10,000 GT and might not be valid for smaller ships.

CNSS proposes a method to calculate ship emissions of ships at berth that needs only ship type, ship size and the time spent in the harbour as input. Tables 6, 7 and 8 provide the information that is necessary to

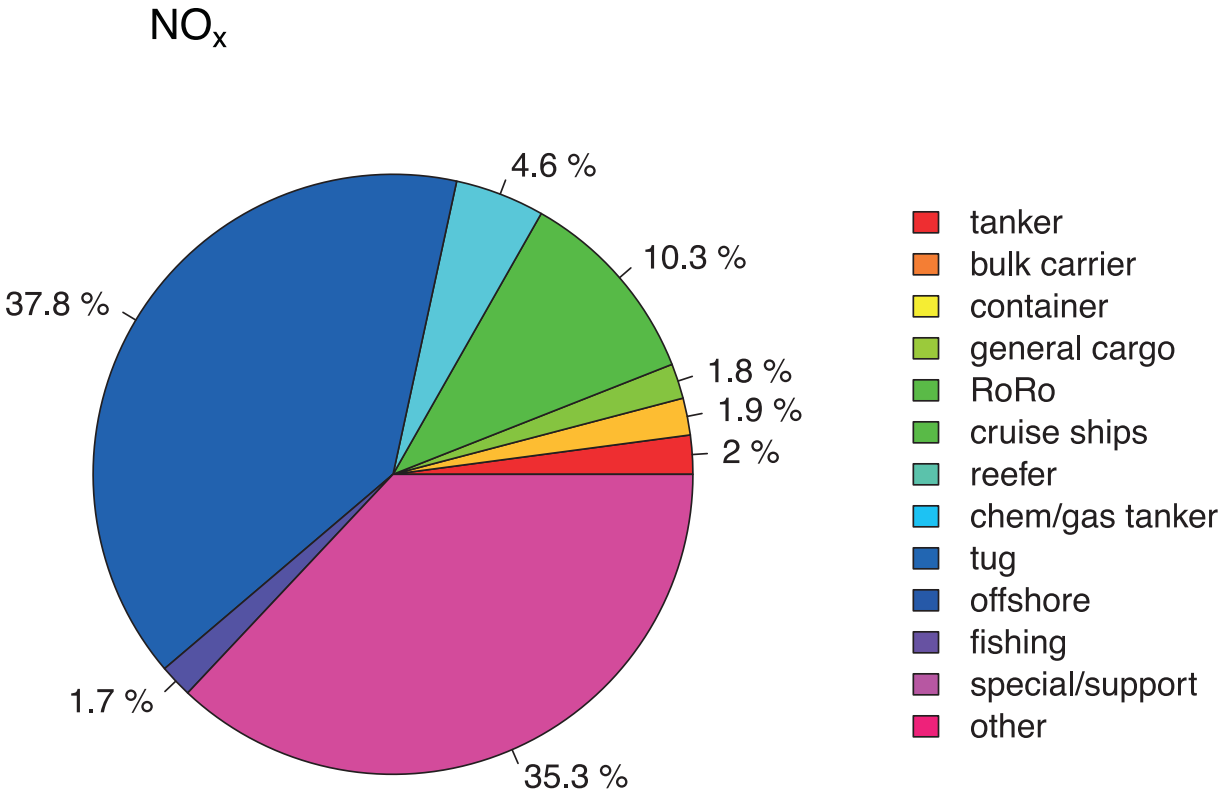


Figure 3 Share of NO<sub>x</sub> emissions from ships at berth in Bergen divided into different ship types

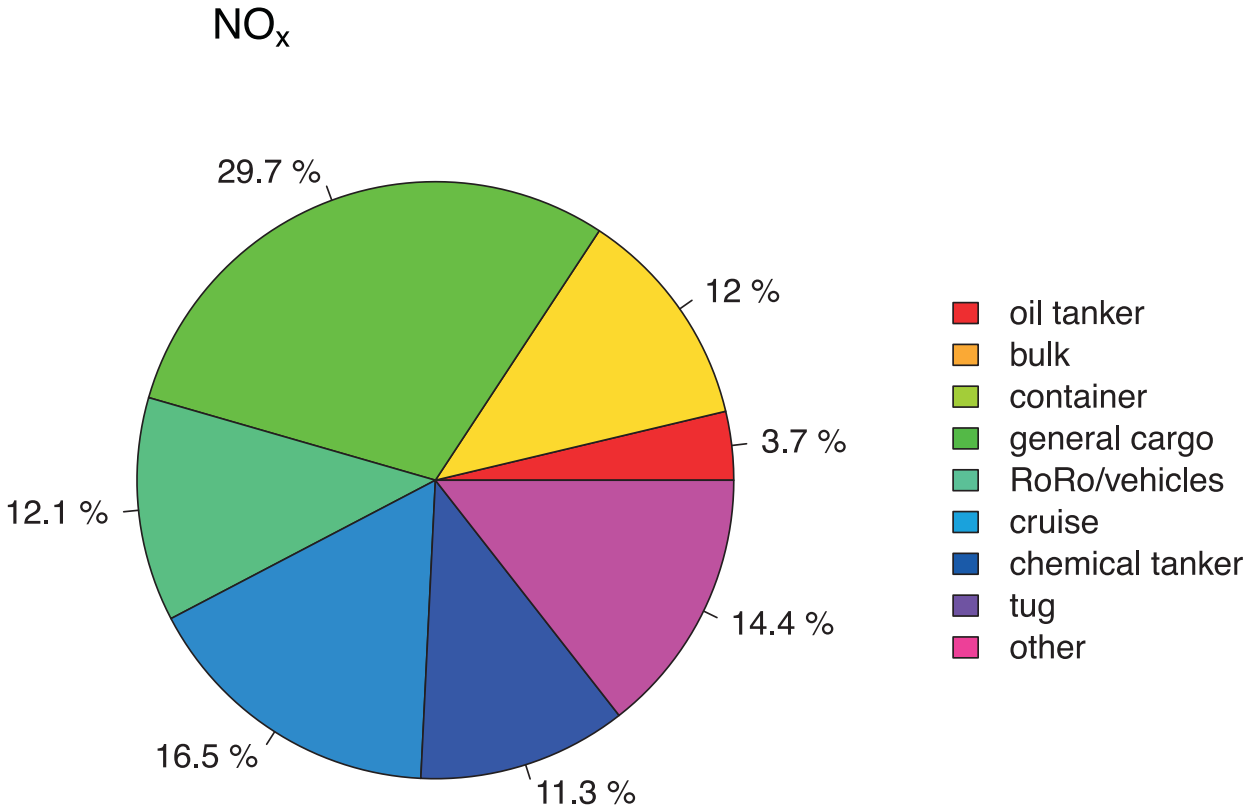


Figure 4 Share of NO<sub>x</sub> emissions from ships at berth in Hamburg divided into different ship types

calculate the emissions of NO<sub>x</sub>, SO<sub>2</sub>, CO, CO<sub>2</sub>, PM and hydrocarbons.

### High resolution harbour emissions – the example of Port of Antwerp

The method described in the previous chapter is simple and easy-to-use because it does not require much data input. It is suitable for providing an overview over annual ship emissions and their distribution among ship types. In order to calculate detailed ship emissions even for single ships and their spatial distribution within the port area at different times a sophisticated model system (called EMPORTANT) has been developed under the leadership of Antwerp Port Authority. The model was

originally configured to fit to the terrain of the port of Antwerp. It is implemented as a web application that is freely available and well documented, so that it can be adapted to any other port. Further requirements to use this model are Automatic Identification System (AIS) data for the specified region and time episode as well as ship characteristics of the vessels visiting or operating in the port of interest. One of the major advantages of this sophisticated model approach is that emission scenarios can be calculated taking any technological and legislative developments into account.

The EMPORTANT model makes use of AIS data to derive the ships' activities within the port (sailing, in lock, mooring and at berth). In combination with a database of ship characteristics using a set of specific





Port of Antwerp

emission factors, the model estimates ship emissions over a certain time or a certain area. The ship characteristics data, such as length, width, draught and engine power, originate from Lloyd's Register (IHS Fairplay). In the case of the Port of Antwerp these activity data are supplemented with their own registrations in Antwerp Port Authority's (APA) database APICS. Provided that AIS data are available in high resolution the model can easily calculate emissions for 250m x 250m geographic grids that are typically used for advanced urban air quality models.

The first step in the model development was to calculate emissions from all ocean going vessels in the Port of Antwerp for the reference year 2012. The

geographical distribution of ship emissions over the port area is shown in figure 5. The maps reveal that emissions are higher at locations where ships berth than along the waterways. This is not implausible, since ships tend to spend a relatively long time (up to 3 days) in the port in order to be charged or discharged, while a ship's trajectory in port is short and generally sailed at slow speeds. Figure 6 illustrates the distribution of emissions over the different activities in percent's while figure 7 shows the same in absolute numbers.

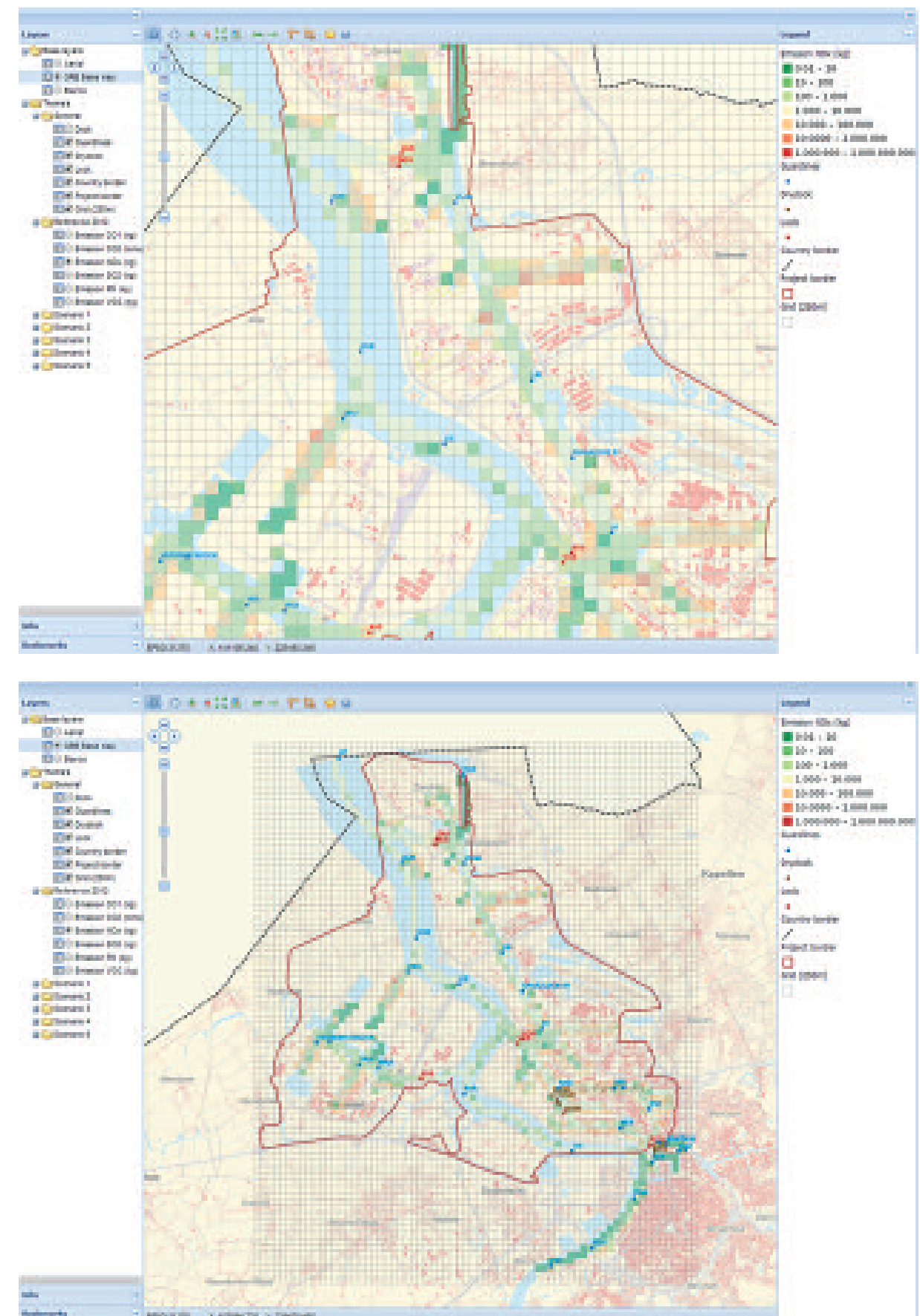


Figure 5 Geovier model – Port of Antwerp



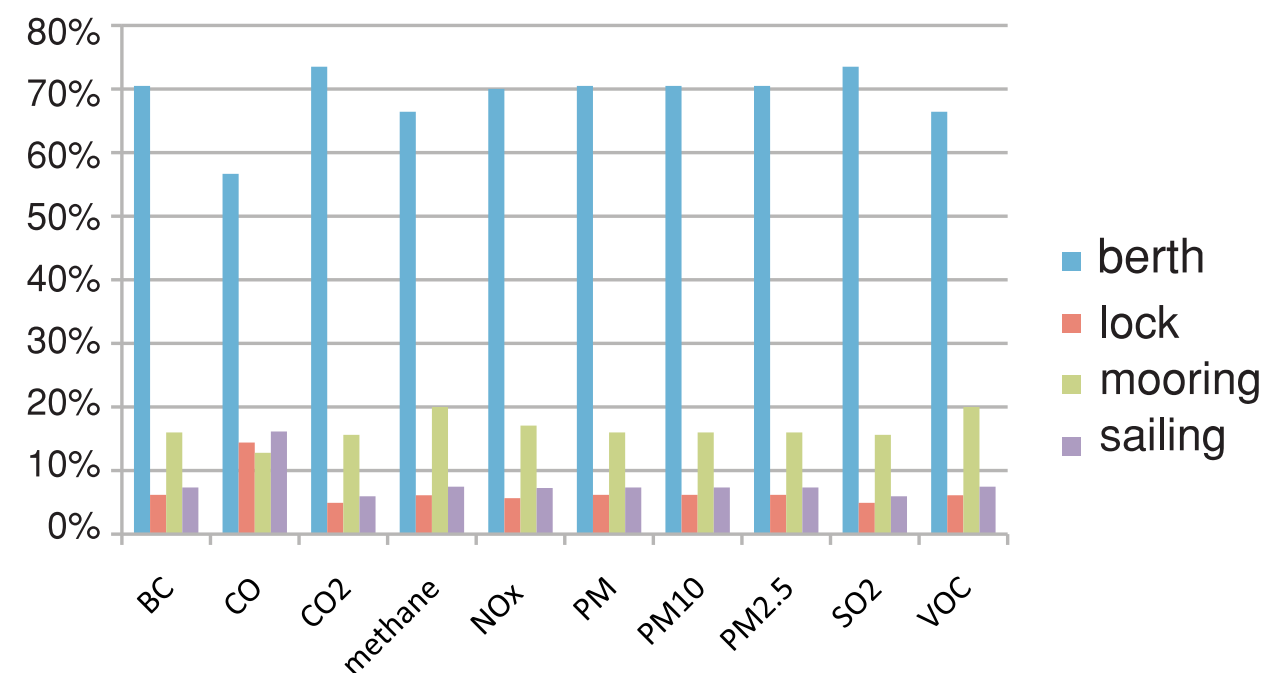


Figure 6

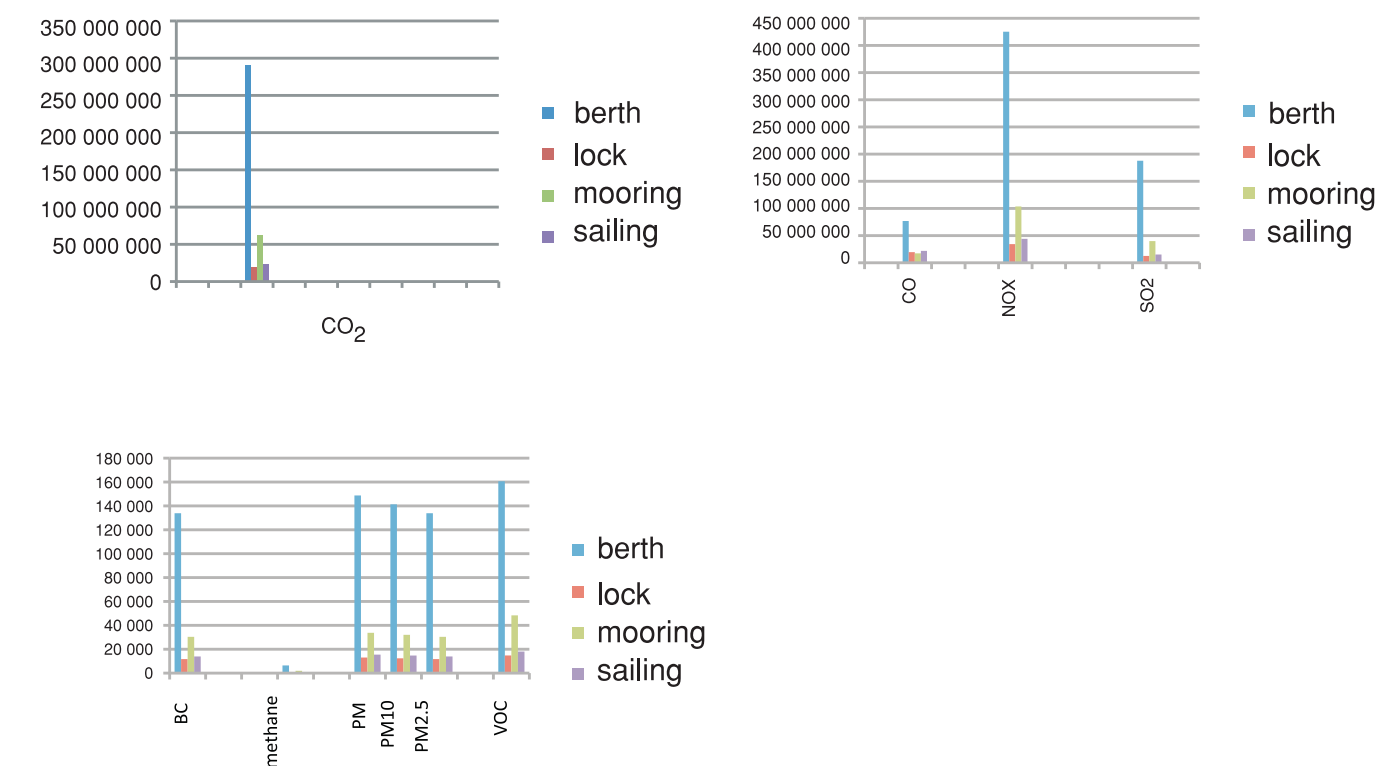


Figure 7 Absolute figures in Kg (2012)

## NO<sub>x</sub>

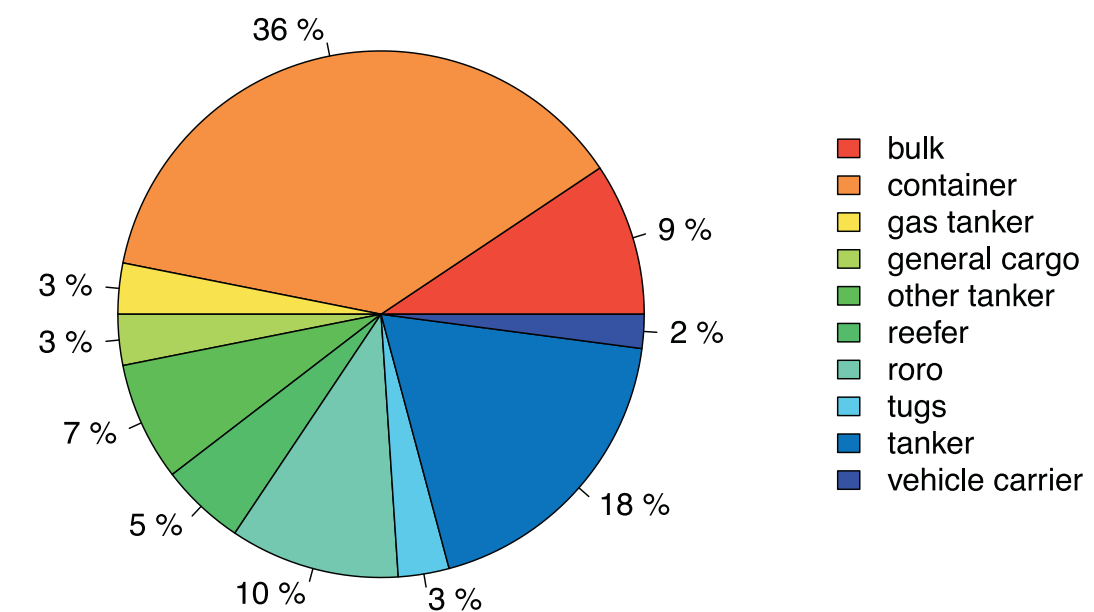


Figure 8 Distribution of emissions across main ship types

Figure 8 suggests that containers ships are the biggest polluters, followed by tankers. This is not only because of the number of ships calling, which is predominant over other ship types, but also because of the mean size of container ships, which is far bigger than the mean size of any other ship type. Moreover, a significant number of containerships transport reefer containers. The continuous cooling of these containers requires extra amounts of energy.

## City scale air quality modelling

In CNSS, model systems with different complexities have been applied and tested for their suitability to quantify the effect of shipping on the concentrations of pollutants in the atmosphere at city scale. To illustrate the impact of shipping in port areas it is important to use models that can tackle higher resolutions than can be achieved by regional models. Therefore the Operational Priority Substances (OPS)<sup>1</sup> model, which is routinely used in the Netherlands and Belgium, was applied to the region of Rotterdam. The OPS model, though lacking atmospheric chemistry routines, is

capable of modelling yearly averaged concentration levels at a resolution down to 0.5x0.5 km<sup>2</sup>. NO<sub>x</sub> and PM concentrations can be modelled. In the specific case of Bergen the OPS model is less appropriate due to the complex topography of the cities surroundings. Therefore the Aermodyn<sup>2</sup> model, that can handle complex terrain, was applied here.

High resolution modelling also requires highly detailed emissions from the sources to be considered. This turns out to be one of the major constraints to the applicability of the models and the validity of the model results. In the case of the Port of Rotterdam area, sufficient data is available for the use of the OPS model. The emissions from different sectors (industry, road traffic, consumers, shipping etc.) are available at a sufficiently high level of detail. Industrial emissions can usually be given as point sources and more diffuse emission sources, such as road traffic and households can be supplied to the model as area sources, usually ranging from 1x1 km<sup>2</sup> (i.e. traffic) to 5x5km<sup>2</sup> (i.e. surrounding agricultural emissions).

<sup>1</sup>[http://www.rivm.nl/en/Documents\\_and\\_publications/Scientific/Reports/2004/december/The\\_Operational\\_Priority\\_Substances\\_model?sp=cml2bXE9ZmFsc2U7c2VhcmNoYmFzZT00NTM4MDtYaXZicT1mYWxzZTs=&pagenr=4539](http://www.rivm.nl/en/Documents_and_publications/Scientific/Reports/2004/december/The_Operational_Priority_Substances_model?sp=cml2bXE9ZmFsc2U7c2VhcmNoYmFzZT00NTM4MDtYaXZicT1mYWxzZTs=&pagenr=4539)

<sup>2</sup>[http://www.epa.gov/scram001/dispersion\\_prefrec.htm#aermod](http://www.epa.gov/scram001/dispersion_prefrec.htm#aermod)

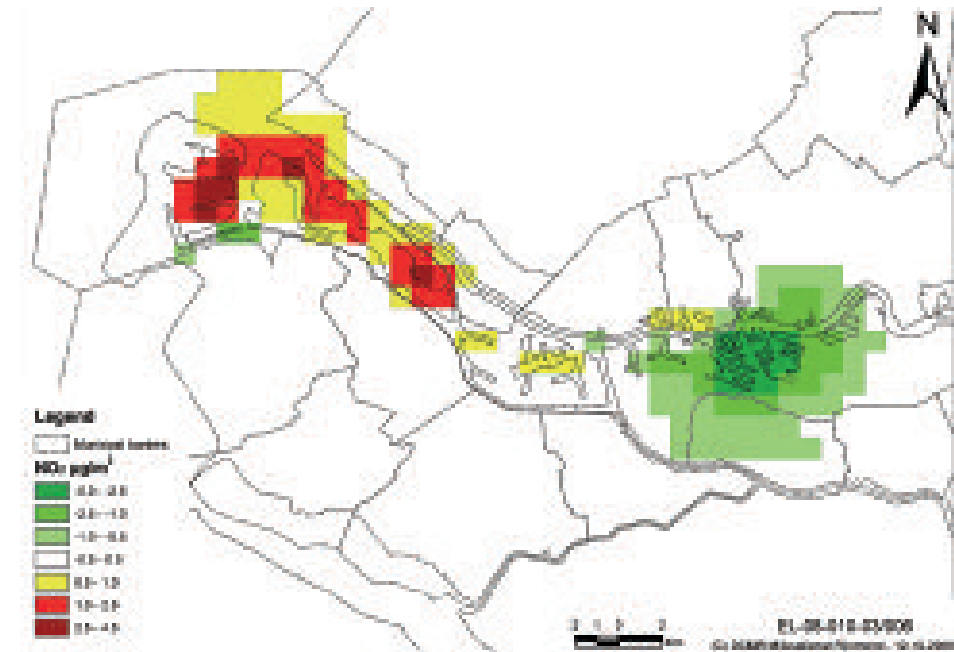


Figure 9 Difference in the contribution of sea going vessels to the NO<sub>2</sub> concentration calculated by AIS-based emissions and by standard emissions for the year 2010 (1x1km)

With this emissions data available the OPS model has been run for the Port of Rotterdam using the available yearly meteorological data and surface roughness data for the region. Also, a winter and summer meteorological dataset was constructed<sup>3</sup>, so that seasonal differences in the dispersion of the emissions

could be evaluated. The results of the model runs allow quantification of the overall impact of shipping emissions on the regional air quality, as well as the relative impact with respect to other emission sources (see Fig. 10 and 11).

