EMISSIONS FROM SHIPPING IN THE ARCTIC FROM 2012-2016 AND EMISSION PROJECTIONS FOR 2020, 2030 AND 2050

Scientific Report from DCE – Danish Centre for Environment and Energy No. 252 2017

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DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Data sheet

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Abstract: This report presents results for spatial distributed emission inventories for the Arctic area above 58.95N from 2012-2016 based on satellite AIS data, ship engine power functions and technology stratified emission factors. Emission projection results for 2020, 2030 and 2050 are also presented for a Baseline scenario and for a SECA and a HFO ban scenario. The full list of emission components estimated in the project are the short lived climate forcers SO_2, NO_x, CO, NMVOC, PM, BC and OC and the greenhouse gases CO_2, CH_4 and N_2O. For 2012 *[2013, 2014, 2015, 2016]* the following total results are calculated for fuel consumption: 4.8 *[5.1, 6.3, 6.6, 5.4]* MTonnes; SO_2: 82 *[84, 108, 60, 53]* kTonnes; NO_x: 320 *[339, 429, 432, 361]* kTonnes and BC: 0.71 *[0.73, 0.86, 0.65, 0.56]* kTonnes. In the Baseline scenario for the forecast years 2020 *[2030, 2050]* the following total results are calculated for fuel consumption: 5.7 *[5.8, 6.3]* MTonnes; SO_2: 17 *[17, 18]* kTonnes; NO_x: 371 *[318, 247]* kTonnes and BC: 0.43 *[0.44, 0.47]* kTonnes. In all scenario years the calculated SO_2 emissions for the SECA and HFO ban scenarios are almost half of the emissions calculated for the Baseline scenario. For BC in 2020 *[2030, 2050]* the HFO ban and SECA emissions are 8 % *[9 %, 12 %]* and 3 % *[3%, 3 %]* smaller, respectively, than the Baseline results

Keywords: Ships, scenarios, EGCS, HFO, MDO/MGO, fuel consumption, SO_2, NO_x, BC

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Contents

List of abbreviations

AIS	Automatic Information System
AMAP	Arctic Monitoring and Assessment Program
BAU	Business As Usual
BC	Black Carbon
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
DANCEA	Danish Cooperation for Environment in the Arctic
DCE	Danish Centre for Environment and energy
DMA	Danish Maritime Authority
EEDI	Energy Efficiency Design Index
EGCS	Exhaust Gas Cleaning System
EMEP	European Monitoring and Evaluation Program
ENVS	Department of ENVironmental Science, Aarhus University
GHG	Greenhouse gas
HELCOM	Baltic Marine Environment Protection Commission
HFO	Heavy Fuel Oil
IFO	Intermediate Fuel Oil
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
MARPOL	International Convention for the Prevention of Pollution from Ships
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
N_2O	Nitrous oxide
NECA	NO_x Emission Control Area
NH_3	Ammonia
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
OC	Organic Carbon
O_3	Ozone
PM	Particulate Matter
SCR	Selective Catalytic Reduction
SECA	SO_x Emission Control Area
Sfc	Specific fuel consumption
SO_2	Sulphur dioxide

Summary

Navigation is one of the most important local sources of emissions in the Arctic area. Navigation emissions are characterized by the fact that the air pollutants formed during ship engine combustion are being injected directly into the Arctic environment along the vessels route at low vessel chimney heights. Hence, the emission deposition from vessels sailing in the arctic area becomes relatively large compared to the total emissions emitted by these vessels (e.g. Corbett et al., 2010; Winther et al., 2014). In this respect the emissions of black carbon (BC) are of particular interest. It is well known that BC has global warming properties due to its ability to absorb light over reflective surfaces e.g. snow covered surfaces and due to its darkening effect when deposited to snow and ice surfaces (e.g. Quinn et al., 2008; Flanner, 2007, 2009).

In a previous ship emission project, carried out by DCE – Danish Centre for Environment and Energy at the Institute for Science and Technology at Aarhus University, a spatial distributed emission inventory for the Arctic area above 58.95N was made for the year 2012 based on satellite AIS data, ship engine power functions and technology stratified emission factors (Winther et al., 2014). Emission projections, emission concentration and deposition calculations were also made for the years 2020, 2030 and 2050, and further calculations were also made by combining the baseline projected emissions with additional ship emissions estimated for polar diversion routes due to the possible extent of polar sea ice in the future.

This report presents the results from the DANCEA project “Emissions from shipping in the Arctic from 2012-2016 and updated emission projections until 2050” carried out by DCE – Danish Centre for Environment and Energy at Department of Environmental Science at Aarhus University with financial support from the Danish Cooperation for Environment in the Arctic (DANCEA). The historical emission estimates now cover the historical years 2012-2016 for the Arctic area above 58.95N, and the emission projections for the years 2020, 2030 and 2050 are improved by using the more robust five year weighted historical data for ship traffic, updated business as usual (BAU) and high traffic growth (HiG) rates and emission factors. Emission factor adjustments for ship engine load are introduced in the calculations as well as updated assumptions for fuel type usage and the deployment of EGCS (Exhaust Gas Cleaning System) for SO_x scrubbing in the projection years. For historical and projected emissions, the report also presents results for the concentration and the deposition of the emissions. Updated ship emission estimations along polar diversion routes are also presented in this report.

In addition to the Baseline emission projections, this report also presents emission results for a SO_x Emission Control Area (SECA) scenario and a heavy fuel oil (HFO) ban scenario. In the SECA scenario the existing SECA zones (i.e. America and North Sea/Baltic Sea SECA’s) are expanded to cover the entire inventory area. In the HFO ban scenario, no use of HFO by ships is allowed in the inventory area at all.

The full list of emission components estimated in the project are the short lived climate pollutants and their precursors SO_2, NO_x, CO, NMVOC, PM, BC and OC and the greenhouse gases CO_2, CH_4 and N_2O. The main report focuses

on the inventory results for fuel consumption, SO_2, NO_x and BC for BAU traffic growth. Results for the remaining emission components and high growth results are shown in the report annex.

For 2012*[2013, 2014, 2015, 2016]*, the following total results are calculated for fuel consumption: 4.8*[5.1, 6.3, 6.6, 5.4]* MTonnes; SO_2: 82*[84, 108, 60, 53]* kTonnes; NO_x: 320*[339, 429, 432, 361]* kTonnes and BC: 0.71*[0.73, 0.86, 0.65, 0.56]* kTonnes.

