Danish Ministry of the Environment
Environmental Protection Agency

Reducing Air Pollution from Ships

- a cost benefit analysis and feasibility study on possible means for further reduction of emissions

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Reducing Air Pollution from Ships

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Content

1 Sammenfatning og konklusioner

1.1 Baggrund og formål

Formålet med denne undersøgelse er at identificere mulige virkemidler til yderligere at reducere luftforureningen fra skibsfarten i danske farvande og vurdere de samfundsøkonomiske konsekvenser af de forskellige virkemidler til reduktion af luftforureningen.

Det anslås, at NO_x-emissioner fra skibe i danske farvande er højere end emissionerne fra landbaserede kilder. Ifølge nylige undersøgelser bidrager disse emissioner væsentligt til NO_x-koncentrationen i luften over Danmark.

IMOs reviderede bilag VI til MARPOL bebuder en betydelig nedbringelse af luftforureningen fra skibe i de kommende år, især hvad angår udledning af SO_x og NO_x. Med henblik på at identificere yderligere muligheder for at reducere luftforureningen har Partnerskab for Renere Skibsfart (Miljøstyrelsen og Danmarks Rederiforening) bestilt en kortlægning af mulighederne for at reducere luftforureningen mere, end, hvad IMO og øvrige institutioner, såsom EU, kræver.

Undersøgelsen fokuserer primært på reduktion af NO_x og partikler (PM), da disse to emissioner ikke er reguleret så strengt som SO_x i de kommende regler fra IMO og EU. SO_x skal reguleres for alle skibe uanset alder; reguleringen af NO_x-emissionerne vil afhænge af alderen på skibsmotorerne, mens partikelemissionerne vil forblive uregulerede.

1.2 Undersøgelsen

Undersøgelsen består af tre overordnede dele. Den første del kortlægger emissionerne i danske farvande. Denne kortlægning er baseret på AIS-data indsamlet i 2007 og stillet til rådighed af DCE – Nationalt Center for Energi og Miljø (tidligere DMU). Denne del af undersøgelsen har til formål at vurdere, hvilken del af emissionerne de danske myndigheder kan regulere. Den anden del af undersøgelsen omhandler teknologier til NO_x-reduktion, identifikation af relevante teknologier og vurdering af omkostninger og gevinster ved teknologierne. Den tredje del af undersøgelsen identificerer og beskriver relevante politiske virkemidler til at understøtte implementeringen af NO_x- og partikelreducerende teknologier. Denne del af undersøgelsen er hovedsagelig baseret på litteraturstudier.

1.3 Resultater og hovedkonklusioner

De vigtigste konklusioner fra undersøgelsen er:

- International søfart udsender større NO_x emissioner i de danske farvande end hele den samlede danske NO_x emission.
- Partikelemissionerne fra international søfart udgør kun ca. 15% målt i forhold til de samlede danske partikel emissioner.

- Danmark kan i praksis kun regulere under 10% af de NO_x- og partikelemissioner, der udsendes i danske farvande.
- Omkostningerne til NO_x reducerende udstyr er små i forhold til gevinsten. Derfor vil der være store samfundsøkonomiske fordele, hvis man kan reducere NO_x emissionerne i farvandene omkring os.
- Reduktion af partikel emissioner er ikke helt så fordelagtig som reduktion af NO_x emissioner. Dels er teknologierne til reduktion af partikler dyrere, dels er reduktionspotentialet mindre.

Skibene i farvandene omkring Danmark udleder ca. 173,000 tons NO_x årligt. 9,530 tons stammer fra national søfart, mens international søfart står for 163,701 tons. Til sammenligning udgør de landbaserede NO_x-emissioner 122,254 tons årligt.

For partikelemissioner er fordelingen omvendt, 85 % af alle partikelemissioner kommer fra landbaserede kilder.

Tabel 1-1 NO_X- og partikelemissioner i og omkring Danmark (tons)

	NO_X	Partikler
Landbaserede	122.254	24.131
National søfart	9.530	320
International søfart	163.701	3.650

Kilde: Landbaserede emissioner baseret på National Environmental Research Institute (2011). National og international navigation baseret på AIS data.

På grund af den internationale søfartslovgivning kan de danske myndigheder kun regulere emissioner fra national søfart omkring Danmark. Det betyder, at de danske myndigheder har mulighed for at regulere 9.530 tons NO_x og 320 tons partikelemissioner.

De danske myndigheder kan i begrænset omfang regulere international søfart, men kun når det gælder fartøjer, der anløber danske havne. Tabel 1-2 viser en opdeling af NO_x-emissioner fordelt på flagstaten og på skibenes danske eller udenlandske destination.

Tabel 1-2 Distribution af NO_X-emissioner fra søtransport omkring Danmark, ifølge flag og dansk destination.

	Anløber jævnligt dansk havn	Anløber aldrig dansk havn	I alt
Dansk flag	7 %	3 %	10 %
Udenlandsk flag	19 %	70 %	90 %
I alt	26 %	74 %	100 %

Kilde: AIS data 2007

Som det kan ses, udledes 70 % af NO_x-emissionerne i danske farvande af udenlandske skibe, der aldrig anløber en dansk havn.

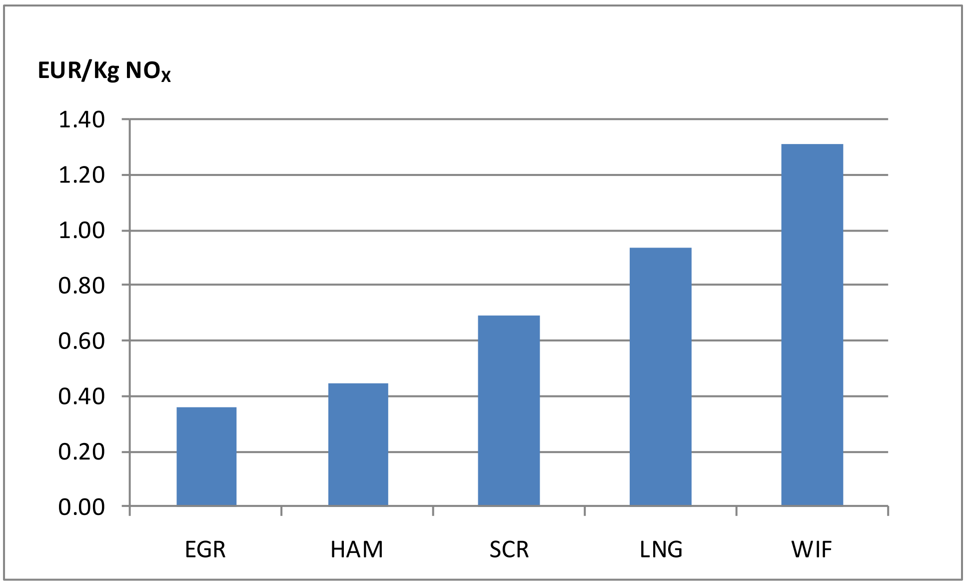
NO_x-emissioner fra nybyggede skibe vil blive reduceret betydeligt med den forventede udpegning af Østersøen og Nordsøen som NO_x-ECA områder. Derfor bør incitamenter til yderligere NO_x-reduktioner målrettes eksisterende skibe.

Tabel 1-3 opgør omkostningerne ved de forskellige teknologier til reduktion af NO_x-emissioner.

Tabel 1-3 Omkostningerne ved at reducere 1 kg NO_X emissioner ved de forskellige teknologier

	EUR pr. kg NO_X
EGR - Recirkuleret udstødningsgas	0,36
HAM - Vandtilsætning i luftindtag	0,44
SCR - NO_X katalysator	0,69
LNG - Naturgas	0,94
WIF - Vandtilsætning til brændstof	1,31

Note: Omkostning beregnet som et vejet gennemsnit baseret på størrelsesfordeling for skibe, der anløber danske havne.



Figur 1-1 Omkostningerne ved at reducere 1 kg NO_X emissioner ved de forskellige teknologier

Den billigste teknologi er EGR med en omkostning på 0,36 euro pr. kg NO_x. LNG omkostningen på 0,94 euro medregner produktion og distribution af LNG til de større færgeruter i Danmark. Et distributionssystem med levering af LNG til alle færgeruter i Danmark vil ikke være økonomisk fordelagtigt[1].

Gevinsten ved en reduktion af NO_x-emissionerne er mellem 7 og 12 euro pr. kg NO_x. Til sammenligning er omkostningen ved at reducere 1 kg NO_x mellem 0,36 til 1,3 euro. Det betyder, at der vil være en nettogevinst på mellem 5 og 10 euro pr. kg NO_x ved en reduktion af NO_x-emissionerne.

Skadesomkostningerne forbundet med NO_x-emissionerne er ikke afhængige af befolkningstætheden, der hvor emissionen finder sted. Det betyder, at skadesomkostningen for NO_x-emissioner er ens for byområder og landdistrikter. Det samme er ikke tilfældet for partikler. Partikler forårsager mere skade i området tæt på emissionsudledningen. Derfor er omkostningerne ved partikelemissioner fra skibe ved kaj tæt på et bycentrum højere i forhold til partikelemissioner på havet langt væk fra land.

[1] EPA (2010): Natural gas for ship propulsion in Denmark, Environmental Project No. 1338 2010

Tabel 1-4 viser omkostningerne for forskellige teknologier til reduktion af partikelemissioner. LNG og partikelfiltre er begge egnede metoder til at reducere emissioner både på åbent hav og ved kaj. Landbaseret elektricitet, også kendt som "Cold ironing", kan kun anvendes ved kaj. LNG er tæt på at være samfundsøkonomisk fordelagtigt, også selv om man ikke medregner gevinsten ved at reducere partikelemissionerne, alene fordi der kan spares ret betydelige beløb på det billigere brændstof. Omkostningerne til de to andre teknologier "landbaseret elektricitet " og partikelfilter varierer fra 32 til 115 euro pr. kg partikelemission.

Tabel 1-4 Omkostningerne ved at reducere 1 kg partikelemission for de forskellige teknologier

	Vægtet gennemsnit
Scrubber (EUR/kg PM)	-482,14
LNG (Flydende naturgas) (EUR/kg PM)	4,30
DPF - Partikelfilter (EUR/kg PM)	32,10
Elektricitet fra land (EUR/kg PM)	115,00

Den store gevinst (negativ omkostning) ved anvendelse af scrubber skyldes brændstofbesparelser, da tung brændselsolie er ca. 25 % billigere end gasolie med lavt svovlindhold. Derudover reducerer scrubberen partikelemissioner med 20 % i forhold til et skib, der anvender svovlfattigt brændstof og ikke har en scrubber. Når gevinsten fra brændstofbesparelserne måles i forhold til den mulige 20 % reduktion i partikelemissionerne, er resultatet en gevinst på 482 euro pr. kg partikler.

Udgiften til investering, drift og vedligehold af det NO_x-reducerende udstyr vil typisk udgøre ca. 2,9-3,8 % af brændstofudgiften. Da der er relativt stærk konkurrence inden for søfart, vil selv denne relativt lille omkostningsforøgelse kunne udgøre en barriere for investeringerne.

En række politiske tiltag er blevet analyseret for at afgøre, hvordan potentialet for reduktion af NO_x og partikler bedst udnyttes. Tabel 1-5 viser den potentielle NO_x emissionsreduktion for de mest relevante tiltag.

Tabel 1-5 Potentiel NO_x reduktion for udvalgte tiltag

	Mål (Ton NO_x/år)	Reduktion (%)	Reduktion (Ton/år)	Omkostning (euro/kg NO_x)	Andel af samlede emissioner (%)[2]
Emissionsnormer for færger	4,946	78 %	3,834	0.71	2.2 %
NO_x-afgift i kombination med tilskud	9,530	70 %	6,628	0.89	3.8 %
Omsættelige kvoter	9,530	60 %	5,718	0.95	3.3 %
NO_x-afgift	9,530	39 %	3,682	1.05	2.1 %

Som det fremgår, er det kun muligt at regulere mellem 2,1 % og 3,8 % af de samlede emissioner. Den relativt lave andel skyldes, at den internationale lovgivning i praksis forhindrer danske myndigheder i at regulere emissioner fra international søfart, selvom de udledes i dansk farvand.

[2] Samlede emissioner i danske farvande

Det ser ud til, at indførelsen af emissionsnormer for færger vil være den mest fordelagtige måde til at nedbringe NO_x-emissionerne. Det vil være en rimelig simpel opgave at fastlægge normerne, da der kun er et begrænset antal færger i drift. Da færgerne allerede i dag gennemgår en årlig kontrol, vil yderligere omkostninger til administration og inspektion være begrænsede.

Omsættelige kvoter for national søtransport vil have et højere NO_x-emissionsreduktionspotentiale. Omsættelige kvoter vil imidlertid kræve mere administration sammenlignet med normer, fordi et kvotesystem vil kræve ressourcer til systemdesign og assistance i forbindelse med administration og køb og salg af kvoterne. Omsættelige kvoter ville således være et dyrere virkemiddel sammenlignet med et system, der bygger på normer.

En af udfordringerne i et kvotesystem er den indledningsvise fordeling af kvoterne. Der er to muligheder; enten gives kvoterne gratis til rederne, eller også udloddes kvoterne ved auktion, hvor rederne kan købe den mængde kvoter, som de forventer at skulle bruge i det kommende år. Den første mulighed vil være mest acceptabel for rederne, men det vil være vanskeligt og tidskrævende at fastsætte mængden af kvoter, der skal gives til den de enkelte redere. Hvis kvoterne derimod bortloddes på auktion, vil det være lettere indledningsvis at opnå en optimal fordeling af kvoterne, og man vil spare ressourcer og administrationsomkostninger i forbindelse med den indledende fordeling. Imidlertid vil denne løsning formentlig ikke være helt så politisk acceptabel.

Fra et økonomisk synspunkt er miljøafgifter et effektivt virkemiddel. På grund af den internationale lovgivning kan de danske myndigheder ikke opkræve afgifter fra international søfart i danske farvande[3]. Ifølge FN-konventionen om havret, UNCLOS, artikel 24, må en kyststat ikke hindre udenlandske skibes passage gennem sit søterritorium, med mindre det er i overensstemmelse med konventionen. Artikel 21 (3) tillader dog, at et land kan "fastsætte særlige krav til forebyggelse og begrænsning forurening af havmiljøet som betingelse for at lade udenlandske skibe anløbe landets havne". Dette betyder, at der i praksis ikke er retsgrundlag for regulering af skibe, der passerer gennem de danske farvande, med mindre de anløber en dansk havn.

Derudover indebærer artikel 26, at de danske myndigheder ikke kan afgiftspålægge udenlandske skibe udelukkende på grund af passage gennem dansk territorialfarvand. Afgifter kan alene opkræves som betaling for specifikke ydelser til skibet, og afgifterne må ikke udsætte skibene for forskelsbehandling. Det betyder, at der i praksis ikke kan opkræves afgifter baseret på skibenes NO_x-udledning, selvom udenlandske skibe anløber en dansk havn.

Subsidier kan være medvirkende til at overvinde økonomiske barrierer, der kan stå i vejen for samfundsnyttige investeringer. En kombination af subsidier og afgifter vil øge effekten af afgiften, fordi subsidier kan reducere investeringsomkostningerne i de tilfælde, hvor investeringen i sig selv ikke kan betale sig for skibsrederen. Kombinationen af NO_x-afgifter og subsidier kendes fra Norge og Frankrig.

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[3] Selvom UNCLOS artikel 21 tillader kyststater at indføre individuelle love og forskrifter, kan denne mulighed ikke anvendes i stræder som Øresund og Storebælt, som skibene skal passere igennem for at nå andre lande/områder. Det er endvidere ikke almindelig praksis at regulere international søfart ved nationale bestemmelser.

EU-lovgivningen tillader almindeligvis ikke tilskud og statsstøtte. Dog kan visse kategorier af støtte tillades[4]. EU skal underrettes om alle former for støtte, og derefter vil Kommissionen vurdere, om støtten kan undtages fra det generelle forbud.

Den norske NO_x fond er en kombination af afgifter og tilskud, og i en tilsvarende dansk konstellation vil tilskuddet sandsynligvis være foreneligt med statsstøttereglerne af to årsager. Kombinationen af afgift og tilskud i det norske system er afbalanceret, således at søfarten som helhed ikke stilles ringere end andre transportformer. Desuden kan alle skibsredere, der opererer nationalt[5] i norske farvande søge om tilskud til installation af NO_x-reducerende udstyr. Ordningen favoriserer således ikke én skibsreder på bekostning af en anden.

I denne rapport skal differentierede havneafgifter forstås som havneafgifter baseret på et fartøjs emissionskarakteristika. Differentierede havneafgifter kan således skabe et økonomisk incitament til at reducere emissionerne. Fordelen ved at anvende havneafgifter er, at der allerede findes et administrationssystem, som i dag anvendes til at opkræve afgifter for brug af havnefaciliteter. Der vil således ikke være behov for at etablere et nyt administrationssystem til brug for opkrævning af en ny afgift. Rent administrativt vil der dog blive brug for ekstra ressourcer til at fastsætte standarder og til at kontrollere emissionerne på skibene.

Effekten af differentierede havneafgifter afhænger af antallet af deltagende havne. Hvis kun et begrænset antal havne deltager, vil der være en risiko for, at skibe med høje emissioner søger til havne uden differentierede afgifter i stedet for at investere i emissionsreducerende udstyr. Det kan betyde, at skibene vælger at tage en omvej, hvorved emissionerne vil stige i stedet for at blive reduceret.

Selvom differentierede havneafgifter kan have et stort potentiale i forbindelse med reduktion af NO_x, kan det være vanskeligt at realisere dette potentiale. Først og fremmest, fordi havneafgiften kun udgør en mindre andel af de samlede omkostninger ved søfart. I mange tilfælde vil havneafgiften ikke være tilstrækkelig høj til at begrunde kostbare investeringer i NO_x-reducerende udstyr. Dernæst vil der være stor risiko for, at rederen vælger en anden havn uden høje NO_x-afgifter, hvis havneafgiften for skibe med høje NO_x-emissioner forøges kraftigt. Det kan betyde længere transportafstande og øgede emissioner.

Mængden af partikelemissioner fra søfart er lavere end NO_x-emissionerne. Alligevel er skadesomkostningen pr. kg partikler større end for NO_x-emissionerne. Samlet set er skadesomkostningerne fra NO_x-emissionerne dog ca. 10 gange højere i forhold til skadesomkostningerne fra partikler.

På grund af den relativt begrænsede gevinst ved at reducere partikelemissionerne og det begrænsede antal tilgængelige teknologier er vurderingen, at markedsbaserede virkemidler ikke nødvendigvis er det bedste virkemiddel til at reducere partikelemissioner fra søfart. Derudover er skadesomkostningen fra partikler højere, når de udledes i tætbefolkede

[4] Artikel 87 i EU-Traktaten

[5] Kan omfatte såvel nationale som udenlandske redere, blot ruten er mellem to norske destinationer.

områder. Dette indebærer, at et markedsbaseret virkemiddel må opkræve en højere afgift i tætbefolkede områder.

På den baggrund foreslås det at anvende mere målrettede virkemidler såsom:

- Krav om anvendelse af LNG på bestemte ruter
- Krav om anvendelse af partikelfilter
- Krav om anvendelse af landbaseret elektricitet, når et skib ligger ved kaj

Tabel 1-6 viser disse virkemidlers potentiale for at reducere partikelemissionerne.

Tabel 1-6 Potentiel reduktion i partikelemissioner for udvalgte virkemidler

	Mål (Ton PM/år)	Reduktion (%)	Reduktion (Ton/år)	Omkostning (euro/kg PM)	Andel af samlede emissioner (%)[6]
LNG anvendelse på 80 % af danske færgeruter	141	90 %	101,52	6,62	2,6 %
Krav om partikelfilter på 80 % af danske færgeruter	141	80 %	90,24	34,56	2,3 %
Landbaseret elektricitet	20	60 %[7]	12	136	0,3 %

Note: Administration anslået til 250.000 euro pr. år.

Gevinsten ved en reduktion i partikelemissionerne anslås til 33 euro pr. kg partikler på havet og 233 euro pr. kg partikler i byområder. Denne gevinst opvejer de fleste af omkostningerne ved de tiltag, der er præsenteret i Tabel 1-6.

Et virkemiddel, som indebærer, at 80 % af danske færgeruter skifter til LNG-brændstof ville være det mest fordelagtige. Et skift til LNG vil være økonomisk fordelagtigt, især fordi besparelsen på det billigere LNG er tæt på at opveje investeringsomkostningerne. De administrative omkostninger betyder imidlertid, at der samlet set vil være en lille nettoomkostning også ved dette virkemiddel. Obligatorisk brug af LNG-brændstof på færger vil være et effektivt virkemiddel, da det vil sikre optimal udnyttelse af produktions- og bunkeringfaciliteter.

En anden mulighed er at gøre partikelfiltre obligatoriske på danske færgeruter, men det kræver at sådanne filtre bliver kommercielt tilgængelige. En del af emissionerne fra færgerne udledes i havne tæt på byer, hvor skadesomkostningerne fra partikelemissionerne er væsentligt højere end på havet. Gevinsten ved en reduktion i partikelemissionerne fra danske færgeruter ligger derfor mellem 33 og 233 euro pr. kg partikler.

Skat på partikelemissioner ved kaj vil fremme anvendelsen af "landbaseret elektricitet", hvor skibet gør brug af strømforsyningen fra et kraftværk på land i stedet for elektricitet produceret af hjælpemotorer ombord. I dette tilfælde kan en afgift være et mere effektivt virkemiddel end en norm. En norm vil kræve, at alle fartøjer investerer i teknologi til at konvertere landbaseret elektricitet. Sådan en afgift vil betyde, at faste brugere af havnen med fordel kan investere i udstyr, der muliggør brug af landbaseret elektricitet, mens

[6] Samlede emissioner i danske farvande

[7] Landbaseret strømforsyning antages at flytte 60 % af elforbruget fra kaj til kraftværk.

mere uregelmæssige brugere og skibe, hvor installation af sådant udstyr er vanskeligt, kan vælge at betale afgiften i stedet.

Endelig bør det nævnes, at følsomhedsanalyser har vist, at cost benefit-analysen af de tekniske foranstaltninger ikke er følsomme over for ændringer i investeringsomkostninger, brændstofomkostninger eller en alternativ værdiansættelse af skadevirkningerne fra emissionerne.

2 Summary and conclusions

2.1 Background and objectives

The purpose of this study is to identify possible means for further reducing air pollution from shipping in Danish waters and to assess the socio-economic consequences of the different means of reduction.

It is estimated that NO_x emissions from ships navigating in Danish waters are higher than emissions from land-based sources. Recent studies have shown that these emissions contribute substantially to the NO_x concentration in the air over Denmark.

The IMO's revised MARPOL Annex VI implies a considerable reduction of air pollution from ships in the coming years, especially from SO_x and NO_x. To identify additional opportunities to reduce air pollution, the Partnership for Cleaner Shipping (Danish Environmental Protection Agency and the Danish Ship owners' Association) has commissioned a mapping of the potential for reducing air pollution beyond the requirements of the IMO and other bodies, such as the EU.

The study primarily focuses on the reduction of NO_x and particulate matter (PM), since these two emission types are not regulated as strictly as SO_x in the coming regulations from IMO and the EU. SO_x will be regulated for all ships irrespective of age, while regulation of NO_x emissions will depend on the age of the engines, and PM will remain unregulated.

2.2 The study

The study has three main elements. The first element focuses on mapping the emissions in Danish waters. This mapping is based on AIS data collected in 2007 and received from NERI (National Environmental Research Institute). One purpose of the mapping is to estimate which part of the emissions the Danish authorities can regulate. The second part of the study relates to the technologies for NO_x reductions, identification of relevant technologies, assessment of the cost and benefits from the technologies. The third major part of the study identifies and discusses relevant options for policy measures to support implementation of the NO_x reducing technologies. This part of the study is mainly based on literature surveys.

2.3 Results and main conclusions

The main conclusions from the study are:

- International navigation in Danish waters emits more NO_x emissions than the entire Danish NO_x emissions.
- Particulate matter emissions from international navigation accounts for only 15% relative to the total Danish particulate matter emission.

- Due to international legislation, the Danish authorities can only regulate approximately 10% of the NO_x and particulate matter emissions that are emitted in the Danish waters.
- The cost of NO_x reducing equipment is small relative to the benefit. Therefore NO_x reductions would be very beneficial to society.
- Reductions of particulate emissions are not quite as beneficial as the case for NO_x emissions. The cost of technologies for particulate reductions is higher and at the same time, the reduction potential is smaller.

NO_x emissions from ships in the waters around Denmark reach approximately 173,000 tons annually. Only 9,530 tons of these emissions come from national navigation, while 163,701 tons come from international navigation. By comparison, land-based NO_x emissions amount to 122,254 tons annually.

The opposite is the case for particulate emissions. 85% of all particulate matter emissions come from land-based sources.

Table 2-1 NO_x and particulate emissions in and around Denmark

	NO_x	Particulate matter
Land-based	122,254	24,131
National navigation	9,530	320
International navigation	163,701	3,650

Source: Land-based emissions based on National Environmental Research Institute (2011). National and international navigation based on AIS data.

Due to international legislation on sea transport, the Danish authorities can only regulate emissions from national navigation around Denmark. This means that the Danish authorities can regulate 9,530 tons of NO_x and 320 tons of particulate matter.

There is a limited possibility for Danish authorities to give rules for international navigation provided vessels call at a Danish port. The following table shows a breakdown of NO_x emissions by flag state and the connection with Danish destinations.

Table 2-2 Distribution of NO_x emissions from sea transport around Denmark, according to flag and Danish destination.

	Occasionally calling at a Danish port	Never calling at a Danish port	Total
Danish-flagged ships	7%	3%	10%
Foreign-flagged ships	19%	70%	90%
Total	26%	74%	100%

Source: AIS data 2007

As can be seen, 70% of NO_x emissions in Danish waters are emitted by foreign ships that never call at a Danish port.

NO_x emissions from new-built ships will be reduced considerably with the expected designation of the Baltic Sea and North Sea as NO_x ECAs. (Emission Control Area), and therefore additional NO_x reduction incentives should target existing ships.

Table 2-3 shows the cost of alternative technologies for reducing NO_x emissions.

Table 2-3 Cost of reducing 1 kg emissions by the different technologies

	Weighted Average
EGR - Exhaust gas recirc.(EUR/kg NO_X)	0.36
HAM - Water injection in air(EUR/kg NO_X)	0.44
SCR - Selective catalysis (EUR/kg NO_X)	0.69
LNG - Natural gas (EUR/kg NO_X)	0.94
WIF - Water in fuel (EUR/kg NO_X)	1.31

Note: Weighted average based on size distribution for ships calling Danish ports.

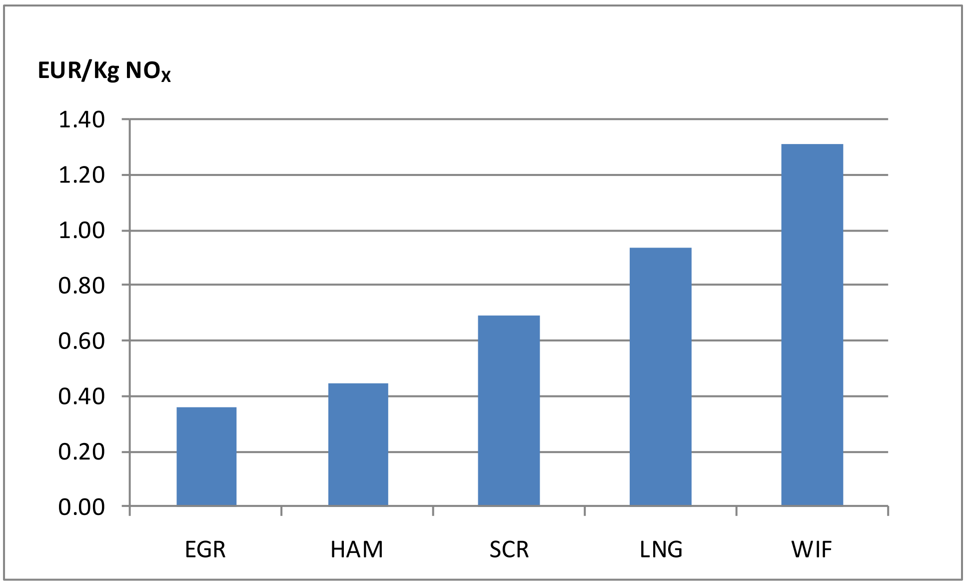

Figure 2-1 Cost of NO_X reductions in sea transport (EUR/kg NO_X)

The cheapest technology is the EGR technology with EUR 0.36 per kg of NO_x.