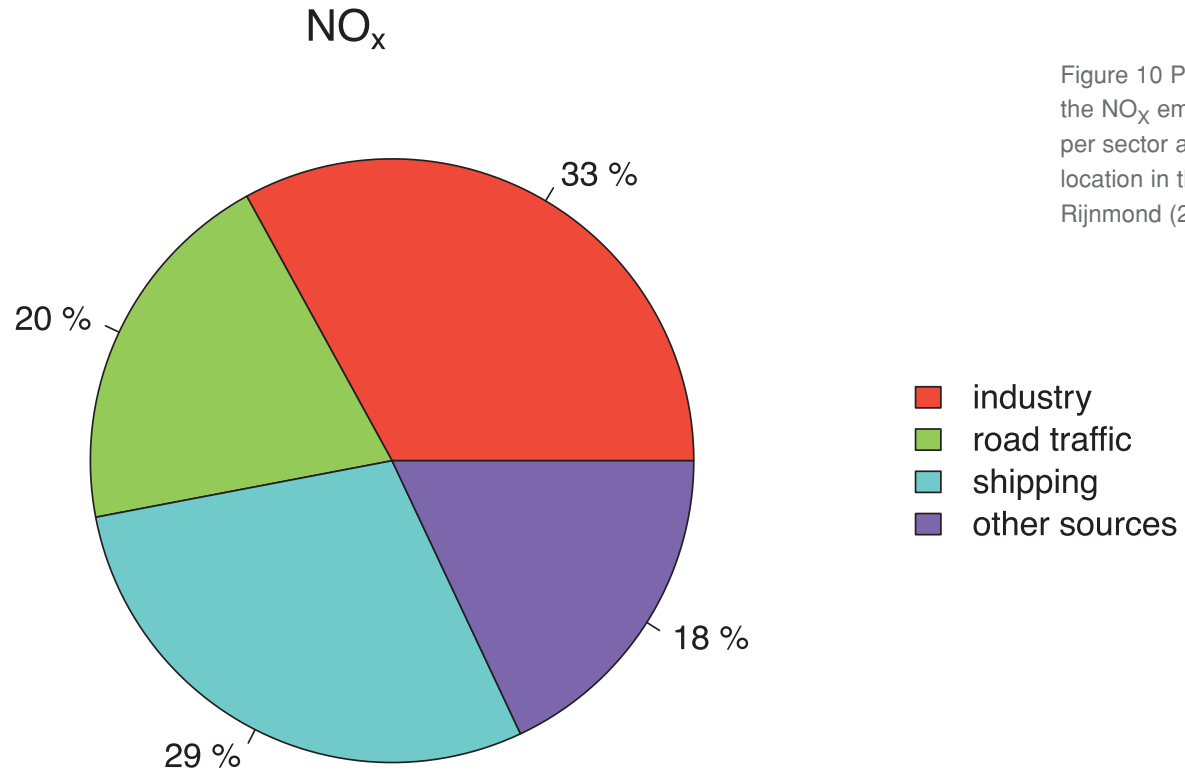


Figure 10 Pie chart of the NO<sub>x</sub> emissions per sector at a typical location in the Rijnmond (2011)

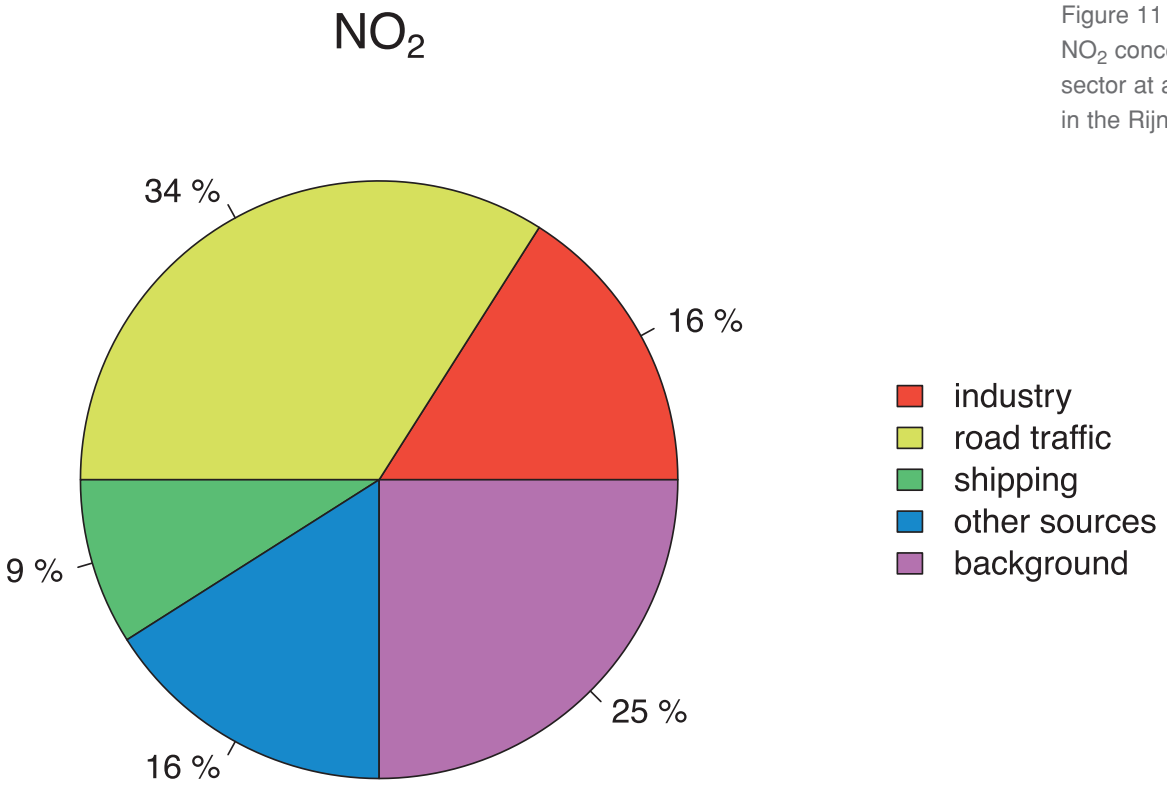


Figure 11 Pie chart of the NO<sub>2</sub> concentrations per sector at a typical location in the Rijnmond (2011)

Since OPS renders high resolution yearly averages, the spatial variation of the impact of shipping can be shown, too. This allows for the evaluation of the absolute and relative impact of shipping emissions on air quality in specific areas of the Port of Rotterdam. This spatial variation is illustrated by model results for

the entire area when only shipping emissions were considered (Figure 12) and by drawing cross-sections through the Port of Rotterdam area where contributions from all sectors can be seen (Figures 13 & 14).

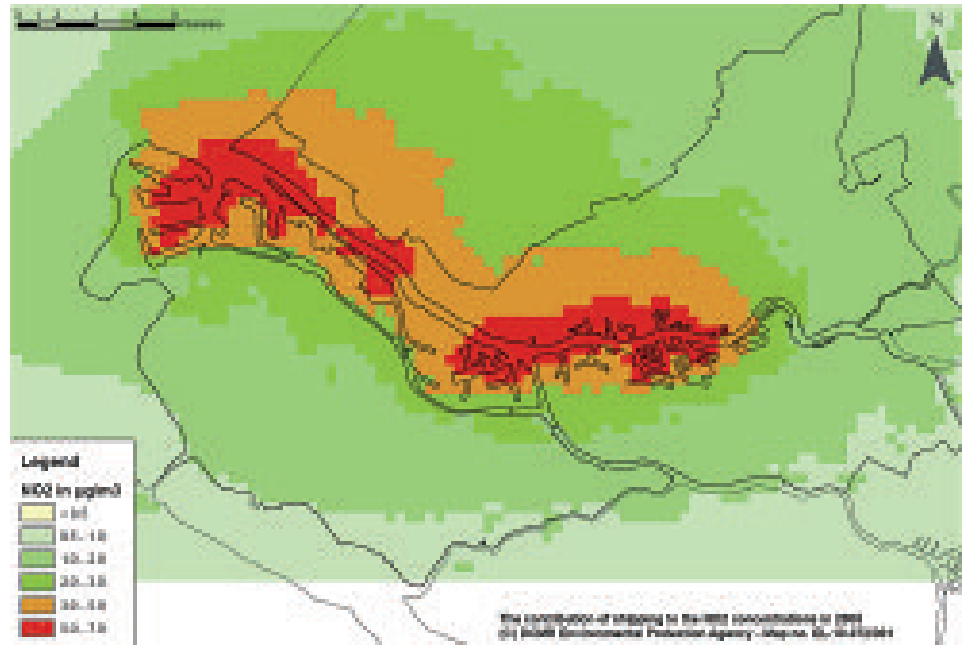


Figure 12 Contributions of shipping to NO<sub>2</sub> concentrations in 2008 in the Rijnmond region

<sup>3</sup>This data was made available by Hans van Jaarsveld, author of the OPS model

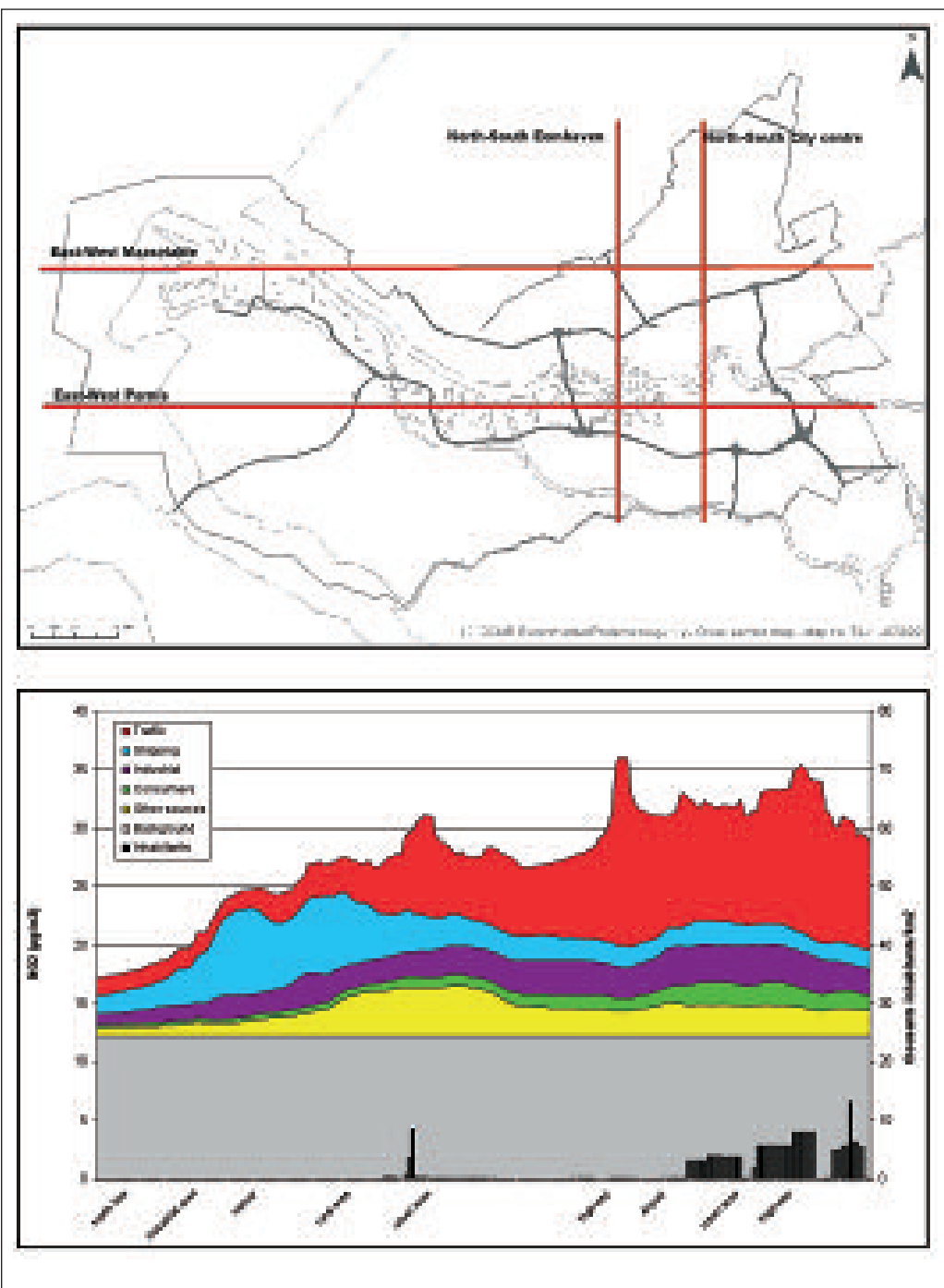


Figure 13 Cross section map of the Rotterdam area.

Figure 14 NO<sub>2</sub> concentrations from different sectors in the East-West-Maasvlakte cross section (See Fig. 12) and number of inhabitants living in the different areas.

Separate model runs were performed for the different source sectors (i.e. shipping, road traffic, industry), thereby determining the contribution of each of these sources to each point in the area. The background NO<sub>2</sub> level (from sources outside the region and calibrated on local air quality measurements) was nearly constant and was averaged over each cross section. Population density data were added to the resulting graph for each cross-section (see Figure 14). As previously mentioned, high resolution modelling

requires highly detailed emissions data. This has proven to be one of the key limitations for the application of these models in the case of Bergen and Hamburg. To apply the OPS model for other areas, it is important to have a complete database of emission sources in the format required by the model.

Another limitation of the OPS model is the meteorological data input file. This Dutch model consists only of Dutch meteorological data. For

modelling in areas outside of the Netherlands a new meteorological file needs to be compiled. This can be difficult, mainly due to a lack of relevant documentation. Furthermore, an appropriate roughness length needs to be defined. For Hamburg, the standard roughness lengths as used for the Netherlands were applied. The OPS model was subsequently run successfully for the Hamburg area.

The last limitation of the OPS model is that it can only be used for 'flat' areas. Therefore, the model cannot be used for areas with complex terrain, like Bergen. For the case of Bergen the AERMOD model was used successfully. Geospatial data (elevations) and emission data (shipping, road traffic, housing, industrial sources) were supplied by the city of Bergen and the use of this data into the model was relatively straightforward.

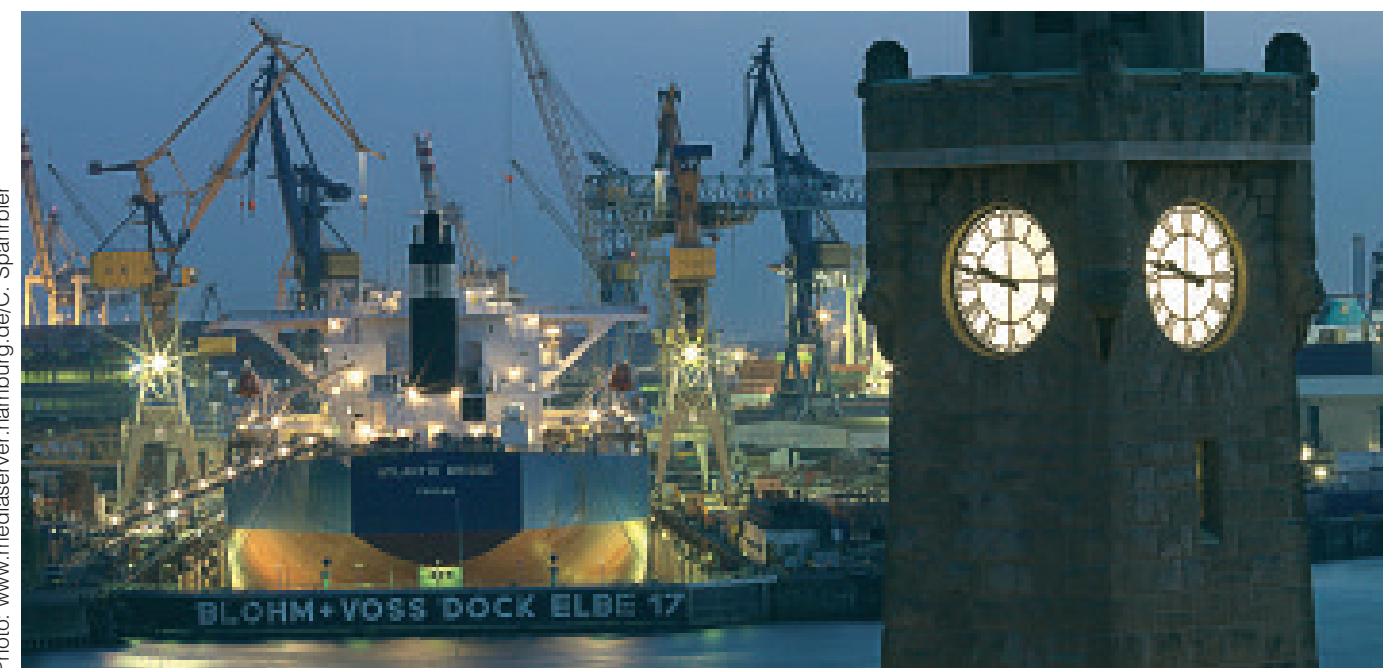
In conclusion, the use of the Operational Priority Substances (OPS) model has proved to be useful for city scale modelling. Differentiated shipping emissions (i.e. berth and sailing) can be fed into the model together with land based emissions, thus rendering information on the absolute and relative impact of shipping on the in-port air quality. In the case of complex topography (i.e. Bergen, Norway) the

AERMOD model is a good alternative.

In most cases, the construction of an accurate emissions database, including land based emissions has proved to be a difficult task. This however is a necessary step in order to highlight the impact of shipping emissions relative to land based sources. Land based emissions should at least be captured for industrial sources, road traffic and consumers on a yearly basis. As a first step, overall emissions within the boundaries of the region under consideration should be known and subsequent geospatial detailing of these emissions (especially road traffic and consumers emissions) can then be taken at hand, using generalised dispersion characteristics for these sources. Care should be taken to evaluate emissions data from different source categories over the same time period.

The emissions database is a major premise to come up with reliable air quality model results. The application of sophisticated models - such as computational fluid dynamic (CFD) models - is only appropriate if sufficiently accurate and detailed emissions data is available. The experience during the CNSS project shows that this is the most urgent task to solve.

Photo: www.mediaserver.hamburg.de/C. Spahr/bier



## North Sea

### Emission factors for sea going ships

Formerly, when little was known about ship activities and the emission behaviour of their engines the only way to estimate emissions of air pollutants from ships was to estimate fuel consumption by means of fuel sales numbers and multiply them with emission factors per fuel burned. This method bears large uncertainties because the amount of fuel bunkered in Northern Europe is not necessarily the same amount of fuel consumed there. Deriving emissions from combusted fuel is generally a suitable approach for sulphur dioxide and carbon dioxide emissions that depend only on the mass of fuel and the sulphur content in that fuel. However, the emissions of substances like NO<sub>x</sub>, CO, hydrocarbons and particulate matter (PM) depend strongly on combustion temperature and fuel to air ratio, which are related to the engine load.

With the introduction of the Automatic Identification System (AIS) for ships it became much easier to track ship movements and estimate their actual engine loads provided the necessary engine characteristics are known. When this project started emission factors were only available as constant values that had to be multiplied by the energy consumption of a ship. The energy consumption was calculated by estimating the

duration of a ship's movement and multiplying this time by a fixed ratio of the maximum continuous rating (MCR in kWh) representing an average load.

In the CNSS project load dependent emission factors from about 250 ship engines have been collected and subsequently analysed. These emission factors stem from test bed measurements carried out at DNV GL. Based on correlation analyses the test bed results were generalized to specific emission factors consisting of functions of engine load. Particular emission factor functions were attributed to different engine types, power classes and compliance to different IMO standards. Figure 15 shows as an example the functions for calculating the NO<sub>x</sub> emission factors for E3 type engines (classification according to MEPC.177 (58)) fulfilling Tier II requirements. The entity of these functions provides load dependent emission factors for different types and power classes of engines and different pollutants that are emitted. These factors are currently representing the most reliable information on load dependent emissions for ships. They can be used in emission models to determine the total amount as well as the temporal and spatial evolution of SO<sub>2</sub>, NO<sub>x</sub>, CO, CO<sub>2</sub>, hydrocarbons and particulate matter (PM) emissions from ships on the open ocean. All details are published in Zeretzke et al., 2014.

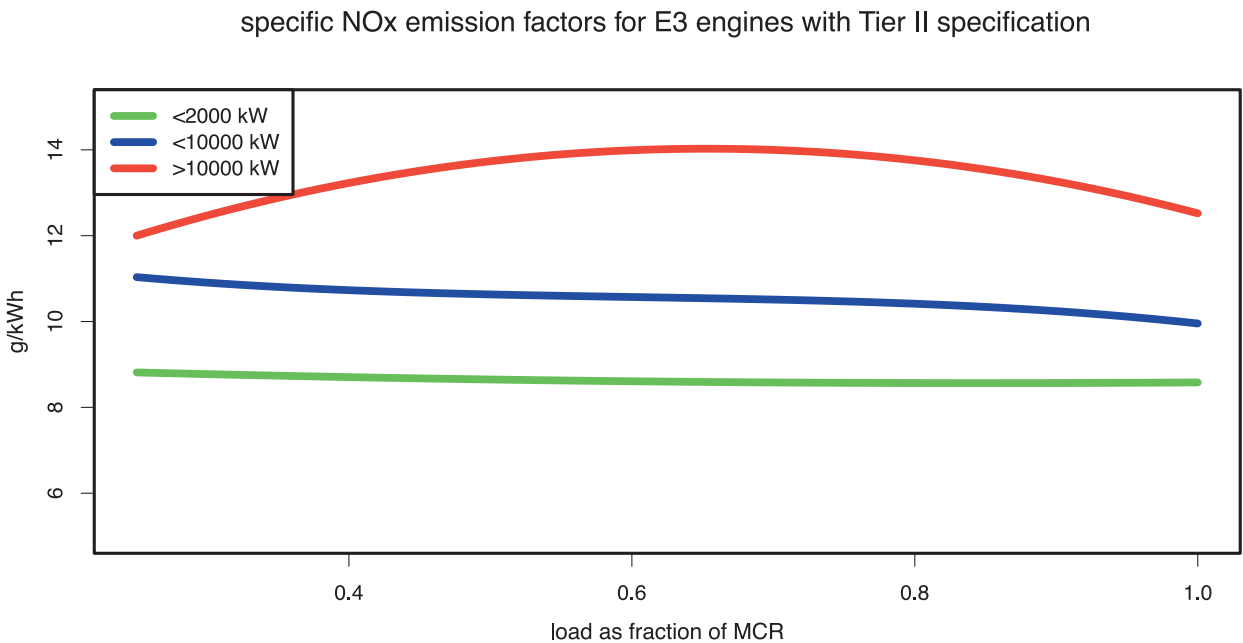


Figure 15 Load dependent emission factors for NO<sub>x</sub> for three engine power classes.

### North Sea emission model

The North Sea is one of the areas with the highest ship traffic density worldwide. At any time, about 1000 ships are sailing the North Sea. It has been shown in past scientific publications that ships contribute significantly to atmospheric concentrations of particulate matter in regions far away from the main shipping routes. In order to quantify the effects of North Sea shipping on air quality in the riparian states, an accurate determination of the emissions from shipping is essential.

In CNSS a bottom-up approach has been developed and applied to compile such an accurate emission inventory for 2011 that serves as the base year for the current emission situation. The required information for this approach is activity data of ships and characteristics of the ships in 2011. The ships' activities were determined from hourly records of AIS signals. The AIS is mandatory for all ships bigger than 100 GT since a few years. The associated ship characteristics were received from a data base that contains the technical details about the engine and the service speed of the ships to calculate the fuel use of the ships. Combined with the load dependent emission factors developed in CNSS, a detailed and up-to-date emission inventory for the North Sea has been created. To distinguish the emission characteristics of different ship types and classes we divided the ships into seven types: cargo (containing container ships), bulk carrier, tanker, cruising ships, ferries, tug boats and other vessels, and nine size classes defined by gross tonnage (see Table 9).

### Ship activities

The AIS data base that was acquired from IHS Fairplay contains hourly updated AIS data in the greater North Sea region for the whole year 2011. If necessary the broadcasted positions along a ship track were interpolated linearly to get enough points for transferring the track to the Eulerian grid of the air quality model. In particular, if a ship travels on the open sea where no signals were caught interpolation was crucial. At the same time it was made sure that the interpolation routine did not lead the track over land. The steps to derive ship routes are as follows:

1. Read data sets of a defined time interval from the AIS data base.
2. Sort by time stamp: this yields the track of one ship travelling the North Sea within the specified time interval.
3. Interpolate the ship track so that it consists of equidistant points. The distance between the track points is set to 1/3 of the length of a model grid cell. Make sure the track doesn't lead over land.
4. Calculate the speed at every track point.

The speed of the ship and the time needed to travel from one track point to the next one constitute the activity information required for emission calculations.

### Attribute ship characteristics to track

Ships in the AIS data base were usually identified by their unique IMO number. In some cases where the IMO number of a record in the data base was missing or invalid vessels were identified by the MMSI number of their broadcasting devices.

By means of the IMO number of the vessel whose track was re-constructed like explained above the technical characteristics needed to calculate the emissions of that track were looked after in a ship characteristics data base that was also acquired from IHS Fairplay or in a second one provided by DNV GL. If the IMO number was present in both data bases and the values were contradictory the values of the IHS data base were preferred. Table 9 shows a summary of technical information as median values per size class for cargo ships. Such a table was calculated for all of the seven ship types and its values were used in case some information of a particular ship was missing.



	MCR (kWh)	Speed (kn)	MCR (1/Min.)	Year of build	Aux. power
<100	-	-	-	-	-
<1600	-	-	-	-	-
<3000	749				
	11.5	750	1995	328	
<5000	2400	12.5	600	1997	550
<10000	4690	15.5	500	2004	1213
<30000	10400	19	127	2002	2284
<50000	21068	22	104	2005	7400
<100000	57100	25	102	2005	9416
>100000	68640	24.9	104	2010	13188

Table 9 Summary of technical information per class size for cargo ships

Energy consumption, fuel consumption and the emissions of NO<sub>x</sub>, SO<sub>2</sub>, CO, volatile hydrocarbons, CO<sub>2</sub>, mineral ash, sulphuric acid, black carbon (BC) and primary organic carbon (POA) are calculated for every track point where the calculated speed was larger than 2kn. 2kn was assumed to be the threshold indicating that the ship was neither mooring nor manoeuvring. The emissions of non-moving ships are calculated with the harbour emissions method according to Jan Hulskotte and Volker Matthias (see harbour emissions section). Consumption and emissions depend on the actual load of the ship which is calculated using a power-of-three function with the speed at MCR and the calculated actual speed at the track points. Calculating the energy consumption is then straightforward using MCR, the actual load and the time difference between two track points. For auxiliary engines the load for moving ships is kept constant at 30%.

For deriving the fuel consumption and pollutant emissions the formulas for calculating the emission factors (in g/kWh) derived from the test bed measurements of DNV GL were used. The emission factors are a function of load, propulsion type (diesel electric or direct/gear drive), fuel (Heavy Fuel Oil or Marine Diesel Oil) and year of build.

The last step is to transfer the emissions along the ship track to the model domain. The model domain consists

of equally spaced grid cells in a lambert conformal conic projection. Therefore the track points defined by latitude-longitude coordinates are converted to lambert x-y coordinates. Then the grid cells are found in which the track points lie. Finally, all emissions in a cell are summed up and added to the domain. This procedure can be done by single ships, ship types or classes to separately investigate their emission behaviour.

### Ship emission profiles

The exhaust of pollutants is most of all connected with the fuel consumption and, thus, with the energy demand of the ships. Therefore the sections of the North Sea where the highest emissions of pollutants in general occur are those where the majority of the big ships with high energy demand travel. This is the English Channel and the route along the North Sea coast between Belgium and Germany because the largest ships head for the three biggest ports in Europe, Rotterdam, Antwerp and Hamburg from where goods are distributed to smaller ports with medium size ships that account for regional and inner-European shipping. The main routes for medium sized ships extend between central-western Europe and Scandinavia. Figures 16 and 17 show two examples for the annual NO<sub>x</sub> emissions of typical ship types for regional and international shipping.