Per ship type in the latest historical year 2016, the largest shares (percentage values in brackets) of fuel consumption (by mass), BC, NO_x and SO_2 are calculated for fishing ships (45 %, 33 %, 39 %, 7 %) followed by passenger ships (21 %, 22 %, 18 %, 25 %), general cargo (10 %, 16 %, 13 %, 22 %), tankers (10 %, 12 %, 14 %, 21 %), bulk carriers (4 %, 6 %, 5 %, 12 %) and container ships (3 %, 4 %, 5 %, 7 %).

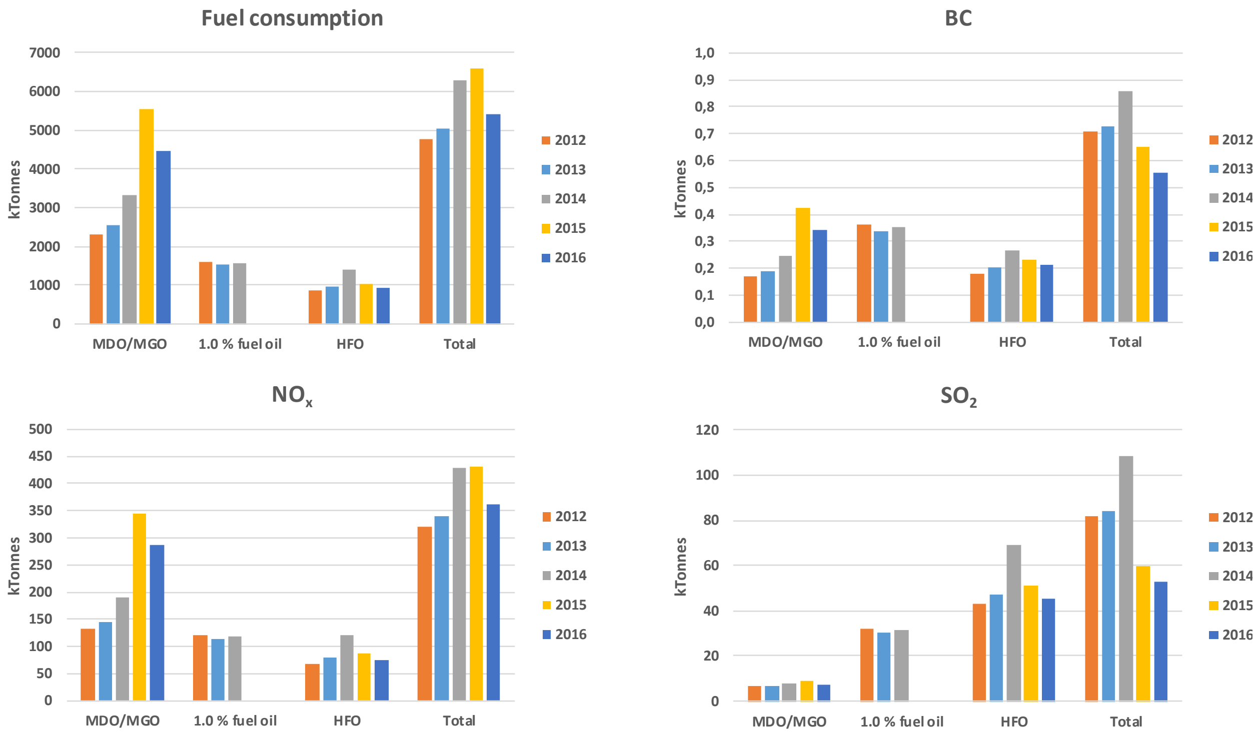


Figure ES 1 Total fuel consumption (by mass), NO_x, SO_2 and BC emissions in 2012-2016.

For the years 2012-2016, the total NO_x emissions levels are quite similar to the fuel consumption levels (Figure ES 1). In 2015 and 2016, the calculated SO_2 emissions drop significantly due to the stricter fuel sulphur regulations in SECA's from 1.1.2015 causing a fuel switch from 1.0 % fuel oil to marine diesel oil (MDO) / marine gas oil (MGO) in SECA's by ships using HFO by origin. The latter fuel switch also brings significant BC emission reductions due to the lower BC emission factors for MDO / MGO compared to 1.0 % fuel oil.

The SO_2 emission reductions in the SECAs from 2012 to 2016 are clearly visible from Figure ES 2. Although less visible, BC emission reductions in the SECAs also appear from Figure ES 2 whereas for NO_x there are no clear visual differences in the overall emissions distributions shown for 2012 and 2016.