The LNG cost includes investment and distribution costs for a system that can supply the major routes in Denmark with LNG. Setting up a system that facilitates LNG supply of all ferry routes in Denmark would not be economically feasible[8].

The benefit reducing of NO_x emissions is between EUR 7 and 12 per kg NO_x. A comparison of the benefits with the cost ranging from EUR 0.36 to EUR 1.3 shows a net gain of EUR 5 to 10 per kg NO_x of reducing NO_x emissions.

The damage cost of NO_x emissions is not dependent on the population density where emissions occur. This is reflected in the unit cost of NO_x emissions that is identical for emissions in urban and rural areas. This is not the case for particulate matter. Particulate matter causes more damage in the

[8] EPA (2010): Natural gas for ship propulsion in Denmark, Environmental Project No. 1338 2010

area close to the emissions. This is why particulate emissions from ships at berth close to a city centre are more damaging compared with particulate matter emissions at sea far from land.

Table 2-4 shows the cost of alternative technologies for reducing emissions of particulate matter. LNG and particulate filters may be applied to reduce emissions both at open sea and at berth. Shore-side electricity, also known as cold ironing, can only be applied at berth. The costs of cold ironing and particulate filter technologies vary from EUR 32 to EUR 115.

Table 2-4 Cost of reducing 1 kg particulate matter emissions by the different technologies

	Weighted Average
Scrubber (EUR/kg PM)	-482.14
LNG - Natural gas (EUR/kg PM)	4.30
DPF - Particulate filters (EUR/kg PM)	32.10
Cold ironing(EUR/kg PM)	115.00

The large gain (negative cost) in the case of the scrubber is achieved from fuel cost savings, given that heavy fuel is approximately 25% cheaper than low sulphur gas oil. The scrubber reduces particulate emissions by 20% compared with a ship using low-sulphur fuel and without a scrubber. When the gain from fuel savings is measured relative to the 20% particulate matter reduction, the gain is EUR 482 per kg of particulate matter.

The costs of investment, operation and management of emission reducing equipment typically account for approximately 2.9 to 3.8% of the annual fuel consumption cost. With the relatively strong competition within maritime transport, even this small cost may constitute a barrier to the investment.

A number of measures have been analysed to see how the potential for reducing emissions of NO_x and particulate matter is best exploited. Table 2-5 shows the NO_x emission reduction potential of the most relevant measures.

Table 2-5 Potential NO_x reductions for selected measures

Potential, estimated savings, cost per kg NO_x	Target (Ton NO_x/year)	Reduction (%)	Reduction In tons Annually	Cost (EUR/kg NO_x)	Share of total emissions (%)[9]
Norms for national ferries	4,946	78%	3,834	0.71	2.2%
NO_x tax and Subsidy	9,530	70%	6,628	0.89	3.8%
Tradable emission credits	9,530	60%	5,718	0.95	3.3%
NO_x tax	9,530	39%	3,682	1.05	2.1%

The share of the various measures ranges from 2.1% to 3.8% of the total NO_x emissions around Denmark. The relatively low share is due to international legislation preventing, in practice, Danish authorities from regulating emissions from international sea transport, even if it navigates in Danish territory.

Setting norms for emissions from national ferries seems to be the most beneficial way of reducing NO_x emissions, since it would be a reasonably simple task to establish norms due to the limited number of ferries in

[9] Total emissions in Danish waters.

operation. As ferries already undergo an annual check, additional administrative and inspection costs are expected to be limited.

Tradable emission credits for national sea transport would have a higher NO_x emission reduction potential. However, the required administration would be higher compared with the norms approach because the former would require resources for initial design of the system and subsequently for the facilitation of a market for emission credits. Thus, emission credits would be a more expensive measure compared with establishing norms.

One of the challenges in the emission credit system is deciding on the initial distribution of credits. Basically, there are two options. The first option is to give away credits to ship owners. The other option is to set up an auction where ship owners can purchase the amount of credits they plan to use in the next year. While the first option may be quite easily accepted by the parties involved, notwithstanding the very difficult and time-consuming task of estimating the amount of credits given to individual ship owners, it may prove more difficult to obtain political acceptance of the second option. However, if this solution is chosen, it will give a more efficient allocation of emission credits initially and save administrative costs.

Emission taxation is an effective measure from an economic point of view. Unfortunately, international law prevents Danish authorities from charging international sea traffic navigating in Danish waters based on emissions.[10] According to the UNCLOS Article 24, the coastal state should not hamper the innocent passage of foreign ships through the territorial sea except in accordance with the Convention. However, Article 21 (3) permits states to "establish particular requirements for the prevention, reduction and control of pollution of the marine environment as a condition for the entry of foreign vessels into their ports". This means that there will be no legal basis for regulating ships passing through Danish waters except when they are calling at a Danish Port.

Further, Article 26 declares that no charge may be levied upon foreign ships by reason only of their passage through the territorial sea, and that charges may be levied upon a foreign ship passing through the territorial sea as payment only for specific services rendered to the ship and only in a non-discriminatory manner. This may be interpreted to rule out the use of distance-related charges[11]. Thus, vessels in international traffic cannot be charged based on NO_x emissions even though they actually call at a Danish port.

Subsidies may help overcome economic barriers to investments that would benefit society. Combining subsidies with an emission charge would increase the impact of the emission charge because it can reduce the cost of investments in cases where the economic incentive from emission charges is not sufficient to make the investment beneficial to the ship-owner. Combinations of a NO_x charge and a subsidy are known from Norway and France.

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[10] Although UNCLOS Article 21 allow costal states to adopt individual laws and regulations, this option is not available in Straits as the Oresund and the Great Belt, which ships need to traverse in order to reach other countries/areas. Furthermore, it is not common practice to regulate ships in innocent passage by national regulations.

[11] Kågeson, 2009

While subsidies or state aid are generally prohibited by EU legislation, certain categories of aid are exempted[12]. As a rule, the EU should be notified of all aid, and then the Commission will assess whether the aid can be exempted from the prohibition.

In a system like the Norwegian NO_x Fund, the subsidy element would probably be compatible with state aid rules for at least two important reasons. First, the combination of tax and funding in the Norwegian system is balanced, meaning that the sector as a whole is not distorted. Second, the funding of NO_x reducing equipment is open to all who wish to apply as long as they pay the tax, i.e. national traffic[13] in Norwegian waters. Thus, the scheme does not favour one ship owner at the expense of another.

Differentiated port dues mean that some of the dues are based on the vessels' air emission characteristics, thus providing a financial incentive for reducing emissions. One obvious advantage is that the administration is already in place to collect charges for the use of port facilities. Thus, there will be no need to establish completely new procedures for the payment of charges. On the other hand, the administration will need extra resources to set standards and to enforce the emission scale.

The potential effect of differentiated port dues will depend on the number of participating ports in the system. If only a limited number of ports participate, there will be a risk that ships with high emissions will look for ports without differentiated dues instead of investing in emission-reducing equipment. If ships choose to make a detour, cost and emissions may increase.

Although differentiated port dues show the largest potential for reducing NO_x, it may be difficult to realise this potential. To many of the ships coming from far away, a port due in Denmark may only be a very small share of the total cost of the journey. Thus, to the ship-owner, there may be no economic justification for making costly investments just to save a minor port due in Denmark. On the other hand, in case the port dues are raised to a substantial level, there is a higher risk that ship-owners will choose another port without high NO_x port dues. In this case, other costs from road transport will incur.

Emissions of particulate matter from sea traffic are much lower in amount than NO_x emissions. On the other hand, emissions of particulate matter cause more damage compared with NO_x emissions, but even if the more poisonous character of particulate matter is taken into account, the damaging effect of NO_x from sea traffic around Denmark is approximately 10 times higher compared with the damaging effect of particulate matter.

Given the relatively limited benefit of reducing particulate emissions and the limited number of technologies available, market-based instruments may not be an efficient measure to reduce particulate matter emissions in general. Furthermore, particulate matter is more damaging when emitted in densely populated areas. This means that a market-based instrument should in principle consider this circumstance by levying a higher charge in densely populated areas.

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[12] Article 87 of the EC Treaty.

[13] May include national as well as foreign ship-owners, as long as the route is between two Norwegian destinations.

In this situation, precisely targeted measures should be considered, such as

- requirement to use LNG on specific routes
- mandatory use of particle filters
- requirement to use land-based power supply.

Table 2-6 shows the potential of these measures for reducing particulate matter emissions.

Table 2-6 Potential particulate matter reductions for selected measures

Potential, estimated savings, cost per kg NO_X	Target (Ton PM/year)	Reduction (%)	Reduction In tons Annually	Cost (EUR / kg PM)[14]	Share of total emissions (%)[15]
LNG 80% of national ferries	141	90%	101.52	6.62	2.6%
Required PM filter 80% of ferries	141	80%	90.24	34.56	2.3%
Power supply from land	20	60%[16]	12	136	0.3%

Note: Administration estimated to be EUR 250,000 per year.

The benefit of particulate matter emission reductions is estimated to be EUR 33 per kg of particulate matter at sea and EUR 233 per kg of particulate matter in urban areas. This benefit more than outweighs the cost of the measures in Table 2-6.

A measure requiring 80% of national ferries to use LNG fuel would be most beneficial. Switching to LNG would yield a net saving because fuel cost savings more than outweigh the investment cost on board the vessel. However, administrative cost means that there will be a small net cost involved in the measure.

Making LNG fuel mandatory for ferries would be an efficient measure since it would secure optimal use of expensive bunkering facilities.

Another, more expensive, measure could be to make particulate filters mandatory for national sea transport, if such filters become commercially available. Part of the emissions from national ferries is emitted in ports or close to cities. Setting norms for particularly densely populated areas would make this measure more beneficial than estimated in this report.

A tax on particulate emissions at berth would promote "cold ironing" where the power supply is provided from land instead of from the auxiliary engines onboard. In this case, a tax may be more efficient compared with a norm. A norm would require all vessels to invest in electricity converters. A tax would cause frequent users to install equipment to reduce particulate emissions. Infrequent users and ships at which installation is difficult can choose to pay the tax instead.

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[14] Cost (EUR / kg) allocated proportionally to NO_X and PM reduction benefits.

[15] Total emissions Danish waters.

[16] Power supply from land assumed to switch 30% of electricity consumption from berth to power plant.

Finally, it should be mentioned that the sensitivity analysis found that the cost benefit analysis of the technical measures from the survey is not sensitive to reasonable changes in investment costs, fuel costs or alternative valuation of damage effects.

3 Background

The IMO's revised MARPOL Annex VI will introduce a considerable reduction of air pollution from ships in the coming years, especially in relation to SO_x and NO_x. To identify additional opportunities for reducing air pollution, the Partnership for Cleaner Shipping (Danish Ministry of the Environment and the Danish Ship owners' Association) has commissioned a study of potential incentives for reducing air pollution from ships beyond requirements by IMO and other bodies such as the EU.

The study primarily focuses on the reduction of NO_x and particulate matter (PM), as these two emission types are not regulated as strictly as SO_x in the coming regulations from the IMO and the EU. SO_x will be regulated for all ships irrespective of age, while regulation of NO_x emissions will depend on the age of the engines and PM will remain unregulated.

3.1 Purpose

The purpose of this study is to identify incentives for reducing air pollution from coastal shipping in Denmark and to assess the socio-economic consequences of reducing these emissions.

The Partnership for Cleaner Shipping has described the task as follows:

"Partnership for Cleaner Shipping requests a mapping and analysis of the possible measures to reduce air pollution from ships in Denmark. The analysis shall include a feasibility assessment and a socio-economic analysis. The latter should contain a statement of the socioeconomic costs and benefits of the tools and the assumptions made in the calculations. Finally, it must include an assessment of indirect effects associated with the instruments. The study will aim at both national and foreign vessels in waters around Denmark. "

The goal is a reduction of air pollution. The aim of the analysis is to show to what extent the various incentives may reduce the different air pollutants, and to demonstrate whether it is practically and politically feasible. The costs to both society and stakeholders, i.e. the ship owners, are also included in the study.

3.2 Overview of emissions in waters around Denmark[17]

Data on air emissions are based on AIS[18] data for ships navigating in Danish waters[19] for 24 days, 2 days in each month in 2007. To calculate one year's emissions these emissions are up scaled by the factor 365/24.

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[17] Data for emissions based on National Environmental Research Institute (2009)

[18] Automatic Identification System. After 2006, it is required that all ships greater than 300 GT carry an AIS transponder. With very short time intervals, the transponder transfers signals to land-based stations, providing information on ship identity, position, destination etc.

The AIS data provide vessel identification, ID number, speed and destination. In order to calculate fuel consumption and emissions for the vessels, these data are combined with vessel technical characteristics from Lloyd's Register, engine load functions from DTU (Technical University of Denmark), and emission factors from NERI.

The fuel consumption and emissions from each vessel between two consecutive AIS signals were calculated by combining engine size, engine load, time duration between the AIS signals, and fuel consumption and emission factors corresponding to the vessel's engine and fuel type.

Calculations in this report are based on 2011[20] fuel consumption and emission factors from NERI. The map below shows the distribution of fuel consumption in the data source and illustrates the coverage of the AIS study area.

[19] AIS data and background data are made available by the National Environmental Research Institute, Aarhus University

[20] AIS data collected in 2007, but fuel consumption and emission factors in the remainder of this study are adjusted to 2011 level according to the national emissions inventory.

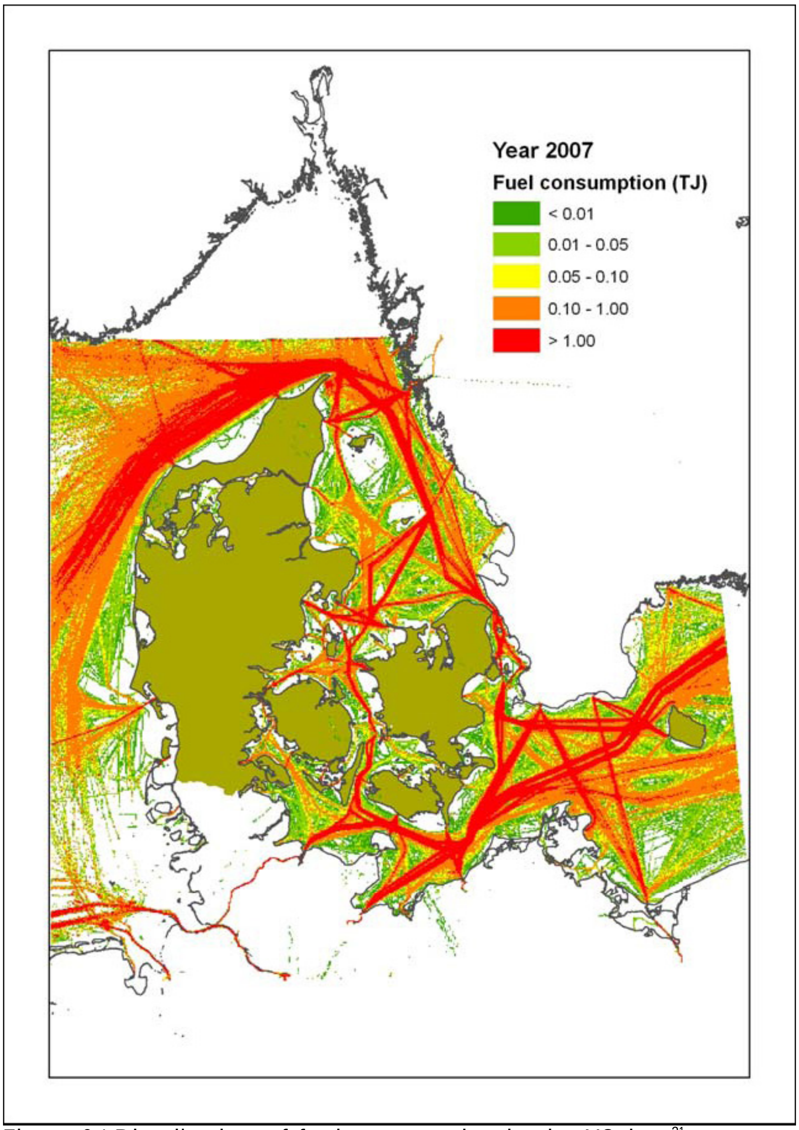

Figure 3-1 Distribution of fuel consumption in the AIS data[21].

Emissions from the waters around Denmark are shown in the following tables. In the first table, emissions are broken down by ship type.

[21] Source: National Environmental Research Institute (2009)

Table 3-1 Overview of air pollution from sea transport, tons per year.

Ship type	SO_2	CO_2	NO_X	VOC	CO	PM2.5
Bulk carrier	2,844	493,010	14,116	416	1,332	262
Cargo Ro-Ro	6,397	1,032,894	22,769	824	2,636	570
Container	8,412	2,014,584	44,532	1,614	5,164	918
Passenger Ro-Ro	14,447	2,715,275	49,850	2,041	6,186	1,385
Tanker	8,960	1,587,435	41,964	1,316	4,209	834
Total	41,061	7,843,198	173,231	6,211	19,528	3,970
Share of Danish emissions	399%	12%	129%	23%	8%	34%

Source: AIS data 2007. Emission factors for 2011, NERI 2009. Danish emissions from Annual Danish Informative Inventory Report to UNECE, Emission inventories from the base year of the protocols to year 2009

The emissions share of total Danish emissions exceeds 100% in Table 3-1 because emissions from international sea transport unrelated to Denmark are included. This part comprises the major share of emissions from Danish waters, but it is not included in the calculation of the Danish emissions in the national emission inventory.

NO_x emissions constitute 173,231 tons per year. This number should be measured against the total NO_x emissions from land-based sources of approximately 133,884 tons annually[22]. The largest, single contributor to NO_x emissions is passenger Ro-Ro traffic emitting 49,850 tons NO_x annually, closely followed by container ships and tankers, which contribute to the NO_x emissions with the same order of magnitude.

Particulate emissions ($PM_{2,5}$) amount to 3,970 tons per year. This number should be viewed in the context of total particulate emissions from land-based sources in Denmark of approximately 11,737 tons annually[23]. As with NO_x, the largest, single contributor to particle emissions is the passenger Ro-Ro traffic with 1,385 tons particulate emissions annually.

SO_2 emissions account for 41,061 tons per year. However, SO_2 emissions will be significantly reduced by the IMO regulation stipulating that the maximum sulphur content of fuel from 2015 is to be 0.1%.

A similar picture is seen in the case of particulate emissions. The 0.1% limit effective from 2015 is estimated to reduce particulate emissions from heavy fuel ships in Danish waters by approximately 50%[24]. The reduction would have the same order of magnitude if the scrubber technology were selected instead of low-sulphur fuel.

As can be seen from Table 3-1, sea transport around Denmark contributes significantly to air pollution in Denmark. Table 3-2 shows how these emissions are distributed in the seas surrounding Denmark.

[22] Source: National Environmental Research Institute (2011).

[23] Source: National Environmental Research Institute (2011). The major share of land-based particle emissions comes from heating in the housing sector.

[24] Emission factors from Emissions Inventory.

Table 3-2 Air emissions from shipping traffic around Denmark

Area	SO_2	CO_2	NO_x	VOC	CO	$PM_{2.5}$
The Great Belt and Samsoe Belt	10,598	1,958,939	41,922	1,549	4,915	1,008
The Kattegat	7,123	1,448,009	31,803	1,124	3,399	711
The North Sea	6,937	1,270,879	31,565	1,039	3,317	657
The Skagerrak	3,532	668,547	15,891	540	1,717	340
The Sound (Øresund)	1,287	278,590	5,705	219	698	133
The Baltic Sea	11,584	2,218,233	46,344	1,740	5,481	1,121
Total	**41,061**	**7,843,198**	**173,231**	**6,211**	**19,528**	**3,970**

Source: AIS data 2007. Emission factors for 2011.

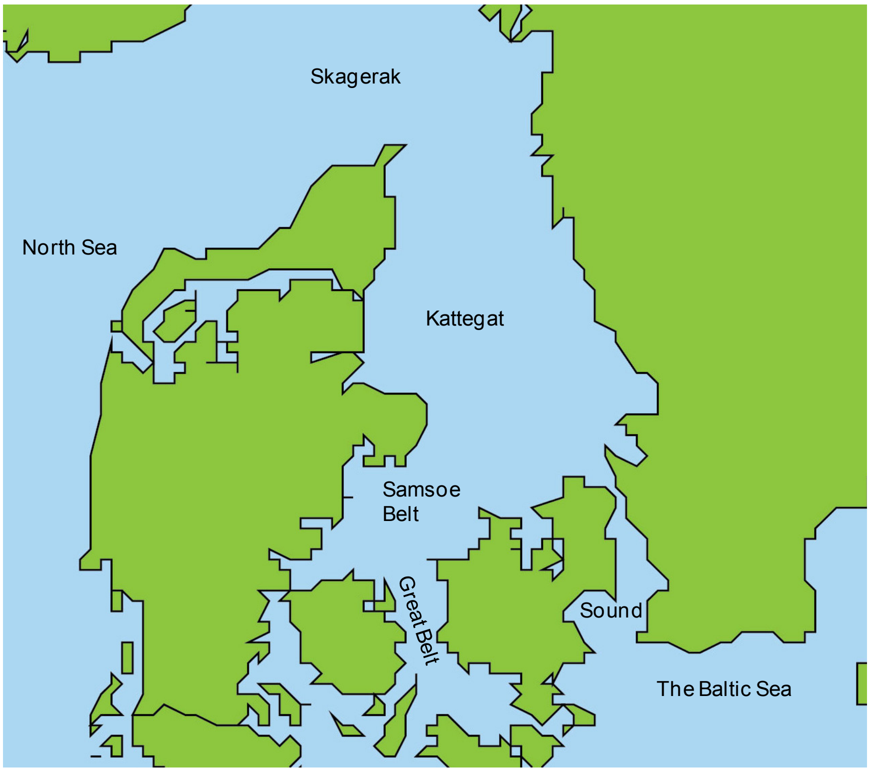

Figure 3-2 Waters around Denmark

The major share of air emissions occur in the Great Belt and the Baltic Sea. However, ships in the Kattegat and the North Sea also contribute substantially to air pollution.

3.3 Technologies to be analysed

A large number of technologies have been identified and their potentials have been estimated.

Technologies are classified in four categories:

- Ship design and construction
- Propulsion/hydrodynamics
- Machinery and fuels
- Operation.

Technologies in the three of these categories, namely ship design, propulsion and operation, all aim at reducing fuel consumption and thereby air emissions. Most of these technologies have limited potential for NO_x and particulate reductions compared with the more dedicated abatement technologies described in this report. Furthermore, these three technologies are likely to be supported by the coming greenhouse gas regulations (EEDI = Energy Efficiency Design Index and EEOI = Energy Efficiency Operational Index) and by ship owners striving to obtain fuel savings in general.

The main potential for reduction of SO_x, NO_x and particulate emissions is in machinery and fuel technologies. In this category, we find the well-known technologies, such as the Selective Catalytic Reduction (SCR) that uses a catalyst to convert NO_x emissions into nitrogen and water, and Exhaust Gas Recirculation (EGR) where part of the exhaust gases is filtered, cooled and recirculated back into the engine's charge air. Scrubbers and particulate filters for removal of SO_2 and particulates from exhaust gases are also some of the leading abatement technologies.

The report focus is on the following technologies:

- Technologies for NO_x reductions
    - SCR - Selective Catalytic Reduction
    - HAM - Water injection in turbo-charge-air (Humid Air Motor)
    - EGR - Exhaust Gas Recirculation
    - WIF - Water In Fuel
    - LNG.
- Technologies for particulate reductions
    - Particulate filters
    - Scrubbers
    - LNG.

The project includes a cost-benefit analysis for each of these technologies. The benefit mainly consists of reductions in NO_x and particulate matter while the costs include the investment cost and operating costs, including costs due to changes in fuel consumption caused by the introduction of the different technologies.

3.4 Measures to analyse

Furthermore, the report discusses the following measures for reduction of NO_x and particulate matter.

- NO_x tax
- Subsidies
- Differentiated port dues
- Special rules for domestic ferries
- Tradable emission credits
- Voluntary agreements
- Consortium benchmarking.

4 Mapping of NO_X emissions around Denmark

This chapter presents the mapping of sea transport and the associated emissions from vessels navigating in Danish waters. As a starting point, the amount of transport and emissions has been broken down by ship type, engine type, flag state administration and destination. The reason for breaking down transport and emissions by engine type is to cater for the different options for NO_x reductions, which depend on the engine type. The flag state and destination categories have been included in recognition of the different options for targeting transport depending on flag state and destination. According to international regulation, it is not possible to apply national legislation, e.g. a Danish NO_x tax, to ships exercising their right of "innocent passage", or in other words ships passing through Danish waters of foreign origin and destination.

4.1 Breakdown of sea transport by type of transport

Table 4-1 shows the allocation of the energy consumption broken down by type of sea transport based on NERI AIS data 2007.

Table 4-1 Distribution of energy consumption for sea transport around Denmark by ship type

	MJ	Share
Bulk carriers	6,351	6%
Ro-Ro cargo ships	13,252	13%
Container ships	26,347	26%
Ro-Ro passenger ships	35,128	35%
Tankers	20,474	20%
Total	**101,551**	**100%**

Source: AIS data 2007, emission factors for 2011.

Passenger Ro-Ro ships account for 35% of the total energy consumption of all sea transport around Denmark. Also, container ship transport makes up a relatively large share with 26% of the energy consumption in sea transport.

Additional details can be seen in the below table, in which sea transport is broken down by ship type and engine type.

Table 4-2 See transport by ship and engine type

	2 stroke	4 stroke
Bulk carriers	87%	13%
Ro-Ro cargo ships	32%	68%
Container ships	32%	68%
Ro-Ro passenger ships	21%	79%
Tankers	69%	31%
Total	39%	61%

Source: AIS data 2007. Emission factors for 2011.

Table 4-3 Distribution of particulate matter emissions from sea transport around Denmark by ship type.

	PM2.5 (ton)	Share
Bulk carriers	262	7%
Ro-Ro cargo ships	570	14%
Container ships	918	23%
Ro-Ro passenger ships	1,385	35%
Tankers	34	21%
Total	3,970	100%

Source: AIS data 2007. Emission factors for 2011.

Tankers, Cargo Ro-Ro and Bulk carriers have slightly higher $PM_{2.5}$ emissions per energy unit (due to generally higher sulphur content in the oil used by these ship types). Therefore, the PM emission share of these types is slightly higher than the energy demand share of the same ship types.

Table 4-4 Distribution of NO_X emissions from sea transport around Denmark by ship type.

	NO_X (ton)	Share
Bulk carrier	14,116	8%
Cargo Ro-Ro	22,769	13%
Container	44,532	26%
Passenger Ro-Ro	49,850	29%
Tanker	41,964	24%
Total	173,231	100%

Source: AIS data 2007. Emission factors for 2011.

Looking at the total NO_x emissions of 173,231 tons NO_x from sea transport around Denmark, it should be kept in mind that Denmark has agreed to limit land-based NO_x emissions to 127,000 tons annually from 2010. Although the amount of NO_x emitted from sea transport does not contribute to this share of NO_x emissions, it shows that the air quality could be enhanced and NO_x concentrations could be reduced considerably if NO_x emissions from sea transport around Denmark were reduced.

As tankers and bulk carriers have higher NO_x emissions per energy unit, the shares of these two types are higher, measured as NO_x emissions compared with energy units. Contrary to this, passenger Ro-Ros have lower NO_x

emissions compared to the average emissions and contribute with less NO_x emissions relative to their share based on energy consumption.

4.2 Flag and Destination

One of the main boundary conditions or limitations to the Danish possibilities of regulating emissions from ships around Denmark is international legislation, according to which it is illegal to set mandatory regulations for ships on innocent passage in Danish waters. This means that the Danish authorities are not allowed to regulate emissions from sea transport around Denmark unless the ships are calling at a Danish port.

To illustrate the potential for regulation, the following table breaks down sea transport around Denmark according to flag and destination.

As can be seen from this table, the major share of emissions in the waters around Denmark comes from ships under foreign flag on their way to a foreign destination. This illustrates one of the major problems of emissions regulation for shipping in Danish waters; there is no legal basis for regulating the major share of emissions.

Table 4-5 Distribution of NO_X emissions from sea transport around Denmark, distributed by flag and destination

	To Danish destination	No Danish destination	Total
Danish-flagged ship	6%	4%	10%
Foreign-flagged ship	7%	83%	90%
Total	13%	87%	100%

Source: AIS data 2007

The analysis of AIS data only includes destination, not origin. As a result, we do not know the number of vessels with Danish origin destined for foreign ports.