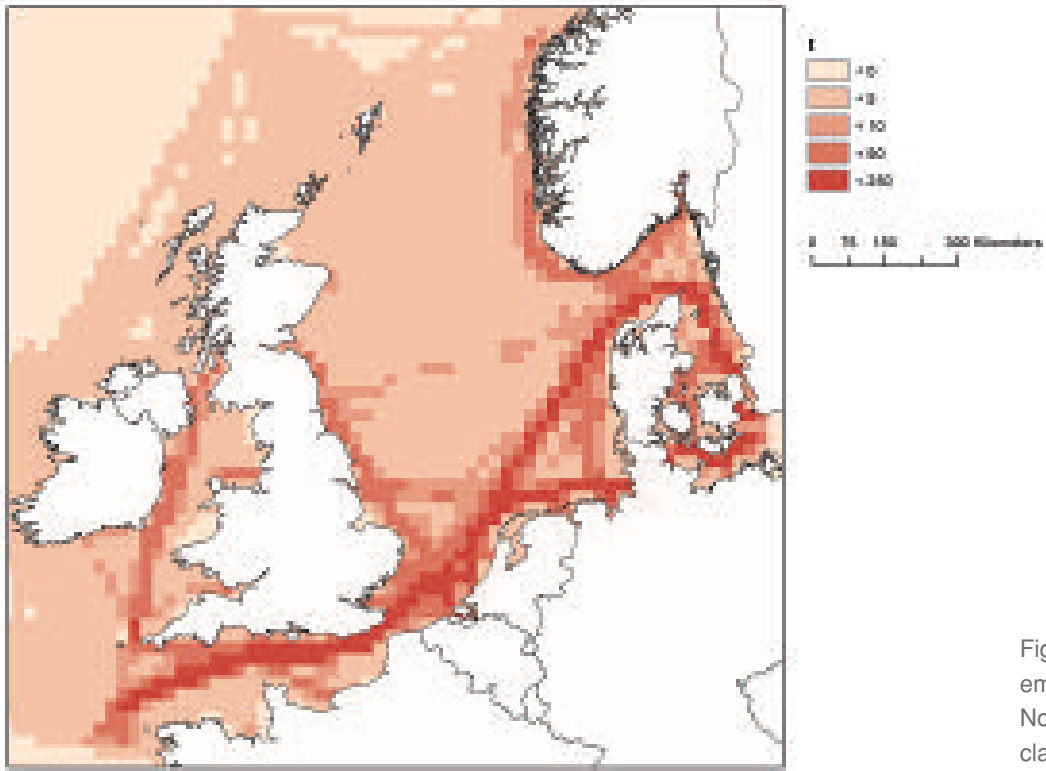


Figure 16 Annual NO<sub>x</sub> emissions of cargo ships in the North Sea in 2011 for the size class 5000 - 10000 GT

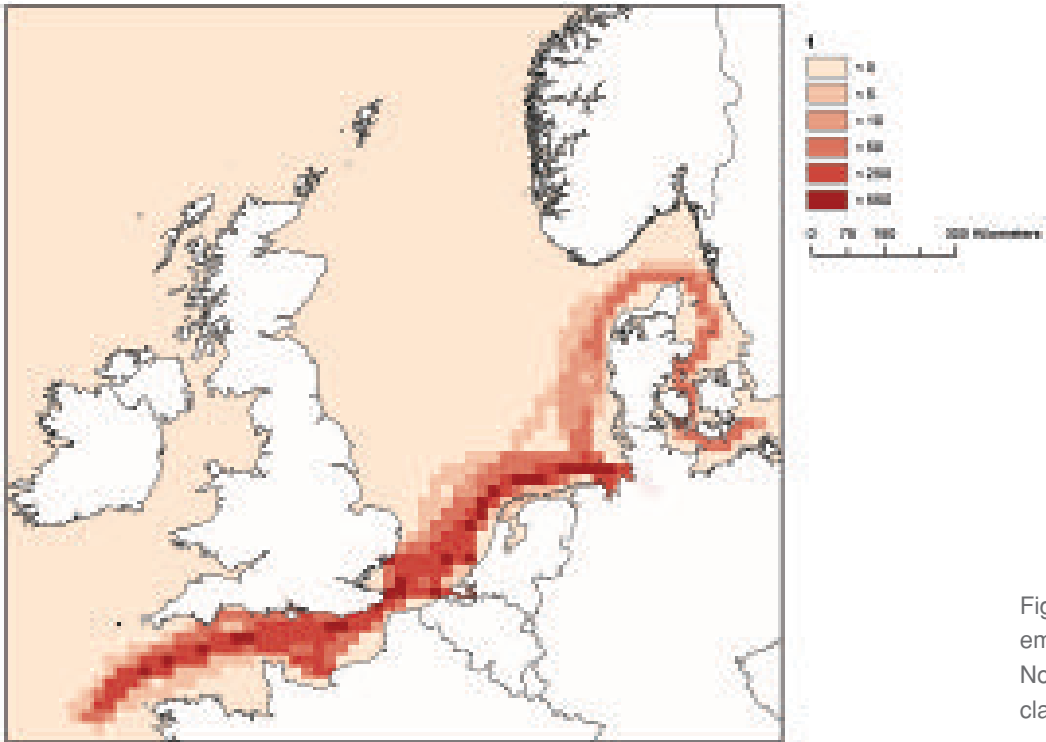


Figure 17 Annual NO<sub>x</sub> emissions of cargo ships in the North Sea in 2011 for the size class > 100000 GT.

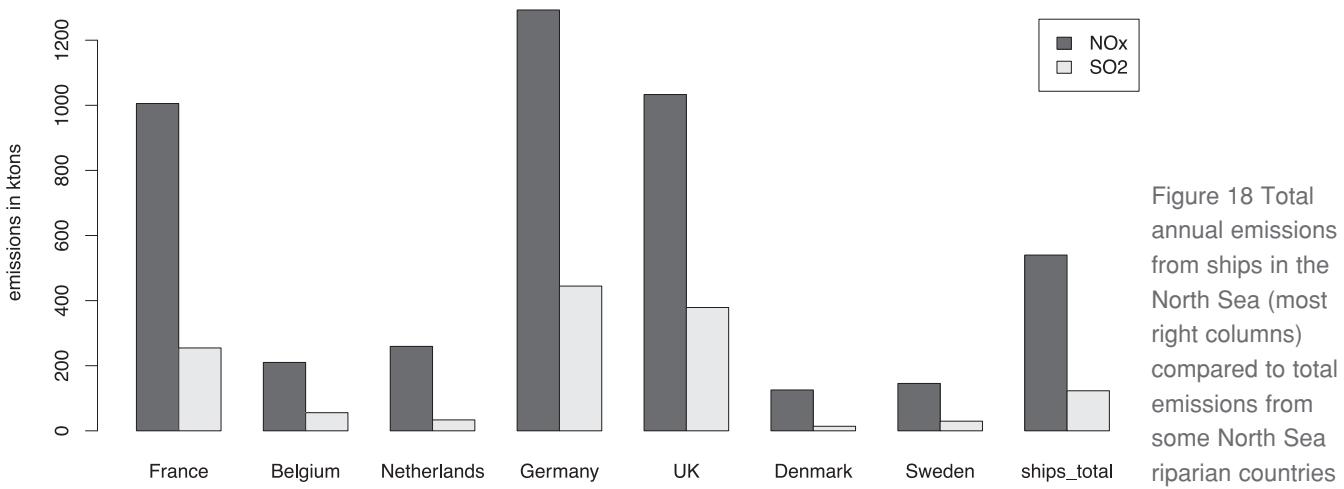
It is a first plausibility check for the bottom-up emission approach that these main shipping lanes could be reconstructed from the AIS data base. It is also evident that the big vessels do not contribute significantly to emissions if reckoned for the whole North Sea on the one hand. On the other hand their contribution is remarkable along densely populated coasts where the

major international shipping routes lead along. Figure 18 shows the total annual NO<sub>x</sub> and SO<sub>2</sub> emissions by ships in the North Sea in 2011 in comparison to the emissions of some European countries. Table 10 details the relative contributions of some ship types to the total ship emissions.



Ship type		NO <sub>x</sub> (%)	SO <sub>2</sub> (%)
Cargo	>100000 GT	4.89	4.84
	<100000 GT	33.1	33.6
Bulk	>100000 GT	0.0633	0.0675
	<100000 GT	11.3	11.3
Tanker	>100000 GT	1.19	1.55
	<100000 GT	29.4	28.7
Cruiser	>100000 GT	0.764	0.789
	<100000 GT	2.16	2.12
Ferries		10.2	10.1
Tugs		4.49	4.36
Other vessels		2.56	2.51

Table 10 Relative contributions to total ship emissions



### North Sea air quality modelling

The contribution of shipping to air quality in the North Sea area can be determined by combining accurate emission inventories with advanced three-dimensional chemistry transport (CTM) models. A CTM imports emissions and uses meteorological variables like wind speed, wind direction and temperature to simulate transport and chemical transformation of pollutants in

the atmosphere. In this way, the CTM developed by the US Environmental Protection Agency, called Community Multi-scale Air Quality (CMAQ) model, has been used to calculate air concentrations of a number of pollutants depending on the input emissions. The CMAQ model was used in its version 4.7 with the CB05 chemistry mechanism (refs). It was run for an entire year with a spin up time of 2 weeks and a data output time step of one hour. Boundary conditions for the

model were from the TM5 global chemistry transport model system (ref).

The meteorological fields that drive the chemistry transport model were produced with the COSMO-CLM mesoscale meteorological model for the year 2008. This year was chosen because it does not include very unusual meteorological conditions in central Europe and can therefore be used to represent average weather conditions in Europe.

The simulation of atmospheric chemical processes is of particular importance for estimating concentrations of secondary pollutants which are not emitted directly

but formed from emitted gases by chemical reaction. The most prominent one is ozone, whose formation is enhanced by NO<sub>x</sub>. Also very important for health and environment are secondary particulate matter that emerge from gaseous emissions, mostly NO<sub>x</sub> and SO<sub>2</sub>, and constitute the largest portion of the noxious fine particulate matter. Emissions from other sources like traffic, industry, households and agriculture have been taken from official European emission registries. Model runs were performed both using all available emissions including the ship emission inventory and using land based emissions exclusively. The resulting concentration differences between these runs revealed the impact of shipping emissions.

### Concentration of NO<sub>x</sub> in the summer 2011

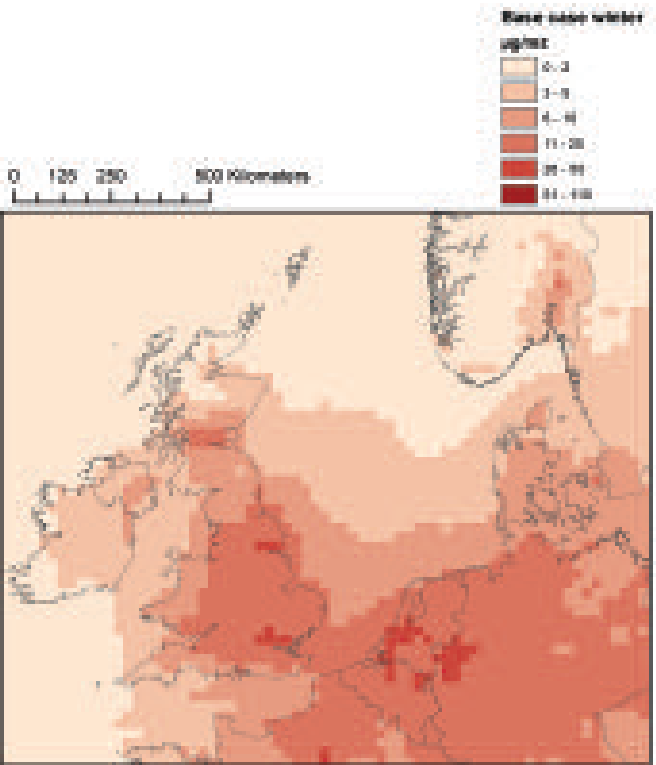
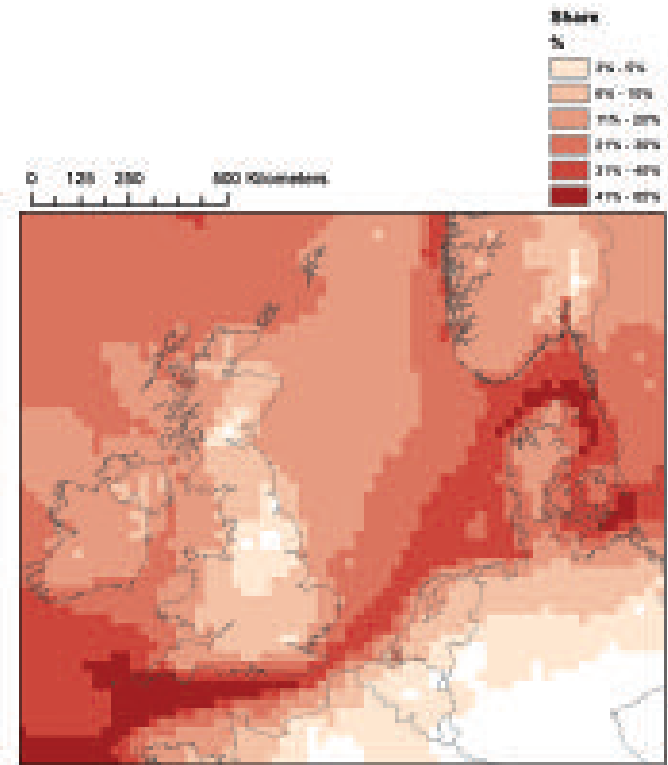


Figure 19 Comparison base Summer NO<sub>x</sub>

### The share of ship emission in NO<sub>x</sub> concentration in the summer 2011



Concentration of NO<sub>x</sub> in the winter 2011

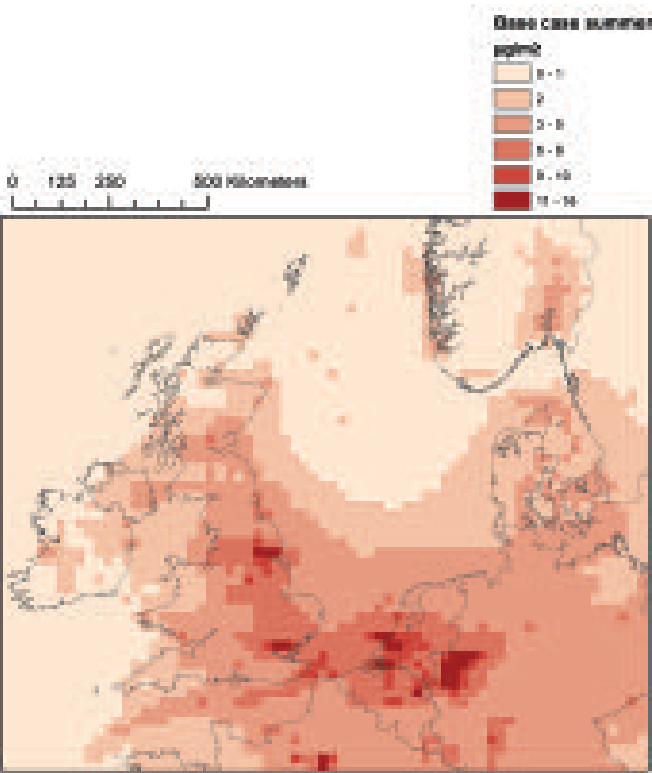
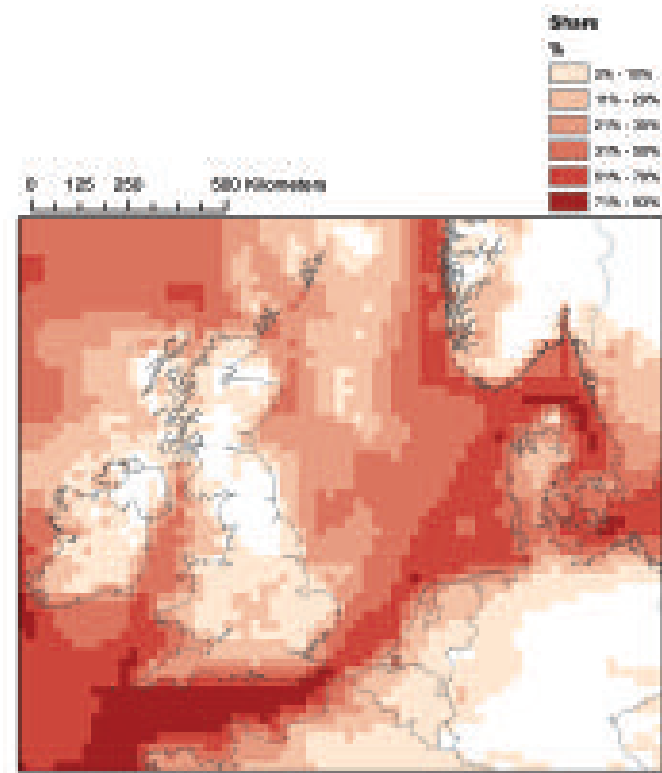


Figure 20 Comparison base Winter NO<sub>x</sub>

The highest pollutant concentrations typically occur over land at highly populated or industrialized areas. Some of these areas in France, Belgium, Holland and UK lie relatively close to the shore and experience therefore moderate concentration increases by ship emissions. While sites east of the English Channel show increases of about 10% much less increase can be discovered along the eastern coast of the UK. The reason is that pollutant clouds from the shipping lanes going through the Channel are transported towards the continent by the prevailing westerly and south-westerly wind directions. In less populated areas like Scotland and large parts of Scandinavia pollution levels are generally lower than in the above mentioned regions. This is why the relative pollution increase by ships can be up to 50% in summer and between 10 and 20% in winter. This is above all the case for Denmark, South Norway and South Sweden, which are surrounded by numerous shipping routes.

One of the largest sources of land based pollution is

The share of ship emission in NO<sub>x</sub> concentration in the winter 2011



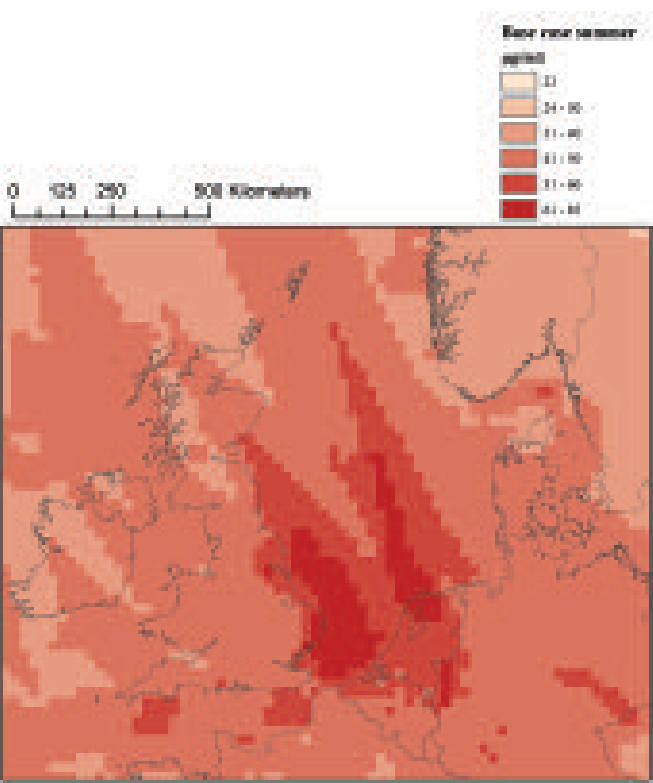
heating, which is subject to seasonality. Therefore, the relative contribution of ship engines to pollution levels is lower in winter than in summer because, while the shipping activity is nearly the same all over the year, more pollution from land based sources is produced in winter than in summer (figures 19 and 20).

Ozone concentrations are usually denoted as eight-hour maximum concentrations. This is the maximum of eight-hour means calculated as gliding average for one day. A value of 120 µg/m³ was recommended by WHO in 2000 as the value below which health risks are low. The same value has been defined as a target value in the EU which should not be exceeded on more than 25 days per year within three subsequent years. Figure 21 illustrates that the eight-hour maximum concentration is highly variable because the formation of ozone is influenced by many factors, e.g. radiation, temperature, humidity and the presence of other substances. In some hot spots additional emission of NO<sub>x</sub> from ships can raise the eight-hour

ozone maximum by more than 10%. An analysis of the daily 8-hour maximum ozone values in selected coastal regions around the North Sea shows that in Germany, the Netherlands and the UK a concentration of 120 µg/m³ is exceeded on more than 25 days (Table

11). Excluding shipping emissions would reduce this number significantly in the UK and in Germany. In the Netherlands the effects would be much smaller because of the high NO<sub>x</sub> emissions from other sources.

8h max. concentration of ozone in summer 2011



The share of ship emission in ozone concentrations in summer 2011

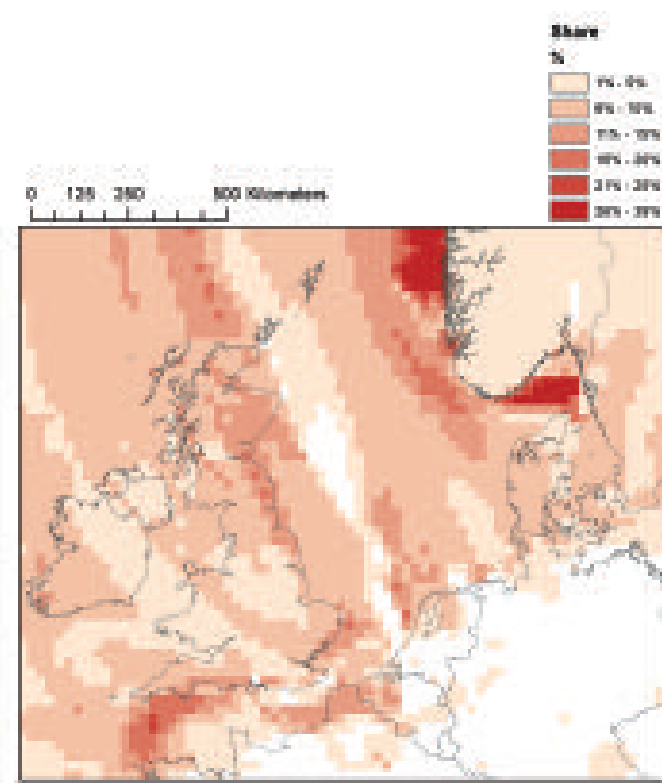


Figure 21 Mean 8-hour maximum ozone concentration in summer 2011 and the share ship emissions have in producing ozone

Number of days with 8-hour maximum ozone concentrations > 120 µg/m³					
	DE	NL	UK	DK	NO
All emissions	27	46	29	19	9
Without ships	14	42	18	6	4

Table 11 Number of days with 8-hour maximum ozone concentrations > 120 µg/m³ in selected regions around the North Sea (see also Figure 21)

The influence of ship emissions on secondary pollutants like particulate matter can be seen even further away from the shipping lines. The reason is that secondary pollutants are formed from direct gaseous

exhaust through chemical reactions. While these reactions are taking place the pollutant clouds can be transported inland (Figure 22).

## Concentration of PM<sub>10</sub> in the summer 2011

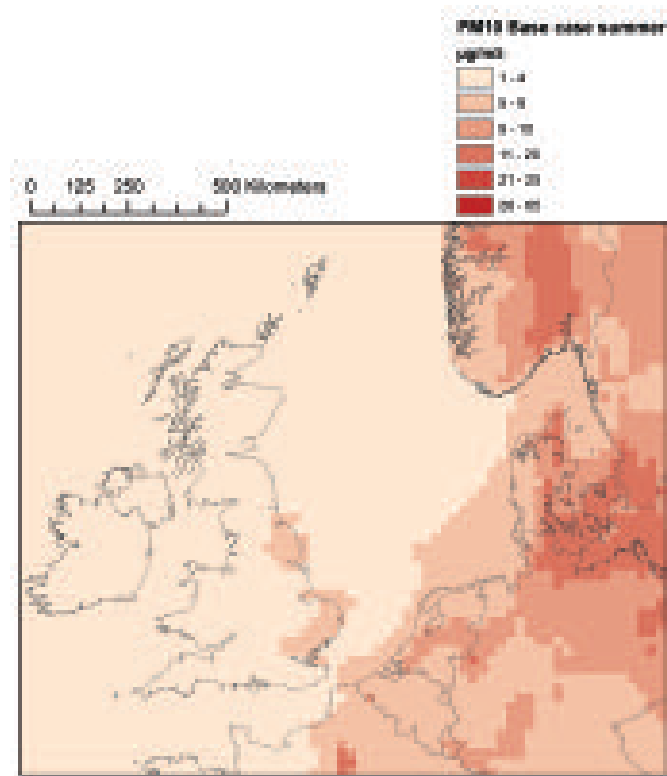
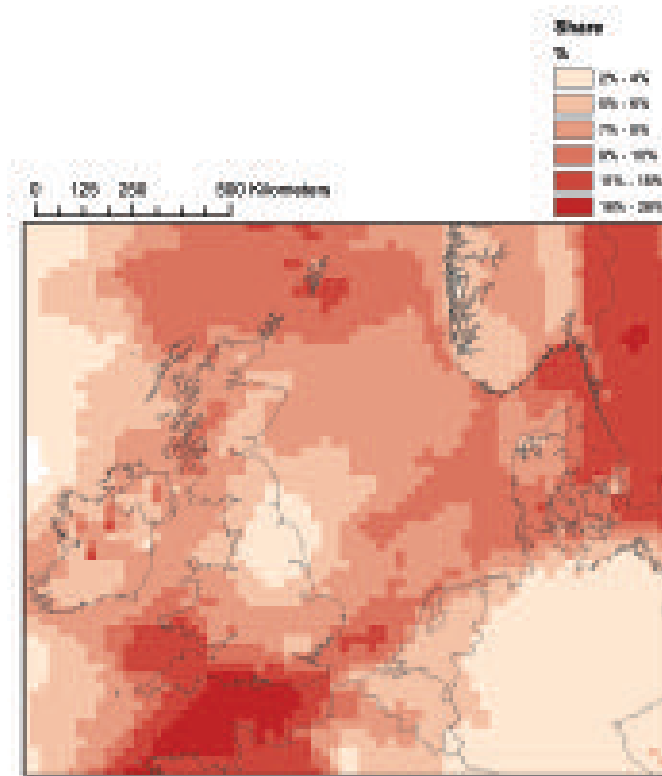


Figure 22 Comparison base Summer PM<sub>10</sub>

Along the major shipping lanes between UK and Germany the pollution levels are comparable to those of mildly polluted land sites in Europe. Nowhere in the investigated domain is the contribution of ship emissions to any pollutant 100%. This means that emissions produced ashore and substances from outside the domain boundaries are transported over the North Sea. Where these influences are low the contribution of ship emissions are the highest provided ships operate in these regions. The most significant example for this is the western entrance to the English Channel where the ship emissions are responsible for over 90% of NO<sub>2</sub> and SO<sub>2</sub> concentrations.

The temporal evolution of concentration levels can be illustrated by time series plots. Figures 23 to 25 show time series of daily concentrations for NO<sub>2</sub>, PM<sub>10</sub> and ozone for a selected area close to the German North Sea coast (see figure 28). The black line belonging to the left y-axis represents daily averages for NO<sub>2</sub> and PM<sub>10</sub> and eight hour maximum values for ozone. The

## The share of ship emission in PM<sub>10</sub> concentrations in summer 2011



green line with the scale on the right y-axis shows the concentration decrease if ship emissions are excluded from the simulation run. Both the total NO<sub>2</sub> concentrations and the contribution from ships is higher in winter than in summer. This seasonality is due to the fact that the degradation of NO<sub>2</sub> is enhanced in summer. The contribution of ships to PM<sub>10</sub> appears to be equally distributed over the year. Like explained above, PM<sub>10</sub> is a secondary pollutant that is only formed from exhaust in suitable ambient conditions, and the temporal concentration pattern could, hence, be very little dependent on the variation of ship emissions. The formation of ozone is most of all driven by radiation and temperature. Thus, there is a clear summer to winter gradient. It is also evident that the contribution of ships can punctually be very significant. The high variability between the days in all of these three figures must be attributed the changeable weather conditions.