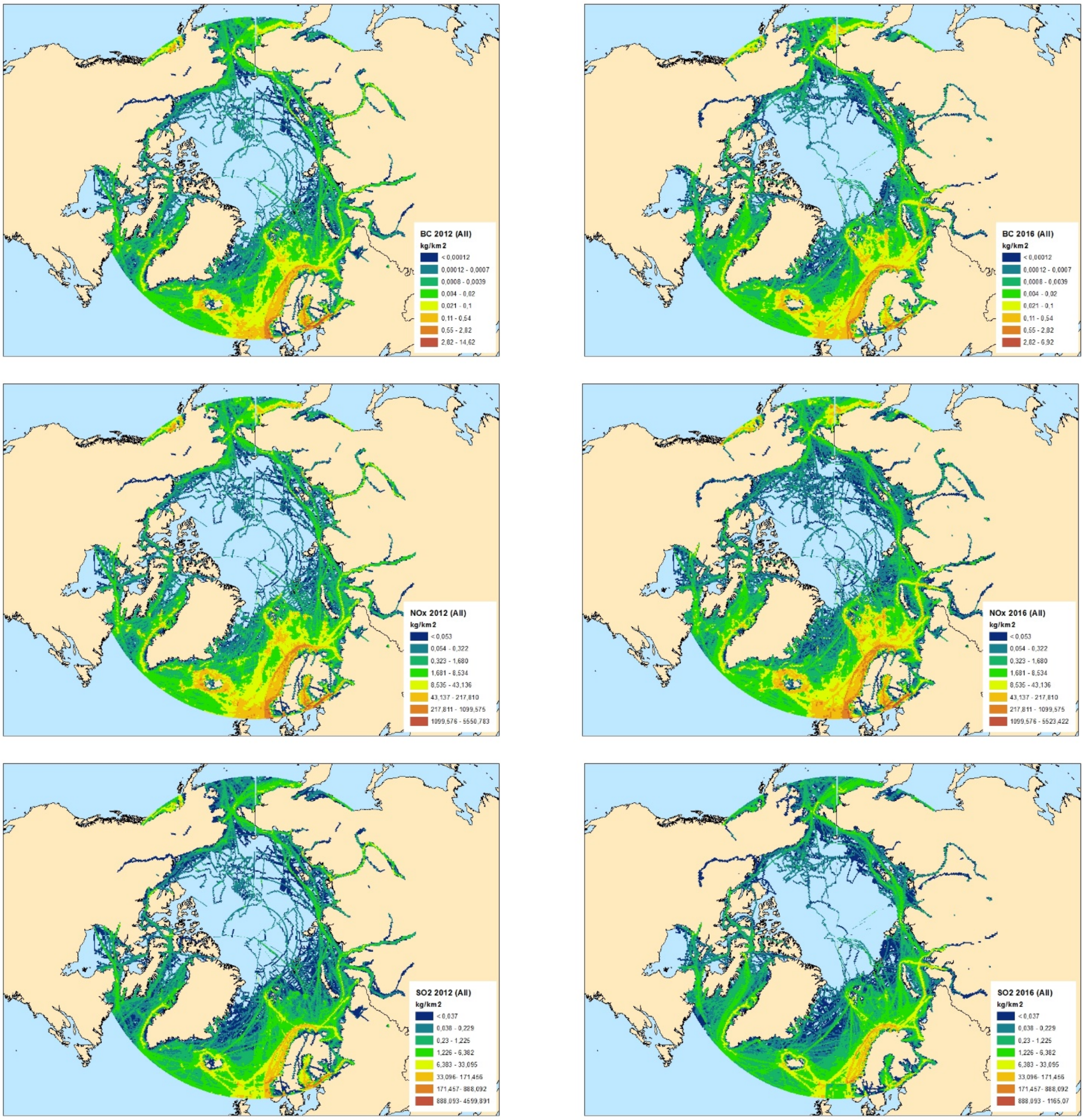


Figure ES 2 Spatial distribution of BC, NO_x and SO_2 emissions for all ships in 2012 and 2016.

In the Baseline scenario for the forecast years 2020*[2030, 2050]*, the following total results are calculated for fuel consumption: 5.7*[5.8, 6.3]* MTonnes; SO_2: 17*[17, 18]* kTonnes; NO_x: 371*[318, 247]* kTonnes and BC: 0.43*[0.44, 0.47]* kTonnes.

The most convenient way to assess the emission results for the Baseline BAU scenario is to explain the emission development from today's emissions calculated by using the consolidated (five-year weighted average) ship activity data and the uniform grid system used to project the ship activity data and emission factors for 2016 (the so-called uniform gridded 2016 inventory).

The following percentage changes between the uniform gridded 2016 results and the Baseline BAU results for the forecast years 2020, 2030, 2050, respectively (results in brackets) are calculated for fuel consumption (+3 %, +5 %, +14 %), BC (-19 %, -18 %, -12 %), SO_2 (-70 %, -70 %, -69 %) and NO_x (+1 %, -14 %, -33 %).

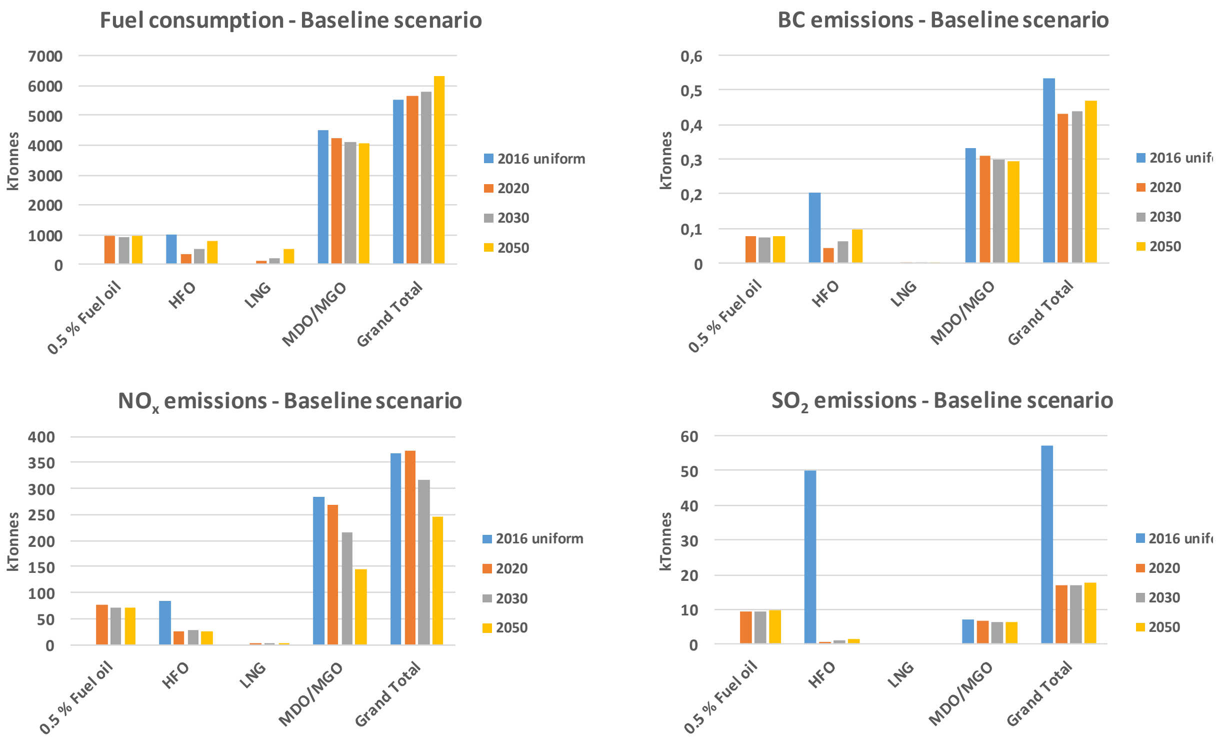


Figure ES 3 Total fuel consumption (by mass), NO_x, SO_2 and BC emissions calculated for 2016 (uniform gridded) and 2020, 2030 and 2050 in the Baseline BAU scenario.

The NO_x emission reductions during the forecast period (Figures ES 3 and ES 4) is due to the decrease in NO_x emission factors. The spatial NO_x emission reductions are most significant for the North SEA / Baltic Sea emission control area (Figure ES 4) where new engines installed on board ships from 1 January 2021 must comply with the most stringent IMO (International Maritime Organization) Tier III NO_x emission standards.

For SO_2 and BC, the major reason for the emission reductions from 2016 (uniform gridded) to 2020 shown on Figure ES 3 is the shift from HFO fuel with a sulphur content of 2.45 % in 2016 to 0.5 % fuel oil in 2020 and the consequently reduced emission factors.