Table 4-5 only includes ships destined for Danish ports. This definition excludes trips by Danish ferries from Danish ports to foreign destinations. The following table shows a breakdown based on a broader definition of the connection with Danish destinations. In Table 4-6 all ships occasionally calling at a Danish port are included in the column "Occasionally calling at a Danish Port".

Table 4-6Distribution of NO_X emissions from sea transport around Denmark, according to Flag and Danish destination.

	Occasionally calling at a Danish port	Never calling at a Danish port	Total
Danish-flagged ships	7%	3%	10%
Foreign-flagged ships	19%	70%	90%
Total	26%	74%	100%

Source: AIS data 2007

However, even with the broader definition of ships calling at Danish Ports, 70% of NO_x emissions in Danish waters are emitted by foreign ships that never call at a Danish port.

4.3 Mapping of passenger ship transport

One of the feasible measures is to target national passenger ship transport. In order to know the emissions from this segment, passenger transport around Denmark has been broken down according to a more detailed definition of the nationality of passenger transport.

Table 4-7 shows the energy consumption from passenger ship transport broken down by type of transport.

Table 4-7 Energy consumption from passenger ship transport around Denmark

	TJ/year	Share
Foreign (innocent passage)	17,722	56%
Cruise ships calling at Danish ports	378	1%
Domestic passenger ship transport	4,438	14%
Passenger ship transport between Denmark and a foreign country	9,317	29%
Total	31,855	100%

Table 4-8 shows the NO_x emissions from passenger ship transport broken down by destination.

Table 4-8 NO_x emissions from passenger ship transport around Denmark

	NO_x (ton/year)	Share
Foreign (innocent passage)	26,812	60%
Cruise ships calling Danish ports	557	1%
Domestic passenger ship transport	4,946	11%
Passenger ship transport between Denmark and a foreign country	12,685	28%
Total	45,000	100%

As can be seen, 60% of NO_x emissions are emitted by ships unrelated to Danish ports. 4,946 tons, corresponding to 11%, are emitted by domestic ferries in Denmark. While 12,685 tons, corresponding to 28% are emitted by ferries travelling between Denmark and another country.

Table 4-9 shows the $PM_{2.5}$ emissions from passenger transport broken down by destination.

Table 4-9 PM2.5 emissions from passenger ship transport around Denmark

	PM2.5 (ton/year)	Share
Foreign (innocent passage)	757	59%
Cruise ships calling Danish ports	15	1%
Domestic	141	11%
Passenger ship transport between Denmark and foreign port	370	29%
Total	1,283	100%

As can be seen, 59% of particulate emissions are generated by ships not destined for Denmark. 141 tons, corresponding to 11% annually, are emitted by domestic ferries in Denmark. While 370 tons, corresponding to 29%, are emitted by ferries travelling between Denmark and another country.

5 General air pollution reductions

A large number of technologies for the reduction of exhaust gas emissions have been identified and their potential has been estimated. The technologies are categorised in four groups:

- Ship design and construction
- Propulsion/hydrodynamics
- Machinery
- Operation.

The main potential for NO_x and particulate emission reductions lies in the cleaning technologies in the machinery category. These technologies are discussed in more detail in section 6.

Ship design, propulsion and operation have to do with general fuel consumption savings and related reductions in air pollution and are described briefly below.

Ship design and construction technologies are mostly aimed at improving the overall fuel efficiency of the ship. From an overall point of view, this means that fuel consumption compared with the cargo transported by the ship is minimised (cargo can also be passengers when passenger ships are considered). An example of improved ship design technology is weight optimized ship structures and the use of other weight-reducing technologies (for example the use of composites) since a lighter ship will require less propulsion power. Improved hull forms with less resistance and better flow to the propellers are also among the ship design features considered, although these may also be part of the propulsion technologies.

Propulsion/hydrodynamics relates to the task of reducing ship resistance as much as possible to minimise propulsion power. The propeller is a very important part of the propulsion system, and the more the efficiency of this can be improved, the better. So-called winglets on the propeller tips can increase efficiency by up to 4-5%. Running two propellers close to each other on the same shaft line either in same direction or opposite to each other as contra-rotation propellers is also a possibility to increase efficiency, although it is a complicated construction. All four ferries serving the Rødby-Puttgarden route are equipped with contra-rotating propellers, which proved to increase the efficiency by 5-10%.

Different 'devices' and local improvements of the hull form can also be considered to lower the propulsion power. A local improvement that is used on relatively fast ships is the so-called stern-wedge, which directs the flow from the stern a bit downward. This can decrease resistance by up to 10%, which has been proven both in model scale and full scale tests on the Danish Navy's latest flexible support ships of the Absalon Class. Alternatively, so-called interceptor trim plates can be applied to both new and existing ships instead of a stern wedge, as the influence of these are equivalent to a stern wedge, but only for ships sailing at relatively high speeds.

Furthermore, different flow direction devices can be attached to the ship hull close to the propeller to improve the flow in front of the propeller. This often has a positive influence on the propulsion efficiency, especially if the initial flow is bad (which should have been omitted already at the design stage). A final propulsion related device is the bulbous bow, with which many ships are equipped. The main purpose of a bulbous bow is to create a good interference between the waves this device creates and the waves, which are created by the remaining ship hull. By careful design, often based on model tests of the ship, a bulbous bow can reduce resistance by 10-20%. The only negative issue is that it performs best within a given draught range. If the ship is operated at draughts outside this range, the influence of the bulbous bow diminishes or resistance may even become worse than in a ship without a bulbous bow.

Common to both ship design measures and the different propulsion devices are that they reduce the overall fuel consumption, which means they reduce exhaust gas emissions with the same percentage as the fuel consumption. The main drawback is that some of these measures require substantial changes in the design of the ship and are only feasible for new building because it can be difficult - if not impossible - and very expensive to apply these technologies to existing ships. Other measures, such as new propeller types and some of the flow enhancing measures have been retrofitted in recent years - often with the expected result.

The remaining types of emission-reducing technologies are the operational technologies, which is a very broad group of different technologies and operational procedures focusing on fuel consumption reduction, such as ship design and propulsion technologies.

One of the operational procedures is maximization of the cargo carried onboard and careful route planning including making more efficient logistic procedures in the total transport chain. Reduction of the port turnaround time and use of effective manoeuvring procedures by using effective rudders and other steering devices (such as thrusters) is an operational way of reducing sailing speed and still keep a given sailing schedule. For this reason, ferry operators have much attention directed to these possibilities.

In the last three to four years, much focus has been given to speed reduction, as the propulsion power is proportional with the speed in the 3rd power and even more in the upper part of the speed range. This means that a 10% speed reduction will decrease fuel consumption by 20-30% per transport unit.

Propeller and hull cleaning procedures and use of new coating types are another way to reduce ship resistance as the growth of algae and organic material on the hull can increase the ship's resistance considerably. Regular cleaning, coating/polishing can therefore help restore the high-energy efficiency of a ship.

Table 6-1 summarises the potential NO_x reductions from the three subgroups of technologies. It should be noted that a pure summation of the reductions by using the different technologies is not possible since not all the technical measures have the same effect on the different ship types as already mentioned in the introduction to these technologies. Furthermore, adding the potential reductions would result in double counting since many measures target the same emissions.

Table 5-1 Overall technologies to reduce NO_X Emissions, incl. indication of reduction potential

	Potential
Ship design	1% - 10%
Propulsion	2% - 10%
Operation	1% - 55%

In general the fuel consumption driven reductions are below 10%. The only exception being the up to 55% reduction in the operation category. The 55% reduction is the result of a large reduction in the speed and should be seen as a special case, not generally achievable.

6 Technologies for NO_X reductions

Based on a literature search, information from MAN Diesel and Turbo and discussions with Hans Otto Holmegaard Kristensen[25] and Flemming Bak[26], it is estimated that the following technologies will be the most widely used NO_x reducing measures in the foreseeable future.

Table 6-1 shows the effect on emissions from the NO_x reducing technologies. Some of the technologies increase other emissions while they at the same time reduce the NO_x emissions. For instance WIF reduces the NO_x emissions by 50% and increases the other emissions by 2%.

Table 6-1 NO_X reducing technologies and their associated effect on other emissions

	NO_X	PM	SO_2	CO	CO_2	VOC
WIF Water in fuel	-50%	2%	2%	2%	2%	2%
HAM (4 strokes)	-65%	0%	0%	0%	0%	0%
SCR	-90%	0%	0%	0%	0%	0%
EGR, Based on Tier I	-80%	-1%	-1%	-1%	-1%	-1%
EGR, Based on Tier II	-80%	2%	2%	2%	2%	2%
LNG (lean burn)	-88%	-90%	-67%	-80%	-10%[27]	-80%

Note: Reductions are given as negative figures. Increases are given as positive figures. EGR Tier I is an engine setup where a Tier II engine is downgraded to a tier I technology, there by saving fuel. EGR Tier II refers to a Tier II engine with EGR technology.

The above-mentioned technologies are possible to implement both in new buildings and in existing ships, i.e. as a retrofit solution. However, regarding existing ships, there may be situations where installation in practice will be difficult due to space constraints or due to too high investment costs compared with the benefits.

The five technologies are discussed in more detail below.

6.1 SCR - Selective Catalytic Reduction

Selective Catalytic Reduction (SCR) is a well known and widely used technology for removing NO_x from exhaust gases.

The SCR uses a catalyst to convert NO_x into nitrogen and water by using reaction reducing agents such as ammonia (NH_3) or urea. There are no limitations to ship types, and application of the technology may lead to a reduction in NO_x emissions of up to 90-95%. To reach a 90% NO_x reduction, approximately 15 g of urea is needed per kWh energy from the engine. In addition to the catalyst that ensures reduction of NO_x, the cleaning technology

[25] Senior Researcher at Technical University of Denmark

[26] Miljøstyrelsen

[27] EPA (2010)

may also include an oxidation step, resulting in significant reduction of HC, CO and particles. In addition to the SCR catalyst, an SCR system consists of a reactor tank and a pump and control system for dosage of ammonia/urea.

One of the most critical problems is the relatively large space requirement for the SCR system and storage of ammonia or urea especially in connection with a retrofit solution. On the other hand, in a recent case from the Danish Navy it was shown to be possible to install a retrofit SCR system on vessels with limited free space, such as for instance the so-called Diana Class patrol vessels.

SCR systems have mostly been used on four-stroke engines, but SCR systems can also be installed on two-stroke engines, and it is expected that the SCR technology will be used increasingly on two-stroke slow-speed engines in the future.

6.1.1 Effect on emissions

It is technically possible to achieve NO_x reductions of more than 95% using SCR systems. However, most common applications are set up to reduce the NO_x emissions slightly below the maximum capacity, most often 85 - 90% in order to reduce the risk of ammonia emissions[28].

6.1.2 Cost

The cost of installation of SCR has been based on data collected from MAN Diesel & Turbo (MAN, 2011) and a study by Entec (Entec, 2005).

The following chart shows the costs of implementing SCR technology in existing ships based on the data collection from MAN Diesel & Turbo.

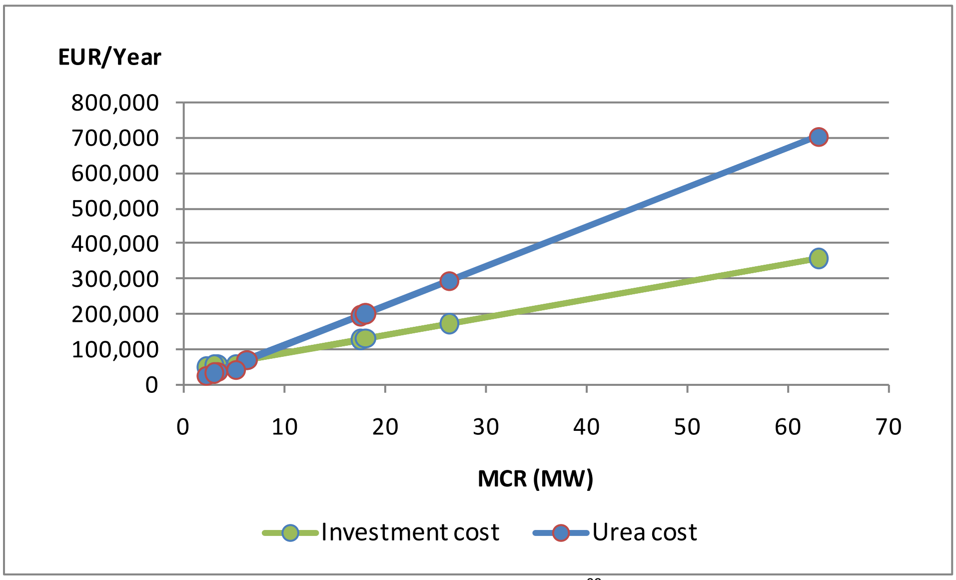

Figure 6-1 Annual cost of SCR NO_x reduction system[29]

[28] Helden, Rinie van et. al. (2004)

[29] Source: MAN, 2011.

The horizontal axis shows the engine power by MCR (Maximum continuous rating). The vertical axis shows the costs measured in EUR.

The major share of the total cost of a SCR system is the urea cost, especially for large engines. For small engines below approx. 3000 kW the installation cost is the major expenditure.

The cost of installing SCR shows an element of economics of scale. The figure below shows the cost of installing SCR per MW MCR based on observations by MAN Diesel and Turbo (MAN/HOK 2011).

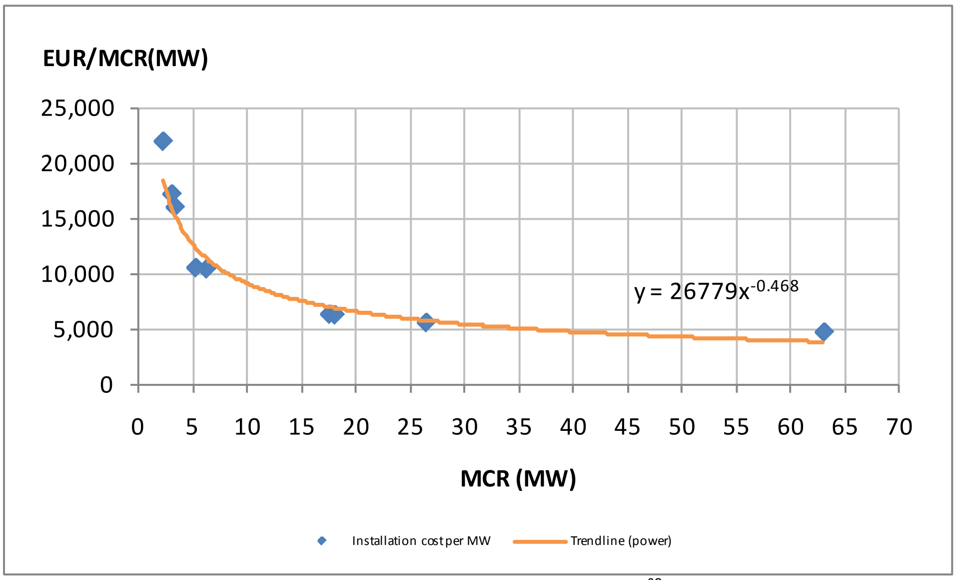

Figure 6-2 Installation cost of SCR NO_x reduction system[30]

For small engines the cost of installation amount to approximately 20,000 EUR per MW (MCR). For large engines the installation amounts to approximately 5,000 EUR per MW (MCR).

The chart below compares the data from MAN Diesel & Turbo with reported cost from the Entec report, Entec (2005).

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[30] Source: MAN/HOK (2011)

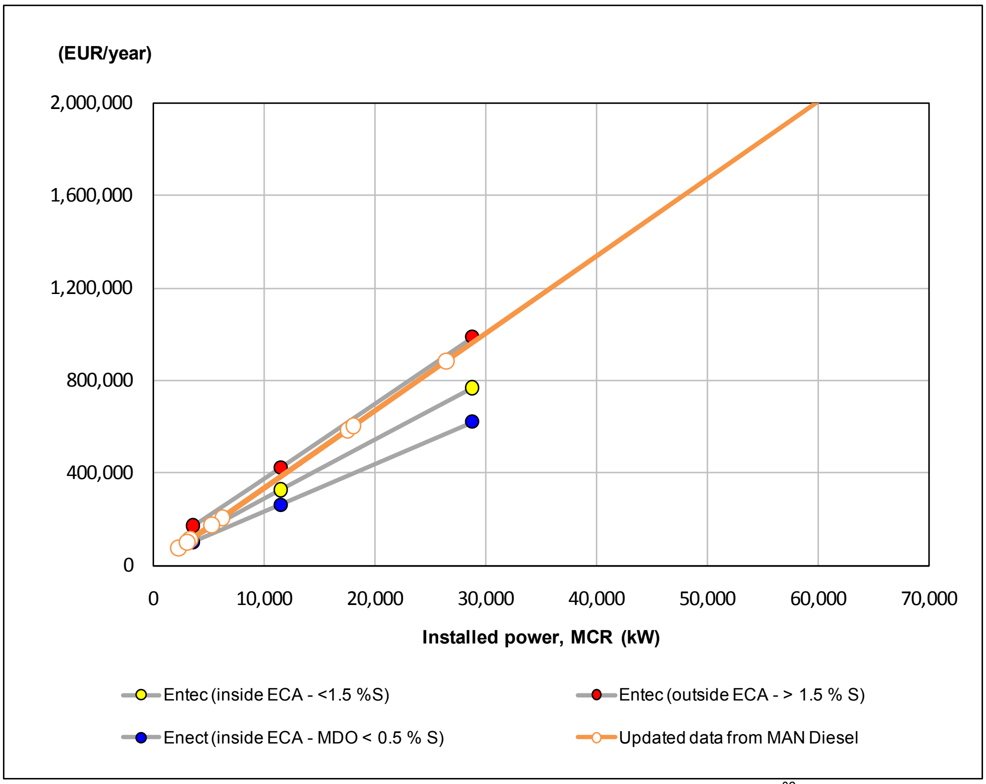

Figure 6-3 Total annual cost[31] of SCR NO_x reduction system, retrofit[32]

As can be seen from the chart above, the cost calculated based on MAN data is close to the cost estimates from Entec.

Assuming the engine is running 6667 hours annually[33]; the annual cost of urea is estimated to be 26.7 EUR per kW installed power.

The total annual cost of the SCR NO_x reduction system would amount to approximately 3.5 % of the annual fuel cost assuming an average fuel price of 753 EUR per ton diesel (MGO)[34].

6.2 HAM - Water injection in turbo-charge-air

The Humid Air Engine (HAM) builds on the same principle as water injection, namely to lower the temperature in the combustion chamber thereby reducing NO_x emissions. HAM uses seawater to humidify the inlet air in order to lower the temperature peaks during the combustion process (Figure below).

In the HAM system, the turbocharger air is saturated with water vapour. With the HAM method, a NO_x reduction level of 40% is achievable without heating of the water. If water is heated, more water can be evaporated, and further NO_x reductions are achievable. HAM can reduce NO_x emissions by 65% without increasing fuel consumption.

[31] Annual operating cost plus annualised investment cost
[32] Source: Entec (2005) and MAN/HOK (2011)
Note: Data from MAN Diesel & Turbo updated by august 2011.
[33] Entec estimates three years to correspond to 20,000 operating hours
[34] We compare with the price of distilled MGO diesel because this will most likely be the fuel used by the ships after SECA enters into force in January 2015 (if the ship is not equipped with a scrubber to clean SO_2 from the exhaust gas).

There is limited operational experience with HAM systems. However, it is found that seawater containing sodium may pose a problem when engines are sensitive to the increase in sodium content in the intake air.

As the HAM technology requires much space, the system can not be installed on vessels with limited engine room space. The HAM technology may be used in new buildings and in existing ships.

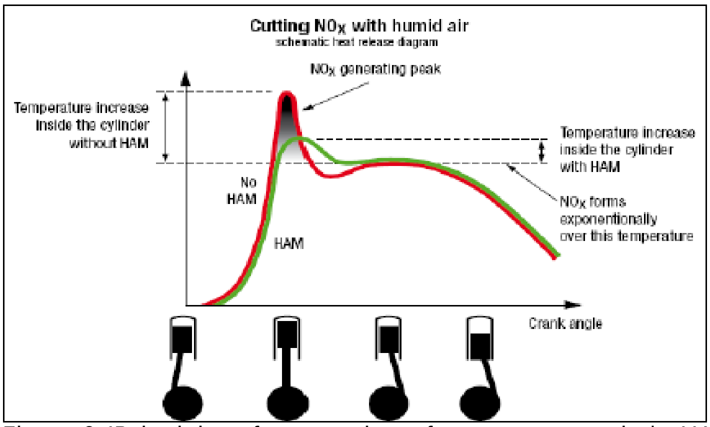

Figure 6-4Principles of suppression of temperature peaks by HAM technology (MAN Diesel information)

6.2.1 Effect

The NO_x reduction potential by HAM technology is estimated to be up to approximately 70 %. The concept has been tested on small fast-running diesel engines as well as on larger engines (the passenger ferry Mariella operates such a system)[35].

6.2.2 Costs

The following chart shows the cost of installing the HAM technology in existing ships.

[35] Entec 2005.

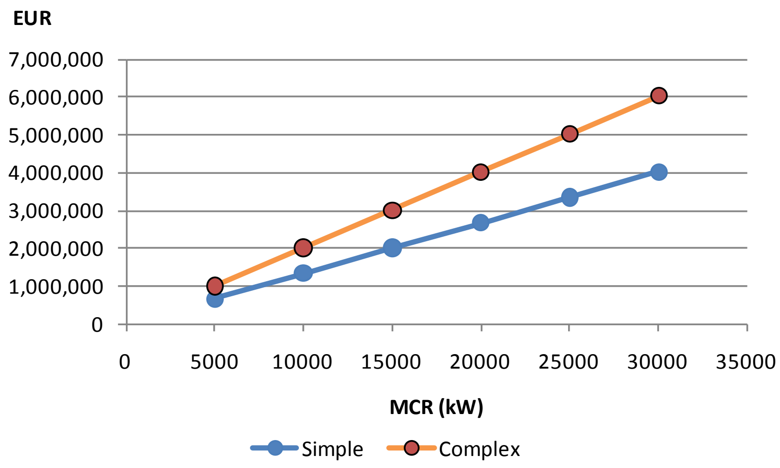

Figure 6-5 Installation cost of HAM NO_X reduction system as a function of engine size[36]

As can be seen from the figure above, the installation cost is proportional to the size of the engine. Furthermore, the cost of installation of HAM depends on the complexity of the installation varying from approximately EUR 135 to EUR 201 per kW.

Based on a HAM installation on the MS Mariella, the cost per kW installed power was reported to be EUR 90-130 per kW for new ships and EUR 110-130 per kW for retrofitting. Operation and maintenance costs are estimated to be EUR 0.15 per MWh (Entec 2005, page 29).

Based on the Entec report and data from MAN Diesel & Turbo, the total average annual costs (investment and operation and maintenance) based on 6667 running hours amount to approximately 2.9 % of the annual fuel costs assuming an average fuel price of EUR 753 per ton diesel (MGO), assuming a 12.5-year average lifetime for a retrofit solution. If the installation is complex due to limited space in the engine room, the total annual cost may increase to approximately 4% of the fuel oil costs.

6.3 EGR - Exhaust Gas Recirculation

By recirculating exhaust gas into the charge air, the oxygen content in the cylinder is reduced and the specific heat capacity increased. Both cause lower combustion temperatures and therefore lower NO_x emissions.

The EGR may be the preferred technology to make new vessels comply with the IMO Tier III regulation from 2016, at least for two-stroke engines.

The sulphur content of heavy fuel oil, however, can lead to soiling and the corrosion of components. To solve this problem, an exhaust gas scrubber is installed in the first stage of the complex recirculation system. It cleans the exhaust gas to remove sulphur and particles before recirculation. The unit is linked to a water purification plant neutralising the resulting sulphuric acid with caustic soda and collecting the solid residues in tanks, so that they can be disposed of on land. After the scrubber, a cooler is installed to reduce the exhaust gas temperature to no more than 100° C. A “droplet catcher” in the next stage removes the final traces of humidity from the exhaust gas. A fan

[36] Source: MAN Diesel & Turbo Frederikshavn (MAN 2011b).

then increases the pressure of the recirculated exhaust gas by 0.4-0.7 bar, before the gas is returned to the charge air.

The exhaust gas recirculation function can be switched on or off depending on the ship's location and the environmental regulations in force. In the event of a fault, the EGR system automatically takes itself out of service. An exhaust gas recirculation system (EGR) can reduce NO_x emissions in ships by up to 80%. The fuel consumption is correlated to the EGR ratio, higher EGR ratio will lead to increased fuel consumption.

6.3.1 Emission reductions

For this study, it has been estimated that the EGR technology may reduce NO_x emissions by approximately 80%[37].

In some cases, EGR will lead to increased fuel consumption. A setup based on a Tier II engine, adding an EGR NO_x reduction system is estimated to result in an increased fuel consumption of approx 2%. However, it will also be possible to combine the EGR technology with a Tier I fuel optimized engine, and in this case the fuel consumption is estimated to be 1% lower compared with a Tier II engine without EGR[38].

6.3.2 Cost

The cost of installation of EGR has been based on data collection from MAN Diesel & Turbo (MAN Diesel & Turbo (2009)). The following chart shows the cost of installing the EGR technology in existing ships:

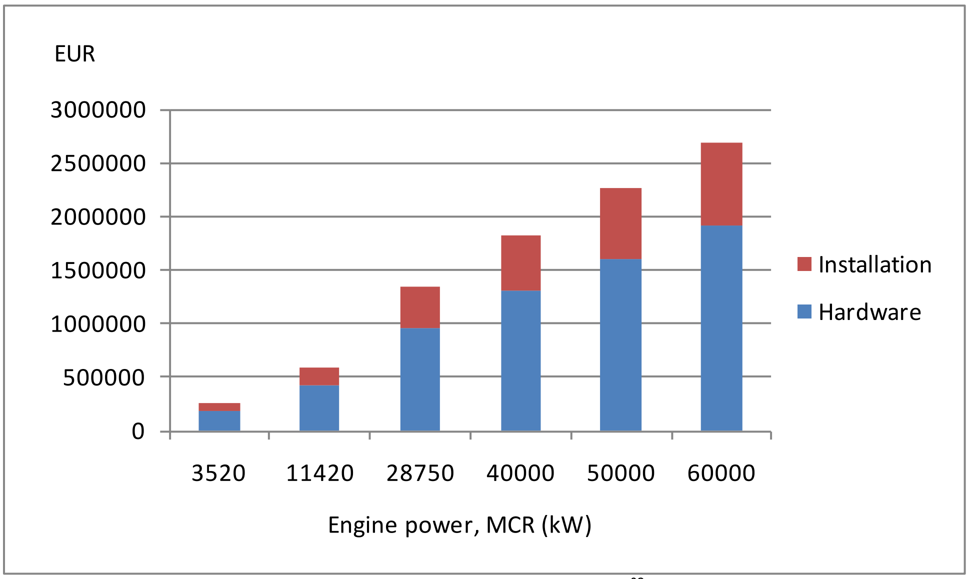

Figure 6-6 Cost of installing EGR NO_x reduction system[39]

As can be seen, the major share of the investment cost of an EGR system is the hardware cost. The total cost of installing an EGR system on a 60,000 kW

[37] Combination with WIF may lead to larger reductions in NO_X emissions. (MAN CIMAC paper 85).

[38] MAN Diesel and Turbo (2009):MAN Diesel and Turbo publication: 'Economical aspects of EGR systems.

[39] Source: MAN Diesel and Turbo (2009)

engine is estimated to EUR 2,700,000 corresponding to approximately EUR 45 per kW.

The operating costs will depend on the ship to be retrofitted. Operating costs are lower on a fuel-optimized Tier I engine compared with a Tier II engine due to the fuel consumption savings of the Tier I engine.

The chart below shows the difference in operating costs depending on which Tier is selected as the basis for the installation. For the Tier II engine, it is estimated that the operating cost will be EUR 1,200,000 annually. For the Tier I engine, it is estimated that the operating cost will be EUR 700,000 annually. The reason for this variation is the difference in fuel consumption. A Tier II engine can be downgraded to comply with Tier I and at the same time save fuel. The fuel saving obtained by downgrading from Tier II to Tier I more than outweigh the extra fuel consumption due to the EGR installation. Thus, downgrading to Tier I and installing EGR may save fuel relative to a standard Tier II engine without EGR.