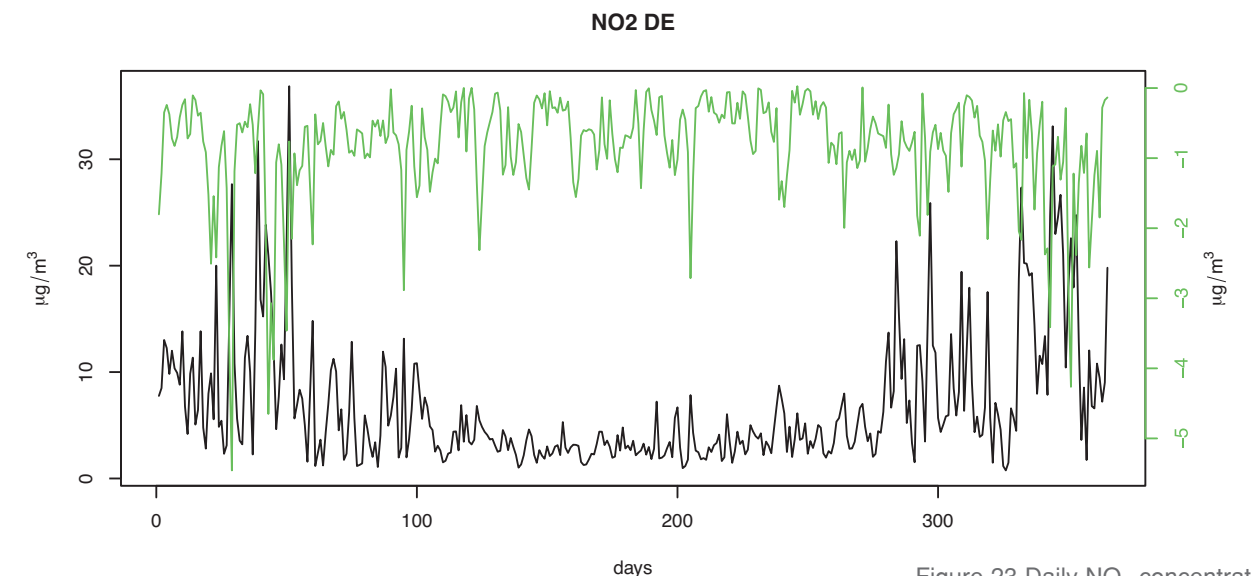


Figure 23 Daily NO<sub>2</sub> concentrations

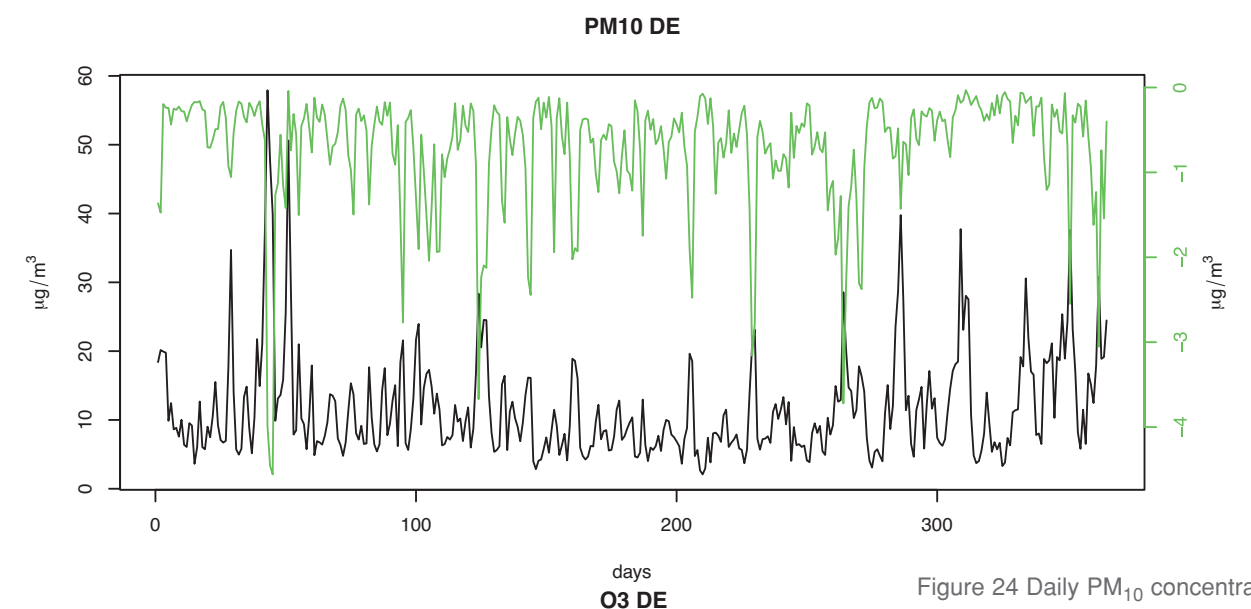


Figure 24 Daily PM<sub>10</sub> concentrations

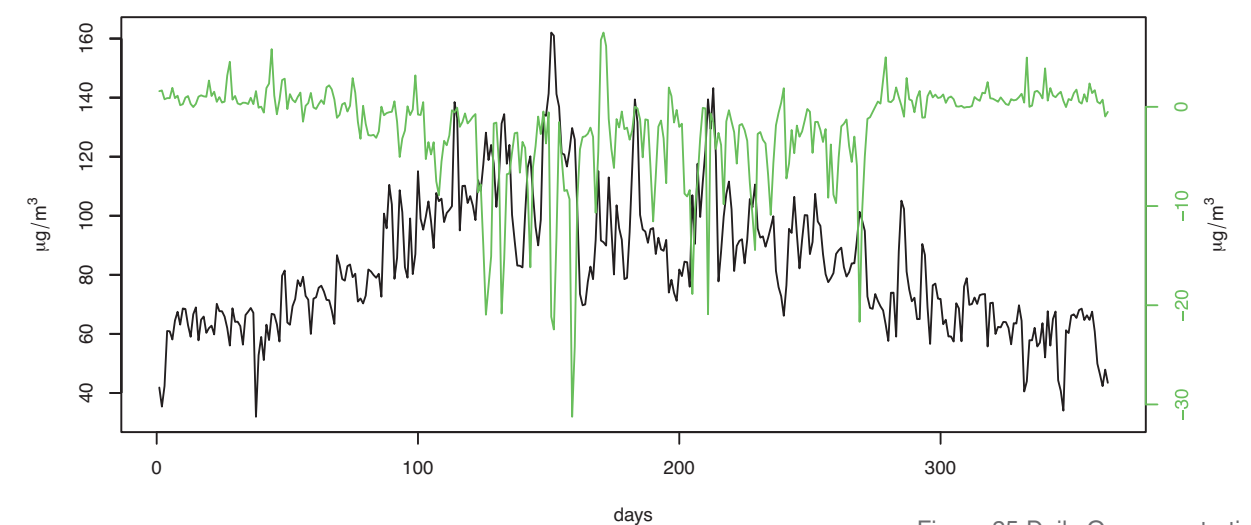


Figure 25 Daily O<sub>3</sub> concentrations



## Analysis of Future Prospects regarding Air Emissions from Ships

CNSS investigates different technologies that are capable of reducing the air emissions from ships in the North Sea. In order to estimate the effect of these technologies and of different legislation with respect to  $\text{NO}_x$  and  $\text{SO}_2$  emissions from ships, emission scenarios have been developed for 2030. These scenarios are implemented as emission maps for the year 2030. The maps serve as input for the chemistry transport model CMAQ that is setup for the North Sea region. CMAQ calculates transport and transformation of the emitted pollutants and finally gives concentration maps that illustrate the impact of shipping emissions on the air quality in the North Sea region.

### Basis of scenarios

The purpose of scenarios is to describe possible future developments. A scenario is not a prediction of the future. Scenarios are often used to describe the boundaries of possible future situations, e.g. a worst case and a best case, but they should not be totally unrealistic.

The CNSS scenarios are centred on the implementation of different emission reduction techniques while the development of the world trade and connected with this the development of the world fleet are not treated as variables. Taking multiple possible developments of the world trade into account would add too much complexity to the scenarios. Therefore we took only one scenario for the fleet development as it is described in publications from IMO (Buhaug et al., 2009) and DNV (Det Norske Veritas, 2012) into account as a basis. We think that this is a likely and not very extreme scenario.

In brief, this fleet development scenario assumes an increase in the number of bigger ships while the number of smaller ships decreases in the North Sea area. This leads to an increase in ship number by 1.0 % p.a. and an increase in transported cargo of 2.5% p.a. Additional to this increase in ship number it has been assumed that per year 2.5% of all ships are

replaced by new ones, no matter what size they have.

The main techniques under investigation are Liquefied Natural Gas (LNG) as an alternative fuel for shipping and end-of-the-pipe technologies like scrubbers and selective catalytic reduction (SCR) to reduce sulphur dioxide and nitrogen oxide emissions.

The main drivers for changes in the use of ship fuels and in the amount of emissions to air are on the one hand regulations, and here mainly what is written in MARPOL Annex VI, and on the other hand the price of different fuels. Therefore the main scenarios include strict and less strict legislation as one axis and the price of LNG compared to MGO or HFO as the second axis.

Some regulations in MARPOL Annex VI (those related to  $\text{NO}_x$  emissions) are only valid for newly built ships after 2016, which means that it needs some time until we will see a higher number of ships in the fleet that follow these new regulations. Others apply to all ships (those related to the sulphur content in ship fuels) and these should have immediate effects on the total emissions of sulphur oxides. To particularly take into account the long term effects of new ships following Tier III regulations, the year 2030 is used in the scenarios as target year. The development of the world fleet until 2030 compared to the reference year 2011 is considered.

### Detailed scenario descriptions

#### Basis

The basis for the ship fleet and the ship movements on the North Sea is a data set with AIS positions from ships for the entire year 2011 together with a **ship characteristics data base** that includes all ships given in the **AIS data set**. The data is used to calculate the power demand of individual ships depending on their actual velocity. From this, fuel use and subsequently  $\text{NO}_x$ ,  $\text{SO}_x$ ,  $\text{CO}_2$ , CO, Hydrocarbon (HC), and PM emissions are calculated with load-dependent emission factors for the different species.

### Fleet development

For the fleet development it is taken into account that ships are scrapped and new ships are built. The total trade volume will increase and so will the size of the ships. The assumptions behind the fleet development are taken from Buhaug (2009) and DNV (2012). They include the following:

- Trade volume increases 2.7%/a (Buhaug, 2009)
- Number of ships increases 1%/a (DNV, 2012)
- Mean ship size increases 1.7 %/a
- New ships built: 3.5%/a (estimated from DNV, 2012)
- Shipbreaking: 2.5%/a (to comply with increased number of ships)
- Older ships are scrapped first
- The technical equipment on board of the ships follow the technical regulations valid at the time the ship is keel laid

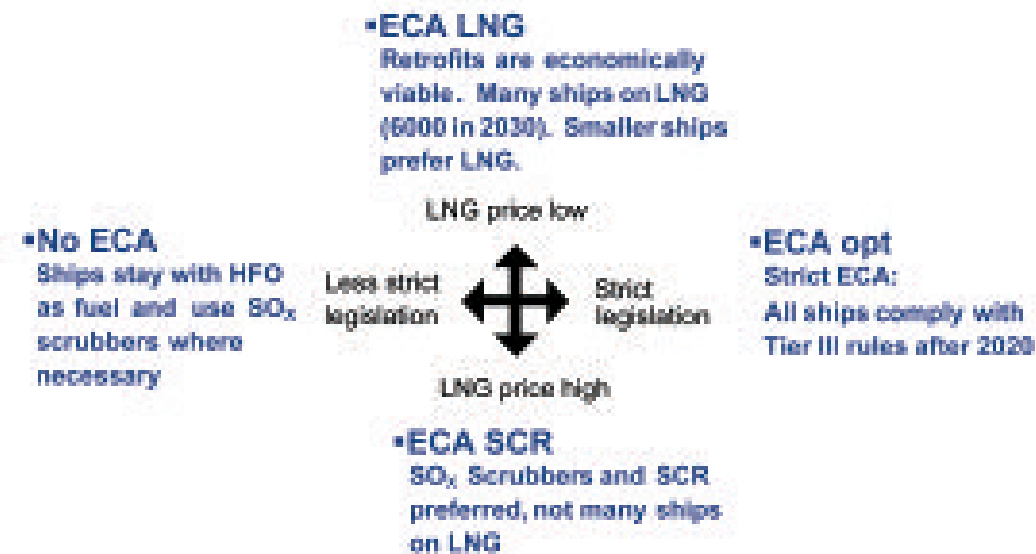
The scenarios for LNG, regulations and other exhaust gas cleaning technologies are developed around the drivers “LNG price” and “legislation”.

1. If the LNG price is low in comparison to MGO and HFO, investments in LNG-driven ships are economically feasible.

2. If the LNG price is high, other techniques to comply with MARPOL Annex VI are less expensive than LNG and exhaust gas cleaning methods like catalysts are preferred by the ship owners.
3. In case of a strict legislation, the North Sea will become an emission control area for  $\text{SO}_x$  and  $\text{NO}_x$ .  $\text{SO}_x$  limits of 0.1%S in the fuel will be valid from 1 January 2015 onwards; Tier III  $\text{NO}_x$  limits apply for all new ships from 1 January 2016 onwards. Globally, a maximum of 0.5%S in ship fuels will come into force in 2020.
4. In a very strict legislation, also older ships would need to comply with the Tier III rules after a certain period that is needed to retrofit these ships. In 2030 all ships would comply with these rules.
5. A less strict legislation would mean that no global  $\text{SO}_x$  limits and no  $\text{NO}_x$  limits will apply in ECAs. However the  $\text{SO}_x$  limits with 0.1%S in ship fuels will come into force in ECAs in 2015 and will be completely followed in 2020.

These drivers are combined into four scenarios that can be arranged in a coordinate system with legislation on the x-axis and LNG price on the y-axis (Figure 26)





Figur 26 Scenarios for technical developments and legislation with respect to ship emissions for 2030.

The stories behind these scenarios can be described as follows:

#### Scenario No ECA:

Economy is still down and in order to put no additional costs on the shipping industry some regulations on SO<sub>x</sub> limits will be postponed (SO<sub>x</sub> limits in ECAs), others will not be implemented (global SO<sub>x</sub> limit, NO<sub>x</sub> limits). This can be considered the worst case scenario, however 0.1% S in fuels in ECAs will be fully implemented in 2020.

#### Scenario ECA LNG:

All regulations currently given in MARPOL Annex VI will be in force. The global sulphur limit of 0.5% S in fuel will be in force in 2020. A NO<sub>x</sub> emission control area will be implemented in the North and Baltic Seas. LNG will be the cheaper solution to comply with the rules. In 2030, 6000 ships in the North Sea will run on LNG. Ships that sail more than 50 % in the North and Baltic Seas will preferably use LNG. Some newer ships will also be retrofitted with LNG engines.

#### Scenario ECA SCR:

The legislation is the same as in scenario 2 but LNG is expensive and the LNG infrastructure is not built up to serve many ships with LNG. Therefore ship owners will prefer low sulphur fuels and catalysts (SCR) or exhaust gas recirculation systems (EGR) to comply with the

rules. Some will also use scrubbers if they do not have to follow the Tier III regulations (older ships).

#### Scenario ECA opt:

This is built on scenario 2 but it assumes that the strict rules for NO<sub>x</sub> emissions for new builds will also apply for older ships in 2030. They will then be retrofitted with exhaust gas cleaning systems in order to follow these rules. This is regarded as the best or optimum case scenario. It can also be seen as a post-2030 scenario, when all ships sailing the North Sea were built after the date for the implementation of Tier III (which is currently 2016).

Scenario ECA LNG and scenario ECA SCR were run with two different dates for the implementation of Tier III for new ships. Scenarios ECA LNG 16 and ECA SCR 16 stand for 2016 as implementation date, which is currently foreseen. Scenarios ECA LNG 21 and ECA SCR 21 assume that the rules are applied 5 years later, i.e. in 2021.

#### Model results

The emission maps that were constructed as input for the CMAQ model are developed from the ship emission inventory for 2011 which is based on AIS data and ship characteristics data. First, the fleet development according to the rules given above is applied. Afterwards the new emissions are calculated,

depending on the scenario and taking into account the age of the different ships in the ECA LNG and ECA SCR scenarios.

The annual average emissions for NO<sub>x</sub> are given for 4

scenarios in Figure 27. ECA SCR and ECA LNG have identical NO<sub>x</sub> emissions. Therefore ECA LNG is not shown in the figure.

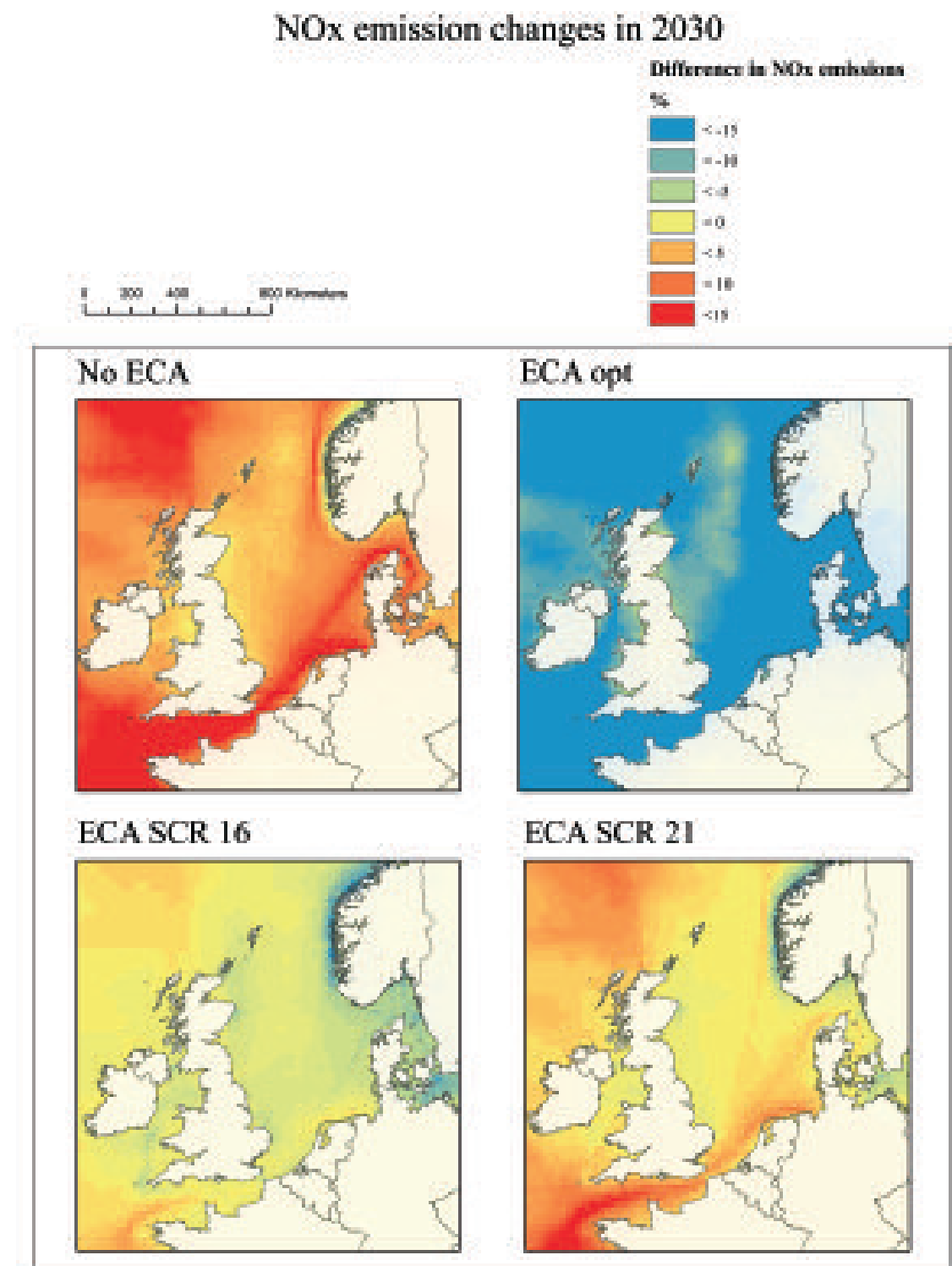


Figure 27 Changes in NO<sub>x</sub> emission from ships in 2030 relative to the base case for 2011 (see Figures 16 & 17) for 4 scenarios shown in Figure 25. ECA SCR and ECA LNG (not shown) have identical NO<sub>x</sub> emissions.



The results for today's situation have been discussed in the City scale air quality modelling section. Here, we refer to the results for the scenarios in 2030. We mainly discuss the consequences of changes in the  $\text{NO}_x$  emissions from ships, because here we see the main differences between the scenarios. Additionally, the strict rules for  $\text{SO}_x$  will come into force in the North Sea ECA in 2015 and there are only small differences between the scenarios with respect to  $\text{SO}_x$  emissions in the North Sea.

$\text{NO}_x$  emissions from ships have an impact on the  $\text{NO}_2$  concentrations, on nitrate aerosol and on ozone. It can be expected that  $\text{NO}_2$  and nitrate aerosol concentrations increase due to ship emissions and that this effect is largest in winter. The impact on ozone will be different in winter and summer. While in the

summer, increased  $\text{NO}_x$  emissions will lead to increased ozone under most weather conditions and in most regions, this will lead to slightly lower ozone concentrations in the winter.

In the following, difference maps illustrating the impact of shipping on  $\text{NO}_2$ , nitrate aerosol and ozone concentrations in 2030 will be shown for scenario 2a (Tier III in 2016) and 2b (Tier III in 2021). The relation to the other scenarios will be illustrated in time series for different North Sea coastal regions (see Figure 28), each of them comprising about 9200  $\text{km}^2$ . These time series nicely show the highly variable impact of shipping emissions, which depends to a large extent on the weather conditions and the concentrations of pollutants from other sources.

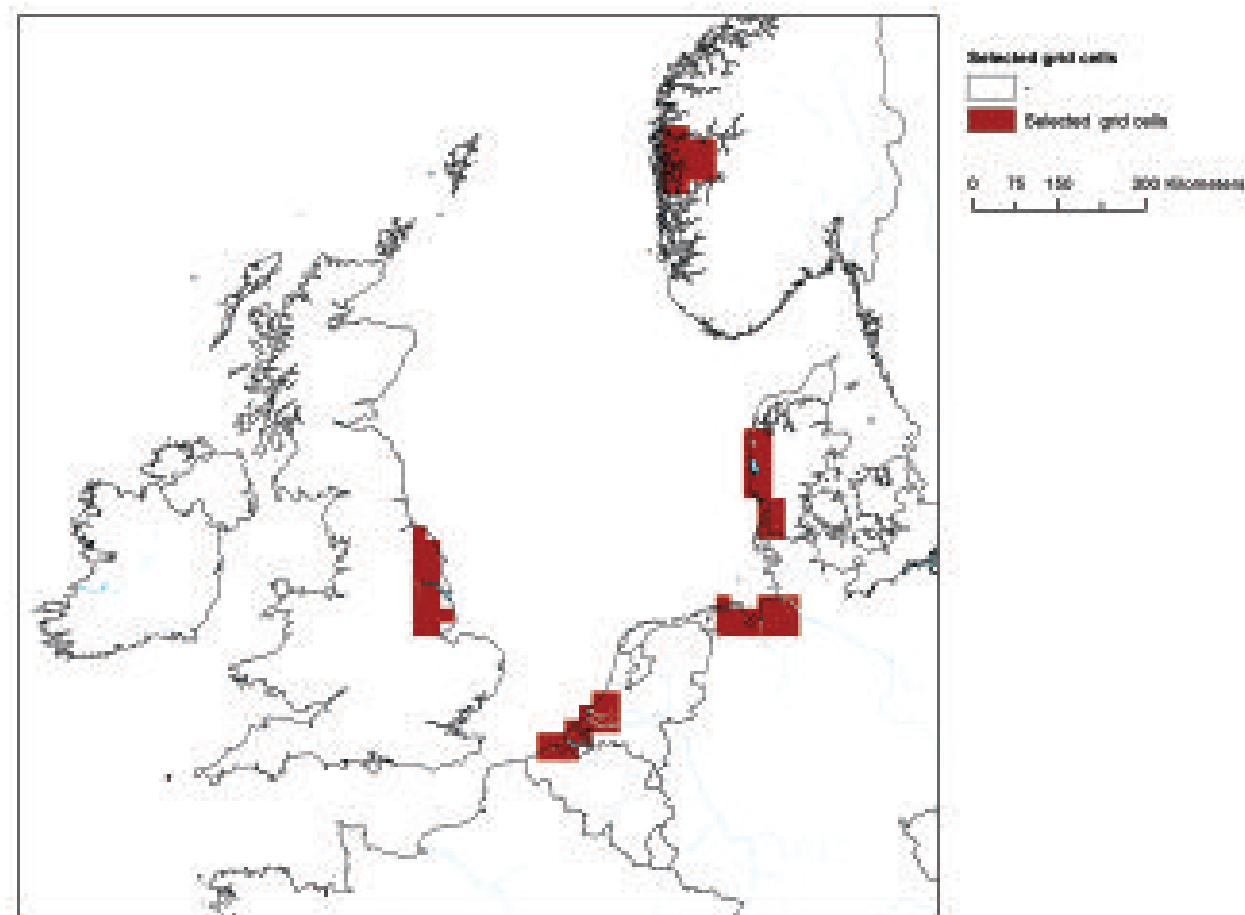


Figure 28 Map of the North Sea region illustrating the five regions (namely NO, DK, DE, NL and UK) for which time series of pollutant concentrations have been derived from CMAQ modelling results.

### Nitrogen dioxide

Scenario ECA SCR 16 on average shows a moderate increase in the  $\text{NO}_2$  concentrations caused by ships. In Figure 29 this is shown for winter. While in the English Channel and the Southern North Sea the concentrations decrease by 1-5 % only, they decrease more than 10 % in all other parts of the North Sea and in particular at the British, Norwegian and Swedish coast. This is caused by the fact that the traffic to the main North Sea ports in Rotterdam, Hamburg and Antwerp will still increase and ships will become bigger, resulting in the smallest decrease in the entire North Sea. Today, smaller and older ships travel to the smaller harbours in the North Sea area, however many of them will be replaced after 2016, which means that a high fraction of those ships will comply with Tier III.

This will lead to a reduction of the contribution of shipping emissions to  $\text{NO}_2$  concentrations in the central and northern part of the North Sea.

Figure 30 shows scenario ECA SCR 21 in which the Tier III rules for new ships come into force only in 2021 instead of 2016 in the previous case. This means that in 2030 a larger part of the fleet will still follow the less strict Tier I and Tier II regulations. Very few ships older than 30 years will not have to comply with any of the  $\text{NO}_x$  regulations. As a consequence, the contribution of ships to the average  $\text{NO}_2$  concentration will be approximately 11-15% higher than in the case with Tier III regulations from 2016 onwards.

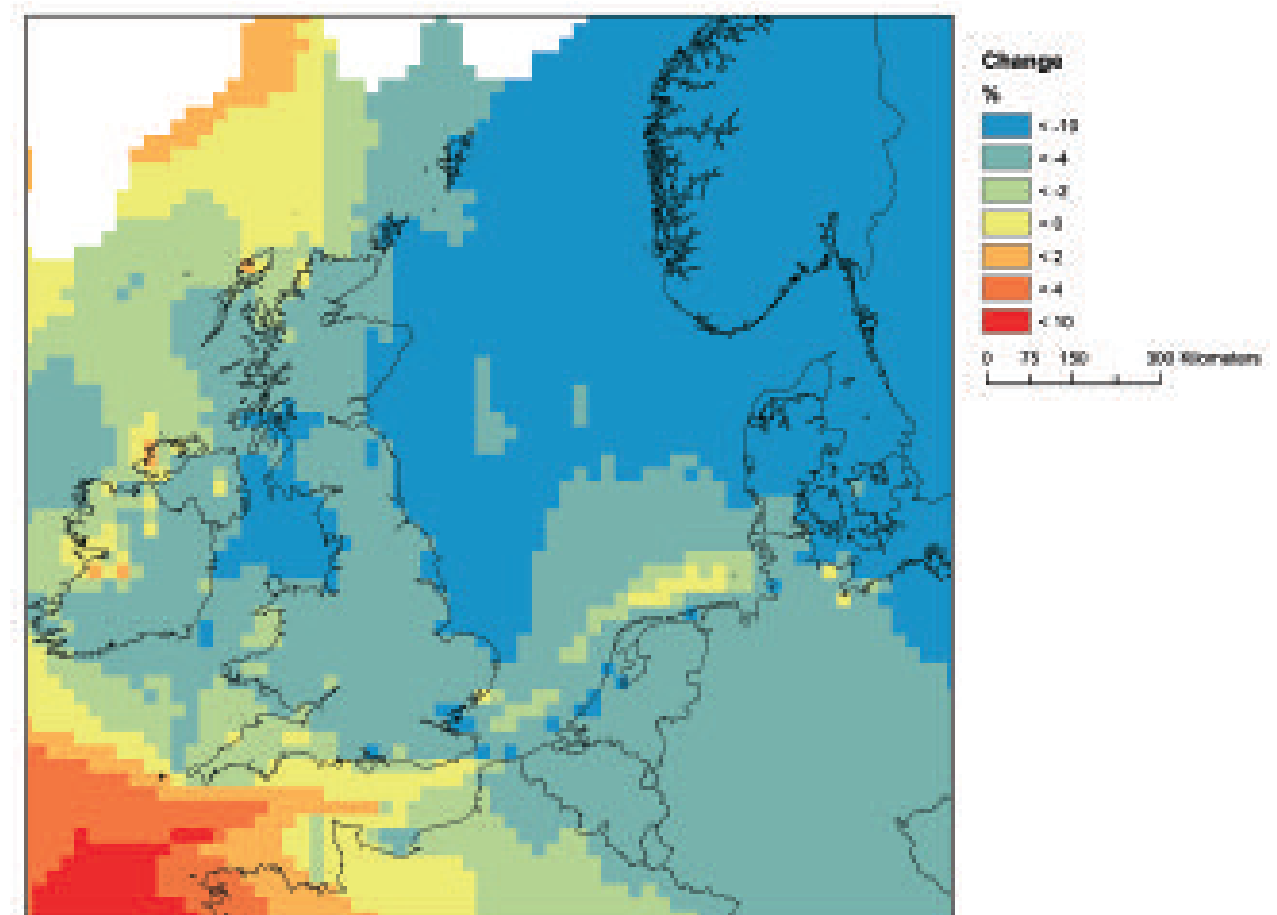


Figure 29 Development of the contribution of ships to  $\text{NO}_2$  concentrations in the winter 2030, when Tier III regulations are implemented in 2016.