Despite the increase in total fuel consumption from 2020 onwards, the total emissions of SO_2 are almost stable during the forecast period due to the increasing amount of HFO being used in combination with EGCS (Figures ES 3 and ES 4). Also the gradually increased liquefied natural gas (LNG) fuel consumption assumed in the Baseline scenario plays an important role in the emission explanation for SO_2. The emissions of BC increase somewhat due to higher BC emission factors for HFO in combination with EGCS compared with the emission factors for the fuel being replaced (MDO / MGO inside SECA's, 0.5 % fuel oil outside SECA's).

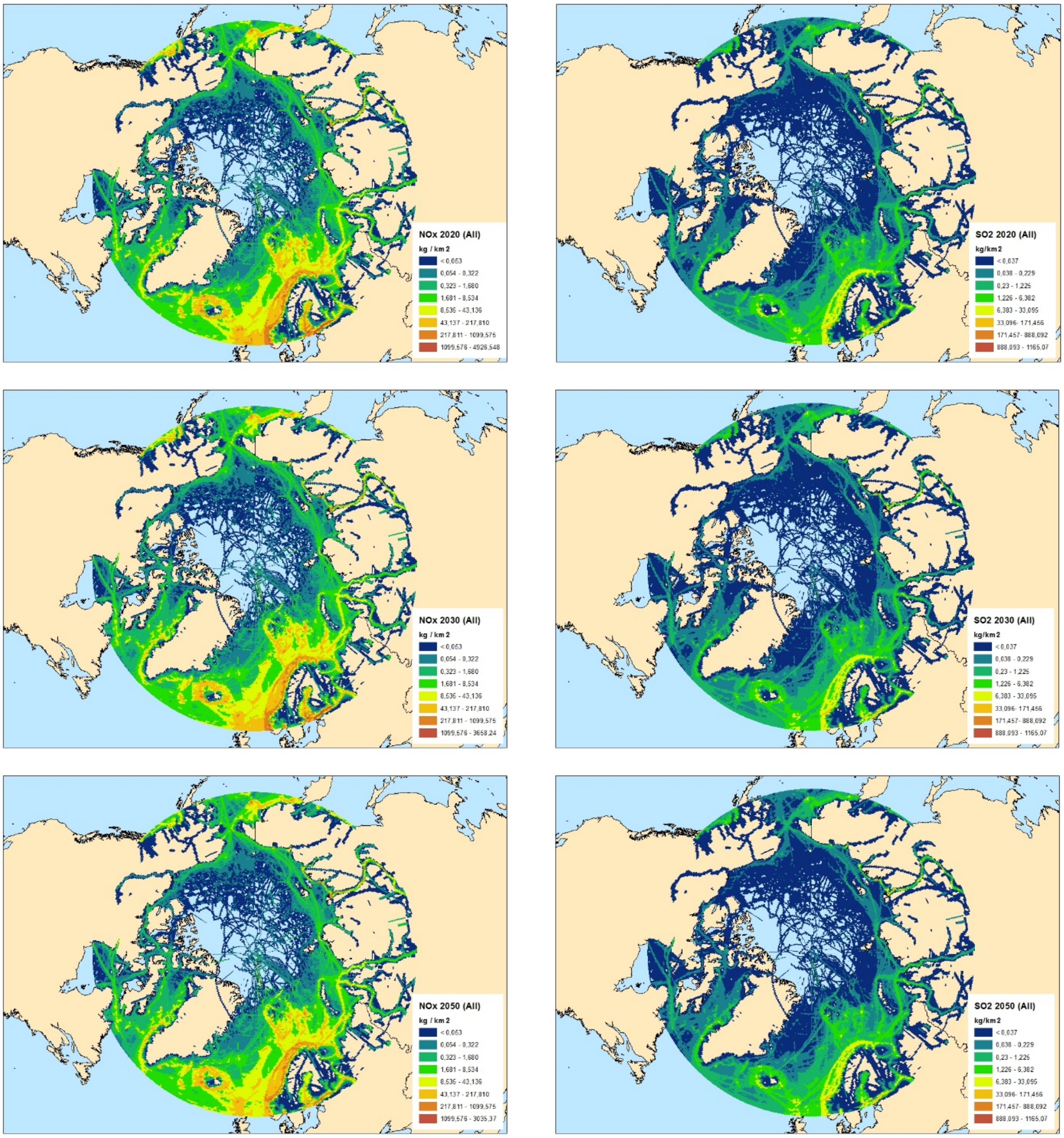


Figure ES 4 Spatial distribution of NO_x and SO_2 emissions for all ships in 2020, 2030 and 2050 calculated in the Baseline BAU scenario.

In the SECA scenario for the forecast years 2020*[2030, 2050]*, the following total results are calculated for fuel consumption: 5.7*[5.8, 6.3]* MTonnes; SO_2: 9.0*[9.1, 9.6]* kTonnes; NO_x: 371*[318, 247]* kTonnes and BC: 0.42*[0.42, 0.46]* kTonnes. For the HFO ban scenario the 2020*[2030, 2050]*, results for fuel consumption become: 5.7*[5.8, 6.3]* MTonnes; SO_2: 8.9*[8.9, 9.3]* kTonnes; NO_x: 371*[318, 247]* kTonnes and BC: 0.40*[0.40, 0.41]* kTonnes.

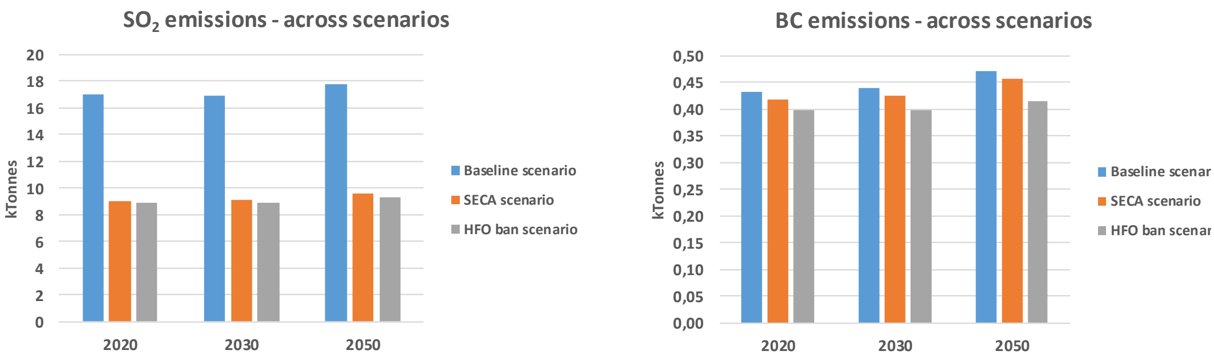


Figure ES 5 Total fuel consumption (by mass), NO_x, SO_2 and BC emissions calculated in the Baseline, SECA and HFO ban BAU scenarios.