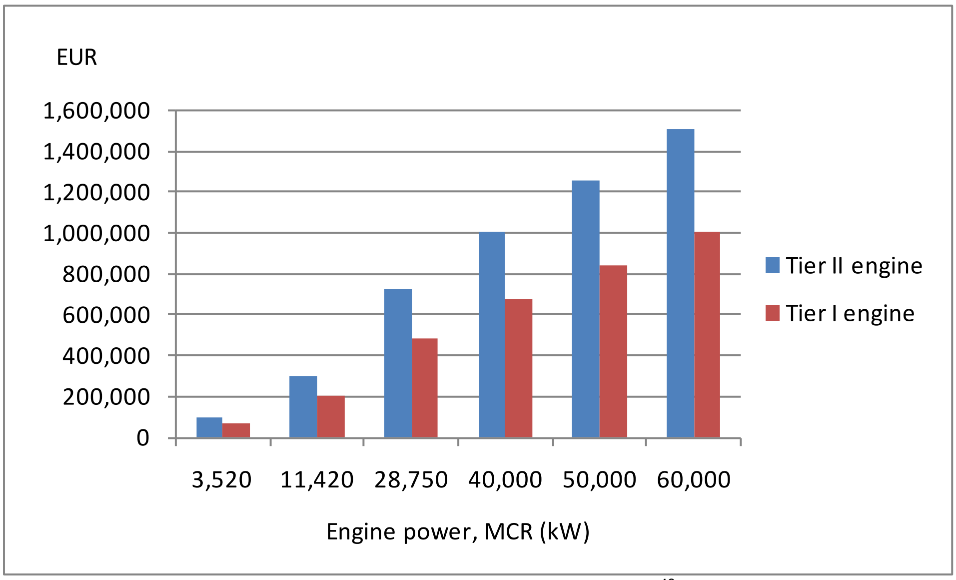

Figure 6-7 Total annual cost of EGR NO_x reduction system[40]

The average annual cost for a medium engine size is 3% of the annual fuel cost assuming an average fuel price of EUR 753 per ton of diesel (MGO).

6.4 WIF - Water in fuel

WIF (water in fuel) is a technique for preventing NO_x formation during combustion by adding water to the fuel.

Fuel is mixed with emulsifier[41], afterwards water is mixed into the fuel/emulsion, and with a control unit it is possible to obtain a given water to fuel ratio from 0 to 85% measured by volume. The fuel water emulsion lowers the temperature in the combustion chamber because of evaporation of the water thereby reducing NO_x emissions. Experience has shown that a very small droplet size is necessary in order to obtain optimal fuel injection and

[40] Source: MAN Diesel and Turbo (2009)

[41] Not needed for HFO

combustion. Therefore, the emulsion should either be homogenised or supplied by a high-pressure pump adding water to the fuel through special nozzles by short impact injections at 100 bar. Thereby very small water droplets are mixed effectively with the fuel. The reduction of NO_x emissions follows water content percentage such that approximately 1% NO_x reduction is obtained per 1% of added water.

The specific fuel oil consumption (SFOC) is influenced by the water/fuel ratio and the engine loading (Figure 6-8). It is seen that up to a 30% water content, the SFOC is only influenced marginally while there is a more pronounced increase in the fuel consumption when the water content increases above 30%.

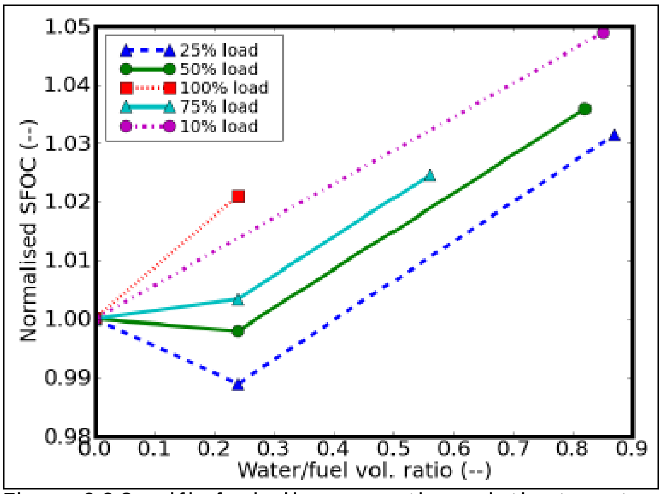

Figure 6-8 Specific fuel oil consumption relative to water content. SFOC values are relative to the SFOC with no water added. (MAN Turbo & Diesel, 2010)

6.4.1 Reductions of emission

Recent studies[42] show a NO_x reduction from water in fuel in the range of 1% for each percent of water added. The maximum amount of water added to fuel depends on the engine load. For this study it has been estimated that a water content of 50%, corresponding to a NO_x reduction of 50%, would be realistic. A water content of 50% would increase the fuel consumption by approximately 2%.

6.4.2 Cost

The cost of installing the WIF technology has been based on data collection made by Entec (2005). The following chart shows the cost of installing the WIF technology in existing ships.

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[42] See MAN (2010)

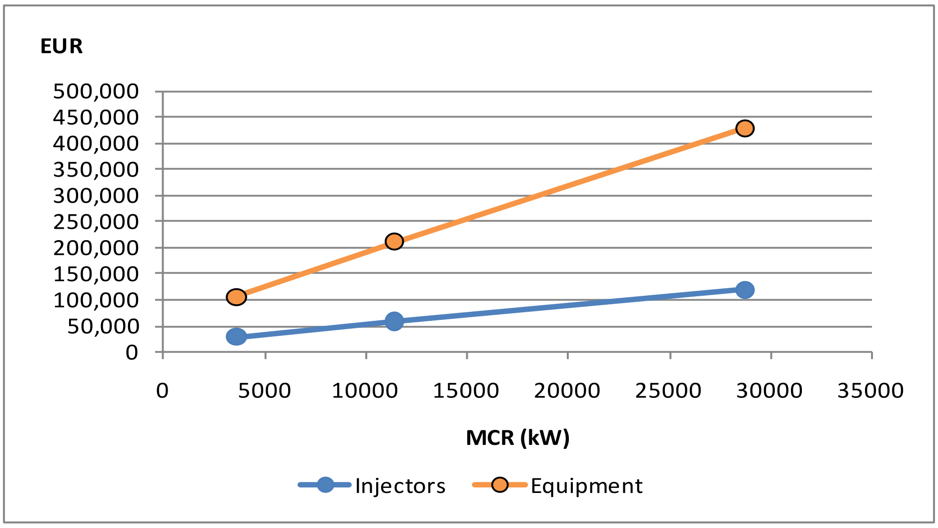

Figure 6-9 Installation cost of WIF NO_x reduction system

Injectors are estimated to have a lifetime of approx. four years, while the rest of the equipment is estimated to have a lifetime of approx 12 years. Thus, investment cost of injectors three times during the lifetime of the entire system of 12 years is in the same order of magnitude as the investment cost of the rest of equipment.

The total annual costs of investment, operation and maintenance are shown in Table 6-2.

Table 6-2 Total annual investment cost of WIF retrofit in 2 stroke engines

	Small	Medium	Large
Engine size (MCR, kW)	3580	11420	28750
Investment (EUR/year)	14,944	29,791	60,438
Operation and maintenance (EUR/year)	33,190	108,560	271,000

Note: Small, Medium and Large refer to the engine size.

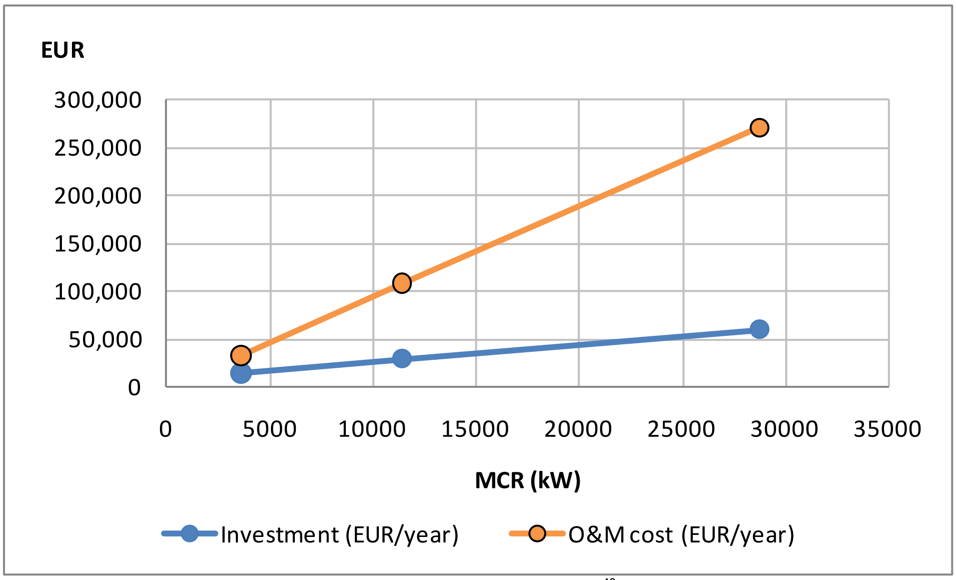

Figure 6-10 Annual cost of WIF NO_x reduction system[43]

[43] Source: Entec (2005).

The average annual cost for a medium-sized engine is 3.8% of the annual fuel cost assuming an average fuel price of EUR 753 EUR per ton of diesel MGO.

6.5 Alternative fuels and natural gas (LNG)

There is increasing focus on gas as an alternative to ordinary fuel for ship propulsion. LNG is natural gas that has been converted temporarily (at low temperature) to liquid form to ease storage and transport.

The main reason for using gas as an alternative fuel is that, in the near future, the production worldwide of LNG from gas wells is expected to increase rapidly. Furthermore, natural gas is cheaper compared to conventional fuels.

LNG is advancing as an important fuel of the future. However, establishing LNG bunkering facilities, comprising small-sized LNG terminals and a network of LNG supply ships, is costly and time-consuming and, furthermore, subject to safety concerns and broad public debate. Currently, only a few countries (e.g. Norway) have a LNG network in place to support the general use of gas as a marine fuel.

Gas gives a much cleaner exhaust regarding NO_x and particulates. Having very low or no sulphur (< 0.01%), SO_x -sulphur oxides are negligible in the exhaust gas and particulates will be reduced considerably [Bengtson, Anderson and Fridell]. For two-stroke engines, the NO_x reduction is 10-20% according to MAN Diesel & Turbo[44] because the two-stroke engines from a combustion point of view are working as diesel engines with a small amount of pilot diesel fuel to ignite the gas.

Table 6-3 lists an arbitrary comparison of emissions from a HFO and a gas 50-bore MAN Diesel & Turbo ME-GI engine, which can burn LPG and LNG when adapted properly to the differences in the physical properties of the two gas types.

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[44] Personal communication with Niels Kjemtrup at MAN Diesel & Turbo

Table 6-3Comparison of emissions from heavy fuel oil and gas

Emission comparison for an S50ME-GI Mark 8 operating on 48% propane and 48% butane and 5% pilot oil compared with HFO operation (3.5% sulphur)											
Load	SFOC	Pilot oil	Gas	CO_2		SO_x		HC		NO_x - Tier II	
				ME/MC	ME-GI	ME/MC	ME-GI	ME/MC	ME-GI	ME/MC	ME-GI
%	g/kWh	%	%	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
100%	170.6	5.00%	95,00%	559	472	11.94	0.60	0.34	0.68	13.5	11.9
95%	169.4	5.26%	94,74%	555	469	11.86	0.62	0.34	0.68	13.9	12.3
90%	168.4	5.56%	94,44%	552	466	11.79	0.65	0.34	0.67	14.2	12.5
85%	167.6	5.88%	94,12%	549	464	11.73	0.69	0.34	0.67	14.5	12.7
80%	167.0	6.25%	93,75%	547	462	11.69	0.73	0.33	0.67	14.6	12.9
75%	166.7	6.67%	93,33%	546	461	11.67	0.78	033	0.67	14.7	129
70%	166.6	7.14%	92,86%	546	461	11.66	0.83	0.33	0.67	14.7	12.9
65%	167.0	7.69%	92,31%	547	462	11.69	0.90	0.34	0.67	14.7	12.9
60%	167.8	8.33%	91,67%	550	464	11.75	0.98	0.34	0.68	14.6	12.9
55%	168.8	9.09%	90,91%	553	467	11.82	1.07	0.34	0.68	14.5	12.8
50%	170.0	10.00%	90,00%	557	470	11.90	1.19	0.35	0.69	14.5	12.7
45%	171.4	11.11%	88,89%	562	474	12.00	1.33	0.36	0.71	14.4	12.7
40%	172.9	12.50%	87,50%	567	478	12.10	1.51	0.37	0.74	14.4	12.7
35%	174.6	14.29%	85,71%	572	483	12.22	1.75	0.41	0.81	14.4	12.7
				IMO NO_x Cycle:						14.4	12.9
				NO_x from fuelbound nitrogen not included in estimated NO_x values							
				Actual emissions may deviate due to actual optimisation of engine							

Other typical NO_x reduction techniques, such as EGR and SCR, can be used in combination with the ME-GI engine, but not water emulsification. When combining the EGR system with gas operation, it is expected that the EGR process can be significantly simplified since the exhaust gas coming from gas operation only holds a small amount of SO_x and particulate matter. The cleaning of the exhaust gas in the EGR scrubber will become less comprehensive since the sludge amount coming from the wash water will be negligible, and it is very likely that the EGR scrubber can eventually be bypassed.

The technology for using LNG as energy source is available in particular for new ships. Retrofitting is possible but is expected to be very costly and can most likely only be applied on newer ships. One of the major reasons is that the volume needed for storage of gas is three to four times the storage volume for oil.

The price of LNG is approximately 8% lower per GJ compared to gas oil, according to the forecast from Danish Energy Agency[45].

6.5.1 Reduction in emissions

There are two main types of engines on the market:

1. Gas only engines
2. Dual fuel engines running on gas and/or oil.

Dual fuel engines have already been described using the MAN Diesel and Turbo GI engine as one example. Engines running only on gas are working as Otto engines (where the fuel is ignited by spark plugs and not by compressed diesel oil as for a normal diesel engine). For an Otto engine running on LNG,

[45] Danish Energy Agency, 2011: Prerequisites for socio-economic analyses in the field of energy, april 2011 shows that natural gas is 40% cheaper compared to gas oil. Including a cost of 4.78 EUR/GJ to production and distribution of LNG the price difference is reduced to 8%.

the reductions of SO_x and particulates are on the same level as for a dual fuel LNG engine. However, the NO_x reduction is higher (80-90%), which means that the engines can easily fulfil the Tiers III requirements.

It should be noted, however, that methane slip, i.e. incomplete combustion of methane in the cylinders[46], releasing methane on the exhaust side, will have a significant negative impact on the reduction of greenhouse gases, and in the worst cases it will eliminate the gains from CO_2 reductions. Taking into account that methane is a 25 times more potent greenhouse gas than CO_2, release of methane is important to consider.

The methane (CH4) slip varies in the different engine technologies and different load factors. The risk of a methane slip is higher in Otto engines while it is not present in the MAN Diesel & Turbo ME-GI engines[47], where the combustion process is initiated by injection of 5% diesel oil as pilot fuel. Recent studies[48] show that with a methane leakage of 2% during the whole life cycle of a ship, the CO_2 reduction from using LNG will be totally cancelled out, which can be the case for Otto engines.

6.5.2 Costs

New ships with LNG propulsion typically have an added investment cost of 10–20% of the total new building price – depending on the ship type. The additional cost is mainly due to the sophisticated LNG storage tanks, the fuel piping system and the additional safety measures, which have to be installed. Based on experience from ships built and currently under construction, the additional investment cost for a small 3,300 kW LNG fuelled general cargo ship has been estimated to USD 3.6 million (DNV, 2011).

The most attractive areas of application seem to be LNG gas tankers that do not require additional storage tanks or gas refuelling facilities in the ports. While construction costs are higher, maintenance costs are significantly lower compared with a diesel engine.

Based on information above it is estimated that the extra cost of a new marine engine will be approximately USD 3,600,000 for a 3,300 kW engine corresponding to approximately EUR 745 per kW.

According to a recent study by the Environmental Protection Agency in Denmark[49], the additional ship investment cost is MDKK 40-100 for retrofitting of a 2-20 MW LNG marine engine. The relationship between engine size (MCR) and investment expenditure is shown in the chart below.

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[46] For some technologies, the methane slip is caused by the fact that the exhaust valves are open when the gas enters into the combustion chamber.

[47] Personal communication with Niels Kjemtrup at MAN Diesel & Turbo

[48] Bengtson, Anderson and Fridell

[49] EPA 2010

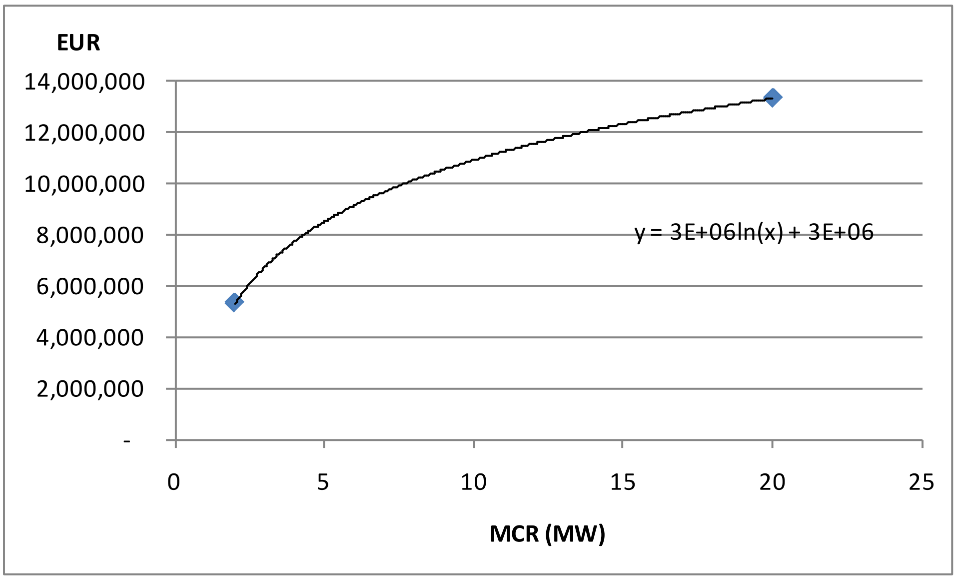

Figure 6-11LNG retrofit total investment cost

The average annual ship investment and operation cost is 10.7% of the annual fuel cost assuming an average fuel price of EUR 753 per ton of diesel (MGO). Savings due to cheaper LNG are taken into account. Investments in LNG production and bunkering facilities are included in the LNG fuel price.

7 Technologies for particulate reductions

7.1 Particulate filters

A Diesel Particulate Filter (DPF) is a device that collects or traps particulate matter from the engine exhaust.

In principle the particle filter technology for marine engines is the same as for heavy duty engines. However, until now the main problem has been too much ash generation from fuel and lubricating oil. With a high ash generation frequent cleaning of particulate filters is necessary to remove the build-up of incombustible residues of particulate matter. Build-up of these materials on the filter can increase engine exhaust backpressure and potentially cause particulate filter failure and damage to the turbo charger[50]. Frequent cleaning is not feasible on a large marine engine.

Reducing the sulphur content of the fuel to 0.1% will reduce the problem. However, because of the demanding operation conditions for a marine engine, the ash problem from the lubricating oil is still unsolved.

Particulate filters are not readily available for marine engines at present. Developers are working on the issues and it is expected that particulate filters will be available for large marine engines in near future when the problems with ash generation from lubricating oil is solved.

7.1.1 Emission reductions

Road engine particulate filters can provide more than a 90% reduction in particulate matter emissions. Particulate filters can also be designed to control up to 90% or more of the HC and CO emitted by a diesel engine[51].

A test on an auxiliary marine engine[52] has shown that it is possible to reduce the particulate matter emissions with 65-85% on a 3-5 MW marine auxiliary engine (DTU, 2009).

According to the German Handbuch of emission factors for heavy-duty vehicles, a vehicle with a particulate filter will consume approximately 1% more fuel compared to a comparable vehicle without particulate filter. However, the additional consumption is related to the back pressure. Lower back pressure on marine engines will reduce or eliminate the additional fuel consumption.

Furthermore, a particulate filter will reduce the emissions of CO and HC by 67%. (HBEFA, 2010).

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[50] Personal communication with Kjeld Johansen from Haldor Topsøe.

[51] Source: US study on retrofit of land-based engines, road as well as non-road. MECA, 2006.

[52] GENSET L16/24 on Technical University of Denmark.

7.1.2 Cost

At present, there is no information available about the cost of particulate filters for large marine engines. Based on information on the cost of cleaning technologies for heavy-duty vehicles, it is estimated that the cost of a particulate filter for marine engines will be at the same level as the cost of a SCR NO_x reduction unit. This may be a conservative estimate because there will be no need for a urea tank installation like the one needed for the SCR technology. Furthermore, there will be no annual cost of urea to the particulate filter.

Regarding operation and maintenance cost, it is expected that the particulate filter will require a small amount of additive, corresponding to a cost of approximately 0.2% of fuel consumption. Beyond that there will be an increase in fuel consumption for increased filter pressure drop and soot regeneration plus a need for compressed air to remove ash. In total it is estimated that the cost of operation and maintenance of a marine particulate filter will amount to 1% - 3% relative to fuel consumption.[53].

Applying these assumptions for the cost of a particulate filter for marine engines, we arrive at the following cost estimates for a DFP to marine engines.

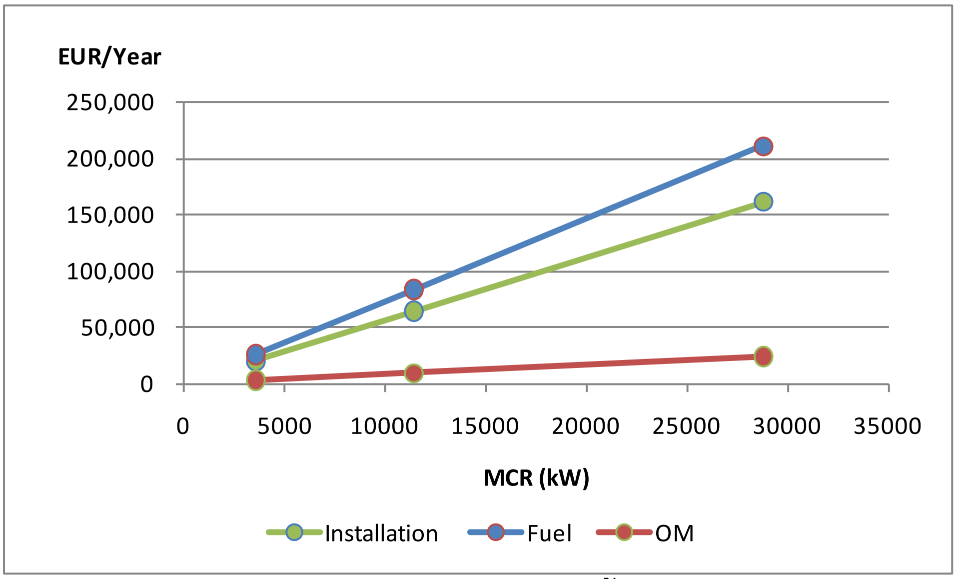

Figure 7-1 Cost of particulate filter reduction system[54]

The average annual cost amount to 2.7% of the annual fuel cost assuming an average fuel price of EUR 753 per ton of diesel (MGO).

7.2 Scrubbers

Scrubbers can be used for washing the exhaust gas from the main engine, and in principle it can be compared to a large shower cabinet placed in the funnel

[53] Personal communication with Keld Johansen from Haldor Topsoe.

[54] Source: Calculations for SCR system in combination with own calculations and information from HBEFA (2010).

of a ship. It is possible to reduce the sulphur emissions to the same level if low sulphur fuel oil was used. Some scrubbers can use both fresh water mixed with caustic soda (NaOH) and salt water in the washing process. Scrubbers can reduce SO_x and particulate matter with a small increasing fuel consumption mainly to feed pumps to circulate water.

In practice, the scrubbing process may contain several steps[55]. During the first step, the heat in the exhaust gas is utilised by cooling it to 160-180°C in an exhaust gas economiser. In the second step, the exhaust gas is treated in a special ejector where it is further cooled by injection of water and where the majority of the soot particles in the exhaust gas are removed. During the third stage, the exhaust gas is led through an absorption duct where it is sprayed with water and thus cleaned of the remaining sulphur dioxide. Water and sulphur react to form sulphuric acid, which is neutralised with alkaline components in the seawater or caustic soda in fresh water.

Filters or similar technology separate particles and oil from the mixture, before the cleaned water is led back into the sea. The solid particles removed from the gases are trapped in a settling or sludge tank and collected for disposal on land.

7.2.1 Emission reductions

It is estimated that a scrubber can reduce SO_x emissions by up to 98% and at the same time reduce particulate emissions by 40-75% (Alfa Laval 2011).

The scrubber technology can be used to reduce SO_x emissions for vessels sailing in SECA areas instead of using distilled fuel with less that 0.1% sulphur. Scrubbers may be also used to reduce particulate emissions.

7.2.2 Costs

The costs of installation of scrubbers have been based on data collection from Alfa Laval 2011. The following chart shows the cost of installing and operating the scrubber technology in existing ships.

Table 7-1 Investment and operation expenditure of a scrubber, EUR/year

	Small	Medium	Large
Engine size (MCR, kW)	3580	11420	28750
Investment (EUR/year)	125,337	309,315	588,042
Operation and maintenance (EUR/year)	79,137	252,444	635,531

Source: Alfa Laval, 2011.

[55] Aalborg Industries' website and Man Turbo & Diesel http://www.mandiesel-greentechnology.com/article_006962.html

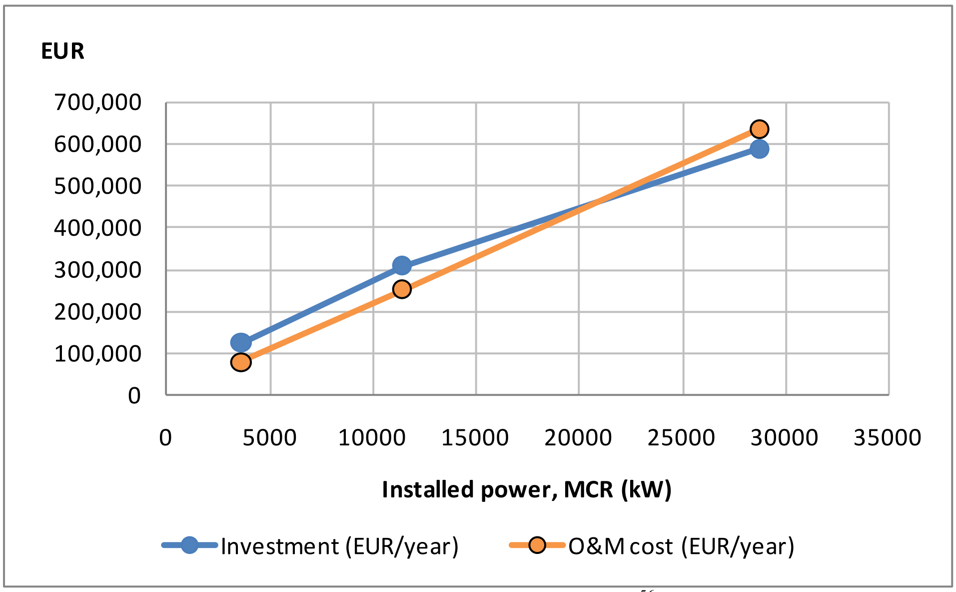

Figure 7-2 Installation and operation cost of a Scrubber[56]

The operation cost of the scrubber consists of the energy consumption of the scrubber, which is 3% of the main engine energy consumption, according to Alpha Laval, August 2011.

7.3 Cold ironing

Ports are frequently situated close to urban areas. Diesel generators on ships are used to make electricity for hotelling loads, cargo handling, and ballast pumping. Oil-fired boilers are used to heat fuel or cargo, make steam for steam driven cargo pumps and to make hot water. Cruise ships have high hotelling loads providing air conditioning, lighting, refrigeration, cooking, etc. Two measures being implemented to reduce emissions at berth are fuel switching and shore side electricity, also known as cold ironing.

The use of low-sulphur fuel while at berth will reduce SO_x and PM emissions. The future may also see ship generators designed to run on LNG at berth to further reduce SO_x and PM emissions and reduce NO_x.

Cold ironing where ship electricity is supplied from the land grid can shift air quality emissions away from the port. The net gain depends on the shore power source, but generally power plants will have lower emissions than auxiliary engines on ships.

This technology would require investments both on the ship and onshore. For a large ocean-going vessel, the investment cost would be in the range of USD 200,000 to USD 574,000[57] corresponding to approximately USD 50 per kW for the auxiliary engine. Apart from that, some ports would need to install additional required equipment to supply the electricity. Land-based costs will vary from port to port and even significantly according to the adjustments needed and the extent to which sufficient power is available at the port. A study conducted in California reports an average investment cost of EUR

[56] Source: Alfa Laval, 2011.