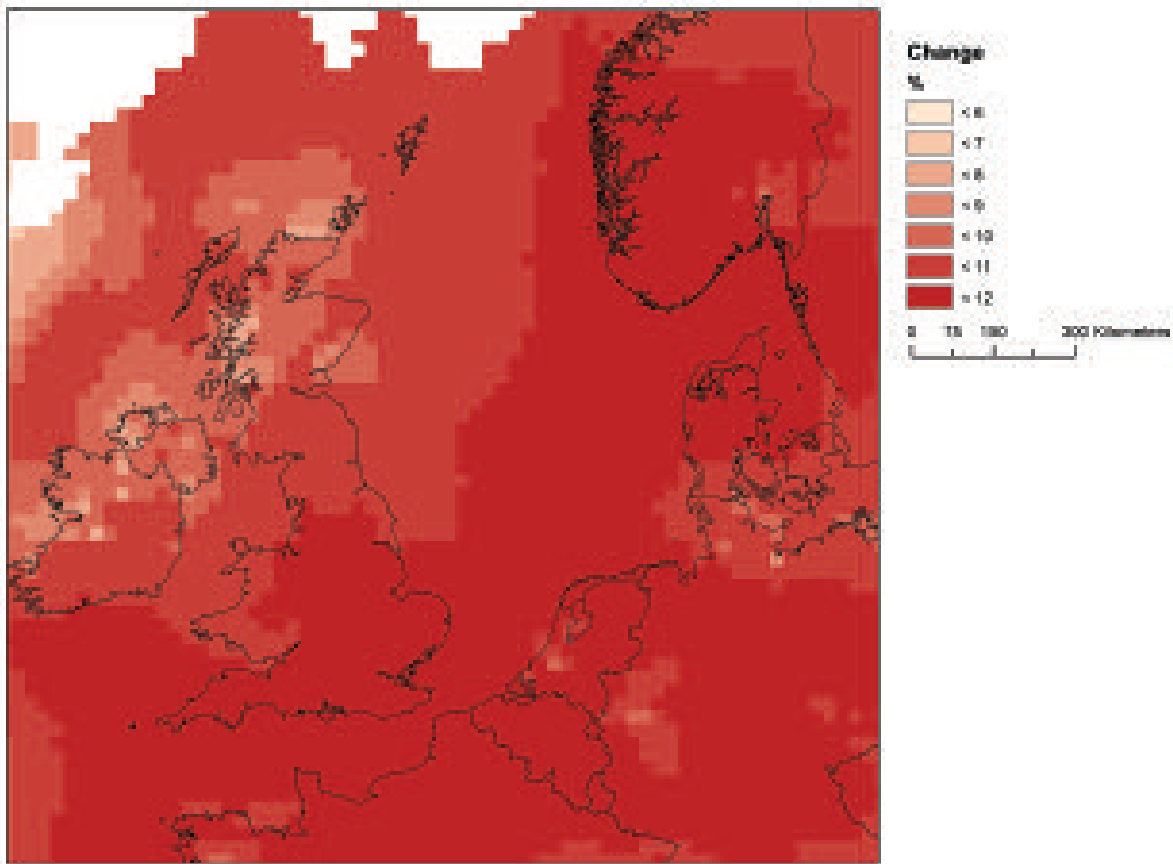


Figure 30 Increase in the contribution from ships when Tier III regulations are implemented in 2021.

Figure 31 exemplarily shows a time series of the contribution of shipping to the daily average  $\text{NO}_2$  concentrations at the coasts of Belgium and the Netherlands (see Figure 28 for the region). If the emissions of all ships were cut down to zero, the  $\text{NO}_2$  concentration would be on average  $2 \mu\text{g}/\text{m}^3$  lower, on many days it would be even more than  $4 \mu\text{g}/\text{m}^3$  lower. From the scenarios for 2030, the implementation of Tier

III in 2016 shows a slight decrease in the contribution of shipping to the  $\text{NO}_2$  concentrations compared to today. If Tier III will be implemented in 2021 or not at all until 2030, the contribution of shipping to the  $\text{NO}_2$  concentration will be higher than today. Large reductions of  $\text{NO}_2$  from shipping are only achieved in scenario 4, i.e. when all ships and not only new builds follow the Tier III regulations.

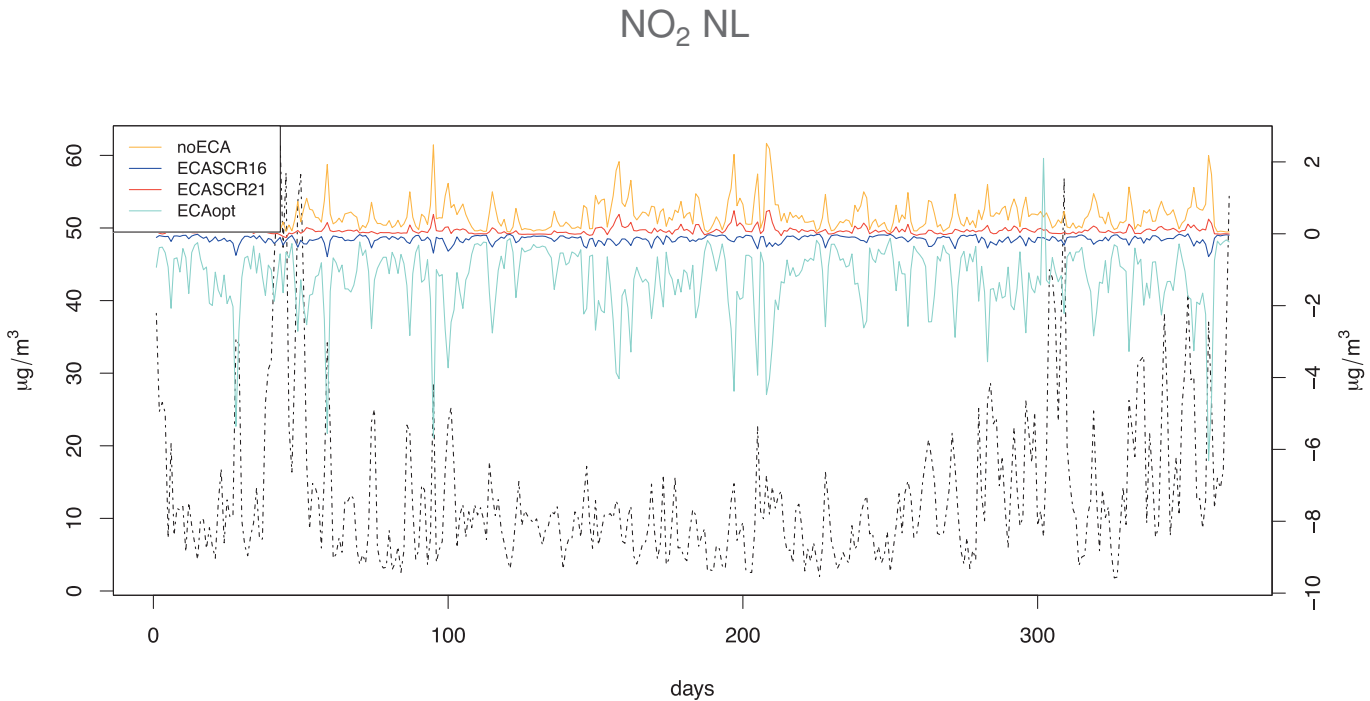


Figure 31 Time series of daily average  $\text{NO}_2$  concentrations in  $\mu\text{g}/\text{m}^3$  (shaded grey, left y-axis) and the contribution of shipping to the  $\text{NO}_2$  concentrations in the coastal areas of Belgium and the Netherlands for all scenarios (right y-axis). No ship denotes the changes if all ship emissions were cut to zero

### Nitrate Aerosol

Nitrate aerosol ( $\text{NO}_3$ ) is formed in the atmosphere as a consequence of the oxidation of  $\text{NO}_2$ . The amount of aerosol particles that are formed highly depends on the presence of other pollutants, in particular on the availability of ammonia ( $\text{NH}_3$ ). Ammonia mainly stems from agricultural activities. The regions with the highest ammonia emissions are western France, the Benelux countries, western Germany and Denmark.

Scenario ECA SCR 16 shows a decrease in the contribution of shipping to nitrate aerosol concentrations by 7-10 % in the north eastern part of the North Sea, in the south western part an increase by more than 10 % can be observed (Figure 32). This is in line with the changes in  $\text{NO}_2$ , although the pattern that

is visible on the map is less confined to the main shipping lanes. This is caused by the fact that the nitrate aerosol formation takes some time in which the air masses are transported in different directions. Additionally the concentrations depend not only on the emissions but also on meteorological conditions and the presence of other pollutants. This is clearly visible in Figures 21 & 22. For the main reason, the differences between scenario ECA SCR 16 and ECA SCR 21 do not show a uniform picture (Figure 33). They vary between 10 and 15 % higher contribution of shipping to nitrate aerosol in the winter for the case of a postponement of the Tier III regulations from 2016 to 2021.

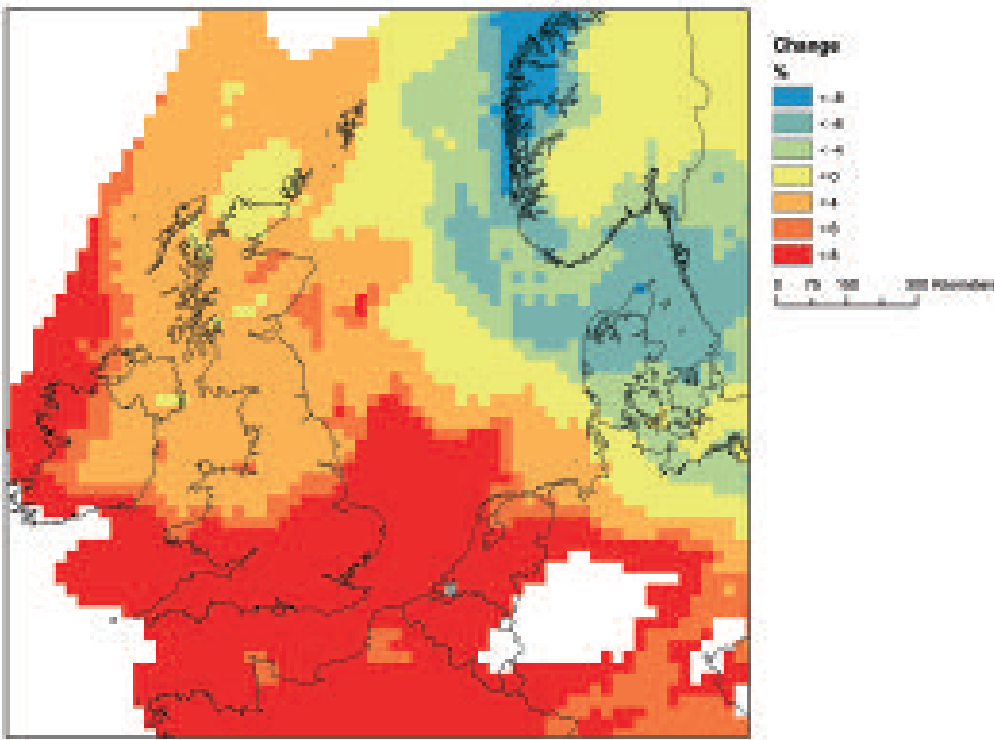


Figure 32 Development of the contribution of ships to nitrate aerosol concentrations in winter 2030, when Tier III regulations are implemented in 2016

Ozone

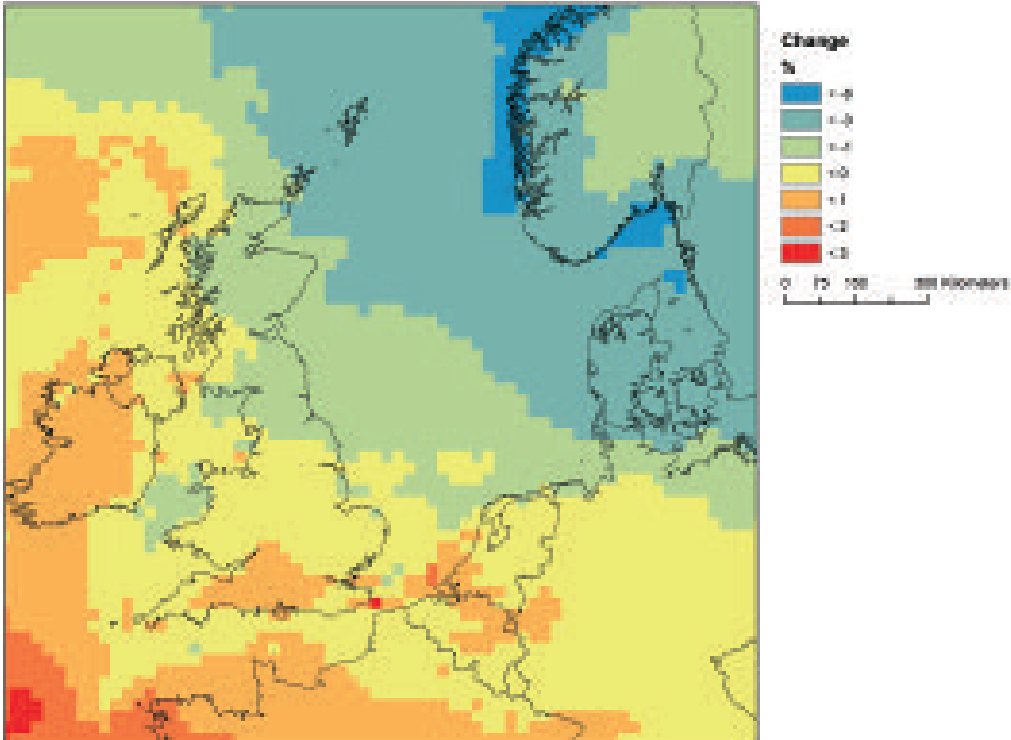


Figure 34 Development of the contribution of ships to 8-hour maximum ozone concentrations in summer 2030, when Tier III regulations are implemented in 2016

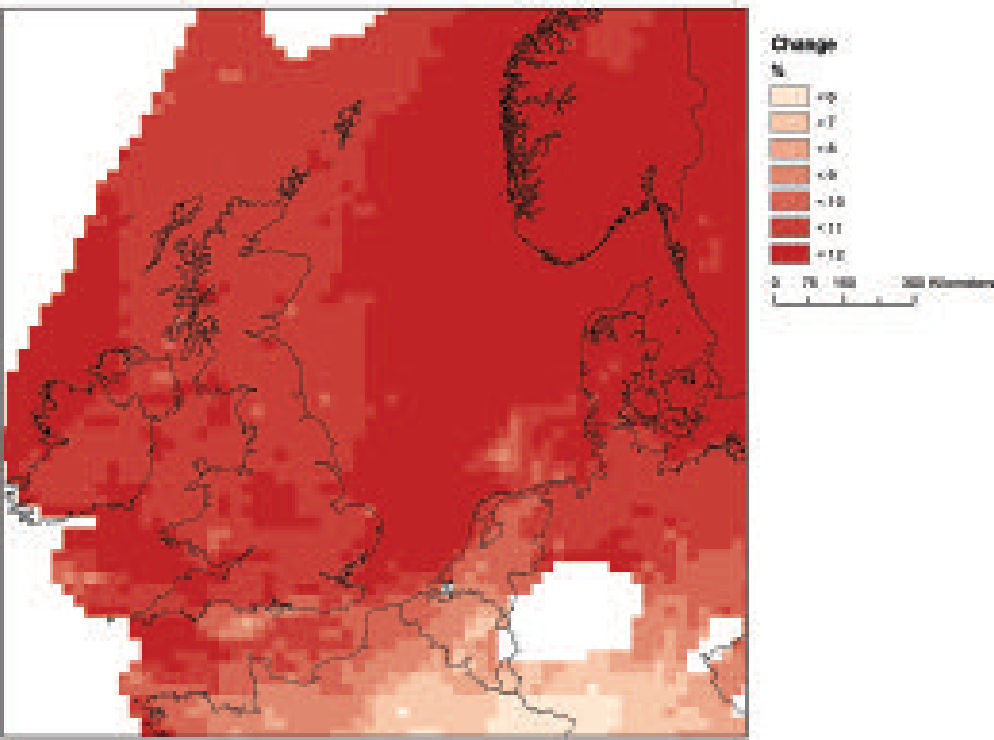


Figure 33 increase in the contribution from ships to nitrate aerosol concentrations in winter 2030 when Tier III regulations are implemented in 2021

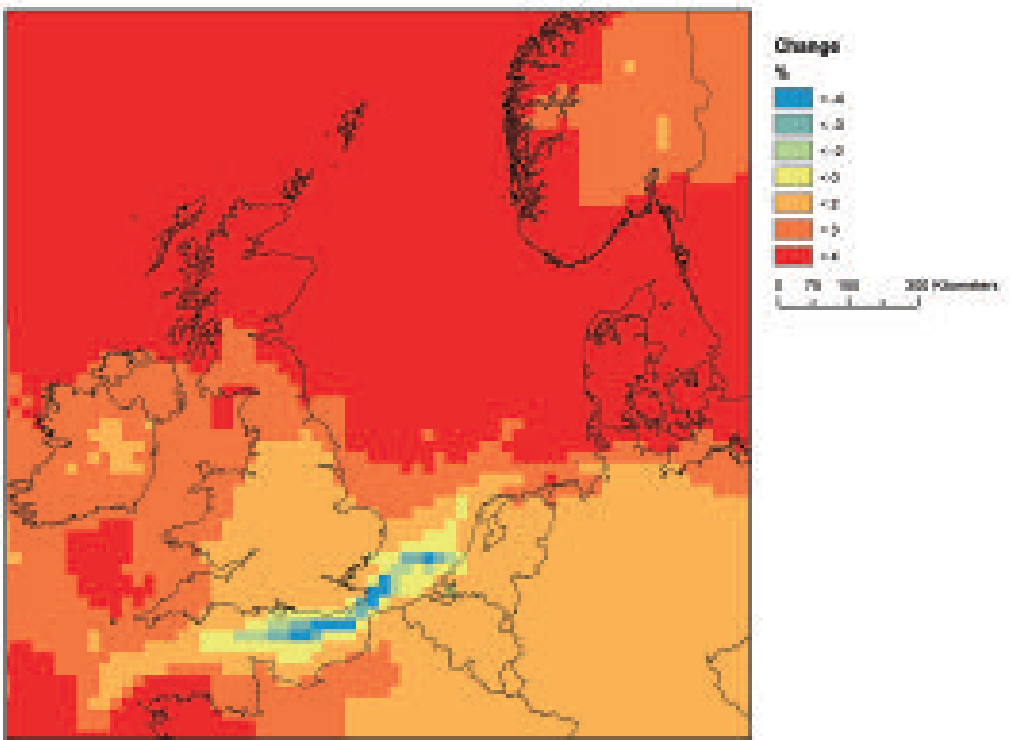


Figure 35 increase in the contribution from ships when Tier III regulations are implemented in 2021

NO<sub>x</sub> emissions from ships have a strong influence on the atmospheric ozone concentrations. Ozone is formed out of NO<sub>2</sub> and atmospheric oxygen in the presence of sunlight. On the other hand NO destroys ozone, particularly during night-time. This leads to a strong diurnal cycle of the ozone concentration and a large difference between winter and summer levels with much higher ozone concentrations in the summer. Here we look at the impact of shipping emissions on the daily maximum of the 8-hour mean ozone values. Figure 34 shows a map of the distribution of the changes in the contribution of ships to the 8-hour maximum ozone concentration for scenario ECA SCR 16. As for NO<sub>2</sub>, the contribution from shipping will decrease slightly in the north eastern part of the North Sea while it will remain more or less unchanged in the south western part. Scenario ECA SCR 21 has higher NO<sub>x</sub> emissions which will result in higher ozone values by up to 6 % compared to scenario ECA SCR 16. An exception is the English Channel, where higher NO<sub>x</sub>

emissions result in decreased ozone concentration. This is caused by the very high NO<sub>x</sub> emissions in this region.

Fig. 36 shows a time series of the 8-hour maximum ozone concentrations in northern Germany. It can be seen that the ozone values would be lower in the summer, on some days more than 20 µg/m<sup>3</sup>, if ships would not emit NO<sub>x</sub>. On the other hand they would be slightly higher in the winter.

The scenarios show that not much change compared to today can be expected in 2030. In case of scenario No ECA (with no NO<sub>x</sub> reductions), higher ozone values than today are expected. Significant reductions in the peak values of the ozone concentration can only happen, when all ships follow the Tier III regulations (scenario ECA opt).

An analysis of the different regions exhibits that the days with concentrations higher than 120 µg/m<sup>3</sup> (a value recommended by the World Health Organization, WHO) would decrease significantly by 50 % or more without shipping emissions in all regions except the Netherlands (see Table 11). The main scenarios for 2030 do not show big differences in the number of days with concentrations above 120 µg/m<sup>3</sup>. While small increases in the number of days can be expected if Tier III rules are not implemented (scenario No ECA), the only case with a strong decrease in exceedance days is scenario ECA opt.

Number of days with 8-hour maximum ozone concentrations > 120 µg/m <sup>3</sup> in 2030					
	DE	NL	UK	DK	NO
2011	27	46	29	19	9
No ECA	29	46	29	20	9
ECA SCR 16	26	46	29	18	8
ECA SCR 21	27	46	29	18	8
ECA opt	16	45	22	12	6

Table 12 Number of days with 8-hour maximum ozone concentrations > 120 µg/m<sup>3</sup> in 2030 in selected regions around the North Sea for the scenarios No ECA, ECA SCR 16, ECA SCR 21, and ECA opt

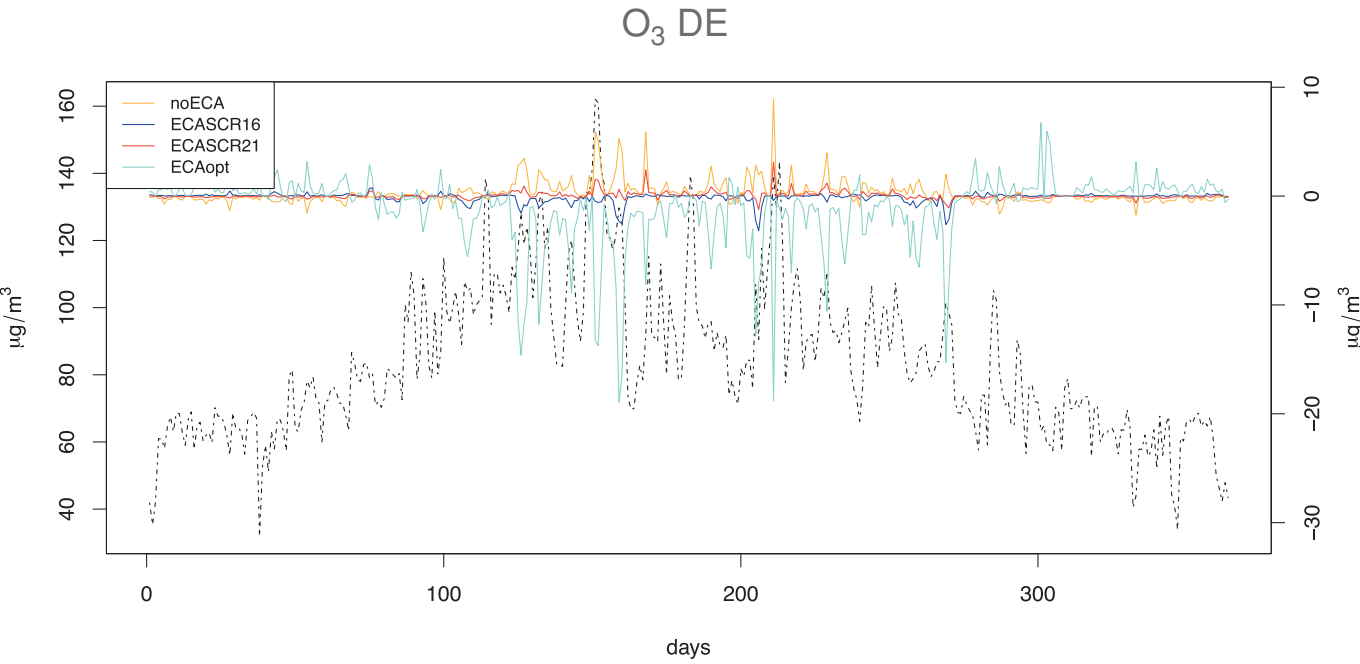


Figure 36 Time series of 8-hour maximum ozone concentrations in µg/m<sup>3</sup> (shaded grey, left y-axes) and the contribution of shipping to the ozone concentrations in the coastal areas of Germany for all scenarios (right y-axes). “noship” denotes the changes if all ship emissions were cut to zero





### Total PM 10

Particulate matter with a diameter less than 10  $\mu\text{m}$  ( $\text{PM}_{10}$ ) is formed in the atmosphere through chemical reactions that lead to a conversion of gaseous  $\text{SO}_2$  and  $\text{NO}_2$  into particulate nitrate ( $\text{NO}_3$ ) and sulphate ( $\text{SO}_4$ ). Both of them are chemical components of  $\text{PM}_{10}$ , many are even small and belong to particulate matter with a diameter less than 2.5  $\mu\text{m}$  ( $\text{PM}_{2.5}$ ).  $\text{PM}_{2.5}$  is included in  $\text{PM}_{10}$ . Even in the scenario with highest emission reductions, ECA opt, shipping typically contributes between 0.5 and 1  $\mu\text{g}/\text{m}^3$  to the total  $\text{PM}_{10}$

in coastal areas; see Figure 37 for average values in northern Germany. There is no clear seasonal cycle for the contribution from shipping; however total  $\text{PM}_{10}$  concentrations are higher in the winter than in the summer.

The scenarios show the same pattern as for the other pollutants. While in 2030 there will not be a large difference to today's concentrations, the application of Tier III rules to all ships will result in a significant reduction of PM from shipping.