The fuel consumption and NO_x emission totals are the same for the Baseline, SECA and HFO ban scenarios due to equal specific fuel consumption and NO_x emission factors for HFO and MDO / MGO and similar LNG shares of total fuel consumption per forecast year assumed in all three cases.

In all scenario years, the calculated SO_2 emissions for the SECA and HFO ban scenarios are almost half of the emissions calculated for the Baseline scenario (Figures ES 5 and ES 6) for the following reasons: in the SECA scenario HFO is only used by ships in combination with EGCS and the 0.5 % fuel oil used outside the original SECA area, and not being replaced by LNG, is being replaced by MDO / MGO. In the HFO ban scenario all HFO consumption by ships not being replaced by LNG is replaced by MGO / MDO.

For BC in 2020*[2030, 2050]* the HFO ban and SECA emissions are 8 %*[9 %, 12 %]* and 3 %*[3 %, 3 %]* smaller, respectively, than the Baseline results. Apart from LNG with similar fuel consumption shares assumed in all scenarios, in the HFO ban scenario only MDO / MGO fuel is used with a correspondingly low BC emission factor. In the SECA scenario, HFO fuel in combination with EGCS is used with a relatively higher BC emission factor. However, in the SECA scenario, the BC emissions from MDO / MGO replacing 0.5 % fuel oil are smaller than the emissions from 0.5 % fuel oil used in the Baseline scenario due to the level of the BC emission factors.

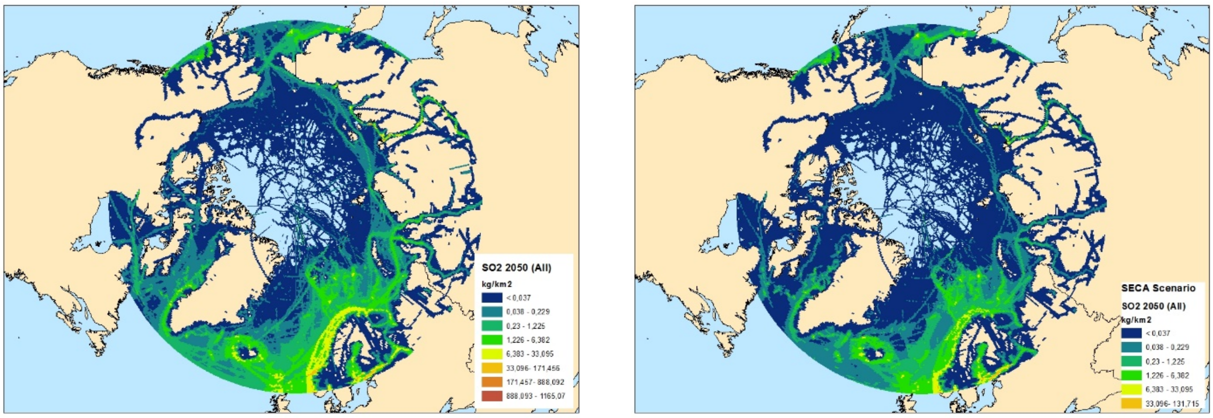


Figure ES 5 Spatial distribution of SO_2 emissions for all ships in 2050 calculated in the Baseline and SECA scenarios.

In the previous ship emission inventory for the Arctic area made by Winther et al. (2014), results were calculated for the historical year 2012 and for the projection years 2020, 2030 and 2050.

The inventory changes for 2012*[2020, 2030, 2050]* becomes -3 %*[8 %, 7 %, 5 %]* for sailed distance, -5 %*[23 %, 22 %, 20 %]* for total fuel consumption, -7 %*[-44 %, -44 %, -46 %]* for SO_2, 4 %*[23 %, 24 %, 18 %]* for NO_x and -55 %*[-73 %, -74 %, -75 %]* for BC.

There are multiple reasons for the above listed changes in the results. The most important qualitative explanations are given in the following.

In the previous inventory, the traffic growth rates were based on 2012 ship activity data. In the present inventory, the traffic growth rates are based on consolidated five-year weighted traffic data. This consequently changes the ship activity distribution by ship type and ship size and impacts the total fuel consumption and NO_x emissions to the most extent.

For SO_2, the emission changes between the previous and the current inventory are predominantly due to adjustments made in fuel sulphur content for MDO / MGO as input for the emission calculations in the present inventory. The introduction of LNG fuel consumption in the current inventory also induces differences in the inventory results and the increasing amount of LNG fuel used in the projection years implicitly brings down the total emission estimates of SO_2 and BC in the present inventory.

For BC, the most important emission changes originate from the changes in emission factors. In this way the previous BC emission factor of 0.35 g / kg fuel regardless of fuel type has been changed in the current inventory to a set of much lower emission factors for MDO / MGO, 2.5 % HFO and 0.5 % fuel oil. Despite being adjusted upwards due to relatively low ship engine loads, the aggregated BC emission factor in the present inventory becomes 0.15 g / kg fuel for the entire area in 2012.

The emission factors used in this work are in agreement with recent BC emission measurement conclusions from the international project on maritime BC emissions coordinated by the International Council of Clean Transport (ICCT, 2016), and important BC emissions review work made by Lack and Corbett (2012) and Lack (2016). However, due to the well-known scarcity of BC emission data for ship engines as input for emission inventories, the calculated results for BC emissions must be regarded with care. Any new data arriving on BC emission factors will be carefully assessed in future shipping emission inventory projects.

The average surface concentration and BC deposition increases from navigation (Figure ES 6) remain on low levels for the baseline scenarios without diversion traffic included. For the projection scenarios with additional diversion traffic, the forecasted increases in surface concentration and BC deposition become far more pronounced. In both cases, with or without diversion traffic, the surface concentration / deposition increases become significantly higher during summertime. Solely for diversion traffic, the summertime average surface concentration / deposition percentage increases for BCcon*[BCdep, SO_2, O_3]* become 0.8 % *[0.2 %, 1.1 %, 3.3 %]* and 3.9 % *[1.1 %, 8.3 %, 8.7 %]*, respectively, for BAU and HiG in 2050. And solely for diversion traffic, the yearly average surface concentration / deposition percentage increases for BCcon*[BCdep, SO_2, O_3]* become 0.2 % *[0.1 %, 0.1 %, 0.8 %]* and 1.0 % *[0.4 %, 1.0 %, 2.1 %]*, respectively, for BAU and HiG in 2050.