[57] www.getpower.us

1,360,516[58] corresponding to EUR 98,588 annually for each port. Furthermore, the operation and management is estimated to EUR 257,522 annually. These figures cover relatively large installations, and they will only apply to the 10 largest ports in Denmark.

Based on the above information the average cost is EUR 477 per kg particulates. However, cold ironing would also cause large benefits from NO_x reductions. Allocating the cost of PM reductions proportionately to the benefits would reduce the cost to EUR 172 per kg PM.

[58] Environ, 2004. Cold Ironing Cost Effectiveness Study, Volume I - Report

8 Assumptions

8.1 Benefit from air emission reductions

The benefit from reducing air pollution is the avoided damage cost of the air pollution.

The damage costs from air pollution are available from three different sources.

The Danish Ministry of transport (MoT)
The Danish National Environmental Research Institute (NERI)
Centre for Energy, Environment and Health (CEEH).[59]

The cost of air pollution from the Centre for Energy, Environment and Health covers emissions from ship transport. The other two sources cover damage cost from land-based transport in rural and urban areas.

Table 8-1 shows the estimated cost per kg of emission based on the different sources.

Table 8-1 Cost per kg emissions based on different sources (EUR/kg), 2011 price level

	Urban		Rural		
	MoT	NERI	MoT	NERI	CEEH
CO_2	0,02		0,02		
$PM_{2,5}$	233,65	216,36	32,57	28,80	39,17
NO_X	7,11	10,00	7,11	10,00	12,23
SO_2	32,22	104,60	27,86	34,47	19,25
HC	0,39		0,33		

The MoT and NERI calculate values for both urban and rural areas. The values to be used here are values for rural areas. Rural areas seem the best proxy for emissions on sea because rural areas are areas with low population density. Using the cost figures for rural areas will underestimate the damage cost of emissions emitted at berth.

The damage effect of NO_x emissions is not dependent on the population density where the emissions take place. This is reflected in the unit cost for NO_x emissions that are identical for emissions in urban and rural areas. This is not the case for particulates. Particulate matter causes more damage in the area close to the emissions. This is why particulate emissions from ships at

[59] CEEH is a collaboration between the Niels Bohr Institute (University of Copenhagen) , the Danish Meteorological Institute, the National Environmental Research Institute (Aarhus University), National Institute of Public Health (University of Southern Denmark), the National Laboratory for Sustainable Energy (Technical University of Denmark), Centre for Applied Health Services Research and Technology Assessment (Southern University of Denmark), Faculty of Health Sciences (Aarhus University)

berth close to a city centre are more damaging compared with particulate matter emissions at sea far away from land.

The main calculations are based on the damage cost from the Ministry of Transport. Furthermore, sensitivity analysis is applied to show the sensitivity of selecting alternative values for the analysis.

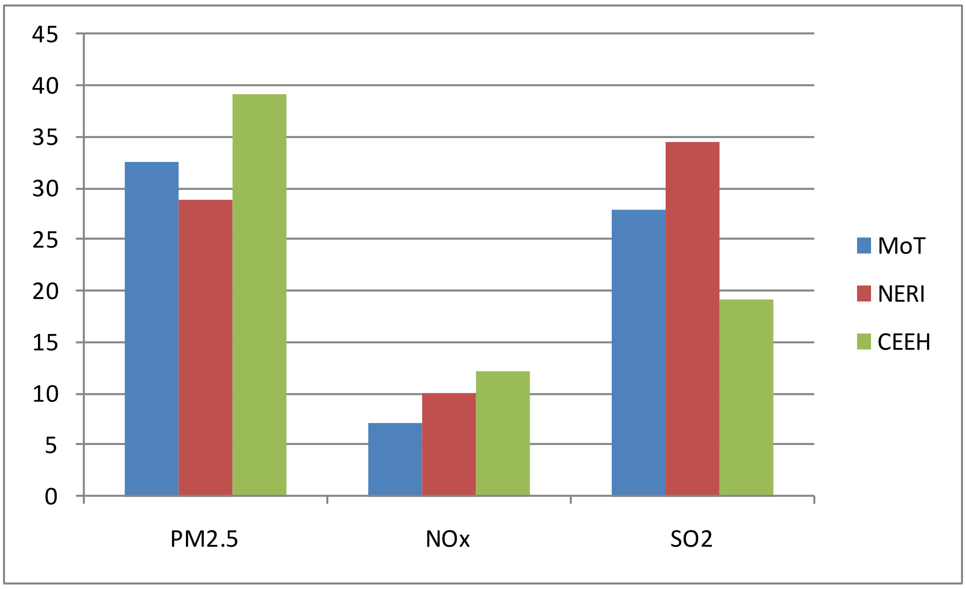

Figure 8-1 Cost per kg of emissions based on different sources (Countryside, EUR/kg), 2011 price level

As can be seen from the figure, the damage costs of NO_x are higher in the study by Centre for Energy, Environment and Health and NERI compared with the values from the Ministry of Transport and the Environmental Protection Agency.

In order to illustrate the sensitivity of the cost-benefit analysis to the valuation of cost of emissions, sensitivity analyses were conducted in chapter 13 using the values from Centre for Energy, Environment and Health instead of the MoT and NERI values.

8.2 External cost

Traffic has external effects in the form of air pollution, climate change, noise, accidents, congestion and wear and tear on the infrastructure. It is important to include these effects in a full cost benefit analysis. The damage from air pollution and climate change were dealt with in the previous sub section. Table 8-2 shows the average cost of noise, accidents, congestion and wear and tear on the infrastructure applied in the study.

Table 8-2 Average cost of noise, accidents, congestion and wear and tear on the infrastructure. 2011 EUR / 100 km

	Noise	Accidents	Congestion	Infrastructure
Passenger car	0.64	2.82	4.53	0.13
Light duty vehicle	0.89	2.22	6.29	0.21
Heavy duty vehicle	1.31	16.82	7.76	13.61
Bus	2.84	6.26	8.47	7.47

Source: DTU Transport 2010 gives values in DKK 2010 prices. Values corrected to EUR 2011 prices with exchange rate of 7.5 and an inflation rate of 0.9% from 2010 to 2011.

8.3 Administration

Administrative costs may vary considerably depending on the complexity of the measure and the framework within which the administrative organisation is operating.

Typical administrative tasks are diverse and may include:

- Handling of applications for authorisation or exemption
- Registration of emitters
- Certification and measurements of products or processes
- Inspections
- Handling of application for subsidy or grant
- Collection of payments.

A recent survey on the administrative costs of NO_x tax in Europe found that the costs vary from 3.3% in Sweden to 25% in France[60]. The considerable variation is caused by major differences in complexity. While the French system is very comprehensive and includes almost all emitters and individual rebate systems, the Swedish system is rather a certification system where the costs only include the metering and certification of the emitters. When certification is in place, it is up to the port authorities to charge taxes according to the certificate.

The competent authority for the administration of the Swedish NO_x charge is the Swedish Environmental Protection Agency (SEPA). Administrative costs are very low, approximately 0.3% of the revenues collected. Metering costs are estimated at approximately 3% of the total charges paid. The total administrative cost of operating the Swedish system is estimated to EUR 2,200,000 annually covering approximately 400 emitters.

In France, the French Agency for Environment and Energy Management (ADEME) is in charge of administering the NO_x tax. ADEME receives 6% of the tax revenue to cover administrative costs, 2.5% to cover research and development and 17% for monitoring. In total the administration fee for the French system amounts to EUR 4,200,000 covering approximately 1,500 emitters.

[60] AP EnvEcon (2009): NOX Taxation, A sample review of examples of NOX taxation systems.

Based on the Swedish and French systems, it is estimated that a Danish regulation system would cost in the order of 2,000,000 EUR annually. EUR 2,000,000 may seem costly, however, it should be kept in mind that measurements and equipment are included, measuring equipment being rather expensive.

From a Danish perspective, the regulation of emission limits/norms for national ferry transport would also require resources and procedures to check if emission limits are met. It is expected, however, that the administration involved can be handled to some extent by the local authorities presently in charge of national ferry routes. In this way, resource requirements would be smaller than for a completely new system.

The ferry sector in Denmark consists of a limited number of ferries with rather well-known technology and emissions. Furthermore, all ferries are subject to annual inspections. Thus, it would be a relatively simple task to regulate such a homogenous sector. The freight transport sector is not regulated to the same extent. Therefore, it would require additional resources to set up administrative procedures and regulation for national freight transport compared with passenger transport.

The situation is somewhat similar for the NO_x-differentiated port dues where the administration is already in place and payment already in progress. In this field, payment procedures have to be changed and a monitoring system have to be established to check that emission limits are met. Thus, it is estimated that the costs of such a system would also be in the lower end of the costs presented by the above study.

Finally, concerning a NO_x tax for sea transport in Denmark, there is already a NO_x tax administration for land-based sources. Thus, there is reason to believe that the additional administrative costs of sea or ferry transport will be limited, especially since the number of emitters is relatively small and homogenous.

8.4 Fuel prices

In the study, fuel prices are based on the energy price forecasts from the Danish Energy Agency[61].

[61] Danish Energy Agency (2011): Prerequisites for socio-economic analyses in the field of energy, April 2011

Table 8-3 Fuel prices applied in the study, EUR per GJ, Fixed prices, 2011 price level

Year	Gas oil (EUR/GJ)	LNG (EUR/GJ)
2011	14.10	13.01
2012	14.53	13.56
2013	14.96	14.11
2014	15.65	14.82
2015	16.34	15.54
2016	16.58	15.71
2017	16.83	15.88
2018	17.06	16.04
2019	17.31	16.20
2020	17.56	16.36
2021	17.73	16.48
2022	17.90	16.59
2023	18.08	16.71
2024	18.25	16.82
2025	18.41	16.93
2026	18.55	17.03
2027	18.70	17.13
2028	18.84	17.23
2029	18.98	17.32
2030	19.12	17.42

Note: The LNG price is based on the Natural gas price plus a production and distribution cost of EUR 4.78[62] per GJ.

8.5 Inflation and Discount rate

All calculations in the study are based on fixed prices in 2011 level. To transfer price levels between different years, the following price index from the Danish Energy Agency[63] has been applied.

Table 8-4 Price index

Year	Price index (2009=100)	Price increase (%)
2005	91.2	2.9%
2006	93.2	2.2%
2007	95.5	2.5%
2008	99,6	4.3%
2009	100	0.4%
2010	103.4	3.4%
2011	104.3	0.9%

[62] The production and infrastructure cost is based on the small-scale LNG production plant in Danish Ministry of the Environment, 2010 appendix 3. 20% have been added to the financing cost to account for the additional cost of public financing. Without this additional cost, the production and distribution costs would amount to EUR 4.41 per GJ.

[63] Danish Energy Agency (2011): Prerequisites for socio-economic analyses in the field of energy, April 2011

9 Cost benefit of technologies

Combining the costs from the above sections with the benefit from reduced emissions shows the cost benefit from the technologies.

Costs from the above sections are based on factor prices exclusive of VAT. In order to adjust to market prices, the costs estimates are multiplied by a factor reflecting the general tax level as recommended in the manual from EPA[64].

Benefits are based on unit prices for damage from the Ministry of Transport. Since the unit prices from the other studies show higher values, the results in the following will represent a lower limit of the benefits from NO_x reductions.

The following section shows key figures from cost-benefit studies of the following technologies SCR, EGR, HAM, WIF, DPF, scrubbers and LNG.

Furthermore, chapter 13 contains a sensitivity analysis analysing the sensitivity of the results in relation to the different values of the benefit from reducing air emissions.

9.1 Selective Catalytic Reduction (SCR)

Selective Catalytic Reduction (SCR) is the most efficient method for removing NO_x from the exhaust gas. Adding urea or ammonia reduces NO_x to N_2 and H_2O.

Table 9-1 shows key figures from cost-benefit studies of retrofitting SCR technology in existing ships.

Table 9-1Key figures from cost-benefit studies of retrofit SCR.

	Small	Medium	Large
Installed capacity	3,580	11,420	28,750
Saved NO_x (kg/year)	168,030	536,005	1,349,401
NPV of net benefits (EUR/year)	620,633	1,979,784	4,984,132
Pay back time (years)	< 1 year	< 1 year	< 1 year
Cost (EUR/kg NO_x)	0.69	0.69	0.69

Note: Assumed 6667 operating hours, 80% NO_x reduction. Emissions without SCR: 11 g NO_x per kWh for a medium-speed engine.

Table 9-1 shows that it is beneficial to society to support the installation of SCR technology to reduce NO_x emissions from ships navigating in Danish waters.

[64] Ministry of Environment, 2010. Net average tax factor (NAF) factor = 1.17.

The total net present value of installing SCR in one small ship would amount to a gain of EUR 620,633 per year in a 24-year time horizon, meaning that the benefits from reducing emissions more than outweigh the costs to society.

The cost to society would amount to approximately EUR 0.69 per kg NO_x, while it has been shown above that the benefit of reducing 1kg NO_x is between EUR 7 and 12 per kg NO_x.

The key assumptions behind the analysis are listed in the tables below.

Table 9-2 Key assumptions for cost benefit analysis

	Small	Medium	Large
Installed capacity (kW)	3,580	11,420	28,750
Investment (EUR)	143,200	456,800	1,150,000
Life time years (years)	12	12	12
Urea cost/year (EUR/year)	76,377	243,639	613,364
Operation and maintenance(EUR/year)	6,874	21,927	55,203
Interest rate	5%	5%	5%

Table 9-3 shows the estimated impact on emissions from installing a SCR unit. For the SCR technology, there will be no change in other emissions than the NO_x emissions. Therefore, all other emissions than NO_x are set to zero in Table 9-3.

Table 9-3 Changes in emissions

	Small	Medium	Large
Installed capacity (kW)	3,580	11,420	28,750
Impact emissions			
NO_x (ton/year)	-168	-536	-1,349
PM (ton/year)	0	0	0
CO_2 (ton/year)	0	0	0
SO_2 (ton/year)	0	0	0

9.2 HAM - water injection in turbo-charge-air

Table 9-4 shows key figures from cost-benefit studies of retrofitting HAM technology in existing ships.

Table 9-4 Key figures from cost-benefit studies of retrofit HAM.

	Small	Medium	Large
Installed capacity (kW)	3,580	11,420	28,750
Saved NO_X (kg/year)	210,992	673,052	1,694,418
NPV of net benefits (EUR/year)	808,954	2,580,520	6,496,492
Pay back time (years)	< 1 year	< 1 year	< 1 year
Cost (EUR/kg NO_X)	0.44	0.44	0.44

Note: Assumed 6667 operating hours, 80% NO_x reduction. Emissions without HAM: 17 g NO_x per kWh for a slow speed engine.

As can be seen, it is clearly beneficial to society to support retrofit installation of HAM to reduce NO_x emissions from ships navigating in Danish waters.

The total net present value of installing HAM in one small ship would imply a gain of EUR 808,954 per year in a 24-year time horizon, meaning that the benefits from reducing emissions more than outweigh the cost to society.

The cost to society would amount to approximately EUR 0.44 per kg NO_x, while it has been shown above that the benefit of reducing 1 kg NO_x is between EUR 7 and 12 per kg NO_x.

The key assumptions behind the analysis are listed in Table 9-5 and Table 9-6 below.

Table 9-5 Key assumptions for cost benefit analysis

	Small	Medium	Large
Installed capacity	3,580	11,420	28,750
Investment (EUR)	716,000	2,284,000	5,750,000
Life time (years)	12	12	12
Operation and maintenance (EUR)	2,864	9,136	23,001
Interest rate	5%	5%	5%

Note: The table shows the cost benefit from retrofitting one ship with HAM.

Installation of a HAM system will give no change in other emissions than NO_x emissions. Thus, the only change in emissions will be a reduction of 211 tons NO_x annually for small vessels, 673 tons NO_x annually for medium vessels and 1,694 tons NO_x for large vessels.

Table 9-6 Changes in emissions

	Small	Medium	Large
Installed capacity (kW)	3,580	11,420	28,750
Impact emissions			
NO_X (ton/year)	-211	-673	-1,694
PM (ton/year)	0	0	0
CO_2 (ton/year)	0	0	0
SO_2 (ton/year)	0	0	0

9.3 EGR - exhaust gas recirculation

Table 9-7 shows key figures from cost-benefit studies of retrofitting EGR technology in existing ships.

Table 9-7 Key figures from cost-benefit studies of retrofit EGR.

	Small	Medium	Large
Installed capacity	3,580	11,420	28,750
Saved NO_X kg/year	259,682	828,372	2,085,438
NPV EUR/year	1,004,666	3,221,165	8,120,644
Pay-back	< 1 year	< 1 year	< 1 year
Cost EUR/kg NO_X	0.38	0.35	0.34

Note: Assumed 6667 operating hours, 80% NO_x reduction. Emissions without EGR: 17 g NO_x per kWh for a slow speed engine.

As was the case with the previous technologies, it would also be beneficial to society to support retrofit installation of EGR to reduce NO_x emissions from ships navigating in Danish waters.

The total net present value of installing EGR in one small ship would imply a gain of EUR 1,004,666 annually in a 24-year time horizon, meaning that the benefits from reducing emissions more than outweigh the cost to society.

The cost to society would amount to approximately EUR 0.34 to 0.38 per kg NO_X depending on the vessel size, which is well below benefit of reducing 1 kg NO_X.

The key assumptions behind the analysis are listed in Table 9-8 and Table 9-9.

Table 9-8 Key assumptions for cost benefit analysis

	Small	Medium	Large
Installed capacity	3,580	11,420	28,750
Investment (EUR)	257,856	596,544	1,345,200
Lifetime (years)	12	12	12
Fuel cost (EUR/Year)	22,994	73,351	184,662
Operation and maintenance (EUR/Year)	34,288	109,378	275,361
Interest rate	5%	5%	5%

Depending on the setup of the ship engine, installation may cause an increase in fuel consumption. In this case, it is assumed that the EGR is installed on a Tier II engine and causing a 1% increase in fuel consumption. The increase in fuel consumption will lead to a small increase in the other emissions from the vessel.

Table 9-9 Changes in emissions

	Small	Medium	Large
Installed capacity (kW)	3,580	11,420	28,750
Impact emissions			
NO_X (ton/year)	-259.7	-828.4	-2,085.4
PM (ton/year)	0.5	1.7	4.2
CO_2 (ton/year)	113.0	360.4	907.3
SO_2 (ton/year)	2.7	8.5	21.4

9.4 WIF - water in fuel

WIF (Water In Fuel) is a technology for preventing NO_X formation during combustion by adding water to the fuel before injecting the fuel into the cylinder.

Table 9-10 shows key figures from cost-benefit studies of retrofit WIF.

Table 9-10 Key figures from cost-benefit studies of new-built WIF.

	Small	Medium	Large
Installed capacity (kW)	3,580	11,420	28,750
Saved NO_X (kg/year)	105,019	335,003	843,376
NPV of net benefits (EUR/year)	347,347	1,121,785	2,838,339
Pay back time (years)	< 1 year	< 1 year	< 1 year
Cost (EUR/kg NO_X)	1.36	1.29	1.26

Note: Investment cost exclude replacement of cylinder heads and replacement of pumps.

Table 9-10 shows the cost-benefit analysis for the installation of WIF in new-built ships. The retrofit investment cost for four-stroke engines will be significantly higher, since the cylinder head needs to be replaced. Furthermore, retrofit may also become more expensive because it may require an increase of the pump capacity and therefore lead to more expensive retrofit investments. Alternatively, if the load can be reduced, it may be acceptable with a slightly lower capacity.

As was the case with the previous technologies, it would also be beneficial to society to support retrofit installation of WIF technology to reduce NO_x emissions from ships navigating in Danish waters, although this technology seems more expensive compared with the previously mentioned technologies.

The total net present value of installing WIF in one small ship would imply a gain of EUR 347,347 annually in a 24-year time horizon, meaning that also here, the benefits from reducing emissions more than outweigh the cost to society.

The cost to society would amount to approximately EUR 1.26 to 1.36 per kg NO_x depending on the vessel size, which is below the benefit of reducing 1kg NO_x.

The key assumptions behind the analysis are listed in the tables below.

Table 9-11 Key assumptions for cost benefit analysis

	Small	Medium	Large
Installed capacity (kW)	3,580	11,420	28,750
Investment (EUR)	135,732	270,578	548,933
Life time (years)	12 (4)	12 (4)	12 (4)
Fuel cost (EUR/Year)	48,288	154,037	387,790
Operation and maintenance (EUR/Year)	33,190	108,560	271,000
Interest rate	5%	5%	5%

Note: Lifetime 12 years for main system and four years for injectors.

It is estimated that the WIF technology will increase fuel consumption by approximately 2%. The increase in fuel consumption will lead to a parallel increase in the other emissions from vessels.

Table 9-12 Changes in emissions

	Small	Medium	Large
Installed capacity (kW)	3,580	11,420	28,750
Impact emissions			
NO_x (ton/year)	-105.0	-335.0	-843.4
PM (ton/year)	0.1	0.3	0.7
CO_2 (ton/year)	257.1	820.2	2,064.8
SO_2 (ton/year)	0.2	0.5	1.4

9.5 Alternative fuels and natural gas (LNG)

One of the major costs of switching to LNG is the establishment of the production and bunkering facilities. Based on a study by the Danish Environmental Protection Agency (EPA, 2010), it is estimated that the cost of producing LNG from natural gas and establishing bunkering facilities would amount to EUR 204 per ton[65] LNG, corresponding to EUR 4,78 per GJ LNG. With production and distribution cost included, the LNG is expected to be approximately 8% cheaper compared to gas oil[66].

Retrofitting to LNG is expensive - if not impossible in many cases due to the practical implications, such as larger and complicated tanks for LNG. Also new and more complicated pipe systems have to be installed.

Table 9-13 shows a rough cost-benefit analysis of retrofit to LNG. As can be seen, it would be beneficial to society to switch to LNG, especially for large engines.

Table 9-13 Key figures from cost-benefit studies of retrofit LNG.

	Small	Medium	Large
Installed capacity	3,580	11,420	28,750
Saved NO_X kg/year	184,833	589,606	1,484,341
NPV of net benefits EUR/year	524,169	2,545,181	7,424,621
Pay back time (years)	< 1 year	< 1 year	< 1 year
Cost EUR/kg NO_X	2.63	0.29	-0.79

Note: Assumed 6667 operating hours, 80% NO_x reduction (Otto spark ignition engine). Emissions without SCR: 11 g NO_x per kWh for a medium speed engine. Fuel cost savings of approximately 8% included.

The total net present value of switching from diesel to gas in one small ship would imply a gain of EUR 524,169 annually in a 24-year time horizon, meaning that the benefits from reducing emissions more than outweigh the cost to society.

Due to economics of scale, the investment cost per kW installed capacity is smaller for large ships compared to small ships. Therefore, the investment cost relative to the fuel cost savings are smaller for large ships compared to small ships. For large size ships the fuel cost savings outweigh the investment cost.

The key assumptions for the analysis are listed in the tables below.

[65] The cost is estimated based on a scenario with a small LNG production plant and a small LNG carrier to distribute the LNG (The Kårtsø example from EPA, 2010).

[66] Danish Energy Agency (2011): Prerequisites for socio-economic analyses.

Table 9-14 Key assumptions for cost benefit analysis

	Small	Medium	Large
Installed capacity (kW)	3,580	11,420	28,750
Investment (EUR)	7,356,157	11,386,422	14,594,196
Life time (years)	12	12	12
Fuel cost savings (EUR/Year)	177,515	566,263	1,425,574
Interest rate	5%	5%	5%

Note. Investment expenditure is difficult to estimate.

Switching from diesel to LNG will reduce SO_x and particulate emissions considerably, but also NO_x emissions will be reduced depending on the engine type (Otto engine or diesel cycle engine).

Table 9-15 Changes in emissions

	Small	Medium	Large
Installed capacity (kW)	3,580	11,420	28,750
Impact emissions			
NO_X (ton/year)	-184.8	-589.6	-1,484.3
PM (ton/year)	-4.1	-13.0	-32.7
CO_2 (ton/year)	-2,571.1	-8,201.6	-20,647.7
SO_2 (ton/year)	-5.6	-17.9	-45.1
Methane (Ton CO_2 equivalents/year)	2571.08	8201.61	20647.67

Note: Otto engine. Methane slip is assumed to outweigh CO_2 emission reductions.

9.6 DPF - Particulate filter

The cost benefit analysis shows that the result it very sensitive to the amount of extra fuel required by the installation of DPF and to the set of unit prices applied for the emissions.

In case of additional fuel consumption of 1.5%[67], the installation of DPF with the applied assumptions will only just be beneficial to society. The reason is that the particulate emissions measured in kg are relatively small compared with NO_x emissions and therefore they contribute to a much smaller extent to the benefit of the cost-benefit analysis.

Table 9-16 shows key figures from cost-benefit studies of retrofit DPF with 1,5% additional fuel consumption and with the MoT unit prices of the cost of emissions.

[67] There is no solid experience of particulate filters in operation. The 1.5% additional fuel consumption is estimated based on interview with Haldor Topsoe.

Table 9-16 Key figures from cost-benefit studies of retrofit DPF.

	Small	Medium	Large
Installed capacity	3,580	11,420	28,750
Saved PM2.5 (kg/year)	3,621	11,549	29,076
NPV of net benefits (EUR/year)	980	3,125	7,867
Pay back time (years)	12 years	12 years	12 years
Cost (EUR/kg PM2.5)	32.10	32.10	32.10

As can be seen, investment in particulate filter is beneficial but only with a small margin. The total NPV from one small ship would amount to a gain of EUR 3,621 annually in a 24-year perspective. Furthermore, the cost to society would amount to approximately EUR 32.10 per kg particulate matter, while it was found above that the benefit of reducing 1 kg particulate matter is between EUR 28 and 32.5 in the NERI and MoT studies. A recent study by CEEH found that the price of the damage of PM was somewhat higher: EUR 39 per kg particulate matter.

The key assumptions behind the analysis are listed in the tables below.

Table 9-17 Key assumptions for cost benefit analysis

	Small	Medium	Large
Installed capacity (kW)	3,580	11,420	28,750
Investment (EUR)	143,200	456,800	1,150,000
Lifetime (years)	12	12	12
Fuel cost (EUR/Year)	36,216	115,528	290,842
Operation and maintenance (EUR/Year)	12,072	38,509	96,947
Interest rate	5%	5%	5%

It is estimated that the DPF will increase fuel consumption by approximately 1.5%. This increase in fuel consumption will lead to a small increase in the other emissions from the vessel.

Table 9-18 Changes in emissions

	Small	Medium	Large
Installed capacity (kW)	3,580	11,420	28,750
Impact emissions			
NO_X (ton/year)	3.2	10.1	25.3
PM (ton/year)	-3.6	-11.5	-29.1
CO_2 (ton/year)	192.8	615.1	1,548.6
SO_2 (ton/year)	0.1	0.4	1.0

9.7 Scrubber

Table 9-19 shows key figures from a cost-benefit analysis of the installation of a retrofit scrubber. The scrubber is installed on a ship using 3% sulphur fuel. The analysis compares the installation of a scrubber with a situation where the ships use the more expensive low-sulphur fuel. The calculations include a 20% reduction[68] in particulate emissions, but no SO_x reductions[69].

Table 9-19 Key figures from cost-benefit studies of retrofit scrubber.

	Small	Medium	Large
Installed capacity	3,580	11,420	28,750
Saved PM (kg/year)	992	3,165	7,968
	0	0	0
NPV of net benefits (EUR/year)	494,837	1,651,920	4,209,607
Pay-back	1	1	1
Cost (EUR/kg PM2.5)	- 466.19	- 489.39	- 495.77

As can be seen, it is beneficial to society to support retrofit installation of scrubbers to reduce SO_x and particulate emissions from ships navigating in Danish waters instead of using distillate low-sulphur fuel.

This is because the savings from cheaper fuel more than outweigh the investment and operation costs. The major share of benefits from the scrubber comes from the savings from using cheaper fuel. Beyond that the scrubber will also bring additional benefits from additional reductions of particulate emissions.

The key assumptions behind the analysis are listed in Table 9-20 and Table 9-21.

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68 Introduction of 0.1% sulphur fuel is estimated to reduce the PM emissions by 50%. The scrubber is estimated to further reduce the PM emissions by 20%.

69 It is estimated that the SO_X reduction from introducing 0.1% fuel and the scrubber are identical.

Table 9-20 Key assumptions for cost benefit analysis

	Small	Medium	Large
Installed capacity (kW)	3,580	11,420	28,750
Investment (EUR)	1,173,600	3,159,733	7,550,000
Lifetime (years)	12	12	12
Fuel cost savings (EUR/Year)	-590,070	-1,882,289	-4,738,688
Operation and maintenance (EUR/Year)	54,730	174,587	439,524
Interest rate	5%	5%	5%

Table 9-21 shows the estimated change in emissions from the installation of a scrubber.