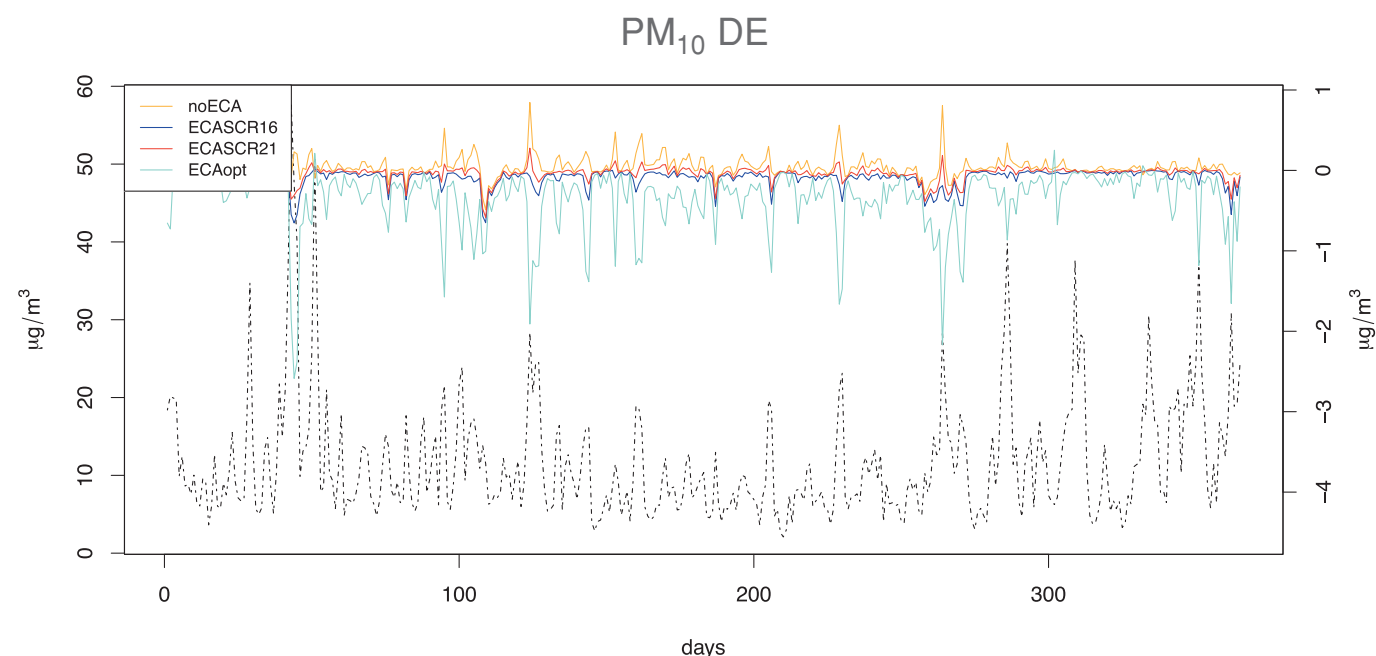


Figure 37 Time series of daily average  $\text{PM}_{2.5}$  concentrations in  $\mu\text{g}/\text{m}^3$  (shaded grey, left y-axis) and the contribution of shipping to the  $\text{PM}_{2.5}$  concentrations in the coastal areas of Germany for the main scenarios (right y-axis).

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## 2. Technology & Fuels

### Recommendations

#### LNG

Use of Liquefied Natural Gas (LNG) instead of conventional diesel based fuels can significantly reduce emissions of all pollutants to air from ships.

- It is recommended that the use of LNG is promoted throughout the North Sea region for all shipping. CNSS has revealed that shipping has a great potential to reduce emissions of practically all air pollutants if LNG is used in contrast to using SCR or scrubbers which reduce the emissions of only single substances while increasing the fuel consumption at the same time. For example, compared to SCR the use of LNG avoids PM, HC and  $\text{SO}_2$  emissions. CNSS does acknowledge that methane slip needs to be minimised.
- Stakeholders need to facilitate and promote the development of international solutions for the future LNG regulatory framework through organisations and regulatory bodies: IMO; ISO; IAPH/WPCI
- With respect to LNG handling, usage and safety, legislators should avoid local, regional, or national regulations or procedures whenever possible.

#### OPS

Use of OPS can reduce the amount of local emissions from ships at berth but we acknowledge that electricity generation may produce emissions of pollutants elsewhere. Nevertheless, it may be easier to mitigate pollution from large land-based power generation stations than locally on board ships. The overall effect of OPS is more effective if it is used on a large scale.

- It is recommended that new ships should be fitted with OPS including small ships with 50Hz requirements.
- It is recommended to increase the OPS infrastructure in harbours

- It is recommended that a standard communication protocol be established in order to control the OPS ship-shore connection.

- It is recommended that the location of the HVSC connection on the ship should be standardised

### Clean Shipping Technology

#### Introduction

*The growth of shipping transport and subsequent impacts on the environment pose many challenges for the maritime industry. The North Sea is one of the most navigated seas in the world and ship movements have a significant impact on the air quality in coastal regions. One of the key challenges is to develop and implement environmentally sound, cost-effective concepts and practical solutions to reduce harmful emissions that meet the stringent environmental standards set for the period after 2015. The ultimate challenge is to develop and implement zero emission technologies.*

In 2000,  $\text{SO}_2$  and  $\text{NO}_x$  emissions from international maritime shipping in Europe amounted to approximately 30% of the land-based emissions in the EU-25. Since stringent technologies for onshore installations and diesel vehicles have been applied to reduce land-based emissions, maritime emissions have become more important in coastal areas. In addition, the IMO agreed a set of guidelines to significantly reduce  $\text{NO}_x$  emissions from shipping in the North Sea. Once the North Sea is designated as a  $\text{NO}_x$  ECA, coastal communities will benefit from significant  $\text{NO}_x$  reduction due to lower ship emissions.

Scientific research shows that the number of people dying from heart and lung disease as a result of under-regulated shipping emissions totalled 60,000 worldwide in 2002, and that death toll was estimated to

grow by 40% by 2012 due to continued significant increase in global shipping traffic. The calculations show that the North Sea region contributes significantly to this mortality figure.

Shipping is also a significant contributor to particulates. There has been strong progress in reducing emissions from truck engines during recent years, but this has not yet given a breakthrough for larger engines. Secondly, the fuel quality used for most ships is very poor. Residual oil usually contains very high levels of sulphur, up to 4.5%, compared with 10 ppm Sulphur for the diesel used for road traffic in European countries. This leads to the formation of large amounts of sulphate particles. What's more, residual oil contains large amounts of poly-aromatic hydrocarbons which are known to be carcinogenic and which are emitted together with soot and ash particles. Several countries have promoted the introduction of PM standards by the International Maritime organisation (IMO). However, to date PM and soot emissions are not regulated.

## Review of technological solutions

CNSS has investigated emission mitigating technologies for NO<sub>x</sub>, SO<sub>x</sub> and CO<sub>2</sub>. Most technologies are directed at the reduction of NO<sub>x</sub> and SO<sub>x</sub> as a result of the legislative framework, however some of the technologies also impact the formation of soot particles (PM) and CO<sub>2</sub>. CNSS have reviewed a number of technology options for reducing NO<sub>x</sub> emissions from ships:

### Engine Tuning

New engines with possible small penalty on fuel consumption (up to 3%) can meet the IMO Tier 2 NO<sub>x</sub> limits. This is achieved by combustion process optimisation, such as:

- Increased fuel injection pressure and delayed injection timing,
- Increased compression ratio,
- Reduced initial air temperature, and
- Optimised injection patterns.

The use of electronically controlled high pressure fuel injection facilitates combustion optimisation, especially at low loads.

### Water introduction to combustion chamber

Emulsion of fuel with water or Direct Water Injection (DWI) can result in 20% to 50% reduction of NO<sub>x</sub> formation. Addition of water to the combustion zone reduces peak combustion temperature and thus reduces NO<sub>x</sub> formation, as it is highly temperature dependent.

Air humidification: Humidification of air is an alternative way of introducing water, by mixing it with the air used for combustion. It can achieve up to 70% reduction in NO<sub>x</sub> in 4-stroke engines.

### Exhaust Gas Recirculation (EGR)

In this system NO<sub>x</sub> formation is partly reduced due to the reduction of oxygen concentration in the combustion zone, and partly due to the presence of water and carbon dioxide in the exhaust gas. The higher molar heat capacities of water and carbon dioxide lower the peak combustion temperature. It can achieve up to 70% NO<sub>x</sub> reduction with a small penalty (around 2%) in fuel consumption, and increased CO and PM emissions.

### Selective Catalytic Reduction (SCR)

Up to 95% reduction can be achieved. Urea is added to the exhaust stream and the mixture passed over a catalyst. The installation and maintenance costs are substantial, but the NO<sub>x</sub> reductions are high and the use of SCR allows the engine to be tuned for minimum fuel consumption. A number of SCR systems are in operation on ships.

### Alternative Fuel

Liquefied Natural Gas (LNG) can achieve very low NO<sub>x</sub> emissions without post-treatment.

### Scrubber

Exhaust gas scrubbers can remove the majority of SO<sub>x</sub> emissions from the exhaust stream, as well as a significant proportion of the particulate matter. Various systems developed for marine use, use sea water, fresh water or chemicals to wash out or neutralise the SO<sub>x</sub> discharge standard of wash water from scrubbers and the discharge quality of exhaust gas after cleaning are regulated in the IMO Resolution MEPC 184(59). All scrubbers need to attain the certificate complying with the standard.

### Low Sulphur Fuels

The most straightforward method of reducing SO<sub>x</sub> emissions is to reduce fuel sulphur content. Heavy fuel oil is largely composed of the thick residue from the crude oil refining process, to which lighter components have been added to bring it to a useable consistency. The majority of shipping runs on heavy fuel oil.

IMO MARPOL Annex VI will allow global fuel sulphur content of 3.5% until 2020, a further decade from now. By comparison, the diesel fuel used for road transport (ULSD) contains only 0.0010% sulphur by mass. Higher quality marine diesel fuels are available, but at a greater cost. These lighter fuels, which are distillates, are known as Marine Diesel Oil (MDO), Marine Gas Oil (MGO) and ULSD. Some ships use MGO or MDO in their auxiliary engines for generating electricity. MDO and MGO are available at low sulphur content, down to around 0.1%.

### Alternative Fuel

Natural gas is composed primarily of methane and contains virtually no sulphur. SO<sub>x</sub> emissions of engines running on natural gas are negligible and they produce less than 20% of the NO<sub>x</sub> and PM compared to those diesel engines burning liquid fuel.

Dual fuel diesel engines use natural gas as the main fuel source with a small amount of diesel fuel injected to initiate the combustion. They can run with 80% to 99% of fuel energy from gas. They are particularly suitable for marine usage because they can revert to

100% liquid fuel operation immediately if the gas supply fails, providing a high degree of propulsion reliability for ship safety.

The use of natural gas can also result in 25% greenhouse gas emission reduction if the combustion system is well designed, so that there are no significant emissions of methane. The emissions from gas engines can meet the most stringent IMO NO<sub>x</sub> and SO<sub>x</sub> emissions limits (IMO Tier 3 in ECAs) without post-treatment. Particulate emissions are very low compared with liquid fuelled diesel engines.

The engine technology is well developed and a range of dual fuel engines are available from the major engine manufacturers. Gas-only engines are also available and will be used in multi-engine arrangements.

Liquefied Natural Gas (LNG) allows greater fuel quantities in a given space than compressed natural gas. The gas is stored as a very cold liquid in highly insulated tanks at moderate pressures. The technology for storage and safe handling is well developed. Norway is establishing significant LNG infrastructure for domestic shipping.

## Feasibility analysis of technological ideas

### Speed Reduction

Speed reduction is an operational measure which offers significant CO<sub>2</sub> reductions. Generally speaking, a 10% speed reduction can reduce fuel consumption by more than 20% over the same distance. Engines can be de-rated to optimise operation at reduced speeds by measures such as increasing compression ratio or turbocharger boost pressure to recover cylinder pressures when less fuel is injected per cycle. DNV GL has recently suggested that speeds of 12 to 14 knots for container ship would be optimum speed and this would save fuel costs and emissions as well as absorbing overcapacity in the fleet.

## Other Measures

Other measures to reduce CO<sub>2</sub> emissions include:

- Alternative energy sources such as gas, wind, second/third generation biofuels (algae, lignocellulosic (e.g. from wood), pyrolysis oil, synthetic diesel, bio methane)
- Improved hull and propeller efficiency
- On-board energy efficiencies
- Weather routing
- New post-treatment technologies, for example CSNO<sub>x</sub> by Ecospec, which is promoted to remove CO<sub>2</sub>, NO<sub>x</sub> and SO<sub>x</sub>. As part of IMO approval certification process, ABS conducted the first load point (50% load equivalent to 5 MW engine output) of this technology on board the Aframax and at 50% gas load (equivalent to approximately 5 MW engine output) and the results showed reductions of 76.5% - 77.1% of CO<sub>2</sub> from exhaust as well as 98.6% - 98.9% of SO<sub>x</sub>, 64.5% - 66.2% of NO<sub>x</sub> burning 380 cSt fuel with a 3.64% sulphur content.

## DWI

### Description

Direct Water Injection is, like emulsified fuel and fumigation, an example of a water injection technology. Freshwater is injected under high pressure in the combustion chamber just before the fuel is injected. This will reduce the cylinder temperature, because the water vaporizes and absorbs heat. The lower temperature reduces the formation of NO<sub>x</sub> during combustion.

The DWI system operates independently from the fuel injection system, which ensures that the DWI can be switched on and off without affecting engine operation. Using a separate nozzle makes a higher input of water and better timing of injection possible. A disadvantage of DWI is that it cannot be used if the load is lower than 30-40% of full load in order to avoid the formation of white smoke and the increase of black smoke. The freshwater should be stored on board. Another aspect is the sulphur content of the fuel; it is recommended to

use a fuel containing less than 3% sulphur.

In combination with EGR, DWI may have the potential to meet IMO Tier III levels.

### Environmental effects

The actual NO<sub>x</sub>-reduction is determined by the amount of water used. Water to fuel ratios of 40-70% can achieve NO<sub>x</sub>-reductions of 50-60%. Higher ratios can even result in 70% NO<sub>x</sub> reduction, but will result in lower engine efficiency. 30-40% water/fuel ratios can be used without compromising fuel consumption, leading to roughly 30% reduction in emissions. Use of higher water /fuel ratios may lead to a 2% increase in fuel use, which also causes a slight increase of SO<sub>x</sub> and CO<sub>2</sub>.

### Maturity

The development of DWI was initiated by Wärtsilä in 2003. DWI is only applied by a couple of engine manufacturers. However, the applicability of DWI is not limited by this, because Wärtsilä has a high market share of the suitable diesel engines. In 2005 DWI was installed on 23 ships. An example of a ship using DWI is MS Silja Symphony, which has used it since 1999. Since the use of DWI, the emission of NO<sub>x</sub> has been reduced from 14 to 5.5 g NO<sub>x</sub>/kWh.

### Costs

DWI requires some major design changes in order to fit the system onto the engine. Capital costs vary between 130,000 US dollars for a tanker and 620 US dollars for a cruise ship. Operational costs are around 2 US dollars per MWh. An example of operational costs is the costs for distilled water. Costs for retrofitting are 25% higher compared to new engines.

Maintenance costs are reduced by up to 25% due to minimised thermal stresses on the engine components and prevention of carbon build-up.

## EGR

### Description

As the name suggests, a fraction of the exhaust gas is filtered and re-circulated back into the combustion chamber after cooling. The formation of NO<sub>x</sub> is reduced since the specific heat capacities of the principal exhaust components are higher than air; a lower oxygen supply also prevents the formation of NO<sub>x</sub>.

A drawback of the technology is the particulate matter in the re-circulated air. This can lead to deposition in the engine and contamination of the lubricating oil. Due to the presence of (gaseous) sulphur, corrosion can occur due to sulphur acids formation. No more than 15-20% of the exhaust gas can be re-circulated.

### Environmental effects

Older research material states the need for a 20% reduction in NO<sub>x</sub> emissions for an existing ship and 40% for a new ship. However, recent MAN Diesel experiments showed that EGR can reach 80% reduction. An EGR test on a MAN 4T50ME-X engine has verified IMO Tier III compliance by measuring an 85% reduction of NO<sub>x</sub> at the beginning of 2011.

Literature also mentions reductions of PM, SO<sub>2</sub> and VOC, but these are caused by the switch from RO to MD and not by the technology itself. A combination of water injection with exhaust gas re-circulation results in a decrease in PM.

### Costs

Cost estimations of capital costs are highly uncertain.

## HAM – Humid Air Motors

### Description

For humid air motors (MAN), NO<sub>x</sub> emissions are reduced by adding water vapour to the combustion air. The air is humidified by guiding the turbo-charged and heated combustion air through a special cell. The Humid Air Motor replaces the conventional engine air inter-cooler.

A couple of advantages are: a smoother combustion, the prevention of so-called 'hot-spots', reduction of the use of fuel and lubricating oil and the fact that seawater can be used. The HAM also uses waste heat, but this can lead to competition with other applications of waste heat. HAM can also be used with HFO with higher sulphur contents. Disadvantages are the fact that the humidifier requires a large surface and volume. The HAM should be integrated in the engine itself and a humidification tower, heat exchanger and water tank should be installed.

### Environmental effects

The reduction of NO<sub>x</sub> depends on the amount of water vapour. There is a wide range of percentages named by literature varying from 20% to 80%. MAN Diesel for example, mentions 40% and 65% NO<sub>x</sub> reduction can be achieved when additional air is used.

### Maturity

In 2005 there were only 4 retrofit installations in use on board of the Viking Line's Mariella. The fishing vessel KVANNØY was retrofitted with a HAM-installation in 2010.

### Costs

Investment costs are relatively high due to the installations needed. A HAM requires a heat exchanger, leading to high investment costs. There are only a few humid air motors in use, therefore cost estimations are uncertain. Operational costs are relatively low thanks to the use of sea water.



## CASS – Combustion Air Saturation System

### Description

Wärtsilä is developing a “Combustion Air Saturation System”. For CASS, water is already injected under high pressure into the inlet air right after the turbocharger. The water enters the cylinders as steam and evaporates causing the combustion temperature to reduce leading to the reduction of NO<sub>x</sub> formation. CASS has a certain advantages: fuel consumption does not increase, no engine modifications are needed and the system can be switched on an off independently from the engine. Compared to the technology of DWI, CASS can also be used at low NO<sub>x</sub> rates. A disadvantage is the high water consumption.

### Environmental effects

A 3 g/kWh NO<sub>x</sub> level can be reached using CASS. The potential reduction of CASS is 30-60% NO<sub>x</sub>. (Wahlstrom 2006) In order to reach this reduction, water consumption should be twice the amount of fuel consumption.

### Maturity and costs

There are no commercial CASS applications yet. Therefore no estimations of costs are available. Pilots were started in the autumn of 2002. Wärtsilä may introduce it as an option for its four-stroke engines. In addition, it is particularly interested in investigating the possibilities of combining CASS with water in fuel emulsion.

## Water in fuel emulsion

### Description

An emulsion is created by mixing immiscible liquids using an emulsifier. Emulsified fuel leads to a more effective atomisation and a better distribution of the fuel in the combustion chamber, which makes the combustion more complete at lower fuel combustion.

The emulsion can be stabilised by adding surfactants

or stabilisers. The recommended size of the water droplets to be sprayed in the combustion chamber is a maximum of 5µm.

### Environmental effects

The reduction of NO<sub>x</sub> depends on the amount of water brought into emulsion. There is a 1:1 relationship: for 20% water content, NO<sub>x</sub> reduction will be 20%. A 50% reduction is possible when the engine is de-rated, since the capacity of fuel injectors is limited. Without this modification, reduction will be around 10-20%.

In theory, NO<sub>x</sub> reduction of 50% can be achieved using emulsified fuel. However, the reduction rate is proportional to the amount of water added to the fuel and this amount is limited by the maximum delivery capacity of the fuel injection pumps. Therefore, the engine has to be de-rated or the reduction is limited to about 10-20%. To obtain better reduction rates at the full load, it is necessary to redesign the fuel injection system, camshaft and its drives. In addition, the injection nozzles have to be modified to the increased amount of fuel. With the new nozzle design, the fuel consumption

## LNG – Liquefied Natural Gas

*The CNSS report “LNG fuelled ships as a contribution to clean air in harbours” gives an overview of the different issues surrounding the implementation of LNG. The main purpose is to increase awareness and understanding amongst policy makers and other stakeholders of gas fuelled ships as a potential clean shipping technology. The report provides an insight into the main questions that stakeholders may have relating to this technology, and a set of recommendations endorsed by CNSS.*

LNG as a shipping technology has gained momentum since the turn of the century. The interest in LNG has been stimulated by the introduction of MARPOL Annex VI regulations and the introduction of Emission Control

Areas (ECAs) in Northern Europe and America.

Global interest in using LNG as marine fuel for all types of shipping, involved in all kinds of trades, continues to grow. Many believe LNG a much more environmentally friendly fuel for all categories of shipping at a similar, or even reduced, cost compared to the present fuel used by shipping.

There are still a number of challenges that must be overcome before LNG will be widely adopted within shipping communities. LNG must kept cold at approximately -160°C, therefore the handling, maintenance and distribution is more complicated and poses higher risk than traditional fuels. This places new demands on the distribution and handling infrastructure, as well as on ship design, knowledge, training etc.

In addition, traditionally LNG has not been traded in small quantities based on short-term contracts. This means a new set of business models and commercial arrangements will be required before the LNG marine fuel market can compete with the existing marine fuel oil market. As these changes all require significant investment, the transition to LNG as the preferred marine fuel has so far been slow except in Norway where the development of LNG has been heavily promoted by the national and regional governments. The primary societal motivation for supporting the adoption of LNG as a new marine fuel is the significant health and environmental improvements to be gained without a significant increase in the transportation costs.

CNSS has identified several key areas which will need to act upon the introduction of LNG as a mainstream fuel source in shipping, and has provided recommendations accordingly (see Technology and Fuels Recommendations section).

## OPS – Onshore Power Supply

*The shipping sector accounts for a significant share of harmful pollutants to the air, which constitutes a pressing problem in many port communities. Increasing concentrations of NO<sub>x</sub>, SO<sub>x</sub>, PM and other substances and gases constitute a major threat to public health in ports and surrounding areas. Large ships are also major contributors to global CO<sub>2</sub> emissions.*

Due to the truly international character of the trade it is has been difficult to enforce regulations to limit the environmental effects of shipping. Similar to aviation, ship fuels and emissions are not regulated as strictly as land-based transport. In addition, the replacement rate for ships is much slower than that for trucks and buses, which means that very few more energy efficient new ships enter the market every year.

The CNSS OPS study is primarily focused on high voltage OPS connections for sea-going ship traffic in the North Sea region, thus excluding onshore power for inland barge traffic from the report. The main emphasis is on High Voltage Shore Connection (HSVC) although throughout this report we refer to the technology with the more general term Onshore Power Supply (OPS).

The result of the OPS study confirms that OPS is a complex issue involving a large number of diverse stakeholders at various levels in society and the shipping supply chain. Although not technically complicated, the question of whether to invest in OPS or not depends on a large number of interrelated issues that ports and ship owners must evaluate, i.e. commercial viability of the investment, environmental impact, rate of utilisation as well as impacts of future emission reduction regulations on the trade.

Globally, OPS is currently far from being a widely used technology, however there are some progressive regions that have taken great strides in deploying the technology, most notably the west coast of the United States. As environmental awareness and concern is



growing in society at large but also specifically in the port and shipping community, OPS is a technology attracting increasing attention as a tool to combat emissions.

In the North Sea region we have found the public sector to be a crucial driving force in promoting OPS, both through incentives (tax reductions and grants) and strict environmental legislation.

A large number of studies have shown that OPS has the potential to significantly reduce emissions of harmful substances and greenhouse gases to the air. OPS is primarily a technology designed to combat local air and noise pollution but if deployed on a large scale it may also provide large CO<sub>2</sub> savings.

Technically, OPS is not a complicated issue and new global standards provide good guidance for implementation. However, there are some issues around frequency (50 or 60 Hz) and the location of the equipment on-board ships that do still pose technical challenges that need to be overcome. Most components used in OPS installations are standard and widely used in other types of electrical power equipment. The 50 Hz to 60 Hz frequency converter needed in most European ports poses a special challenge due to high costs.

With regards to the onshore grid, OPS does not pose any major challenges, with the possible exception of cruise ships that have a very high power demand. Mostly it is a matter of cost and time to reinforce the grid locally.

The environmental and commercial success of any given OPS installation needs to be evaluated on a case-by-case basis as the conditions for individual ports and ship owners vary greatly. In general terms however, one can conclude that OPS is particularly suitable for liner traffic spending considerable time in port. The more power that is generated onshore by renewable sources compared to on-board ships by means of auxiliary engines, the more an OPS investment makes commercial and environmental

sense. In a long term perspective, the issue of rising CO<sub>2</sub> emissions to the atmosphere is likely to result in tougher regulations on all polluting sectors, including shipping. OPS also provides a means for society to indirectly influence the unregulated shipping sector since shore-based electricity generation is included under the CO<sub>2</sub> emissions ceiling whereas fuel used in auxiliary ship engines is not.

The OPS mapping of the North Sea region has shown that Sweden is in the lead when it comes to the largest number of installed OPS systems. There are also very interesting developments in Norway, Germany, and the Netherlands.

Some question marks remain regarding the optimal model for utilisation and the real environmental and commercial impact of OPS. For some time the OPS debate has been dominated by the “chicken or egg” question relating to which actor should take the first step in investing in OPS – the port side or the ship owners. Throughout this project it has become clear that the public sector plays a critical role in promoting the deployment and utilisation of the technology in the shipping sector. It is highly unlikely that ship owners will take the initiative for a sector wide implementation of OPS. Society, in the form of national, regional and local government, has several instruments at its disposal for promoting deployment of OPS and other clean shipping technologies, such as differentiated port dues, tax reductions for shore based power, and grants. In addition, the public side could play a more active role in supporting effective collaboration and knowledge transfer in the sector.

Taking a long-term perspective, OPS does have an important role to play, provided that society is willing to solve the environmental and health problems caused by shipping. There are several examples of successful OPS installations, which more ports and ship owners could learn from.



### 3. Environmental performance - Emission Indices

#### Recommendations

- It is recommended that a unified incentive scheme capable of delivering real (and fair) environmental benefits from ships' exhaust gas emissions, both at sea and near population centres is developed based on an accurate index or measure of a ship's true environmental impact; it should have the following key attributes:
  - consider global GHG emissions (including transient load conditions), and incentivise efforts to reduce them (e.g. through EEOI, as CSI does)
  - consider local air quality impacts (i.e. NO<sub>x</sub>, SO<sub>x</sub>, PM), in particular it should take account of the transient load conditions encountered near shore and in port (updated emission factors)
  - deliver measurable financial benefit to the shipper (as ESI does)
  - provide an opportunity for zero-emission operation in port (OPS) to be rewarded (as ESI does, CSI benefit is small) to encourage ports in turn to provide the infrastructure
  - be simple to administer and comply with, and provide potential net financial benefit.
- It is recommended that any incentivisation of 'green' shipping meet these key criteria in order to have any validity:
  - be adaptable or scalable, to continue to reward early-adopters as international legislation becomes more stringent,
  - be quick, i.e. be in place and available as soon as possible to 'bridge the gap' in terms of the time lag between discussion and adoption of legislation, and its implementation (often staged).
  - demonstrate real value to the shipper (and port if that is to be the means of collection).

#### Environmental Index Schemes for Ships

*CNSS recognises the need for improved air quality in ports and coastlines in the North Sea region, in order to maintain good health for populations living in such areas. To do this, harmful emissions need to be reduced. One approach that has been adopted is the use of indices which attempt to apportion costs to harmful emissions by offering incentives to cleaner ships. Many ports in the North Sea region have adopted this approach in an attempt to encourage greener shipping; however the rationale and effectiveness of these schemes is not completely transparent, therefore an investigation into the use of emission indices has taken place.*

Research has been conducted at Newcastle University to investigate how different regimes of incentive or penalty are used to assess the impact of a ship or fleet on the environment, and how this can be quantified economically. This has been done by explaining what indices are in this context and how they are implemented. The research examines the effectiveness of the two key indicators - The Environmental Ship Index (ESI) and the Clean Shipping Index (CSI) - in the framework of current and future legislation, and makes recommendations as to their implementation based on the research outcomes.

There are numerous different initiatives used to assess the environmental performance of ships. Many of these have been developed to address a single pollutant; however two of the more widely used - the Environmental Ship Index and Clean Shipping Index - have been developed to incorporate several pollutants.

ESI assesses the impact of SO<sub>x</sub> and NO<sub>x</sub> emissions by providing scores based on a ship's emissions compared to current legislative guidelines. The index also incorporates a reporting scheme on Greenhouse Gas (GHG) emissions and attempts to reward 'greener'

ships by recognising the presence of OPS infrastructure on board. ESI classes itself as a 'good indicator of environmental performance of ocean going vessels' (WPCI).