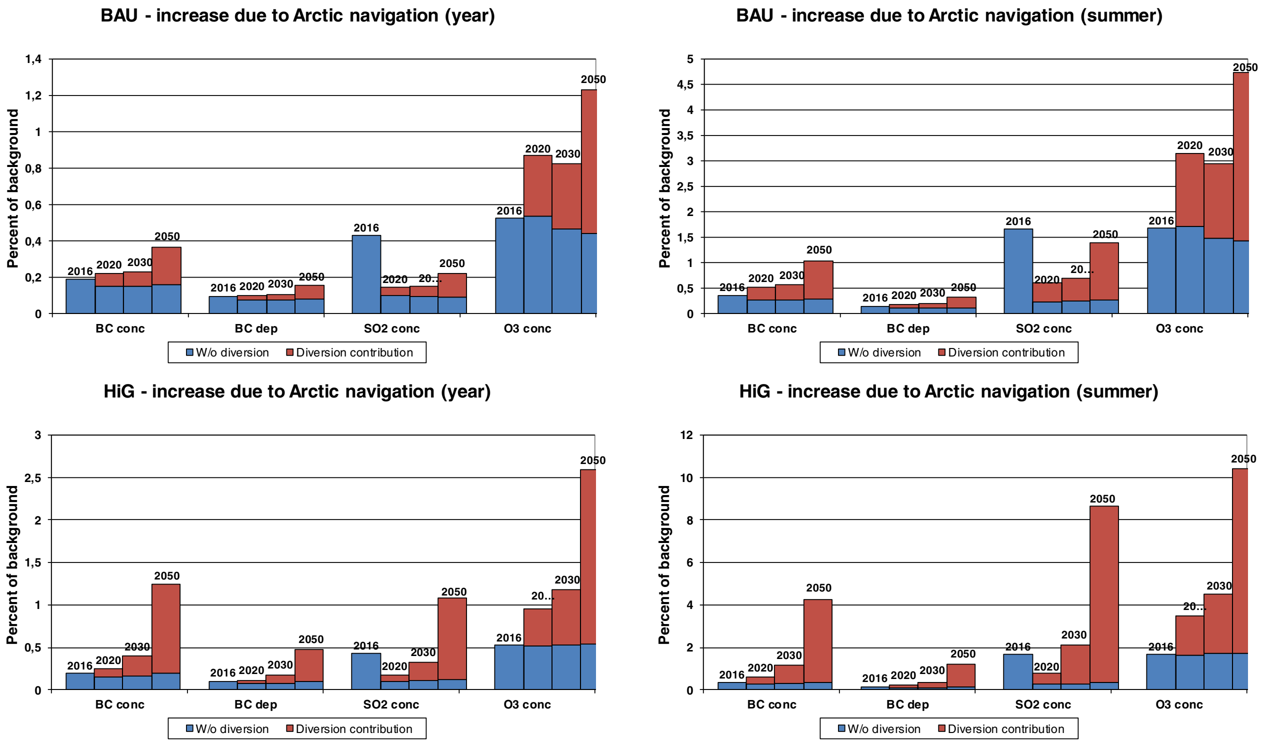


Figure ES 6 Increase of BC deposition and BC, SO_2 and O_3 surface concentrations in 2016 (uniform gridded), 2020, 2030 and 2050 (whole year and summertime average) due to Arctic navigation, as percentage of background.

Also the spatially distributed average navigation contributions are low in most of the inventory area in 2016 (Figure ES 7). The additional contribution to BC surface concentrations, however, reach up to 5 % mainly around Iceland, and high SO_2 additional contributions (20-100 %) are calculated in some sea areas due to reasons explained earlier. In 2050, during summertime, the additional contributions from navigation (mainly from diverted traffic) becomes very visible for BC (20-40 %) and SO_2 (300-1000 %) along the Arctic diversion routes, while the BC deposition (1-2 %) and the O_3 concentration (7-10 %) and become highest over the oceans east of Greenland and in High Arctic, respectively.