Table 9-21 Changes in emissions

	Small	Medium	Large
Installed capacity	3,580	11,420	28,750
Impact emissions (ton/year)			
NO_X	7	22	55
PM	-1.0	-3.2	-8.0
CO_2	-900	-2871	-7227
SO_2	0.0	0.0	0.0

Note. Increased pumping increases fuel consumption by 3%. Saving the refining process saves 10% CO_2.

9.8 Cold ironing

Table 9-19 shows key figures from a cost-benefit analysis of the installation of cold ironing in the 10 largest ports.

Table 9-22 Key figures from cost-benefit studies of retrofit scrubber.

	EUR
Saved PM (kg/year)	11,848
NPV of net benefits (EUR/year)	18,553,485
Cost (EUR/kg PM2.5)	115

Note: Cost per kg of PM has been reduced with the benefit from the NO_x reduction.

9.9 Summary

This section summarises the emission reduction costs for the ships in Danish waters calling at Danish ports.

Table 9-23 shows the cost of alternative technologies for reducing NO_x emissions.

Table 9-23 Cost of reducing 1 kg emissions by the different technologies

	Small	Medium	Large	Weighted Average
EGR - Exhaust gas recirc.(EUR/kg NO_X)	0.38	0.35	0.34	0.36
HAM - Water injection in air(EUR/kg NO_X)	0.44	0.44	0.44	0.44
SCR - Selective catalysis (EUR/kg NO_X)	0.69	0.69	0.69	0.69
LNG - Natural gas (EUR/kg NO_X)	2.63	0.29	-0.79	0.94
WIF - Water in fuel (EUR/kg NO_X)	1.36	1.29	1.26	1.31

Note: Weighted average based on size distribution for ships calling Danish ports.

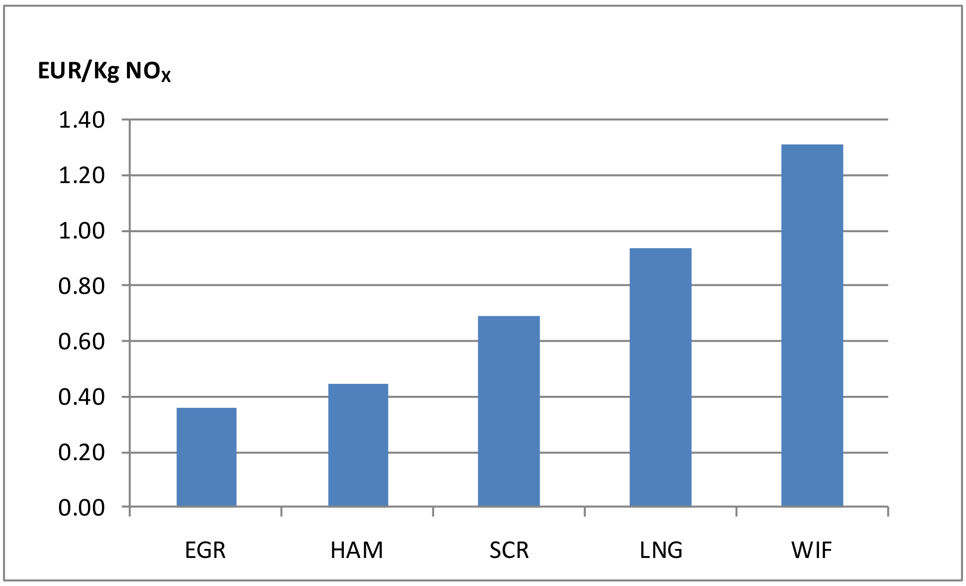

Figure 9-1 Cost of NO_X reductions in sea transport (EUR/kg NO_X)

The cheapest technology is the EGR technology with EUR 0.36 per kg of NO_x.

The LNG cost includes investment and distribution costs for a system that can supply the major routes in Denmark with LNG. Setting up a system that facilitates LNG supply of all ferry routes in Denmark would not be economically feasible[70].

Table 9-24 shows the cost of alternative technologies for reducing particulate matter emissions.

Table 9-24 Cost of reducing 1 kg particulate matter emissions by the different technologies

	Small	Medium	Large	Average
Scrubber (EUR/kg PM)	-466.19	-489.39	-495.77	-482.14
LNG - Natural gas (EUR/kg PM)	12.05	1.33	-3.62	4.30
DPF - Particulate filters (EUR/kg PM)	32.10	32.10	32.10	32.10
Cold ironing (EUR/kg PM)				115.00

The large gain (negative cost) for the scrubber is due to fuel cost savings. The scrubber reduces particulate emissions by 20% compared to a ship fuelled by

[70] EPA (2010): Natural gas for ship propulsion in Denmark, Environmental Project No. 1338 2010

low-sulphur fuel without scrubber. When the gain from fuel savings is measured relative to the 20% particulate matter reduction, a gain of EUR 482 per kg of particulate matter is reached.

10 Existing regulation

10.1 United Nations Convention on the Law of the Sea

For political and institutional acceptance, it is important that an introduction of NO_x related charges or other regulation is in line with the principles expressed in the United Nations Convention on the Law of the Sea (UNCLOS), adopted in 1982. UNCLOS provides a universal legal framework for the management of marine resources and regulates international aspects of marine-related activities.

According to UNCLOS Article 24, the coastal state should not hamper the innocent passage of foreign ships through the territorial sea except in accordance with the Convention. However, Article 211(3) permits states to "establish particular requirements for the prevention, reduction and control of pollution of the marine environment as a condition for the entry of foreign vessels into their ports".

According to UNCLOS Article 21, costal states may adopt individual laws and regulations with respect to for instance conservation of living resource areas and preservation of the environment[71]. However, this option is not available in Straits such as the Oresund and the Great Belt, which ships need to transverse to reach other countries/areas. Furthermore, it is not common practice to regulate ships in innocent passage by national regulations.

This means that in practice there is no legal basis for regulating ships passing through Danish waters except when the ships are calling at a Danish Port.

Furthermore, Article 26 declares that no charge may be levied upon foreign ships by reason only of their passage through the territorial sea, and that charges may be levied upon a foreign ship passing through the territorial sea as payment only for specific services rendered to the ship and only in a non-discriminatory manner. This may be interpreted to rule out the use of distance-related charges[72]. Thus, vessels in international traffic cannot be charged based on NO_x emissions even though they actually call at a Danish Port.

10.2 The MARPOL emission limits

The International Convention for the Prevention of Pollution from Ships (MARPOL 1973/1978) represents the main IMO Convention currently in force regarding the protection of the marine environment.

The Convention's principle articles deal mainly with jurisdiction and powers of enforcement and inspection.

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[71] UNCLOS article 21, paragraph 1f.

[72] Kågeson, 2009

More detailed anti-pollution regulations are given in the annexes, which can be adopted or amended by the Marine Environment Protection Committee (MEPC) of the IMO with the acceptance of a number of parties representing 50% of the GT of the world's merchant fleets.

Six annexes of the Convention cover the various sources of pollution from ships and provide an overarching framework for international objectives. Annex VI of the IMO's MARPOL Convention regulates NO_x emissions from large marine diesel engines.

The NO_x emission limits of the MARPOL Convention are defined in the Tier I, Tier II and Tier III standards.

The Tier I standards were defined in the 1997 version of Annex VI, while the Tier II/III standards were introduced by the Annex VI amendments adopted in 2008. Furthermore, the amendment defines two sets of emission and fuel quality requirements: 1) global requirements, and 2) more stringent requirements applicable to ships in Emission Control Areas (ECA).

The Tier II standard is approximately 20% lower than the current Tier I, while the Tier III standard is approximately 80% lower than the current Tier I.

The following table shows the emission limits in the MARPOL Convention.

Table 10-1 The MARPOL NO_X emission limits (g NO_X / kWh)

Tier	Valid from	Engine revolvements per minute		
		<130	130≤rpm<2000	rpm≥2000
		--- g NO_X / kWh ---		
Tier I	2000	17	45 * rpm - 0.2	9.8
Tier II	2011	14.4	44 * rpm -0.23	7.7
Tier III	2016	3.4	9 * rpm -0.2	1.96

It should be noted that the regulation applies to all diesel engines of 130 kW or larger, implying that the limits are also binding for most auxiliary engines.

Under the 2008 Annex VI amendments, Tier I standards become applicable to existing engines installed on ships built between 1st January 1990 to 31st December 1999, with a displacement ≥ 90 litres per cylinder and rated output ≥ 5000 kW, subject to availability of approved engine upgrade kit[73].

10.3 SECA classifications

MARPOL Annex VI provides an opportunity for coastal states to designate part of the sea as an Emission Control Area (ECA) in order to prevent or reduce the adverse impacts on human health and the environment through measures that control emissions of NO_x and SO_x. The North Sea (including the English Channel) and the Baltic Sea have been designated as Sulphur Emission Control Areas (SECAs). Furthermore, IMO has adopted a proposal from United States and Canada jointly proposing designation of an Emission

[73] www.dieselnet.com

Control Area (ECA) for specific portions of the U.S. and Canadian coastal waters. The proposed ECA area in North America would extend up to 200 nautical miles from the coast[74].

The States surrounding the Baltic Sea and the North Sea are also expected to apply IMO for designation of those waters as ECAs for NO_x, and they are currently in the process of preparing applications.

However, a hypothetical negative side effect of creating ECAs for NO_x could be that ship owners respond by predominantly using ships built before 2016 in the ECAs. This would delay the renewal of the fleets operating in the ECAs, to the disadvantage of safety and the environment. As a range of factors affect the choice of ship for a specific route, this behavioural change might however never take place.

The NO_x ECA classification of the North Sea and Baltic Sea is expected to enter into force by 2016 and will therefore not be discussed in more detail here.

10.4 The EU Directives

The 97/68/EC Directive aims at reducing health and environmental effects from air pollution from non-road mobile equipment.

The motivation for the Directive is that NO_x, HC and particulate matter cause adverse health effects. Furthermore, according to investigations undertaken by the EU Commission, non-road mobile machinery is responsible for a considerable share of NO_x and particulate emissions.

In order to balance emissions from non-road mobile machinery and road transport emissions, the Directive offers an option for Member States to set stricter emission limits in special areas of inland waterways. Such emission limits would be valid for all ships passing through the inland waterway.

The European emission standards for new non-road diesel engines have been structured as gradually more stringent tiers known as Stage I...IV standards. The main regulatory steps were:

Stage I/II. The first European legislation to regulate emissions from non-road (off-road) mobile equipment was promulgated on December 16, 1997 [Directive 97/68/EC]. The regulations for non-road diesels were introduced in two stages: Stage I implemented in 1999 and Stage II implemented from 2001 to 2004, depending on the engine power output. Engines used in ships, railway locomotives, aircraft, and generating sets were not covered by the Stage I/II standards.

Stage III/IV. Stage III/IV emission standards for non-road engines (including engines used in ships) were adopted by the European Parliament on 21 April 2004 [Directive 2004/26/EC], and for agricultural and forestry tractors on 21 February 2005 [Directive 2005/13/EC].

Stage III standards, which are further divided into Stages IIIA and IIIB—are phased in from 2006 to 2013, Stage IV enters into force in 2014. The Stage

[74] http://www.epa.gov/otaq/oceanvessels.htm#emissioncontrol

III/IV standards, in addition to the engine categories regulated at Stage I/II, also cover railroad locomotive engines and marine engines used for inland waterway vessels. Stage III/IV legislation applies only to new vehicles and equipment; replacement engines to be used in machinery already in use (except for railcar, locomotive and inland waterway vessel propulsion engines) should comply with the limit values that the engine to be replaced had to meet when originally placed on the market.

Since the Directive is intended to cover rivers and canals, it is not likely that the Danish Authorities would have the option to define larger areas such as the Kattegat or the Baltic see as inland waterways. The emission limits for inland water ways in the non-road mobile machinery Directive could however be used by Danish authorities to regulate emissions in Danish territorial waters, if the emission limits were used as a required standard, despite that Danish waters are not categorized as inland waterways

10.5 The Danish NO_X tax

Denmark levies a tax on emission of NO_2-equivalents from combustion[75]. The obligation to pay the tax covers emissions of NO_2-equivalents on Danish territory, including the territorial sea and the Danish continental shelf area.

Large industrial units, for instance industrial processes with heavy energy consumption, waste incineration plants and industry processes emitting more than 200 tons NO_x annually must measure NO_x emissions. In 2010, the tax rate was EUR 680 per ton NO_x emitted. The tax rate will increase gradually reaching EUR 730 per ton in 2015.

In the absence of measurements of emissions of NO_2-equivalents to air during combustion, the estimated quantity of NO_2-equivalents is estimated relative to the quantity of goods delivered and consumed. The Tax Minister may lay down rules for the metering and rules for the measurement of NO_2 emissions into the air.

The NO_x tax is also applied to fuel used in the transport sector. However, in the transport sector the tax is very small, approximately EUR 1.56 per ton fuel or approximately EUR 0.026 per kg NO_x.

Sea transport is in general exempted from the NO_x tax, also large ships with emissions above 200 tons NO_x annually.

[75] Act no. 472 af 17/06/2008, Lov om afgift af kvælstofoxider

11 Measures to reduce NO_X emissions around Denmark

11.1 Legal constraints

International legislation is one of the main constraints that limit the Danish options to regulate emissions from ships around Denmark. Although international legislation provides an option for national regulation of innocent passage for special environmental concerns[76], it is not common practice for a country to adopt special national regulations, especially for ships not calling at a Danish port. This means that in practice the Danish authorities can only regulate exhaust gas emissions from ships calling at Danish ports.

According to Annex VI of the MARPOL Convention (MARPOL 73/78) governed by the International Maritime Organisation, tighter SO_x regulations may apply to certain areas (Sulphur Emission Control Areas - SECAs) than in the remaining part of the world. The IMO has designated the Baltic Sea, the North Sea and the English Channel as SECAs.

In order to reduce emissions further, the MARPOL Annex VI was amended in 2008. The amendments reduced the sulphur content limit to 1% as from 1 July 2010 and to 0.10%, effective from 1 January 2015[77].

Progressive reductions in nitrogen oxide (NO_x) emissions from marine engines were also agreed on, with the most stringent controls on the so-called "Tier III" engines, i.e. those installed on ships constructed from 1 January 2016 onwards, operating in Emission Control Areas (ECAs).

Furthermore, the revised Annex VI allows for waters to be designated as SO_x or NO_x ECAs, or as ECAs for all types of emissions from ships, if supported by a demonstrated need to prevent, reduce and control one or all three of these emissions from ships. It is expected that the Baltic Sea and the North Sea will be designated as NO_x ECAs.

Finally, the EU directive allows a Member State to designate special areas as internal waterways, where special emission limits may be applied to the ships sailing through these waters.

Apart from these two exceptions, there are two options for applying regulation to reduce NO_x emissions from ships navigating in Danish waters. These include ships calling at Danish ports or voluntary agreements.

As described earlier, 70% of NO_x emissions in the waters around Denmark are emitted by foreign-flagged ships that never call at a Danish port.

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[76] UNCLOS article 21, paragraph 1f.

[77] http://www5.imo.org/SharePoint/mainframe.asp?topic_id=233

11.2 Tradable emission credits

Market-based instruments, such as tradable permits are often considered an efficient measure to reduce emissions. An interesting feature of the market-based systems is that the emission permits or credits or the tax ensure that the free market forces can still operate, while a specific, environmental problem is taken into account in market choices. It may also be argued that the right tax may even bring the market closer to an optimal situation where prices reflect more correctly the benefits and costs to society.

Furthermore, market-based instruments such as emission charges or cap-and-trade systems give ship owners a large degree of freedom in responding to a given regulation. Where NO_x or particulates are concerned, it makes sense for ship owners to install abatement technologies in ships in response to a market-based instrument if the expected lifetime of the vessel is long enough to allow the equipment to be written off. For ships with few remaining years in operation and infrequent visitors to an area with air pollution regulation, it makes more sense to pay the tax or buy the emission permits.

An emission credit programme provides tradable emission 'credits' to ship owners that reduce emissions below a certain level. The credits can be sold to other sources that would face higher costs in meeting emission requirements. A credit-based programme is a well-known mechanism, for instance from the Kyoto Flexible Mechanisms[78], including credits for greenhouse gas reductions.

A critical issue of the credit-based programme concerns the setting up of a method for measurement of emission savings and the solving of problems of determining the initial level of emissions to avoid giving credits to emission savings that would have occurred anyway.

An emission credit programme would require the development of a reliable monitoring, reporting, and verification method. The degree of detail of such a method depends on the complexity of the programme. In order to get a reasonably detailed system, parameters such as ship location, ship engine characteristics, emissions factor, activity level and energy consumption could be included. There is a trade-off between the cost and precision of the monitoring system. Furthermore, administrative costs will increase with the complexity of systems.

The efficiency of the credit-based programme depends on the number of agents participating in the market for credits. A limited number of actors in the programme limit the potential for emission reductions.

One of the advantages of a credit-based approach is the possibility of making the scheme voluntary, which could prevent it from being challenged by international law. However, to ensure that there is a demand for credits, it may be necessary to be set up a market on which ship owners can sell their credits. This could be either other ship owners that would need to reduce their emissions, or a government subsidy programme, whereby the government simply purchases credits generated by ships.

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[78] Haoran Pan (2001)

11.2.1 Feasibility

From a legal point of view, a credit-based system may be straightforward to implement and should not conflict with Danish or international law as long as it only covers national transport.

In practice, the system would be limited to national transport. Ship-owners could be given an amount of credits corresponding to the expected emissions minus the desired amount of emission reductions. Then, ship-owners will have to decide if they will reduce emissions or choose to purchase extra emission credits. If too few ship-owners choose to reduce emissions, there will be too few credits, and the price of the credits will increase. When the price of the credits increases, it will become beneficial to more ship-owners to reduce emissions and sell emission credits.

Once in force, a credit-based programme would have an impact mainly on existing ships. The reason for this is that is not foreseen that the small Danish demand for ships will have any impact on the design of ships. Having said that, it is reasonable to believe that a credit-based system, properly designed, would give credit to ship-owners who choose to purchase a new ship of a better standard than 'normally' required. Thus, new ship technologies would come into play with this measure as well.

A tradable emissions credit system could cover all NO_x emissions from all Danish national sea transport, corresponding to 9,530 tons of NO_x annually. The reduction would depend on the definition of the baseline. However, since there are technologies that can reduce NO_x by up to 60-80% depending on the technology, it is estimated that the potential reduction would be in the range of 60% to 80% of total NO_x emissions from national sea transport corresponding to 5,718 to 7,624 tons of NO_x annually. The 5,718 tons annually corresponds to 60 % of the NO_x emissions from national navigation transport in Denmark and 4% of total NO_x emissions in Denmark.

The benefit to society of a NO_x reduction will be approximately EUR 7.11 per kg of NO_x, in total EUR 40,661,211 for all 5,718 tons of NO_x. It is estimated that the technologies applied under this scheme would be a mix of the three technologies: EGR, HAM and SCR. The average cost of these three technologies is EUR 0.51[79] per kg of NO_x. Applying these technologies would sum up to EUR 2,916,180.

The cost of this measure would include cost of monitoring and inspection plus additional costs of setting up an organisation that can facilitate emission trading. Furthermore, additional administrative resources would be required to design the system initially and to find the right level of credits to issue in the market. It is estimated that the cost of this measure would be EUR 2.5 million annually.

Table 11-1 Cost benefit from reducing NO_X emissions by a tradable emission credits

	EUR / year
a) Benefit	40,661,211
b) Cost	2,916,180
c) administration	2,500,000

[79] Cost per kg is based on values in Table 9-23. The weighed average is reflecting the share of NO_X emissions that is relevant for each technology.

Cost per kg NO_X (b + c)/kg NO_X	0.95
Cost benefit, a - b - c (EUR/Year)	35,245,031

Thus, the total value to society would be approximately EUR 35,245,031 annually.

Tradable credits may not be the best measure to reduce particulate matter, since there are only a few technologies available for reductions in particulate matter in addition to the reductions that will occur due to the low sulphur content in the SECA areas.

11.3 Emission taxation

Market-based systems such as emission taxation may be an efficient way of reducing emissions in situations where the cost of reduction is lowest. As with emission trading, emission taxation can ensure that the market forces can continue to operate, while a specific environmental problem is taken into account in market choices by setting a tax targeting the specific problem.

However, emission taxes can only be applied to national sea transport. As mentioned above, Article 24 of the United Nations Convention on the Law of the Sea (UNCLOS) rules out emission charging of "innocent passage", while Article 26 rules out distance based emission charges for international sea transport even if the vessel calls a Danish port. Thus only national sea transport can be charged.

11.3.1 NO_X tax

As already mentioned, Denmark levies a NO_x tax on fuels. However, sea transport is exempted from this tax.

Norway levies a substantially higher NO_x tax than Denmark, and the Norwegian NO_x tax is also applied to sea transport. The Norwegian NO_x tax is collected by a Fund and recirculated to the ship owners as a subsidy to NO_x reducing measures.

The Norwegian tax is calculated on the basis of actual emissions of NO_x, calculated as NO_2-equivalents. The Norwegian NO_x tax is NOK 16.43 (1 Jan 2011) equivalent to EUR 2.10 per kg of NO_x [80]. Emissions from sources that are encompassed by an environmental agreement with the State on the implementation of NOx-reducing measures in accordance with a predetermined environmental target are exempted from the tax.

The basis for the tax can be actual, measured emissions or source-specific emission factors and energy consumption or standard emission factors and energy consumption.

The measurements must represent ordinary and representative operating conditions. If actual, measured emissions are not known, the tax must be calculated based on source-specific emission factors and the quantity of energy consumed.

[80] Currency: 1 EUR = 7.82448 NOK, 14 June 2011.

If actual, measured emissions are not available and if source-specific emission factors as provided for calculation based on fuel consumption have not been determined, emissions will be calculated using the following list.

- Engines
  - rpm less than 200: 100 kg NO_x per ton fuel
  - 200 rpm to 1,000 rpm: 70 kg NO_x per ton fuel
  - 1,000 rpm to 1,500 rpm: 60 kg NO_x per ton fuel
  - 1,500 rpm upwards: 55 kg NO_x per ton fuel.
- Turbines
  - Turbines: 16 g NO_x per m^3 LNG
  - Turbines: 25 kg NO_x per ton liquid energy fuel
  - Low NO_x turbines: 1.8 g NO_x per m^3 gas.

These NO_x emission factors are at level with standard emission factors of approximately 12 g NO_x/kWh for medium-speed engines and 17 g NO_x/kWh for low-speed engines.

The Norwegian tax covers:

- emissions from traffic in Norwegian territorial waters, meaning sea areas around the Norwegian mainland encompassed by the Act of 26 June 2003 No. 57 concerning Norway's territorial waters and adjoining zones

- emissions from domestic traffic even if parts of the traffic take place outside Norwegian territorial waters. Domestic traffic is defined as traffic between two Norwegian ports.

- in the case of Norwegian registered vessels, liability for tax will also apply in the case of emissions in near waters, meaning sea areas where the distance to the Norwegian coast (baseline) is less than 250 nautical miles.

Direct foreign traffic, fishing and hunting in remote waters are exempted from the tax. Vessels in direct traffic between Norwegian and foreign ports are exempted from tax for the entire voyage.

Emissions from sources that are encompassed by an environmental agreement with the State on the implementation of NO_x-reducing measures in accordance with a predetermined environmental target are exempted from the tax.

Foreign owners of vessels are liable to pay Norwegian NO_x tax. Foreign owners with no place of business or domicile in Norway are liable to pay tax through a representative registered for taxable traffic. Upon arrival in Norway, the master of the vessel should notify the customs authority of the representative that will pay the tax[81].

[81] This situation is most likely rare since sea traffic between a Norwegian and a non-Norwegian port is exempted from the tax.

11.3.2 Feasibility

From a legal point of view, a NO_x tax on sea transport may be straightforward to implement and would not conflict with Danish or international law. Especially in case the tax revenue is transferred back to the sector.

In Norway, the share of innocent passages is relatively small, which means that the NO_x tax system covers a large part of the sea traffic in Norwegian waters.

For Denmark, a tax like the Norwegian NO_x tax would almost solely be applicable to national ferry transport. This is because national freight transport by sea is limited in Denmark.
Once in force, a NO_x tax would have an impact mainly on existing ships. The reason is that it is not foreseen that the limited Danish demand for ships will have any significant impact on the design of ships. Having said that, it is reasonable to believe that a NO_x tax would to some extent induce ship owners to purchase new ships of a better NO_x standard than 'normally' required. This is especially true if the NO_x tax is substantial.

Bearing in mind that the reduction cost per kg NO_x for EGR, HAM; and SCR is EUR 0.36 to 0.69 per kg NO_x, introducing a tax at the level of approximately EUR 0.68 per kg NO_x would make it beneficial to invest in NO_x-reducing equipment for some of the medium and slow-speed engines. However, it is likely that some of the ship owners will refrain from the investment since the economic gain is limited. In some cases, the actual investment may be more expensive due to special circumstances. In other cases, the time horizon may be too short to make such an investment profitable. Therefore, as an approximation it is estimated that 50% of medium and slow-speed engines will be equipped with NO_x reducing equipment due to the NO_x tax.

Table 11-2 National navigation broken down by engine technology

	Annual NO_x emissions (ton)	Reduction technology
Gas turbine	238	50% SCR
High speed (4-stroke)	326	50% SCR
Medium speed (4-stroke)	5.500	25% SCR and 25% EGR
Slow speed (2-stroke)	3.466	25% HAM and 25% EGR
Total	9.530	

Source: Distribution of technologies based on AIS data. Total NO_x emission for national navigation based on national emission inventory 2011.

Table 11-3 shows the NO_x reduction for a scenario where 50% are equipped with NO_x reducing technology.

Table 11-3 NO_X reduction from national ferries due to NO_X tax on ferry transport

	Annual NO_X emissions (ton)	Annual reduction in NO_X emissions (ton)
Gas turbine	238	95
High speed (4-stroke)	326	130
Medium speed (4-stroke)	5.500	2200
Slow speed (2-stroke)	3.466	1256
Total	9.530	3682

The 3,682 tons annually corresponds to 37 % of the NO_x emissions from national navigation transport in Denmark and 2.8% of total NO_x emissions in Denmark.

The benefit to society of a NO_x reduction will amount to approximately EUR 7.11 per kg NO_x, in total EUR 26,183,167 for all 3,682 ton of NO_x. The weighed average cost of these technologies is EUR 0.51 per kg NO_x, summing up to EUR 1,878,695[82].

The cost of this measure would include additional cost of inspection, monitoring, measuring, collection and administration of payments. It is estimated that the cost of this measure would be 2 million EUR annually.

Table 11-4 Cost benefit from reducing NO_X emissions by a NO_X tax

	EUR / year
a) Benefit	26,183,167
b) Cost	1,878,695
c) administration	2,000,000
Cost per kg NO_X (b + c)/kg NO_X	1.05
Cost benefit, a - b - c (EUR/Year)	22,304,473

Thus the total value to society would be approximately EUR 22,304,473 annually.

One of the advantages of a NO_x tax is its relatively quick impact following introduction. A good time for making NO_x reducing investments would be in connection with the annual inspection/overhaul.

Designing the NO_x tax and preparing the NO_x tax legislation should be a relatively simple and quick process. This is mainly because there is some experience with NO_x taxation of sea transport from other countries and because there is already a NO_x tax in place for land-based fuel consumption. With this in mind, it follows that the whole process including the political process and formulation of legal documents will take approximately 1-2 years.

All in all, a reasonable estimate would be two to three years before any substantial effect of a NO_x tax on sea transport in Denmark would materialise.

[82] Cost per kg is based on values in Table 9-23. The weighed average reflects the share of NO_x emissions that is relevant for each technology.

11.3.3 Tax on particulate matter emissions in port

At present, there is no particulate emission tax in Denmark. The issues of measurement design and legal requirements are similar to those mentioned above for the NO_x tax. In this case, emission factors or actual, measured emissions may be used as the tax base.

A tax may be a flexible instrument when many technologies are available. The ship owners are free to select the technology that they find most appropriate for their ships. However, in the case of particulate emissions, there are few available technologies for marine engines.

At present, there are two technologies available for the main engines of a ship; one is substitution to gas and low sulphur fuels and the other is installation of a scrubber. Since the technologies related to low-sulphur fuels are already to be implemented with the designation of the North Sea and the Baltic Sea as SECA areas, only few technologies are available to achieve additional reductions. One of the technologies for achieving additional reductions in particulate matter emissions involves replacement of fuel oil with gas. However, since one of the major barriers to switching to gas is limited bunkering facilities, it is not foreseen that a particulate matter emission tax would increase the replacement of fuel oil with gas in the shipping sector.