Similarly, CSI adopts a scoring system which assesses exhaust gases (SO<sub>x</sub> and PM; NO<sub>x</sub>; and CO<sub>2</sub>), along with other environmental problems such as cleaning chemicals, refrigerants, treatment of ballast water and other issues associated with shipping (Clean Shipping Project, 2012). Each of the indices are designed to recognise 'greener' ships, and act as an incentive for ships to take a greater interest in their environmental impact.

#### Analysis of ESI

The following equation is used to generate the ESI score from a ship's NO<sub>x</sub> emissions and the sulphur content of the fuel used.

$$ESI = \frac{2(ESI\ NO_x) + ESI\ SO_x + ESI\ CO_2 + OPS}{3.1}$$

This formula has the capacity to generate a value between 0 and 111.3, however, the maximum score that can be assigned to a vessel within the ESI is

limited to 100. The reason for this mis-match between maximum index values is not transparent from the ESI and highlights an example of one of the problems with existing index schemes, namely, the lack of transparency and unexplained rationale.

The terms of the equation contribute different amounts to total ESI score:

$$0 < \frac{2(ESI\ NO_x)}{3.1} < \sim 64.5,$$

$$0 < \frac{ESI\ SO_x}{3.1} < \sim 32.3,$$

$$0 < \frac{ESI\ CO_2}{3.1} < \sim 3.2 \text{ and}$$

$$0 < \frac{OPS}{3.1} < \sim 11.3.$$

These terms are illustrated in Figure 38 which highlights the relative importance within ESI of each score function. These weighting factors combined with the 100 point cap implies that a maximum ESI can be achieved without maximum scoring in each category, allowing a ship the flexibility to prioritise its performance per category.

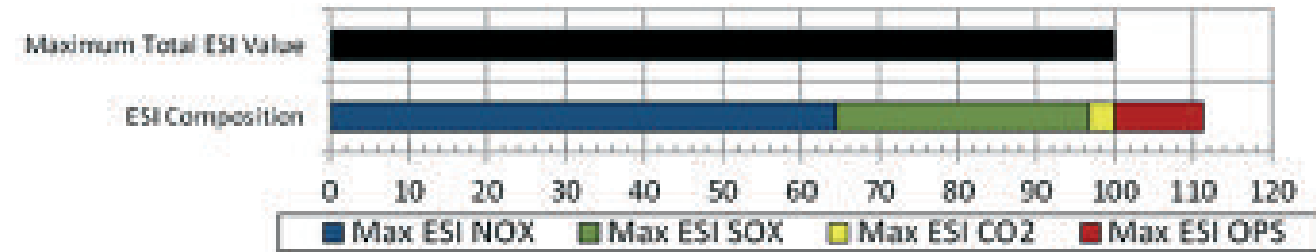


Figure 38 Relative weightings of the terms making up ESI

### The Environmental Ship Index

#### Evaluation of ESI scores

According to the *World Ports Climate Initiative* (WPCI, 2013) there are a total of 2166 participating vessels in the ESI Scheme. Data was acquired for the top 50 scoring vessels and that data was analysed and is presented in ESI rank order showing the breakdown of the constituent elements in Figure 40. The most common ESI score of the top 50 vessels is around 48-49, with the mode value calculated at 48.8. The top score is about 80, jointly held by two vessels, and the lowest score in the top 50 is 47. Figure 39 illustrates

how some ships ESI scores are heavily influenced by the specific score functions e.g. ship 4, whose total ESI score is heavily influenced by a strong score in  $\text{NO}_x$ , has a higher overall score than most of the other ships despite not scoring at all for  $\text{CO}_2$  and OPS, and low scoring for  $\text{SO}_x$ . Indeed, the two highest scoring ships have received 0 points in both the  $\text{CO}_2$  and OPS categories. Conversely, ship 48 is at the lower end of the scoring table despite receiving scores for each category. This exemplifies the earlier observation that despite the fact that the ESI appears to cover a range of emission types, there is flexibility to judiciously prioritise performance per category.

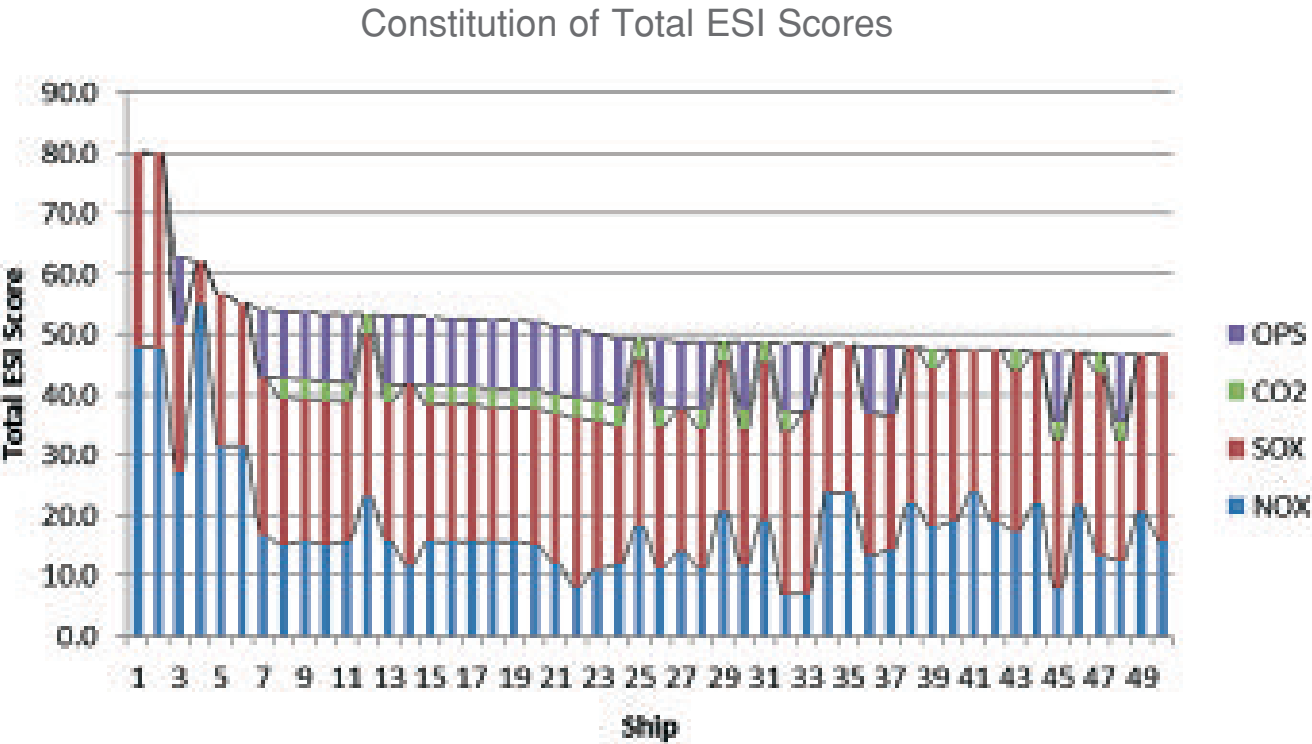


Figure 39 Constitution of Total ESI Score for the top 50 scoring ships

Figure 40 compares the mean ESI score by respective ship categories of the top 50 ESI scoring ships. Aside from LNG ships, there is no significant difference between the mean scores of each of the other categories, suggesting, perhaps surprisingly, that environmental impact does not vary greatly between

ship types. There are in fact only two LNG carriers and these are the two highest scoring ships in Figure 39, illustrating once again the high importance put to fuel type, with zero sulphur content in LNG, and low  $\text{NO}_x$  emission rating in g/kWh.

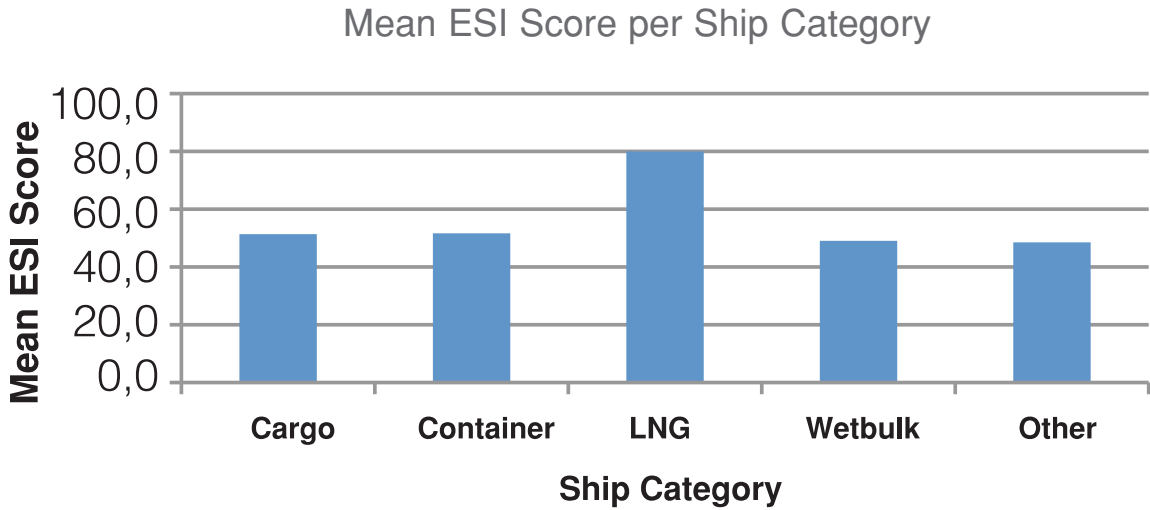


Figure 40 ESI score per ship category for top 50 ESI scoring ship sample

#### Impact of ESI scores on port charges

Many ports offer economic incentives to ship owners to become more environmentally friendly by offering discounted port fees to ships with good ESI scores. For this study participating ports in the North Sea region have been used.

The level of discount offered for ESI participation is left entirely to the discretion of the individual port - there is no legislation or guidance in place to control this. As illustrated in Table 13 this has led to highly variable and complex pricing structures between ports meaning the incentive for a ship to harbour in one port is different to the incentive for the same ship

harbouring in a different port. Discounts are offered by all of the ports listed providing a minimum ESI score of 20 points is achieved by a given ship. It is notable that in all cases the incentives are offered at a fixed rate for simply exceeding a threshold ESI score, ranging from 20 to 50, which are generally low in comparison to the average ESI of the top 50 scoring ships and also suggests a lack of incentive for ships to strive to improve their ESI scores above the thresholds set at the ports they frequent.

The average incentives (discount) per ship type at each port, using the top 50 sample of ships, have been calculated and presented in Figure (below). Ship

discount per ship type varies from port to port as shown above. E.g. at Kiel and Groningen, the biggest discounts are given to LNG ships, while at many of the other ports (Rotterdam, Amsterdam, Oslo, Bremen, Wilhelmshaven, Setubal), the biggest discounts are given to containerships. This suggests that ports do not have a universal policy in terms of port dues for specific ship classifications, as the comparable discount rates are different from port to port.

Interestingly, while Figure 40 demonstrated very little difference in ESI score between ship types (except LNG), the value to each ship type within individual ports is variable (Figure 41).

Port	ESI points requirement	Discount	*Amsterdam GT - Class reward:
Rotterdam	≥ 31 points	10%	ESI ≥ 20 points (bonus given to ships with ESI ≥ 31 points).
	≥ 20 points	10% (if number of ships with 31 points does not meet quota of 25)	
Oslo	25-49 points	20%	Incentive dependent on Gross Tonnage (GT) - For ships with ESI ≥ 20 = ESI score/100* "GT-class reward"; for ships with ESI ≥ 31 add 1/4 GT-class reward.
	≥50	40%	
Bremen & Bremerhaven	≥ 20 points	5%	Discount system: ships categorised with GT-class reward between 1-3000, discount = €200; 3001-10,000, discount = €500; 10,001-30,000, discount = €900; 30,001-50,000, discount = €1,200; > 50,000, discount = €1,400.
Kiel	≥ 31 points	10%	
Setubal	≥ 31 points	3%	
Hamburg	> 50 points	10% (capped at €2,000)	
Antwerp	≥ 31 points	10%	
Wilhelmshaven	≥ 31 points	5%	
Zeebrugge	≥ 20 points	10%	
Groningen sea ports	≥ 20 points	5%	
Amsterdam*	≥ 20 points	For ships with ESI ≥ 20 = ESI score/100* "GT-class reward"	
	≥ 31 points	For ships with ESI ≥ 31 add 1/4 GT-class reward	

Table 13 ESI discount incentives at selected North Sea ports

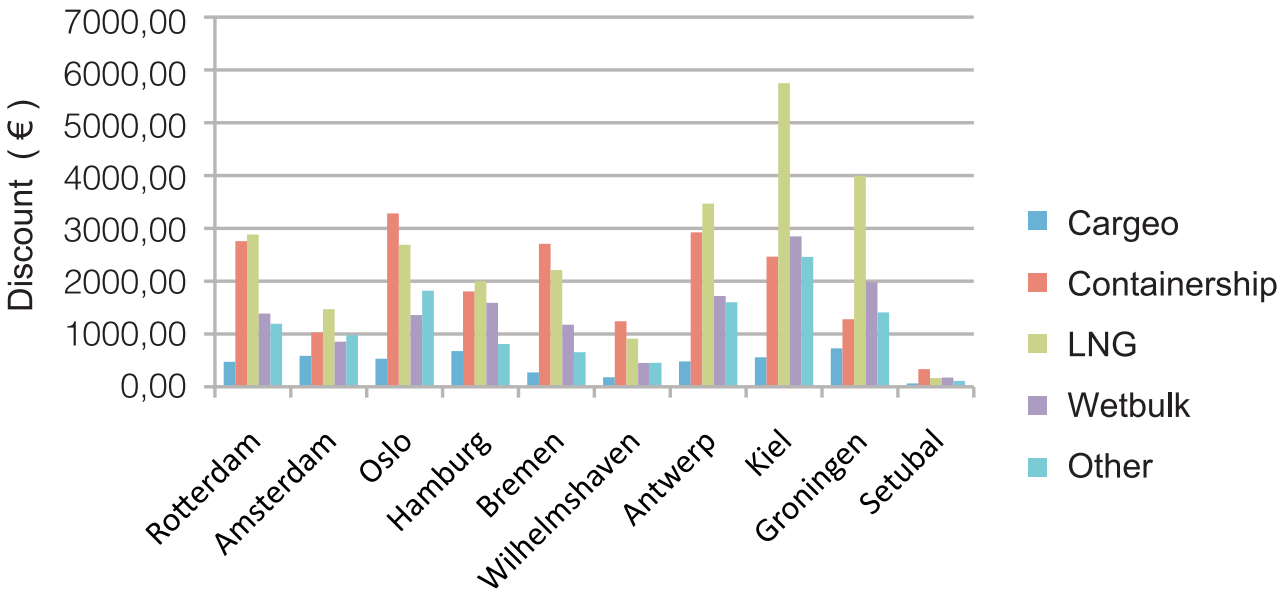
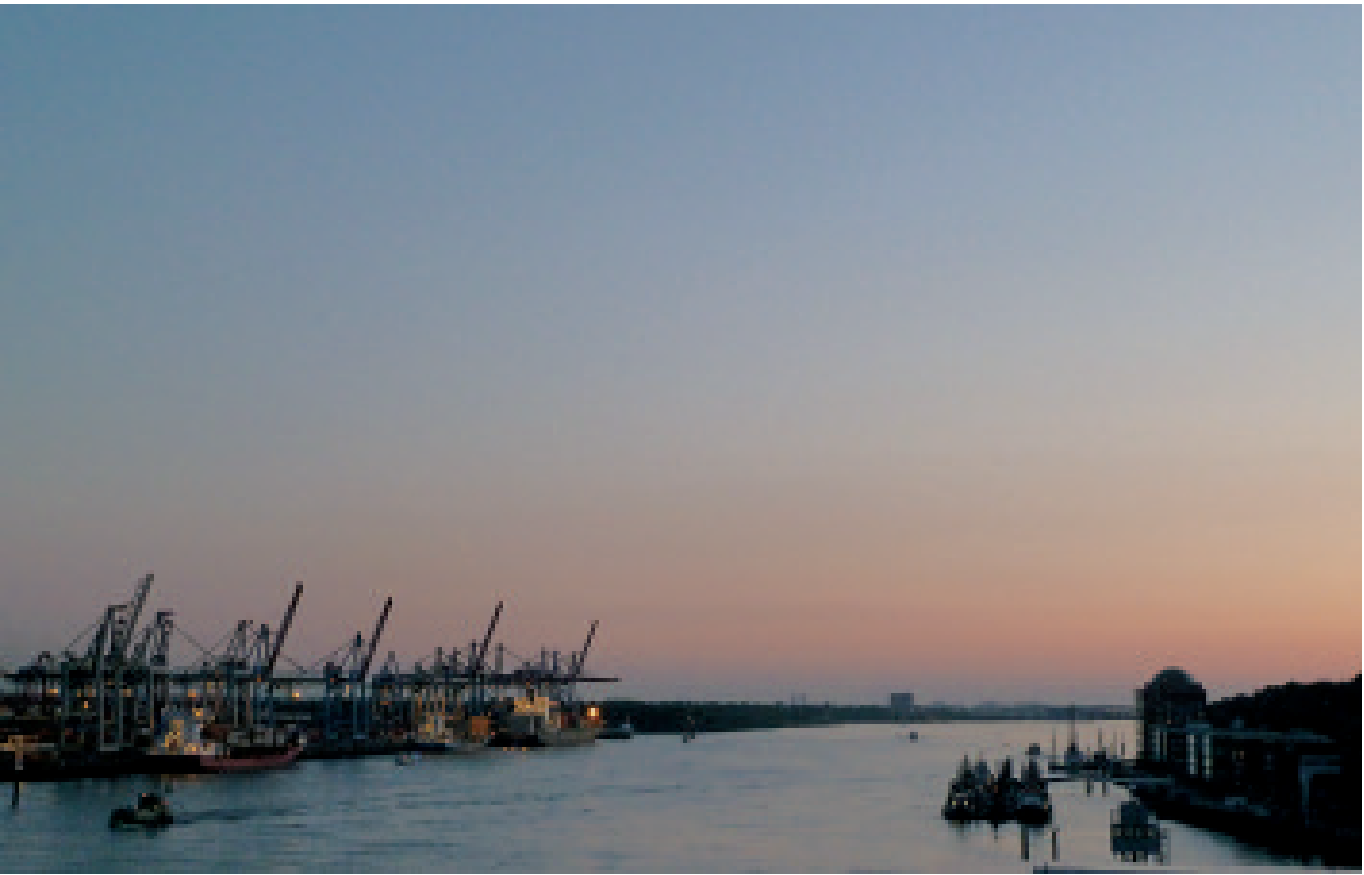


Figure 41 Average discount per ship type at each port based on the top 50 ESI scoring ships





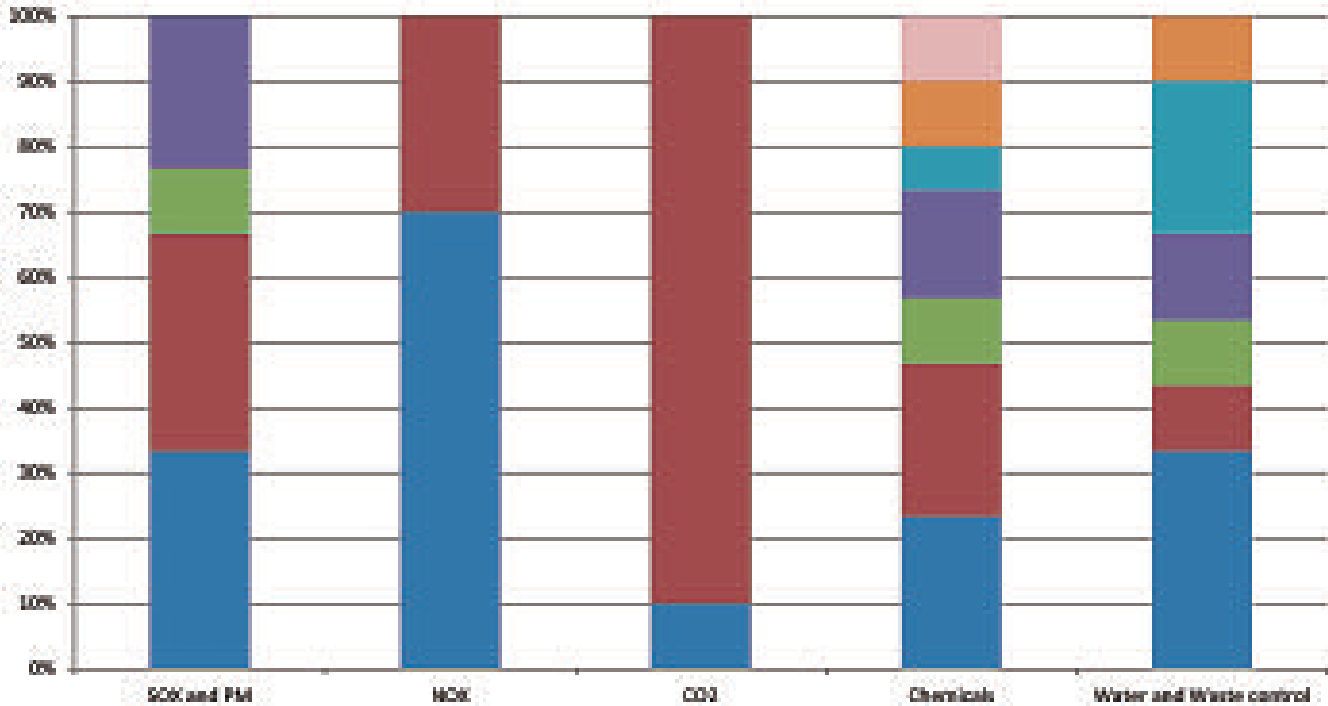
The Clean Shipping Index

Calculation of a CSI score

The Clean Shipping Index is somewhat more complex than the ESI and is made up from five different categories: SO<sub>x</sub> (also noted as a proxy for PM); NO<sub>x</sub>; CO<sub>2</sub>; Chemicals; and Water and Waste. Each category contributes a score out of 30 towards a possible total of 150. Therefore, unlike the ESI, each category carries equal weighting. A full explanation of each category is provided at the Clean Shipping Index website and Figure 42 provides a graphical overview.

In the context of this research, we were only

concerned with the elements of the index relating to exhaust gas emissions. In this respect, there is a similar rationale in the CSI as in the ESI for awarding points for the raw NO<sub>x</sub> score. Points awarded for SO<sub>x</sub> emissions in the CSI is perhaps more rational than in the ESI, since a total mass averaged sulphur content from all fuels is used. Furthermore, also unlike the ESI, the CSI, as well as giving greater relative weight to CO<sub>2</sub> performance, also gives greater attention to it by actually awarding points for CO<sub>2</sub> performance based on a ship's EEOI compared to a reference value on a sliding scale, rather than in the case of the ESI, simply reporting data on the EEOI.



Groningen Seaports

KEY		Chemicals	
SO <sub>x</sub> and PM	max. score	Anti fouling	max. score
operation in non ECA's and ECA's (total yearly average)	10	Stern tube oil	7
Operation in ECA's (yearly average)	10	External hydraulic fluids	3
Harbour bonus	3	Gear oil for thrusters and CP propellers	5
SO <sub>x</sub> /PM aux. engines	7	Boiler/cooling water treatment	2
		Cleaning agents	3
		Refrigerants	3
NO <sub>x</sub>		Water and Waste control	
NO <sub>x</sub> main engines	21	Ballast water treatment	10
NO <sub>x</sub> aux. engines	9	Sewage/black water	3
CO <sub>2</sub>		Garbage handling	3
Reporting of CO <sub>2</sub> emission information	3	Sludge handling	4
CO <sub>2</sub> emission performance	27	Bilge water treatment	7
		crew awareness	3

Figure 42 Constitution of CSI score function

Using a CSI score

In comparison to the ESI, there are no direct financial incentives for using CSI; rather it is promoted as an index to be used as a bargaining tool in procurement situations while attempting to attract business from environmentally conscientious clients. As such, the Index claims to have been designed to provoke more detailed discussion rather than as an absolute indicator of environmental performance. Therefore, rather than directly use the absolute value of the CSI, a ship (or carriers') is classified as green, yellow or red if it meets the respective criteria presented in Table 14. Notably, to be classed as “green” vessels must gain a minimum score in each category as well as a minimum overall score.

Category	For Carriers (Fleets)	For Individual Vessels
GREEN	≥90% vessels reported and the carrier verified, ≥40% weighted total score	The vessel verified, total score ≥50%, ≥35% in all fields
YELLOW	≥20% vessels reported ≥10% weighted total score	Total score ≥20%
RED	<20% vessels reported or, <10% weighted total score	Total score <20%

Table 14 CSI score categories

Comparisons between ESI and CSI

Comparison of CO<sub>2</sub>/OPS components of the ESI and CSI

In the CSI there is not an individual component for OPS, although, it does account for 1 point in the CO<sub>2</sub> term of the CSI and therefore it may be fair to consider OPS and CO<sub>2</sub> together for both Indexes. As noted earlier, in the ESI, there are a total of 3.2 + 11.3 = 14.5 points available in this category – and despite the cap in the ESI, these could be considered as potential % contributions out of 100 total available points. For the CSI, noting that the scale for CO<sub>2</sub> point scoring is perhaps more rational, with essentially a sliding scale according to EEOI performance a total of 30/150 marks is available for the complete CSI – representing a 20% weighting. On the other hand, since we are only concerned here with exhaust-gas emissions, the CO<sub>2</sub> element of the CSI in these terms represents a potential for 33.3%. In either case, the CSI gives a higher importance to low-carbon shipping.

Comparison of NO<sub>x</sub> components of the ESI and CSI

Due to the fact that the two methodologies for calculating the NO<sub>x</sub> scores in each index are somewhat different it is necessary to make some assumptions to compare these. Despite this, the following rationale provides some insight into the relative credit as compares to environmental improvement that each index offers. The CSI scoring system is essentially a stepped scale with a set amount of points available for meeting specific criteria. Table 15 compares the CSI scores for meeting each criteria with the ESI scores for ships assumed to have both main and auxiliary engines all meeting the same criteria. Interestingly, the CSI is generally more generous in awarding points within the NO<sub>x</sub> category (viewed as %) for meeting each criteria – however, when considered as a % of the total index or even just considering the emissions components in the case of the CSI, the ESI is generally more generous than the CSI – essentially meaning that a relatively high ESI score can be gained for producing more NO<sub>x</sub> than is the case for CSI.

Index Level Achieved	ESI Score % of NO <sub>x</sub> component	CSI Score % of NO <sub>x</sub> component	ESI Score % of Total ESI	CSI Score % of Total CSI	ESI Score % of Total ESI	CSI Score % of Emissions Component of CSI
Tier 1 *	0.0%	26.7%	0.0%	8.8%	0.0%	8.8%
Tier 2 **	19.2%	40.0%	12.4%	6.0%	12.4%	13.3%
20% below Tier 1	28.0%	53.3%	18.4%	10.7%	18.4%	17.8%
40% below Tier 1	46.0%	76.0%	29.8%	16.0%	29.8%	28.0%
Tier 3	86.0%	100.0%	51.6%	20.0%	51.6%	33.3%
Zero NO <sub>x</sub>	100.0%	100.0%	64.5%	20.0%	64.5%	33.3%

Table 15 A comparison of the NO<sub>x</sub> scores generated by ESI and CSI

- \* For CSI Tier 1 engines since built after 2000 are awarded a score of 0, this example is given for engines pre-dating 2000.
- \*\* Because Tier 2 NO<sub>x</sub> levels are not a fixed % below Tier 1 across the range of engine speeds and the fact that the ESI NO<sub>x</sub> formula is dependent on the relative power between main and auxiliary engines, engines complying to Tier 2 levels generate a range of scores for the ESI depending on the ratio of main engine to auxiliary engine installed power and what type of engines are assumed to be used. However the variation is

Comparison of SO<sub>x</sub> components of the ESI and CSI

Similar to the case for NO<sub>x</sub>, the methods for generating a SO<sub>x</sub> score in the CSI is a stepped scale for meeting discrete fuel sulphur content criteria, whereas for the ESI the scale is partially based on sliding scales within three subsets of fuel types. Acknowledging the earlier observation that in reality it is possible to generate relatively high ESI SO<sub>x</sub> scores through judicious bunkering strategies, nevertheless a similar rationale as that with the NO<sub>x</sub> scores comparison has been used to provide an indication of the relative importance of reducing fuel sulphur content in each index and this comparison is presented in Figure 43. The CSI scores are based on a mass-averaged sulphur content of all

fuels used in the past year, with a 3 point bonus available for using very low sulphur content fuel whilst in harbour. In this comparison, the graphs for ESI are plotted as if an ocean-going vessel exclusively bunkered a single fuel type of the respective sulphur content over the range. Despite the stepped nature of the CSI points system, there is a good deal of similarity between the ESI and CSI when considering relative progress through the SO<sub>x</sub> component of the index (Figure43a) and also in terms of relative contribution to the exhaust-gas emissions components of the CSI as compared to the total ESI (Figure 43b). Of course, taken across the complete CSI, there is diminished importance put to SO<sub>x</sub> owing to the inclusion of the non- exhaust-gas-emissions components (Figure 43c).