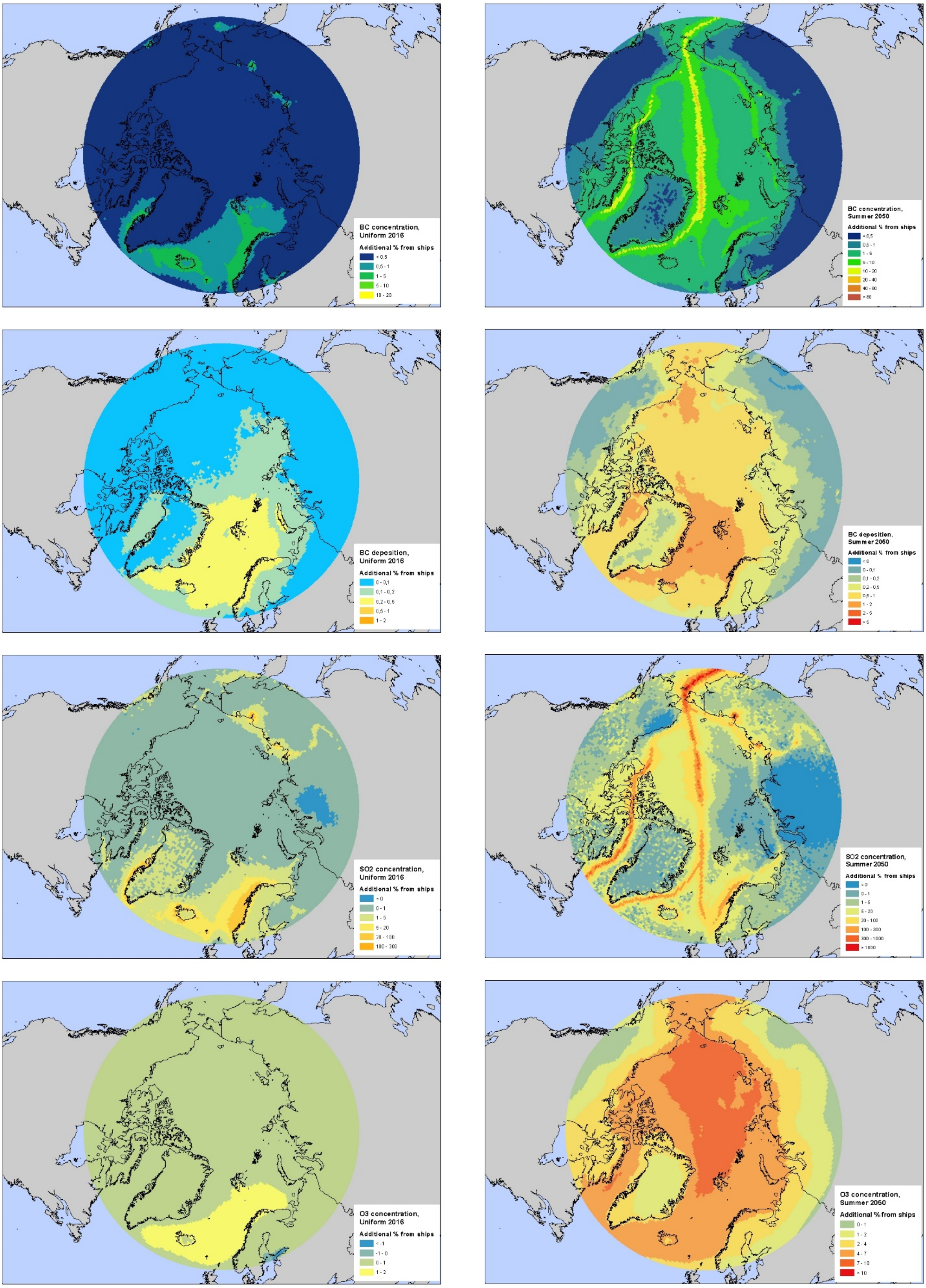


Figure ES 7 Spatial distribution of the increase of BC deposition and BC, SO_2 and O_3 surface concentrations in 2016 (uniform gridded, whole year) and 2050 (summertime) due to Arctic navigation, as percentage of background.

Sammenfatning

Skibe er en af de vigtigste kilder til emissioner i det arktiske område. Det karakteristiske for skibenes emissioner er, at de bliver emitteret i nærområdet og at udledningen sker i lav højde. Dermed bliver depositionen af emissioner relativ stor fra skibene der sejler i det arktiske område, set i forhold til skibenes begrænsede emissionstotal (se f.eks. Corbett et al., 2010; Winther et al., 2014). Emissionen af Black Carbon (BC) er i den forbindelse særligt interessant, idet BC bidrager til den globale opvarmning, især ved sværtning af overflader der hindrer refleksion af sollys i de arktiske egne (f.eks. Quinn et al., 2008; Flanner, 2007, 2009).

I et tidligere emissionsprojekt, har DCE – Nationalt Center for Miljø og Energi ved Institut for Miljøvidenskab på Aarhus Universitet beregnet en rumlig fordelt historisk opgørelse af emissionerne for skibe i det arktiske område nord for 58,95N for året 2012, ved brug af satellitbaserede AIS data, effektfunktioner for skibe og teknologifordelte emissionsfaktorer (Winther et al., 2014). Projektet beregnede også en fremskrivning af skibsemissionerne i det arktiske område for årene 2020, 2030 og 2050, samt en videre beregning af skibsemissionernes koncentrationer og deposition. Yderligere beregninger blev også lavet, ved at kombinere basisemissionsfremskrivningerne med et yderligere emissionsbidrag for trafik langs polarruter i fremtiden pga. formindsket udbredelse af havis.

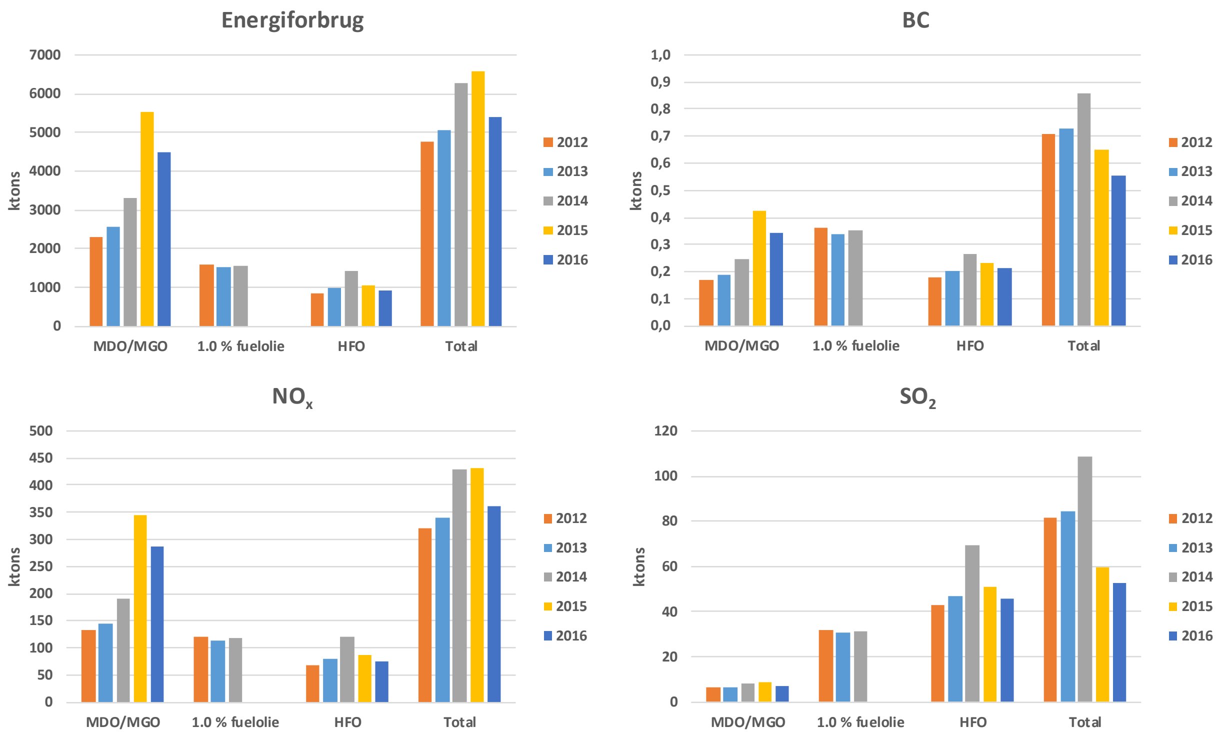
Denne rapport præsenterer resultater for DANCEA-projektet "Emissioner fra skibstrafik i det arktiske område i perioden 2012-2016 og en opdateret emissionsprognose frem til 2050" udført for Miljøstyrelsen af DCE ved Institut for Miljøvidenskab på Aarhus Universitet. De historiske emissionsresultater omfatter nu årene 2012-2016 for det arktiske område nord for 58,95N, og emissionsfremskrivningerne for 2020, 2030 og 2050 er forbedret ved at bruge det mere robuste femårige vægtede datagrundlag for skibstrafik, opdaterede vækstrater for 'business as usual' (BAU) og høj trafikvækst (HiG) samt opdaterede emissionsfaktorer. I de nye beregninger justeres emissionsfaktorerne for motorbelastning, og der gøres nye antagelser for valg af brændstoftyper og udbredelsen af EGCS (Exhaust Gas Cleaning System) til svovlrensning ombord på skibe i prognoseårene. For de historiske emissioner og emissionsprognosen, præsenterer rapporten også resultater for skibsemissionernes koncentration og deposition. Opdaterede emissionsberegninger for fremtidig skibstrafik langs polarruter præsenteres også i rapporten.