Thus, a tax on particulate matter may be a less favourable instrument to target particulate emissions compared with the NO_x tax targeting NO_x emissions.

The damaging costs of particulate matter are higher in densely populated areas[83]. To this end, a tax on particulate emissions should in principle be higher in locations close to densely-populated areas.

Cold ironing where ship electricity is supplied from the land grid can shift air quality emissions away from the port. The net gain depends on the shore power source, but generally power plants will have lower emissions than auxiliary engines on ships.

At present Article 14(1)(c) of the Energy Taxation Directive (2003/96/EC) obliges Member States to exempt electricity produced on board a craft (including while at berth in a port) from taxation. In order support incentive for development of cold ironing, the Commission proposes to exempt from energy taxation shore-side electricity provided to ships while at berth in port. This exemption should apply during a period of eight years[84].

These technologies fit well with the local character of the particulate emissions, since it reduces the emissions in areas close to densely populated areas. A tax on particulate emissions at berth would promote such technologies.

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[83] Damage costs calculated by the Ministry of Transport, National Environmental Research Institute (2010) show substantially higher cost of particulate matter emissions in urban areas compared with rural areas, while the damage costs from NO_x emissions are unaffected by population density. The Centre for Energy, Environment and Health does not report emissions for urban and rural areas. However, from the maps in the report it can be seen that damage effects of particulate emissions are more local than the damage effect of NO_x emissions.

[84] COM(2011) 169 final

In 2009, the Danish tax authorities introduced a tax increase for diesel vehicles without particulate filter. Although this is not a real particulate emission tax, since it is unrelated to the amount of particulate emissions, it is an example of a tax that promotes a technology for reducing particulate emissions.

A few countries levy a tax on particulate matter emissions from stationary sources. The Czech Republic applies a tax of EUR 100 per ton[85], and Australia applies a tax of EUR 50 per ton of coarse particulates and EUR 347 per ton of fine particles[86] from stationary sources.

11.3.4 Feasibility

From a legal point of view, a charge on particulate matter emissions from sea transport may be easy to implement and should not meet major obstacles in Danish or International law.

However, since there are only few technologies available for reducing particulate emissions after the sulphur content has been reduced or scrubbers implemented, a general charge on particulate emissions may not be the most efficient way to reduce particulate emissions. It is likely rather to become a fiscal tax.

Limiting the charge to emissions at berth would make it more feasible since there more alternatives are available here, for instance the so-called "cold ironing" where ship electricity is supplied from the land grid or ultra low-sulphur fuel to auxiliary engines at berth. Furthermore, a tax on particulate matter emissions at berth would also tend to reduce the particulate emissions at locations where the damage effect is highest.

According to EPA[87], particulate emissions in Danish ports amount to approximately 57 tons annually. It is estimated that approximately half of the ships calling at Danish ports are national transport, the rest being international transport.

It is estimated that the charge will only affect the emissions from the auxiliary engines producing electricity for light, air consumption etc. The emissions for this component amount to 20 tonnes of particulate matter and 1.174 tonnes of NO_x annually[88]. Manoeuvring cannot be based on electricity from land[89]. In some cases, pumping is driven by a boiler/steam turbine combination, which cannot easily be substituted by electricity from land.

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[85] MINISTRY OF THE ENVIRONMENT OF THE CZECH REPUBLIC (2011), 2005 prices

[86] Zaida Contreras et al. (2011)

[87] Calculations of emissions based on energy consumption from Work report No. 11, 2003, Emissions from ships at berth combined with new emission factors from national emission inventory.

[88] Based on EPA, 2003, it is estimated that auxiliary engines use 109,000 MWh for light, air consumption etc. in Danish ports every year. This amount combined with average emission factors of NO_x and PM of 12 g/kWh and 0.18 g/kWh respectively give the total emissions per annum.

[89] Work report No. 11, 2003,

In practice, not all auxiliary energy consumption can be substituted with land-based electricity. First, some ships only stay a short time in the port, and secondly not all ships are designed to use land-based electricity[90]. Thirdly, it may be costly to install the required equipment on the ship.

Thus, it is estimated that a charge of EUR 100 per kg of particulate matter would shift 60% of the energy consumption from the auxiliary engines to land-based electricity. This measure would shift 10 tons of particulate matter away from the port area to the electricity production where the particulate emissions from 1 kWh is only 15% compared to the emissions from an auxiliary engine onboard a ship. The 1,174 tons of NO_x would be reduced even further since the NO_x emissions from electricity production is only 4% of emissions from an auxiliary engine on board a ship[91].

The total benefit to society of switching 60% of energy consumption to land-based electricity production would be EUR 7,257,412.

Based on the AIS data, it is estimated that approximately 2,100 different vessels call at a Danish Port each year. These vessels have a total installed capacity of 703 MW of auxiliary engines. The annual cost of installing the electrical power converter in 60% of these vessels sum up to EUR 1,529,209 annually.

Table 11-5 Cost benefit from reducing PM emissions by a PM tax

	NPV (1000 EUR)
a) Benefit	100,142,431
b) Cost	78,138,946
c) administration	3,450,000
Cost per kg PM (b + c)/kg PM	136
Net present value of net benefit, a - b - c (1000 EUR)	18,553,485

Note: Cost per kg of PM has been reduced with the benefit from the NO_x reduction.

Thus ,the total value to society would be a gain of EUR 18,553,485 in a 24-year time horizon. Tailoring the measure to large ships and ports might save investment costs and make it more beneficial than estimated here.

11.3.5 Fuel tax

Fuel taxes are commonly known for road transport. The purpose of the fuel tax is to reduce the demand for vehicle fuels. All revenues are transferred to the public budget.

In 2005 a CO_2 tax was introduced, however, at the same time basic excise was lowered to maintain the overall rate.

[90] Work report No. 11, 2003,

[91] Emissions from electricity production based on average electricity production according to the TEMA2000 model from Ministry of Transport.

EU sets minimum levels of fuel taxation, at present 0.359 EUR per litre petrol and 0.330 EUR per litre diesel. The Danish taxes are shown in Table 11-6

Table 11-6 Fuel taxes in Denmark

	Petrol	Diesel
	EUR per litre	
Production price	0.74	0.86
Energy tax	0.52	0.33
CO_2 tax	0.05	0.05
VAT	0.33	0.31
Consumer price	1.64	1.55

Prices at 5th November 2011.

Sea transport is exempted from fuel taxes.

11.3.6 Feasibility

Introducing a fuel tax for sea transport in Denmark would require special measures to avoid import of tax free fuel from foreign countries.

Since fuel tax targets fuel consumption and not specific emissions, a fuel tax would be a rather inefficient measure to reduce NO_x and particulate emissions in Denmark. A fuel tax would only slightly reduce NO_x and particulate emissions in the same order of magnitude as energy consumption.

Fuel tax is common for road-based vehicles where the consumer is taxed by the pump. Such procedure would not be possible in international traffic because ships would then refrain from bunkering in Danish ports.

Furthermore, the pressure for achieving reductions in GHG emissions focuses on reductions in fuel consumption, and this will automatically lead to reductions in NO_x and particulate matter with the introduction of the new GHG regulations, which were adopted at the last meeting of the Marine Environment Protection Committee in IMO in July 2011 (MEPC 62). This piece of legislation will enter into force in 2013 for new ships. With the introduction of the so-called Energy Efficiency Design Index (EEDI), there will be a new upper limit for allowable CO_2 emissions per transport unit (g CO_2 per ton dead weight per nautical mile.

11.4 Subsidy

Subsidies may be an efficient way of supporting new technologies that are not economically beneficial for ship owners to apply. However, subsidy programmes have to be introduced with care in order to avoid subsidising activities that would have been undertaken anyway. Supporting activities that would have been undertaken anyway reduces the resources available to support other activities and thereby the potential effect of the subsidy.

Subsidies, or state aid are prohibited by the EU, but certain categories of aid are exempted. As a rule, the EU should be notified of all aid, and then the Commission will assess whether the aid can be exempted from the prohibition. Article 87 of the EC Treaty provides the legal basis for the rules of subsidy:

Save as otherwise provided in this Treaty, any aid granted by a Member State or through State resources in any form whatsoever which distorts or threatens to distort competition by favouring certain undertakings or the production of certain goods shall, in so far as it affects trade between Member States, be incompatible with the common market (article 87).

In this context, state aid is defined as follows[92]:

- Financed by public funds
- Beneficial to the recipient
- Only beneficial to some sectors/industries/companies
- Influences trade and competition.

By issuing framework conditions, the Commission has stipulated how state aid in different areas will be assessed. This relates to, for example, aid for research and development, the environment, as well as small-and medium-sized enterprises.

The rules describe which type of support is allowed, to which extent and under what conditions.

The Commission has issued various regulations, framework conditions and statements. Common to all regulation is that the aid should be accessible for all companies. The Commission distinguishes between three overall types of state aid; horizontal, sectoral, and regional aid.

Horizontal schemes[93] allow multiple companies across sectors to receive aid. Aid schemes are designed to improve the conditions for business by allowing support for e.g. research and development. The purpose of this aid is primarily to correct market failures thereby improving the way the market functions.

Sector schemes exclusively address companies in certain sectors. In a large part of the sector schemes, the aid is granted to the transport sector. There are, inter alia, arrangements for sectoral aid to shipbuilding, the motor industry, coal and steel as well as rail and aviation industry[94].

Regional aid schemes are designed to support regions with particular economic or employment problems.

By far the largest part of Danish aid schemes, 85%, are horizontal schemes. A very small part of the Danish aid is regional aid, while approximately 14%, and is applied to specific sectors[95].

Many of the reviews by the Commission satisfy the conditions laid down in the guidelines and are therefore considered to be compatible with state aid rules.

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[92] Source: Danish Competition and Consumer Authority

[93] A horizontal scheme is a scheme that is not targeted towards a specific sector or industry but rather towards a specific issue.

[94] Danish Competition and Consumer Authority.

[95] Source: Danish Competition and Consumer Authority

Environmental subsidies support specific environmental-friendly activities financially. The subsidy can take many forms, e.g. grants, guarantees, interest rate deductions, wage support, tax deduction.

Typically, subsidies are used to support desired policy options, in this case low emission technologies. An example is the subsidy programme in Sweden by which low-emitting NO_x technologies, such as SCR and HAM were supported in connection with the introduction of environmentally differentiated port dues in 2002.

One point of discussion is the nationality of the vessels. It could be politically problematic for Danish authorities to support foreign ship owners with subsidies. On the other hand, restricting subsidies to Danish ships would limit the impact of a subsidy scheme.

As is the case with other measures for regulating emission from ships, the subsidy scheme will require monitoring and enforcement.

Typically, subsidies have not been used as stand-alone measures. This is because it may be difficult to raise sufficient revenue from other sectors in the economy. On the other hand, it could be a good supplement to a tax scheme, as in Norway where the NO_x Fund financed by the NO_x tax subsidises NO_x-reducing technologies and associated costs.

Subsidy programmes would see the same trade off between effectiveness and administrative costs as many other subsidy programmes. Large reductions will require a detailed system, which would, in turn, require more expensive administration.

11.4.1 Feasibility

The NO_x tax system applied in Norway consists of a NO_x tax combined with a subsidy system, where investments and operational costs may be partly covered by financial grants from the NO_x fund.

As mentioned above, state subsidies are not legal in the EU. However, in a system such as the Norwegian NO_x Fund, the subsidy element would probably be found to be compatible with state aid rules for at least two important reasons. First, the combination of tax and funding in the Norwegian system is balanced meaning that the sector as a whole is not distorted. Second, the funding of NO_x reducing equipment is open to all who wish to apply as long as they pay the tax, i.e. national traffic in Norwegian waters. Thus, the scheme does not favour one ship-owner at the expense of another.

The combination of NO_x tax and subsidy has several benefits:

- The system does not increase the overall general costs of sea transport, and therefore does not in general transfer transport to road.

- A balanced system seems to be accepted more easily by industry stakeholders, since it does not generally increase the costs of ship operations. On the contrary, it improves the capability of the industry to deliver more environmentally friendly services to clients who demand such services.

- The tax increases the cost of NO_x emissions and thus the incentive for introducing NO_x reducing measures supported by the NO_x Fund.

- As an economic incentive, focusing on NO_x emissions rather than on technologies, it is an efficient measure since it promotes NO_x reductions where it is beneficial.

The NO_x tax/subsidy system may also involve inefficiencies:

- The subsidy part may involve some inefficiency, since it may support investments, which would also have been implemented in the absence of the Fund.

- Since it will require administrative and evaluation efforts to find the projects worth supporting, administrative costs will incur.

In this case, where the subsidy is applied in combination with a NO_x tax, the subsidy would target the same coverage as the NO_x charge. Thus, the reduction potential is all national NO_x emissions from national navigation equal to 9,530 tons of NO_x annually.

Introducing a subsidy element would increase the share of ships equipped with NO_x reducing equipment significantly because the amount of subsidy available from the NO_x charge is approximately at the same level as the cost of NO_x reducing equipment. It is estimated that adding a subsidy of this magnitude would increase the coverage of the ships equipped with NO_x reducing technologies from 50% to 90% of ships in national navigation. Table 11-8 shows the NO_x reduction for a scenario where 90% of the engines are equipped with NO_x reducing technology.

Table 11-7 NO_x reduction from national navigation due to NO_x tax and subsidy in combination

	Annual NO_x emissions (ton)	Annual reduction in NO_x emissions (ton)
Gas turbine	238	171
High speed (4-stroke)	326	235
Medium speed (4-stroke)	5,500	3,960
Slow speed (2-stroke)	3,466	2,262
Total	9,530	6,628

The 6,628 tons annually corresponds to 70% of NO_x emissions from national navigation transport in Denmark and 5% of total NO_x emissions in Denmark.

The benefit to society of a NO_x reduction will amount to approximately EUR 7.11 per kg of NO_x, in total EUR 47,129,700 for all 6,628 tons of NO_x. The average cost for these technologies is EUR 0.51[96] per kg of NO_x, summing up to EUR 3,381,650.

Table 11-8 Cost benefit from reducing NO_X emissions by a combination of a NO_X tax and a subsidy

	EUR / year
a) Benefit	47,129,700
b) Cost	3,381,650
c) administration	2,500,000
Cost per kg NO_X (b + c)/kg NO_X	0.89
Cost benefit, a - b - c (EUR/Year)	41,248,050

Thus, the total value to society would be approximately EUR 41,248,050 annually.

11.4.2 Examples

There are several European examples of combinations of tax and funding.

11.4.2.1 The Norwegian NO_x fund

All enterprises obligated to pay NO_x tax may join the Environmental Agreement, regardless of nationality.

Enterprises, which have joined the Environmental Agreement, and enterprises with process emissions may apply for support from the NO_x Fund to cover investments and operating costs in accordance with the rules stipulated by the Board.

The NO_x fund subsidises investments with up to 80% and urea consumption with up to 90% of the actual cost[97].

11.4.2.2 The French tax refunding

In France, stationary sources pay a NO_x tax of 53,60 EUR pr ton[98]. Of the total tax revenue received, 75% were earmarked for subsidies to abatement investments or for research and development. Any firm paying the air pollution tax is eligible to apply for the subsidy. The subsidy is awarded based on the level of the additional fixed capital investment the firm invested to reduce emissions.

The rates are 15% for standard abatement technologies, 30% for particularly innovative technologies with an additional 10% subsidy for small and medium-sized companies[99].

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96 Cost per kg is based on values in Table 9-23. The weighed average is reflecting the share of NO_X emissions that is relevant for each technology.
97 See annex for a more detailed list of subsidy limits in the Norwegian NO_x fund
98 Source: OECD/EEA database on instruments used for environmental policy and natural resources management
99 AP EnvEcon, 2009.

11.5 Differentiated port dues

Another way of redirecting revenue to the industry could be a fee bate system. A fee bate system consists of a fee for vessels with emissions above a certain level and a rebate for vessels below a certain level.

Differentiated charges mean that we base some of the dues on vessels' air emissions characteristics, thus providing a financial incentive for reducing emissions. The scheme considered here is based on the voluntary participation of ports.

The differentiated charge would be based on an environmental index, including emissions intensity (e.g. g/kWh) and level (e.g. engine size). Existing port dues already vary with regard to vessel class and size, the type of port and the frequency of visit and type of service in port. Beyond this, the environmentally differentiated port dues would need to set up an organisation for calculation and validation of the emissions. Public authorities may assist in the set-up of a certification scheme to secure valid calculations of the environmental index to use by the ports, perhaps assisted by the classification societies which, in the coming years, will play a more and more pronounced role with respect to new environmental legislation (EEDI Energy Efficiency Design Index).

There will be a need for substantial differentiation to make ship owners change behaviour. Existing port dues may be too small to enable sufficient differentiation.

The potential effect of differentiated port dues will depend on how many ports participate in the system. If only a limited number of ports participate, there will be a risk that ships with a low environmental index will look for ports without differentiated dues instead of investing in emission-reducing equipment. In case the ships choose to make a detour, this may increase the cost and emissions.

The negotiating element of port dues where the port due is negotiated in competition on a bilateral basis means that the port operator may be uncertain how to get extra dues from badly performing ships.

The Swedish Maritime Administration is funded by fairway dues for ships calling at Swedish ports. The fairway consists of two parts, one related to the size of the ship and one related to the amount of goods the ship is carrying. Only the ship size part is differentiated relative to NO_x emissions. The differentiation consists of a rebate starting at 10 g/NO_x per kWh and proportional down to zero emissions. When the differentiation was introduced in 2002, the general level was raised to keep the revenue constant.

The rebate in the Swedish system requires a certificate from the Swedish Maritime Administration. In 2009, 37 ships were registered as ships with low NO_x emissions. Almost all of these were supplied with a SCR unit. However, the reason for the SCR installations is probably not the environmental differentiation, but rather a subsidy scheme that was in place in the beginning of 2002.

In 2009, 19 Swedish ports had introduced environmentally differentiated port dues according to the Swedish Maritime Administration method.

11.5.1 Feasibility

One advantage is that the administration is already in place to collect charges for the use of port facilities. Thus, there will be no need to set up new procedures for the payment of charges. On the other hand, the administration will need extra resources to set standards and to enforce the emission scale.

Differentiated port dues only target ships calling at Danish ports and there will therefore not be any conflicts with international law on "innocent passage".

The potential for a proposal to apply NO_x or particle matter differentiated port dues is shown in Table 11-9 and Table 11-10 where the emissions from the ships are split up according to the nationality of the port at which they call.

Table 11-9 NO_x emission from ships broken down according to the nationality of the port at which they are calling, Tonnes NO_x per year.

	DK port	Foreign
Gas turbine	832	529
High speed (4-stroke)	582	1,899
Medium speed (4-stroke)	12,622	71,169
Slow speed (2-stroke)	5,557	80,040
Total	19,593	153,638

The amount of NO_x emitted from ships calling at Danish ports amounts to 19,593 tonnes NO_x annually. 9,530 tonnes of these are emissions from national sea transport included in the national emissions inventory. These emissions account for 7.7% of total NO_x emission in the national inventory. The rest 10,000 tonnes of NO_x emissions are emissions from international transport which is not part of the Danish national emissions inventory.

Table 11-10 Particulate matter emission from ships broken down according to the nationality of the port at which they are calling, Tonnes particulate matter per year.

	DK port	Foreign
Gas turbine	49	31
High speed (4-stroke)	11	35
Medium speed (4-stroke)	497	2,781
Slow speed (2-stroke)	153	2,208
Total	710	5,055

Table 11-10 shows that the amount of particles emitted from ships calling at Danish ports amounts to 710 tonnes particulate matter annually. 70% of the particulate matter emissions are emitted by medium-speed engines. These emissions include all emissions from the ships entering Danish waters.

Regarding the implementation, it seems that there are no overwhelming legal or political obstacles. Port dues are already differentiated according to other characteristics of the vessels and it is not expected that NO_x or particulate matter emissions will cause legal problems. On the other hand, it may cause some practical problems to calculate end enforce many different dues for different types of ships with different emissions.

Although Table 11-9 and Table 11-10 show a large potential for reductions of both NO_x and particulate matter emissions from ships calling at Danish ports, it may be difficult to harvest the potential.

First of all, for many of the ships coming from far away the port due in Denmark may only be a very small share of the total cost of the journey. Thus, it might not be economically reasonable for the ship owner to make costly investments just to save a minor port due in Denmark.

On the other hand, in case the port dues are raised to a substantial level, the risk is larger that the ship owners will choose another port without high NO_x port dues. In this case we will have other costs from road transport instead.

Furthermore, the already existing differentiation aiming at efficient organisation of the work process and organisation in the port may be hampered if yet another differentiation was added.

Finally, in case ship owners do change behaviour and reduce their emission, then the ship owners will pay a lower charge in the future. This means lower revenue to the port authorities, and then the port authority will have to increase the charge in order to keep the revenue constant.

Particles from ships at berth are a special problem because the particles are emitted close to densely populated areas and thus cause more damage. One way to reduce this problem is the so-called "cold ironing" where the ship's electricity is supplied from the land grid. This solution eliminates the air pollution from the ship at berth. This technology could be supported by a particulate matter charge on the emissions from the auxiliary engines at berth. This issue is discussed in more detail in section 11.3.3 above.

11.6 Norms for national ferries

One proposal for limiting emissions from ferry transport is to implement the emission limits laid down in the Inland Waterways Directive.

The Inland Waterways Directive aims at reducing the health and environmental effects from air pollution caused by traffic on the inland waterways.

According to the Inland Waterways Directive, the emissions of CO, the emissions of the sum of HC and NO_x and the emissions of particulates shall for stage III A not exceed the amounts shown in Table 11-11.

Table 11-11 Emission limits from the Inland Waterways Directive

Category	Displacement (L)	CO (g/kWh)	HC+NO_x (g/kWh)	PM (g/kWh)	Due date
V1:1	<0,9	5	7.5	0.4	1. Jan, 2007
V1:2	0,9<SV<1,2	5	7.2	0.3	1. Jan, 2007
V1:3	1,2<SV<2,5	5	7.2	0.2	1. Jan, 2007
V1:4	2,5<SV<5	5	7.2	0.2	1. Jan, 2009
V2:1	5<SV<15	5	7.8	0.27	1. Jan, 2009
V2:2	15<SV<20 P<3300	5	8.7	0.5	1. Jan, 2009
V2:3	15<SV<20 P>3300	5	9.8	0.5	1. Jan, 2009
V2:4	20<SV<25	5	9.8	0.5	1. Jan, 2009
V2:5	25<SV<30	5	11	0.5	1. Jan, 2009

Category: swept volume/net power (SV/P) (litres per cylinder/kW)

The relevant limits are the ones in the lower part of the table. As can be seen from the table, the emission limits for the sum of HC and NO_x are in the range 7.8 to 11 g NO_x and HC per kWh. Taking into account that the typical HC emission is below 1 g per kWh, the effective NO_x limit will be in the range 7 - 10 g NO_x per kWh. This is 20 - 40% lower than a typical medium- or high-speed marine engine and 40 - 60% lower than a typical slow-speed marine engine.

NO_x emissions in this range will be possible to achieve with engine optimisation and will not require after treatment of exhaust gasses.

11.6.1 Feasibility

Access to operating ferry services in Denmark is free, in the sense that the right to exercise the ferry operation is not regulated by the Ministry of Transport or other agency-specific permission.

The administration of ferry routes is taken care of by local authorities and the Ministry of Transport[100]. There is no reason why local authorities or the Ministry of Transport should not set up specific environmental requirements for the local ferry routes, especially if such environmental requirements are based on a set of new national requirements.

The potential for applying the emission limits for vessels on inland waterways to national ferry routes is shown in Table 11-12 where the emissions from the Danish national ferry transport have been split up according to destination.

[100] The Transport Minister can direct the A/S Storebæltsforbindelsen (Great Belt A/S) to maintain, to an extent specified, a car ferry route between Zealand and Jutland across the Kattegat and a car ferry route between Spodsbjerg and Tårs. In addition, the Transport Minister must secure the society-motivated ferry service for passengers, mail and goods to and from Bornholm. Source: Act on ferry service, LBK No. 915 of 27 August 2008.

Table 11-12 NO_X emission from ferry transport and cruise in Danish waters

	NO_X tonnes/year	Share
Foreign (innocent)	26,812	60%
Cruise	557	1%
Domestic	4,946	11%
Denmark - Foreign	12,685	28%
Total	45,000	100%

As can be seen, the amount of NO_x emitted from national ferry transport amounts to 4,946 tons of NO_x annually. Table 11-13 breaks down NO_x emissions by technology.

Table 11-13 National ferries broken down by engine technology

	Share of NO_X	Average NO_X/kWh
Gas turbine	15%	4.0
Slow speed (2-stroke)	33%	17.6
High speed (4-stroke)	2%	10.8
Medium speed (4-stroke)	50%	11.8

Source: NERI background data. Average emissions factors 2011.

50% of the NO_x emissions are emitted by medium-speed engines where the Directive would require a reduction of 20-40 % relative to the current emission level. 33% of the NO_x emissions are emitted by slow-speed 2-stroke engines. These are not covered by the Directive because the volume of these engines is above 30 litres per cylinder. 15% of the emissions are emitted by gas turbine engines that have lower emissions than required in the Directive limits.

In sum, implementing emission limits from the EU directive would result in an estimated NO_x reduction of approximately 15% or 740 tons of NO_x annually. The benefit to society of this reduction in NO_x emissions would be EUR 5,262,206 annually.

The average cost for these technologies amount to EUR 0.51 per kg of NO_x, summing up to EUR 377,400.

The cost of this measure would include the cost of monitoring and inspecting a limited number of ferries. In Sweden, the administrative costs of approximately 400 entities add up to EUR 2,000,000 annually[101]. The number of Danish ferries is much lower, even if small ferries are included. Furthermore, ferries in Denmark are inspected once a year, meaning that the additional cost of a NO_x inspection is limited. It is estimated that the cost of inspection and administration will be EUR 500,000 annually. Total costs amount to EUR 1.19 per kg of NO_x.

[101] Source: AP EnvEcon (2009): NOX Taxation, A sample review of examples of NOX taxation systems.

Table 11-14 Cost benefit from reducing NO_X emissions by limits from EU Directive

	EUR / year
a) Benefit	5,262,206
b) Cost	377,400
c) administration	500,000
Cost per kg NO_X (b + c)/kg NO_X	1.19
Cost benefit, a - b - c (EUR/Year)	4,384,806

Thus, the total net benefit to society of setting emission limits according to the EU Directive for inland waterways would be approximately EUR 4,362,606 annually or EUR 5.13 per kg of NO_x.

The total effect of enforcing the limits stipulated in the EU Directive is limited. Table 11-15 shows the maximum effect of regulating emissions from national sea transport by ferry.

Applying NO_x reducing equipment to all engine technologies would result in an average NO_x reduction of 78%, corresponding to 3.834 tons of NO_x or 3% of total NO_x emissions. The benefit from this saving is EUR 27,266,666 annually.

The average cost for this option is EUR 0.51[102] per kg of NO_x, summing up to EUR 1,955,537 plus administration. Administration of a more comprehensive regulation system would be more expensive compared with the limits stipulated in the EU Directive.

Table 11-15 Cost benefit from reducing NO_X emissions by emission limits

	EUR / year
a) Benefit	27,266,666
b) Cost	1,955,537
c) administration	750,000
Cost per kg NO_X (b + c)/kg NO_X	0.71
Cost benefit, a - b - c (EUR/Year)	24,561,129

Thus, the overall net benefit to society of this more comprehensive regulation would amount to 24,561,129 EUR annually or 6.4 EUR per kg of NO_x.

Regarding the particulate emissions, the limit set in the Directive requires the emissions of particulate matter to be below 0.5 g/kWh. However, with sulphur content of 0.1% or less the particulate emissions are estimated to be well below 0.5 g/kWh[103] Thus, the Directive would not cause a further reduction of the particulate emissions.

It should be noted that the EU Directive gives no incentive to further reduce the emissions beyond the limits. Thus, it is expected that the reduction potential of the installed cleaning technology will not be utilised to a maximum. For instance, a SCR can reduce NO_x emissions by 80%, but in

[102] Cost per kg is based on values in Table 8-22. The weighed average reflects the share of NO_x emissions that is relevant for each technology.
[103] Emission factors from NERI emission inventory.

this case some ship owners would act economically rational and only reduce their emissions to the required limit to save urea consumption.

To the extent that environmental requirements increase the cost for the passengers, a modal shift to road transport could occur, especially in cases where there is a close alternative, for instance between Zeeland and Jutland, Denmark and Sweden, and Denmark and Germany.