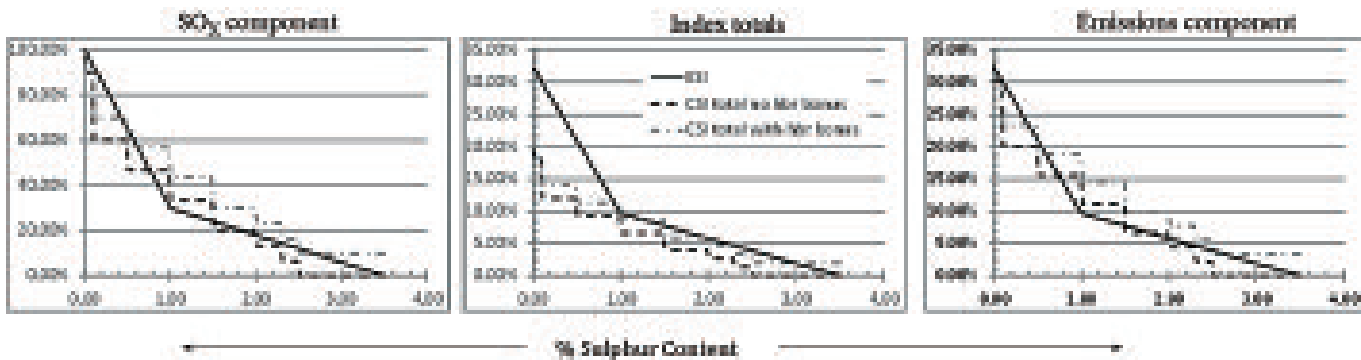


Figure 43 A comparison of SO<sub>x</sub> scores generated by ESI and CSI. (a) Compares % contributions to SO<sub>x</sub> component of each index. (b) Compares % contributions to the total of the respective indexes. (c) Compares % contributions to the emissions components for the case of the CSI.

Summary of ESI and CSI

An analysis of each index was carried out to determine how the scoring systems are influenced by input data. The output from the analysis indicates that ESI and CSI are heavily influenced by the impact of exhaust gases - driven by a requirement to meet current legislation. ESI considers NO<sub>x</sub> to be the most important factor, which is highlighted by a heavy weighting for NO<sub>x</sub> in the index (up to 64.5%). CSI treats NO<sub>x</sub>, SO<sub>x</sub> and CO<sub>2</sub> equally however the three exhaust gases combined account for 60% of the total number of points available.

CSI is a more rounded index in that it focuses on 5 environmental parameters in equal measure, so is likely to provide a more balanced assessment of a ships total impact on the environment. The analysis suggested that high total ESI scores can be achieved without focussing on high scores in each environmental category. For CSI, at least 1/3 of the available points in each category are required in order to achieve 'good' environmental status.

Both indicators measure NO<sub>x</sub> and SO<sub>x</sub> exhaust gases, and hence comparisons were drawn between the two scoring systems. CO<sub>2</sub> was also compared however CSI includes other environmental parameters which could not be. The analyses showed CSI to be more generous than ESI in the NO<sub>x</sub> category in terms of point scoring, however when considered as a % of total index or even just the emissions components in the case of CSI (NO<sub>x</sub> SO<sub>x</sub> and CO<sub>2</sub>), NO<sub>x</sub> carried more weight in ESI than CSI.

Economic differences were also observed. Good ESI scores can result in actual financial rewards, as selected ports have offered discounted dues for ships with good ESI scores. The economic rewards of CSI are less obvious, with no tangible incentives offered at present; however it is recommended that the index be used as a bargaining tool in procurement situations as it is thought that a higher CSI score will provide a greater likelihood of procuring business.



Port of Antwerp

Factor	ESI	CSI	Notes
Application	Monetary value as reduction in port dues, but complex, port-specific & varies with ship type	No direct monetary value attributed, used as a 'green badge' for environmentally conscious customers	
Spread	International, but voluntary (WPCI)	Sweden	
Overall emission balance	Dominated by NO <sub>x</sub> emissions, hence high scoring LNGCs. Actual operation of ship of less importance. Very similar scores for other ship types.	Equal weighting applied to 3 main categories, scores are broadly scaled with impact throughout.	ESI is more susceptible to 'rule-breaking' and 'box-ticking' endeavours as a number of elements can generate high scores without the actual emissions being reduced. CSI is more complex to administer but more reliable as a measure of environmental impact.
NO <sub>x</sub>	64.5% of total, maximum available score (zero NO <sub>x</sub> )	33.3% of total, maximum available score (zero NO <sub>x</sub> or tier III)	A more polluting ship can gain a higher equivalent normalised ESI score; conversely, ESI provides greater incentive to reduce NO <sub>x</sub> towards zero, e.g. a Tier III engine will score maximum points under CSI, but only equivalent to 51.6% ESI (of 64.5%).
SO <sub>x</sub> /PM	Based on fuel Sulphur content of bunker types, but not relative mass, so a high score can be artificially gained	Based on mass-averaged fuel Sulphur content plus bonus for use of very low S fuel in port.	Both show similar contribution of SO <sub>x</sub> component to air emissions total if 1 fuel type only is bunkered. Whilst ESI score can be massaged to appear artificially high, if presence of ECA near port is assumed, then reduced SO <sub>x</sub> near port is enforced, so from port's perspective, goal is achieved?
CO <sub>2</sub> /OPS	Score of up to 14.5 available (3.2 for EEOI reporting, 11.3 for OPS capability) out of 111.3 (but capped at 100). No scale applied, scores are either awarded or zero.	33.3% of air emissions score, scaled w.r.t. EEOI performance	More comprehensively considered by CSI, notable that highest scoring existing ships reporting ESI score zero here. ESI only requires existence of EEOI reporting/OPS capability, not its use/value.

Table 16 Summary of ESI vs. CSI



# SUMMARY OF RECOMMENDATIONS



Photo: www.mediaserver.hamburg.de/C. Spahr/bier

*The following recommendations are as a result of the work carried out by CNSS and have been agreed by the CNSS consortium. Our recommendations have been designed to target improving air quality in the North Sea region using technological, political and strategic improvements. We consider our recommendations a priority of great importance in order to tackle the issues surrounding reduced air quality as a result of shipping practices.*

## Air Quality

CNSS encourages the use of cutting edge scientific methods to estimate current and future ship emissions and their impact on air quality. We have developed FREE models and methods to do this.

## Technology and Fuels

CNSS promotes LNG fuel and in certain cases OPS as key alternatives to diesel by building infrastructure in ports and on-board ships. LNG is proven to reduce emissions of all pollutants with no waste deposit.

## Environmental performance - Emission Indices

CNSS encourages better use of incentive/indexing schemes to provide a universal approach to green shipping by implementation of MRV (Monitoring, Reporting and Verification) of vessel performance.

## Cross-thematic Policy and Regulation

CNSS recommends TIER 3 regulations of NO<sub>x</sub> emissions be introduced ASAP rather than postponing to January 2016. Our studies show that postponement will deteriorate air quality significantly.



## Air Quality

*Substantive work has been carried out by CNSS into the emission status of the North Sea. CNSS have used emission modelling and emission factors to gain a better understanding of how pollutants convolute in the atmosphere at a regional and local level.*

### Harbours and cities

- CNSS recommends that authorities and ports use size dependent fuel use functions for different ship types for calculating emissions from ships at berth (method developed by CNSS). The share of boilers in the total fuel used depends on ship type and must be taken into account.
- It is recommended that harbours estimate emissions from ships in port, including manoeuvring and at berth using the proposed freely available CNSS model. This will help improve reliability and comparability between different harbours, and test the effectiveness of different incentive schemes.
- For assessing the impact of shipping on air quality in cities it is recommended that authorities use models of an appropriate level of sophistication such as computational fluid dynamics (CFD) models. Applying these models requires skilled personnel and highly sophisticated input data on emissions and meteorological conditions.

### North Sea

- It is recommended that load dependent emission factors be used and that further development of emissions factors continues, especially for those emissions for which estimation is still uncertain (e.g. NO<sub>x</sub>, CO, SO, HC & PM) and engine types other than Diesel engines [using all types of fuel] should also be considered i.e. gas turbines.

- It is recommended that more data on actual emission production on board ship be collected and made generally available through promotion of monitoring campaigns, reporting of monitored data. This will allow further improvement of emissions factors and improve verification of emission production models.
- It is recommended that AIS data with the maximum available coverage at the North Sea, and the maximum available detail in port areas, be used as the basis for models of ship movement and traffic density. This will ensure that the most realistic geographic and temporal distribution of emissions from sea going ships is captured which will help to develop and improve the accuracy of emission scenarios in the North Sea region. This can also be extended to other regions.
- In order to achieve emission estimates as realistic as possible it is recommended to use emission factors that consider measurement based functional relationships between the ships' activities and their technical specifications. It may be worth considering even external factors like wind and currents if it can be excluded that those increase the uncertainty of the emission estimates. The open source emission model developed within CNSS considers engine load, engine power, fuel type and propulsion type for estimating pollutant emissions.
- It is recommended that advanced three-dimensional chemistry transport model systems be used for regional modelling of air quality because of the complex chemistry. For example, the main contribution to PM concentrations on shore from shipping is due to particle formation from gaseous SO<sub>2</sub> and NO<sub>x</sub> emissions, produced offshore.

## Technology & Fuels

*CNSS have carried out extensive work on the use of technologies and alternative fuels to reduce exhaust gas emissions from ships (see clean shipping technology section). More information on technologies and fuels can be found on the website: [www.cleantech.cnss.no](http://www.cleantech.cnss.no).*

### LNG

Use of Liquefied Natural Gas (LNG) instead of conventional diesel based fuels can significantly reduce emissions of all pollutants to air from ships.

- It is recommended that the use of LNG is promoted throughout the North Sea region for all shipping. CNSS has revealed that shipping has a great potential to reduce emissions of practically all air pollutants if LNG is used in contrast to using SCR or scrubbers which reduce the emissions of only single substances while increasing the fuel consumption at the same time. For example, compared to SCR the use of LNG avoids PM, HC and SO<sub>2</sub> emissions. CNSS does acknowledge that methane slip needs to be minimised.
- Stakeholders need to facilitate and promote the development of international solutions for the future LNG regulatory framework through organisations and regulatory bodies: IMO; ISO; IAPH/WPCI

- With respect to LNG handling, usage and safety, legislators should avoid local, regional, or national regulations or procedures whenever possible.

### OPS

Use of OPS can reduce the amount of local emissions from ships at berth but we acknowledge that electricity generation may produce emissions of pollutants elsewhere. Nevertheless, it may be easier to mitigate pollution from large land-based power generation stations than locally on board ships. The overall effect of OPS is more effective if it is used on a large scale.

- It is recommended that new ships should be fitted with OPS including small ships with 50Hz requirements.
- It is recommended to increase the OPS infrastructure in harbours
- It is recommended that a standard communication protocol be established in order to control the OPS ship-shore connection.
- It is recommended that the location of the HVSC connection on the ship should be standardised

## Environmental performance - Emission Indices

*Extensive studies of ESI and CSI within CNSS have revealed significant weaknesses and shortfalls within ESI and CSI, including rule-breaking scenarios and a lack of transparency or obvious rationale in their composition.*

- It is recommended that a unified incentive scheme capable of delivering real (and fair) environmental benefits from ships' exhaust gas emissions, both at sea and near population centres is developed based on an accurate index or measure of a ship's true environmental impact; it should have the following key attributes:
  - consider global GHG emissions (including transient load conditions), and incentivise efforts to reduce them (e.g. through EEOI, as CSI does)
  - consider local air quality impacts (i.e. NO<sub>x</sub>, SO<sub>x</sub>, PM), in particular it should take account of the transient load conditions encountered near shore
- and in port (updated emission factors)
- deliver measurable financial benefit to the shipper (as ESI does)
- provide an opportunity for zero-emission operation in port (OPS) to be rewarded (as ESI does, CSI benefit is small) to encourage ports in turn to provide the infrastructure
- Be simple to administer and comply with, and provide potential net financial benefit.
- It is recommended that any incentivisation of 'green' shipping meet these key criteria in order to have any validity:
  - be adaptable or scalable, to continue to reward early-adopters as international legislation becomes more stringent,
  - Be quick, i.e. be in place and available as soon as possible to 'bridge the gap' in terms of the time lag between discussion and adoption of legislation, and its implementation (often staged).
  - Demonstrate real value to the shipper (and port if that is to be the means of collection).

## Cross-thematic Policy & Regulation

*Policies and regulation have a significant impact on air quality. Regulations are typically implemented in order to control or reduce the amount of a particular pollutant being emitted.*

- It is recommended not to postpone Tier III introduction from 2016 to 2021 because scenario runs in CNSS show that this will result in an increase in the contribution from shipping to NO<sub>2</sub> and PM concentrations by approx. 20 % by 2030. If the IMO does postpone then the EU should consider its own equivalent.
- It is recommended that the EU initiate immediate actions to avoid the postponement of the global sulphur cut started in MARPOL Annex VI from 2020 to 2025. We promote the extension of ECAs with NO<sub>x</sub> and SO<sub>x</sub> restrictions for all vessels in European Seas in addition to the present ECAs in the North and Baltic Seas
- It is recommended that the EU implements standards for NO<sub>x</sub> and PM emissions from ships at berth in addition to the sulphur limits for fuels used in harbours.
- It is recommended that PM standards require further investigation. While we acknowledge that PM is already mitigated with reduction in SO<sub>x</sub>, the issue of the impact of black carbon on health is outstanding
- It is recommended that more use is made of incentive schemes for the promotion of cleaner shipping, specifically:
  - a. Rational and a unified use of indices for incentivising clean shipping
  - b. Incentive schemes/targeted subsidy/financing for adoption of clean tech including LNG/OPS/and others (existing examples include Norwegian NOX fund)
- It is recommended that a rigorous programme of education, training, accreditation and certification be established to help the adoption of LNG as a widespread marine fuel.
- It is recommended that equal conditions for all ports be promoted – including better cooperation between ports to avoid competitive issues that ship owners can take advantage of.
- It is recommended that a tax regime similar to that of conventional fuel oils is implemented for OPS within all EU / EEA ports.
- It is recommended that the emissions calculations used to determine "Differentiated port dues" should be mandatory and standardised for all harbours.



Groningen Seaports

# APPENDICES



## CNSS References

The following list is not exhaustive. The full collection of reports and other deliverables from CNSS will be made available at the web site <http://cnss.no> by end of March 2014.

### Reports

1. "Policies and instruments – A baseline of knowledge" (February 2012)
2. "Data analysis and emission model: Ship activities in the Port of Antwerp" (in production)
3. "The challenge of emission control in maritime law: A summary of the current international and European regulations and their implementation" (in production)
4. "A review of present technological solutions for clean shipping" (September 2011)
5. "LNG fuelled ships as a contribution to clean air in harbours" (May 2013)
6. "Onshore Power Supply - Status and future" (in production)
7. "A review of present technological solutions for clean shipping" (September 2011).
8. "Monitoring & simulation of pollutant generation and spread" (March 2012)

### Miscellaneous

1. Video: "LNG workshop, European Maritime Day in Gothenburg (2012)" - <http://cnss.no/a-short-film-lng-for-shipping-the-chicken-or-the-egg/>
2. Video: "Animation of LNG bunkering" - <http://cnss.no/lng-bunkering-in-ports/>
3. Web site: <http://cleantech.cnss.no>
4. Database: "Emission from shipping – North Sea...." (in production)
5. Low Carbon Shipping Conference, London 2013 paper - "Modelling Ship Emission Factors and Emission Indices" Murphy, A.J. Landamore, M.J. Pazouki, K. Gibson, M.

Abbreviations & Definitions

A	AERMOD	– Atmospheric dispersion modelling system	N	NECA	– Nitrogen Emission Control Area
	AIS	– Automatic Identification System		NO <sub>x</sub>	– Nitrogen Oxides
	APICS	– Antwerp Port Information and Control System		NSC	– North Sea Commission
C	CMAQ	– Community Multi-scale Air Quality model	O	O <sub>3</sub>	– Ozone
	CO	– Carbon Monoxide		OPS	– Onshore Power Supply
	CO <sub>2</sub>	– Carbon Dioxide		OPS	– Onshore Power Supply
	CSI	– Clean Shipping Index	P	PM	– Particulate Matter
	CTM	– Chemistry Transport Model		PM <sub>10</sub>	– Particulate matter with a diameter of 10 micrometres or less
E	ECA	– Emission Control Area		PM <sub>2.5</sub>	– Particulate matter with a diameter of 2.5 micrometres or less
	EEDI	– Energy Efficiency Design Index	S	SECA	– Sulphur Emission Control Area
	ESI	– Environmental Ship Index		SEEMP	– Ship Energy Efficiency Management Plan
	EU	– European Union		SO <sub>2</sub>	– Sulphur Dioxide
G	GHG	– Greenhouse gas		SO <sub>x</sub>	– Sulphur Oxides
I	IMO	– International Maritime Organisation	T	Tier I	– IMO regulations for NO <sub>x</sub> emissions implemented on 1st January 2000 (see Table 1 for details)
L	LNG	– Liquefied Natural Gas		Tier II	– IMO regulations for NO <sub>x</sub> emissions implemented on 1st January 2011 (see Table 1 for more details)
				Tier III	– IMO regulations for NO <sub>x</sub> emissions proposed to be implemented on 1st January (see Table 1 for more details)
M	MARPOL Annex VI	– Regulations for the prevention of air pollution from ships		2016	
	MGO	– Marine Gas Oil	V	VOC	– Volatile Organic Compound





## List of Figures

Figure 1	Energy losses from a ship (Source: Second IMO Greenhouse Gas Study 2009 pp. 166)	15	Figure 27	Changes in NO <sub>x</sub> emission from ships in 2030 relative to the base case for 2011 (see Figures 16 & 17) for 4 scenarios shown in Figure 25. ECA SCR and ECA LNG (not shown) have identical NO <sub>x</sub> emissions	47
Figure 2	Overview of potential measures, GHG reduction and costs Source: 2010 DNV Pathways to low carbon shipping Abatement potential towards 2030 (for further info see website: <a href="http://www.cleantech.cnss.no">www.cleantech.cnss.no</a> )	15	Figure 28	Map of the North Sea region illustrating the five regions (namely NO, DK, DE, NL and UK) for which time series of pollutant concentrations have been derived from CMAQ modelling results.	48
Figure 3	Share of NO <sub>x</sub> emissions from ships at berth in Bergen divided into different ship types	24	Figure 29	Development of the contribution of ships to NO <sub>2</sub> concentrations in the winter 2030, when Tier III regulations are implemented in 2016	49
Figure 4	Share of NO <sub>x</sub> emissions from ships at berth in Hamburg divided into different ship types	25	Figure 30	Increase in the contribution from ships when Tier III regulations are implemented in 2021	50
Figure 5	Geoviwer model – Port of Antwerp	27	Figure 31	Time series of daily average NO <sub>2</sub> concentrations in µg/m <sup>3</sup> (shaded grey, left y-axes) and the contribution of shipping to the NO <sub>2</sub> concentrations in the coastal areas of Belgium and the Netherlands for all scenarios (right y-axes). No ship denotes the changes if all ship emissions were cut to zero	51
Figure 6		28	Figure 32	Development of the contribution of ships to nitrate aerosol concentrations in winter 2030, when Tier III regulations are implemented in 2016	52
Figure 7	Absolute figures in Kg (2012)	28	Figure 33	increase in the contribution from ships to nitrate aerosol concentrations in winter 2030 when Tier III regulations are implemented in 2021	52
Figure 8	Distribution of emissions across main ship types	29	Figure 34	Development of the contribution of ships to 8-hour maximum ozone concentrations in summer 2030, when Tier III regulations are implemented in 2016	53
Figure 9	Difference in the contribution of sea going vessels to the NO <sub>2</sub> concentration calculated by AIS-based emissions and by standard emissions for the year 2010 (1x1km)	30	Figure 35	Increase in the contribution from ships when Tier III regulations are implemented in 2021	53
Figure 10	Pie chart of the NO <sub>x</sub> emissions per sector at a typical location in the Rijnmond (2011)	30	Figure 36	Time series of 8-hour maximum ozone concentrations in µg/m <sup>3</sup> (shaded grey, left y-axes) and the contribution of shipping to the ozone concentrations in the coastal areas of Germany for all scenarios (right y-axes). "noship" denotes the changes if all ship emissions were cut to zero	54
Figure 11	Pie chart of the NO <sub>2</sub> concentrations per sector at a typical location in the Rijnmond (2011)	31	Figure 37	Time series of daily average PM <sub>2.5</sub> concentrations in µg/m <sup>3</sup> (shaded grey, left y-axis) and the contribution of shipping to the PM <sub>2.5</sub> concentrations in the coastal areas of Germany for the main scenarios (right y-axis).	56
Figure 12	Contributions of shipping to NO <sub>2</sub> concentrations in 2008 in the Rijnmond region	31	Figure 38	Relative weightings of the terms making up ESI	67
Figure 13	Cross section map of the Rotterdam area.	32	Figure 39	Constitution of Total ESI Score for the top 50 scoring ships	68
Figure 14	NO <sub>2</sub> concentrations from different sectors in the East-West–Maasvlakte cross section (See Fig. 12) and number of inhabitants living in the different areas.	32	Figure 40	ESI score per ship category for top 50 ESI scoring ship sample	69
Figure 15	Load dependent emission factors for NO <sub>x</sub> for three engine power classes.	34	Figure 41	Average discount per ship type at each port based on the top 50 ESI scoring ships	71
Figure 16	Annual NO <sub>x</sub> emissions of cargo ships in the North Sea in 2011 for the size class 5000 - 10000 GT	37	Figure 42	Constitution of CSI score functions	73
Figure 17	Annual NO <sub>x</sub> emissions of cargo ships in the North Sea in 2011 for the size class > 100000 GT.	37	Figure 43	A comparison of SO <sub>x</sub> scores generated by ESI and CSI. (a) Compares % contributions to SO <sub>x</sub> component of each index. (b) Compares % contributions to the total of the respective indexes. (c) Compares % contributions to the emissions components for the case of the CSI.	75
Figure 18	Total annual emissions from ships in the North Sea (most right columns) compared to total emissions from some North Sea riparian countries	38			
Figure 19	Comparison base Summer NO <sub>x</sub>	39			
Figure 20	Comparison base Winter NO <sub>x</sub>	40			
Figure 21	Mean 8-hour maximum ozone concentration in summer 2011 and the share ship emissions have in producing ozone	41			
Figure 22	Comparison base Summer PM <sub>10</sub>	42			
Figure 23	Daily NO <sub>2</sub> concentrations	43			
Figure 24	Daily PM <sub>10</sub> concentrations	43			
Figure 25	Daily O <sub>3</sub> concentrations	43			
Figure 26	Scenarios for technical developments and legislation with respect to ship emissions for 2030.	46			

List of Tables

Table 1	NO <sub>x</sub> regulations	12	Table 9	Summary of technical information per class size for cargo ships	36
Table 2	SO <sub>x</sub> regulations	12	Table 10	Relative contributions to total ship emissions	38
Table 3	Technologies for reducing SO <sub>x</sub> , NO <sub>x</sub> and CO <sub>2</sub> (for further info and sources please see website: <a href="http://www.cleantech.cnss.no">www.cleantech.cnss.no</a> )	16	Table 11	Number of days with 8-hour maximum ozone concentrations > 120 µg/m <sup>3</sup> in selected regions around the North Sea (see also Figure 21)	41
Table 4	Number and type of ship visited in 5 harbours in the North Sea region	21	Table 12	Number of days with 8-hour maximum ozone concentrations > 120 µg/m <sup>3</sup> in 2030 in selected regions around the North Sea for the scenarios No ECA, ECA SCR 16, ECA SCR 21, and ECA opt	55
Table 5	Parameters for the calculation of the hourly fuel consumption (FC) of ships at berth. Ratio and slope in (kg/(GT*h/1000)), I in kg/h	22	Table 13	ESI discount incentives at selected North Sea ports	70
Table 6	Fraction of energy produced by boilers on board of different ship types. Comparison of values from a previous study (HD2010) and this survey and recommendation for emission calculations.	23	Table 14	CSI score categories	74
Table 7	Emission factors for different fuels depending on engine type/machine, (g/kWh)	23	Table 15	A comparison of the NO <sub>x</sub> scores generated by ESI and CSI	75
Table 8	Emissions from ships at berth in 2010	23	Table 16	Summary of ESI vs. CSI	77



# CNSS: Competitive Marine Transport Services and Reduction of Emissions – a North Sea Model

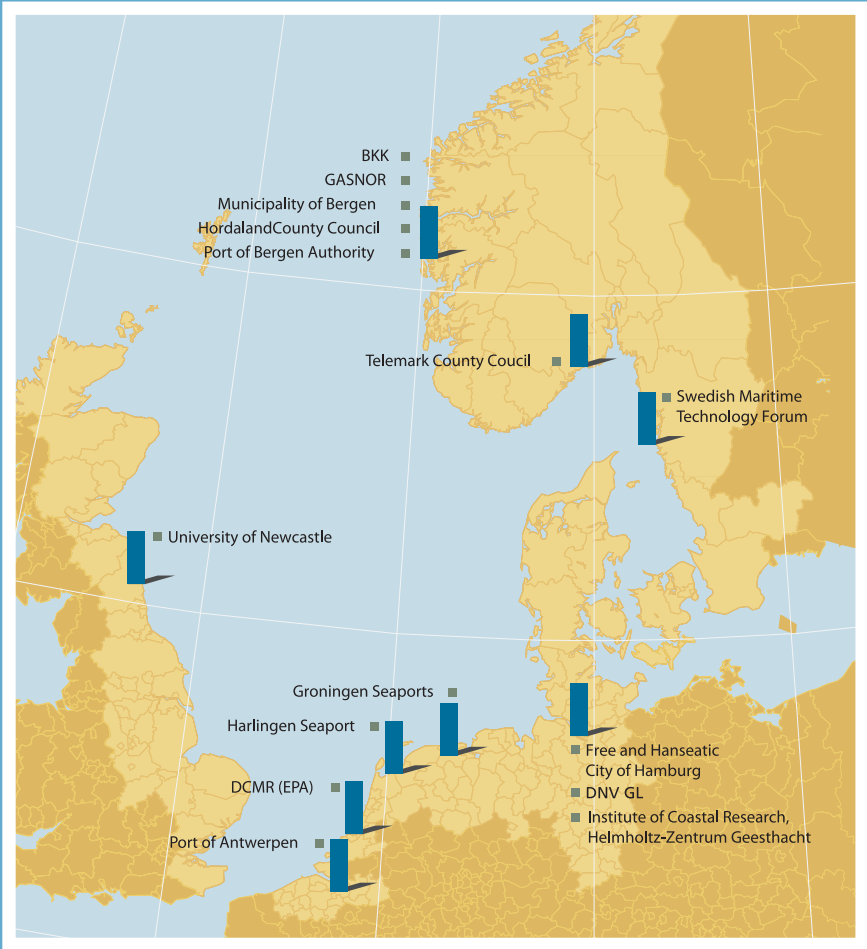


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