11.7 Voluntary agreements, consortium benchmarking

In consortium benchmarking, vessels join a "consortium" that would voluntarily commit to achieving an average emission rate, known as the benchmark. The programme could be 100% voluntary, i.e. ships could form consortia and trade among themselves to achieve the average rate. Participation in a consortium would be entirely voluntary—the alternative would be for a vessel to comply directly with whatever existing regulation applied.

In contrast to a credit-based approach, there is no need to establish and certify a baseline emission rate in the case of benchmarking, because the benchmark rate effectively serves as the baseline. The programme would, however, require a definition of the benchmark. This may be difficult to set. Part of the administration of participating and reporting could be handled by the consortium itself.

If appropriate penalties (to the consortium) are in place, all consortium members have an interest in ensuring that consortium members comply with the requirements.

Setting the benchmark emission rate is a key element of the consortium benchmark programme design, corresponding to the baseline in a credit-based programme. Benchmark rates based on inputs (e.g. emissions per unit fuel) are the easiest to define, while benchmarks based on outputs (e.g. emissions per kWh, transport service rendered, etc.) would offer stronger incentives to reduce emissions.

11.7.1 Feasibility

The consortium benchmarking requires some mandatory regulation to offer incentives for trading consortia to form. This means that the relevant regulator needs to have jurisdiction over consortium members, including the legal right to fine non-compliant vessels and non-compliant consortia. In addition, consortium members would need to sign up to a binding agreement both with each other and with government authorities that would commit them to achieve a collective emission rate and individually to discharge their responsibilities to pay into the consortium if their emission levels exceed this level.

The reporting and verification of emissions would lie with the consortium as a whole to make sure that emissions from the consortium do not exceed those permissible. A special problem in the consortium benchmarking is that individual members are allowed to exceed what would otherwise be allowable emissions limits—provided that these emissions are offset by lower emissions from other members in the consortium. Thus, random inspections will not be able to identify violations without additional cross-checking of consortium and vessel records, which would probably take a lot of effort.

One example where consortium benchmarking could be relevant is the small national ferry routes in Denmark, e.g. the small ferry routes within a limited geographic area.

It is estimated that setting the emission benchmark for the consortium would be very difficult. Not least in the light of ever changing technologies which would require a regular update of the benchmark to keep incentives from lower emissions alive.

11.8 Other voluntary agreements

Large companies who market themselves as environmentally friendly may also require their suppliers to act environmentally friendly. Therefore there is a trend that some environmental improvements may be implemented because the customers require it.

According to Maersk, there is a increasing focus on the environmental impact of transportation. Many companies require the transporters to be ISO certified and to contribute to environmental networks like Green shipping. However, it is still the pure economic cost of transportation which is the main decision parameter for companies when they choose transporters[104].

Two examples are taken from IKEA and Posten Norden.

"At IKEA we recognise that our business has an impact on social and environmental issues, in particular people's working conditions, as well as the environment, both locally and globally. The IKEA supplier shall always comply with the most demanding requirements whether they are relevant applicable laws or IKEA IWAY specific requirements[105]".

"Posten Norden has as a major purchaser an opportunity, but also an obligation to provide requirements to suppliers when talking about sustainability. Therefore, we require in all vendor contracts that our suppliers and their subcontractors fulfil certain criteria on the environment, quality and safety[106]".

[104] Personal communication with Mearsk Line.
[105] IKEA web site.
[106] PostDanmark 2010.

12 Modal shift

A modal shift may be relevant when sea transport becomes more expensive compared to the alternatives. To what extent we will see a modal shift will depend on the availability of the alternative modes and will further depend on how large price increases the additional costs will cause.

For many local ferry routes alternative routes are not available. In this case we would not see a modal shift. However, for ferry routes between e.g. Zeeland and Jutland a modal shift may happen because it is possible to shift the route to the bridge instead of the ferry.

NO_x differentiated port dues are the only measure that is able to target international transport. Since for some of these transports there will be quite close alternatives, these may constitute a basis for modal shifts in connection with this measure. In some cases ship owners (the shipping industry) may decide to call at Rotterdam and send the goods by road to Denmark instead of sailing all the way to Copenhagen or Århus if new NO_x based port dues make it very expensive to call at Copenhagen or Århus.

The subsections below give an estimate of the environmental impact and the costs and benefits from shifting from sea transport to road transport in such situations.

The calculations below include

- Passenger transport across the Kattegat
- Freight transport across the Kattegat
- Freight transport from Rotterdam to Copenhagen.

12.1 Passenger transport across the Kattegat

This calculation estimates the impact of a modal shift due to a cost increase of the ferry transport crossing the Kattegat.

The Kattegat passenger transport is in close competition with the fixed link via Funen. The example shows the environmental impact and socioeconomic cost of shifting passenger car transport from the ferry Odden - Århus to the fixed link crossing the Kattegat.

We have chosen to look at a trip from Copenhagen to Ålborg since this type of trip is the most common travel pattern for travellers using the ferry from Odden to Århus.

The trip with the ferry includes a trip by car from Copenhagen to Odden, the ferry trip and a trip from the ferry to the final destination.

Table 12-1 shows the cost of these two trips.

Table 12-1 Cost of travelling from Copenhagen to Ålborg by car or by ferry

	Car all way	Car - ferry - car
Km cost (EUR)	135	76
Fixed link and ferry (EUR)	27	73
Total cost (EUR)	162	149

Note: Market prices including tax. Time cost not included. The price of crossing both by the fixed link and by ferry is based on estimated prices including a rebate. For both alternatives the traveller can obtain a rebate at specific times and week days. Km cost at 0.32 EUR/km based on standard prices from the Ministry of Transport.

As can be seen from the table, the travel costs are quite close, although it is somewhat more expensive to go all the way by car.

From a society point of view, the analysis looks somewhat different. First of all, the prices faced by the consumers include taxes which are just a transfer from private consumers to the state budget. Secondly, travelling by car or by ferry will result in external costs, which are not taken into account by the private consumers. Table 12-2 shows the cost-benefit analysis of travelling between Copenhagen and Aalborg taking into account external effects and taxes.

Table 12-2 Cost of travelling from Copenhagen to Ålborg by ferry or by the fixed link seen from a society point of view

	Car all way	Car - ferry - car
Vehicle, ferry and fixed link cost (EUR)	162	149
Time cost (EUR)	54	65
Air pollution and GHG (EUR)	3	23
External cost, noise, congestion, accident (EUR)	34	19
Total cost (EUR)	256	256
Taxes and VAT (EUR)	82	60
Total cost of trip from Copenhagen to Ålborg (EUR)	171	195

Including the time cost and an external cost turns the conclusion around and makes it more beneficial for society to let people travel by car instead of by ferry part of the way. There are several reasons for this. First of all, the time cost is higher for the ferry alternative; secondly, the ferry alternative gives rise to a substantially higher air pollution compared to the car all the way alternative[107]. And, finally, the car all the way contains higher tax payments compared to the ferry alternative. These additional tax revenues should be seen as a gain and deducted from the total cost of the alternatives.

Thus the conclusion for passenger transport in the above cost-benefit analysis shows that from a society point of view, it would be beneficial if some of the passenger traffic crossing the Kattegat is shifted from the ferry alternative to the car alternative. Furthermore, since the NO_x emissions are lower in the car

[107] Emissions calculated by the Ministry of Transport emission calculation model, TEMA2010, using a EURO V diesel car and the ferry Mette Mols.

all the way alternative, we would also see an additional NO_x reduction due to the modal shift.

The negative impact of the modal shift will be increases in other external costs from road traffic like noise, congestion and accidents. But the above results show that these negative effects are more than outweighed by the positive effects.

It should be noted that there may be trips where the start point is closer to the ferry at Odden than Copenhagen. In this case the extra kilometres of travelling all the way by car makes it less favourable compared to the ferry alternative. It is therefore expected that these trips will stay on the ferry and not be part of the modal shift issue.

12.2 Freight transport across the Kattegat (trailers)

The calculation estimates the impact of a modal shift in freight transport due to a cost increase in the sea transport crossing the Kattegat.

As is the case for passenger transport, also freight transport by ship across the Kattegat is in close competition with the fixed link via Funen. The calculation shows the environmental impact and the socioeconomic cost of shifting freight transport from the ferry Kalundborg - Århus to the fixed link crossing the Great Belt.

The trip crossing the Great Belt goes by truck all the way. The trip by ferry includes a trip by truck from Copenhagen to Kalundborg, the ferry trip brings the trailer to Århus and another truck brings the trailer from the ferry at Århus to the final destination at Ålborg.

Table 12-3 shows the cost of these two types of trips.

Table 12-3 Cost of travelling from Copenhagen to Ålborg by car or by ship

	Truck all way	Truck - ferry - truck
Truck km cost (EUR)	207	116
Truck time cost (EUR)	287	160
Fixed link and ferry (EUR)	126	224
Total vehicle cost (EUR)	620	500

Note: Market prices including tax. Km cost at 0.50 EUR/km and hourly cost at 55 EUR/hour based on standard prices from the Ministry of Transport

The above table shows that the cost of the ferry alternative is 120 EUR[108] lower per trailer seen from the transporter's point of view.

Seen from the point of view of society, the analysis looks somewhat different. First of all, the prices faced by the travellers include taxes which are just a transfer from private agents to the state budget. Secondly, travelling by truck or by ferry will result in external costs, which are not taken into account by the private agents. Table 12-4 shows the cost-benefit analysis of transporting one trailer between Copenhagen and Ålborg taking into account external effects and taxes.

[108] VAT and taxes included.

Table 12-4 Cost of travelling from Copenhagen to Ålborg by ferry or by the fixed link seen from a society point of view

	Truck all way	Truck - ferry - truck
Vehicle, ferry and fixed link cost (EUR)	620	500
Air pollution and GHG (EUR)	18	248
External cost, noise, congestion, accident (EUR)	164	92
Total cost (EUR)	801	839
Taxes and VAT (EUR)	152	116
Total cost of trip from Copenhagen to Ålborg (EUR)	650	723

Including the time cost and an external cost turns the conclusion around and makes it more beneficial for society to travel by truck instead of by ferry part of the way. There are several reasons for this. First of all the ferry alternative gives rise to substantially higher air pollution compared to the truck all the way alternative. And, secondly, the truck all the way contains higher tax payments compared to the ferry alternative. These additional tax revenues should be seen as a gain to society and deducted from the total cost of the alternatives.

Thus, the conclusion for freight transport in the above cost-benefit analysis shows that from a society point of view, it would be beneficial if some of the freight transport crossing the Kattegat is shifted from the ferry alternative to the truck alternative. Furthermore, since the NO_x emissions are lower in the truck all the way alternative, we would also see an additional NO_x reduction due to a modal shift from sea to road transport.

As is the case for passenger transport, a modal shift to road transport will also here show negative effects, for instance increases in noise, congestion and accidents. The above results show, however, that these negative effects are more than outweighed by the positive effects.

12.3 Container transport from Rotterdam to Copenhagen

The impact of a modal shift in long distance container transport has been illustrated by an example transporting one container from Rotterdam to Copenhagen by container ship and by truck.

The trip by truck would be approximately 963 km via the fixed link crossing the Great Belt. The cost per km for the truck amounts to 0.50 EUR per km including VAT plus 55 EUR including VAT per hour. These figures include the total cost of fuel, maintenance depreciation etc.

The cost for the trip by container ship is calculated based on information on the time charter cost for a 700 TEU container ship. The time charter for this ship is estimated to be 120 EUR/hour plus 25 EUR per km for fuel.

The road trip crossing the Great Belt goes by truck all the way. This trip will be approximately 963 km. The trip with the container ship goes north of Skagen and is estimated to be 1162 km.

Table 12-5 shows the cost of these two types of trips.

Table 12-5 Cost of transporting one container from Rotterdam to Copenhagen by truck or container ship

	Truck all way	Container ship
Truck km cost (EUR)	481	66
Truck time cost (EUR)	665	14
Fixed link and ferry (EUR)	140	0
Total vehicle cost (EUR)	1,286	79

Note: Market prices including tax.

The table shows that the cost of the road alternative is much higher than the alternative by container ship. Thus, it is rather unlikely that a transporter would choose to ship the container by truck.

Table 12-6 Cost of transporting one container from Rotterdam to Copenhagen by truck or container ship seen from a society point of view

	Truck all way	Truck - ferry - truck
Vehicle, ferry and fixed link cost (EUR)	1,286	79
Air pollution and GHG (EUR)	41	233
External cost, noise, congestion, accident (EUR)	380	0
Total cost (EUR)	1,704	313
Taxes and VAT (EUR)	330	12
Total cost of trip from Copenhagen to Ålborg (EUR)	1,377	301

Seen from the point of view of society, the analysis looks somewhat different, although the conclusion is very much the same. The container ship has higher air pollution costs compared to the truck, while the transport by truck results in relatively high external costs of noise, congestion and accidents.

Thus, also seen from a society point of view, it would be unwise to send a container from Rotterdam to Copenhagen by truck.

Regarding the air pollution, the road alternative has lower emissions compared to the container ship measured per container. So in case an eventual NO_x or particulate matter measure would shift a share of containers from ship to truck, this would further reduce the NO_x and particulate matter emission impact of the measure.

The conclusions above are not sensitive to the calculation method of the damage cost. A sensitivity analysis applying values from NERI and CEEH shows almost identical results to the results shown above.

13 Sensitivity analysis

Making a cost-benefit analysis for reduction technologies that are still under development and covering many years in the future implies that there is a large degree of uncertainty regarding the data input and therefore also the results from the study. Therefore this section includes a sensitivity analysis in order to estimate the robustness of the conclusions from the study.

Some of the major components of the analysis and some of those with considerable uncertainty is the valuation of damage cost from air pollution, but also investment costs and future fuel prices are elements with a certain level of uncertainty.

The subsections below make a sensitivity analysis on the following elements:

- Valuation of damage from air pollution
- Investment costs
- Fuel prices.

13.1 Benefit valuation

The damage costs from air pollution are available from three different sources.

- The Ministry of transport (MoT)
- The National Environmental Research Institute (NERI)
- The Centre for Energy, Environment and Health (CEEH)

The costs of air pollution available from the Centre for Energy, Environment and Health cover emissions from ship transport. The other two sources cover damage cost from land-based transport in rural areas.

Table 13-1 shows the estimated cost per kilogram emission based on different sources.

Table 13-1Cost per kg emissions based on different sources (EUR/kg) , 2011 price level

	TRM	DMU	CEEH
CO_2	0,02		
$PM_{2,5}$	32,57	28,80	39,17
NO_X	7,11	10,00	12,23
SO_2	27,86	34,47	19,25
HC	0,33		

The source of value used in the main results is the values from the Ministry of Transport in the first column. As can be seen, the values from the two alternative sources are higher for NO_X. For particulate matter and SO_2, the damage costs from the Ministry of Transport lie between the costs from the NERI and the CEEH.

Table 13-2 shows key figures from the sensitivity analysis with alternative use of damage valuation.

Table 13-2 Net present value of benefits from investment in emission-reducing technologies (EUR/year)

	MoT	NERI	CEEH
NO_x reductions			
SCR - Selective catalytic reduction	1,979,784	2,869,230	3,556,499
EGR - Water injection in turbo-charge-air	3,221,165	4,596,412	5,657,065
HAM - Exhaust gas recirculation	2,580,520	3,697,381	4,560,372
WIF - Water in fuel	1,121,785	1,676,391	2,108,913
LNG - Natural gas (lng and lpg)	2,545,181	3,558,748	4,235,514
Particulate reductions			
DPF - Particulate filters	3,125	-40,068	19,434
Scrubber	1,651,920	1,576,987	1,560,906

Note: Values for medium-size engine, 11 MW engine. Size like Mette Mols from Molslinien.

For almost all technologies the gain increases when we use an alternative measurement of the value of the damage caused by the emissions. Thus, it will be fair to say that a conclusion saying that almost all technologies imply a gain to society is very robust.

Table 13-3 shows cost per kg emission from the sensitivity analysis with alternative use of damage valuation.

Table 13-3 Cost per kg emission from investment in emission-reducing technologies (EUR/year)

	MoT	NERI	CEEH
NO_x reductions			
SCR - Selective catalytic reduction	0.69	0.69	0.69
EGR - Water injection in turbo-charge-air	0.35	0.35	0.35
HAM - Exhaust gas recirculation	0.44	0.44	0.44
WIF - Water in fuel	1.29	1.29	1.28
LNG - Natural gas (lng)	0.29	0.13	0.56
Particulate reductions			
DPF - Particulate filters	32.10	34.83	36.24
Scrubber	-489.39	-469.49	-454.03

Note: Values for medium-size engine, 11 MW engine. Size like Mette Mols from Molslinien.

13.2 Fuel price

Another source of uncertainty is the fuel price. The fuel price is fluctuating heavily and it is uncertain whether it will keep on increasing in the future or whether it will fall back to the level from past years[109].

[109] Fuel prices in the study is based on a forecast from EPA (2011).

To illustrate the impact of changes in the fuel price we have decided to analyse the results with a fuel price 25% lower than the EPA forecast and another example with a fuel price 50% higher than the EPA forecast.

Table 13-4 Net present value from investment in emission-reducing technologies (EUR/Year) with alternative fuel prices

	- 25%	Today's price	+ 50%
NO_X reductions			
SCR - Selective catalytic reduction	1,979,784	1,979,784	1,979,784
EGR - Exhaust gas recirculation	3,223,807	3,221,165	3,215,879
HAM - Water injection	2,580,520	2,580,520	2,580,520
WIF - Water in fuel	1,153,239	1,121,785	1,058,877
LNG - Natural gas (lng and lpg)	2,439,484	2,545,181	2,756,576
Particulate reductions			
DPF - Particulate filters	34,579	3,125	-59,783
Scrubber	1,139,961	1,651,920	2,675,840

Note: Values for medium-size engine, 11 MW engine. Size like Mette Mols from Molslinien.

Looking at the total there are only small changes and no change in the conclusions. This is because the fuel cost constitutes a very small part compared to the benefits. SCR and HAM are identical in all 3 scenarios because the fuel cost are not affected by these technologies.

However, as can be seen below when looking at the cost of the investments in technologies where the additional fuel consumption plays a role, the cost per kg emission increases considerably. This means that the ship owner's costs may change considerably depending on the future fuel prices.

Table 13-5 Cost per kg emission from investment in emission-reducing technologies (EUR/Year) with alternative fuel prices

	-25%	Today's price	+50%
NO_X reductions			
SCR - Selective catalytic reduction (EUR/kg NO_X)	0.69	0.69	0.69
EGR - Exhaust gas recirculation (EUR/kg NO_X)	0.34	0.35	0.36
HAM - Water injection (EUR/kg NO_X)	0.44	0.44	0.44
WIF - Water in fuel (EUR/kg NO_X)	1.12	1.29	1.61
LNG - Natural gas (lng and lpg)(EUR/kg NO_X)	0.57	0.29	-0.28
Particulate reductions			
DPF - Particulate filters (EUR/kg PM)	27.37	32.10	41.58
Scrubber (EUR/kg PM)	-327.62	-489.39	-812.92

Note: Values for medium-size engine, 11 MW engine. Size like Mette Mols from Molslinien.

13.3 Investment price

The final source of uncertainty is the investment cost. Table 13-6 shows a sensitivity analysis varying the investment cost by ±25%.

Table 13-6 Net present value from investment in emission-reducing technologies (EUR/Year) with alternative investment cost

	- 25%	Today's price	+ 25%
NO_X reductions			
SCR - Selective catalytic reduction	1,988,039	1,979,784	1,971,529
EGR - Exhaust gas recirculation	3,231,945	3,221,165	3,210,385
HAM - Water injection	2,621,792	2,580,520	2,539,247
WIF - Water in fuel	1,125,609	1,121,785	1,117,961
LNG - Natural gas (lng and lpg)	2,750,939	2,545,181	2,339,423
Particulate reductions			
DPF - Particulate filters	11,379	3,125	-5,130
Scrubber	1,751,231	1,651,920	1,552,610

Note: Values for medium-size engine, 11 MW engine. Size like Mette Mols from Molslinien.

Looking at the total net present values from the sensitivity analysis, there are only small changes and no change in the conclusions. This is because the investment cost like the fuel cost above constitutes a very small part compared to the benefits.

However, as can be seen below when looking at the cost of the investments in technologies where the additional investment plays a role, the cost per kg emission increases considerably. This means that the ship owner's costs may change considerably depending on the investment costs.

Table 13-7 Investment operation and management cost per kg emission from investment in emission-reducing technologies (EUR/year) with alternative fuel prices

	75%	Today's price	150%
NO_X reductions			
SCR - Selective catalytic reduction (EUR/kg NO_X)	0.66	0.69	0.71
EGR - Exhaust gas recirculation (EUR/kg NO_X)	0.33	0.35	0.37
HAM - Water injection (EUR/kg NO_X)	0.34	0.44	0.55
WIF - Water in fuel (EUR/kg NO_X)	1.27	1.29	1.31
LNG - Natural gas (lng and lpg)(EUR/kg NO_X)	-0.26	0.29	0.84
Particulate reductions			
DPF - Particulate filters (EUR/kg PM)	30.86	32.10	33.35
Scrubber (EUR/kg PM)	-520.77	-489.39	-458.01

Note: Values for medium-size engine, 11 MW engine. Size like Mette Mols from Molslinien.

The sensitivity analysis above clearly shows that the conclusions in this report are not sensitive to changes in the central input to the analysis. This conclusion is valid for the valuation method, fuel prices and investment costs.

14 Conclusions

NO_x emissions from ships in Danish waters account for 60% of the total NO_x emissions in and around Denmark. However, due to international legislation governing sea transport, Danish authorities can only regulate national emissions, which correspond to 6% of NO_x emissions from sea transport around Denmark. Table 14-1 shows the reduction potential from implementing the measures analysed in this report.

Table 14-1 Reduction potential from measures

Measure	Reduction (tons annually)	Share of emissions in Danish Waters
Tradable emission credits	5718	3.3%
NO_x tax	3682	2.1%
NO_x tax plus subsidy	6628	3.8%
Norms for national ferries	3834	2.2%

NO_x emissions from newly built ships will be reduced considerably with the expected designation of the Baltic Sea and North Sea as NO_x ECAs. Therefore, the NO_x-reducing technologies should be targeted towards existing ships.

The value of NO_x reductions from existing ships is EUR 7 to EUR 12 per kg of NO_x. A comparison of the emission reduction benefits at a cost ranging from EUR 0.36 to EUR 1.3 per kg of NO_x shows a net gain of EUR 5 to EUR 10 if NO_x emissions are reduced.

From the ship-owner's point of view, the costs of investing, operating and managing NO_x -reducing equipment typically amount to approximately 1-3% of the fuel consumption cost. However, since there is no incentive for ship-owners to invest in NO_x-reducing equipment, even limited costs will constitute a barrier to such an investment.

The lack of incentives to invest in NO_x reducing equipment calls for other measures that may promote such investments. There are two feasible options. One option is to let the existing NO_x tax for land-based sources of approximately 0.68 EUR per kg of NO_x apply also to ships used for national transport in Danish waters. It is, however, questionable whether a tax in the order 0.68 EUR is sufficient to overcome the cost barrier. To strengthen the incentive to invest in NO_x- reducing equipment, a system for refunding costs of NO_x-reducing equipment could be established along the lines of the Norwegian NO_x Fund. Another option could be to set specific emission norms for national ferry transport in Danish waters. A starting point could be the emission limits specified by the EU Directive for internal waterways.

Emissions of particulate matter from sea transport in Danish waters are 4,000 tons annually. This figure is relatively small compared with the annual NO_x emissions of 173,000 tons. Although particulate matter is three to five times more damaging than NO_x emissions at sea, the damage caused by NO_x

emissions is still approximately 10 times higher than the damage caused by emissions of particulate matter in Danish waters.

Furthermore, the designation of the Baltic Sea and the North Sea as SECAs and the related SO_2 reduction will also reduce emissions of particulate matter considerably, probably by approximately 50%[110]. Thus, it will be relatively costly to reduce particulate emissions even further.

Since the benefits of reducing particulate emissions further are relatively limited, and as there is only a limited number of technologies available, market-based instruments may not be an efficient measure to reduce particulate matter emissions in general. Furthermore, particulate matter is more damaging when emitted in densely populated areas. This means that, in principle, a market-based instrument should consider this circumstance by levying a higher charge in densely populated areas.

Such a situation calls for precisely targeted measures, such as

- requirement to use LNG on specific routes
- mandatory use of particle filters
- requirement to use land-based power supply.

These measures can be tailored to target the majority of emissions, for instance heavily-trafficked ferry routes, or special areas where emissions are more damaging than the average.

Natural gas appears to be one of the most favourable technologies due to the fuel cost savings that can be achieved. However, this option will require the establishment of new costly infrastructure for natural gas bunkering. A recent study from the Danish EPA found that LNG would be advantageous if the most important Danish ports are included. This scenario could cover 80% of the fuel required for short sea transport and national ferry transport[111].

One of the arguments voiced against regulating sea transport is that it makes sea transport more expensive and results in a modal shift from sea to road transport. The present study investigated the impact of a modal shift to see how it would influence the outcome of the measures. The conclusion is that a modal shift from short distance ferry transport to road would most likely imply an extra gain to society and would further reduce NO_x emissions. This is not the case for long distance freight transport where a shift from sea to road transport would most probably lead to a loss to society. However, since long distance transport by sea only costs 5%-10% of that of road transport initially, the modal shift would probably be very modest. This conclusion is not sensitive to the different damage values used for the calculations.

Finally, it should be mentioned that the sensitivity analysis shows that the cost benefit analysis of the technical measures from the survey is not sensitive to reasonable changes in investment costs, fuel costs or alternative valuation of damage effects.

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[110] Emission factors from Emissions Inventory by NERI 2009.

[111] EPA 2010: Natural gas for ship propulsion in Denmark

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Annex A: The Norwegian NO_X fund

All the enterprises that are obligated to pay NO_x tax may join the Environmental Agreement, regardless of whether they are Norwegian or foreign owned or operated.

Enterprises which have joined the Environmental Agreement and enterprises with process emissions may apply for support from the NO_x Fund to investments and operating costs in accordance with the rules stipulated by the Board.

From 1.1.2011 the NO_x Fund may grant according to the following support rates:

Table 0-1 Subsidy levels in the Norwegian NO_X fund

New buildings and retrofitting gas propulsion	Subsidy up to 80% of total investment cost, Maximum NOK 350 per kg NO_X reduced
Filling stations for gas	Individual handling of applications
New and promising NO_X reducing measures	Subsidy up to 80%, Maximum NOK 225 per kg NO_X reduced
Catalytic reduction with the use of urea	Subsidy up to 60%, Maximum NOK 100 per kg NO_X reduced
SCR reinvestment	Subsidy up to 80%,
Urea consumption	Up to 90 % of the urea costs Max. NOK 2.50 per kg consumed
Battery-powered propulsion of car and passenger ferries	Subsidy up to 80%, Maximum NOK 350 per kg NO_X reduced
Gas in land based industry	Subsidy up to 80%, Maximum NOK 225 per kg NO_X reduced
Engine modifications and retrofitting	Subsidy up to 80%, Maximum NOK 225 per kg NO_X reduced
Other NO_X reducing measures	Subsidy up to 80%, Maximum NOK 225 per kg NO_X reduced
Measures with NO_X reduction as a positive side effect	Maximum NOK 50 per kg NO_X reduced

Only consumption of urea in waters subject to the NO_x tax is eligible for support.

Summary
The report identifies a number of possible means for further reduction of air pollution from shipping in Danish waters. The main conclusions are:

- Danish authorities can regulate less than 10% of the air pollution emitted in Danish waters.
- The cost of reducing air pollution from ships is small compared to the benefit to the society, especially for NOx.
- Reduction of air pollution from ships through national regulation will lead to costs related to installation, operation and administration. This can create uneven competition between Danish and foreign ship owners.

The report is prepared for Partnership for Cleaner Shipping, which consists of the Danish Environmental Protection Agency and the Danish Ship Owners Organisation.

Dansk opsummering
Rapporten peger på en række virkemidler til at nedbringe luftforureningen fra skibsfarten i danske farvande yderligere. De væsentligste konklusioner er:

- Danmark kan i praksis regulere under 10 % af luftforureningen fra skibe i danske farvande.
- Omkostningerne til reduktion af luftforurening fra skibe er små set i forhold til den samfundsøkonomiske gevinst, særligt for NOx.
- Reduktion af luftforurening fra skibsfart gennem national regulering vil medføre en række omkostninger til installation, drift og administration. Det skaber risiko for konkurrenceforvridning

Rapporten er udarbejdet for Partnerskab for Renere Skibsfart, der er et samarbejde mellem Miljøstyrelsen og Danmarks Rederiforening.

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