Ud over baseline emissionsfremskrivningerne, præsenterer denne rapport også emissionsresultater for et svovlemissionskontrolområde (SECA)-scenario og et tung fuelolie (HFO) forbud-scenario. I SECA-scenariet udvides de eksisterende SECA-zoner (dvs. det amerikanske SECA-område og Nordsøen / Østersøen) til at dække hele emissionsopgørelsens område. I HFO forbud-scenariet er det forbudt for skibe at bruge HFO som brændstof i området.

I projektet beregnes emissionsresultater for de kortlivede drivhusgasser SO_2, NO_x, CO, NMVOC, PM, BC og OC og drivhusgasserne CO_2, CH_4 og N_2O. Hovedrapporten fokuserer på resultaterne for energiforbrug, SO_2, NO_x og BC beregnet for BAU-trafikvækst. Resultaterne for de øvrige emissionskomponenter og resultater for høj trafikvækst er vist i rapportens bilag.

For årene 2012*[2013, 2014, 2015, 2016]* beregnes følgende totalresultater for energiforbrug: 4.8*[5.1, 6.3, 6.6, 5.4]* Mtons; SO_2: 82*[84, 108, 60, 53]* ktons; NO_x: 320*[339, 429, 432, 361]* ktons og BC: 0.71*[0.73, 0.86, 0.65, 0.56]* ktons.

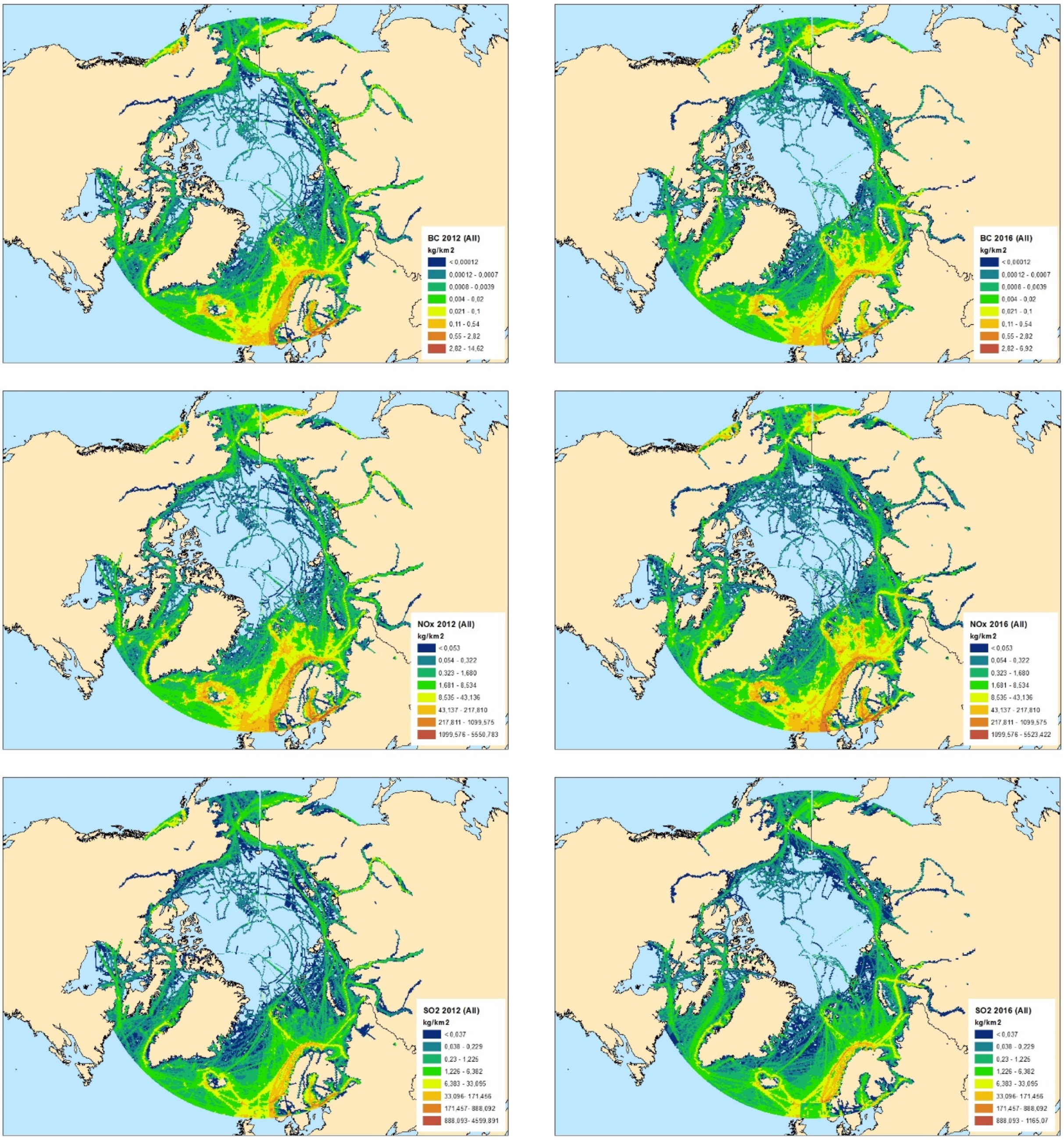
For det seneste historiske år 2016 beregnes de største andele af energiforbruget (massebasis), BC, NO_x og SO_2 (procentandele i parentes) for fiskeskibe (45 %, 33 %, 39 %, 7 %) efterfulgt af passagerskibe (21 %, 22 %, 18 %, 25 %), general cargo (10 %, 16 %, 13 %, 22 %), tankskibe (10 %, 12 %, 14 %, 21 %), bulkskibe (4 %, 6 %, 5 %, 12 %) og containerskibe (3 %, 4 %, 5 %, 7 %).



Figur DS 1   Totaler for energiforbrug (massebasis), NO_x, SO_2 og BC emissioner beregnet i 2012-2016.

For årene 2012-2016, følger NO_x-emissionsniveauerne udviklingen i det totale energiforbrug (Figur DS 1). I 2015 og 2016 falder den beregnede SO_2-emission markant pga. de skrappere lovgivningskrav til svovlindholdet i skibsbrændstoffer forbrugt indenfor SECA-områderne fra 1. januar 2015. De skrappere svovlkrav har generelt medført, at skibe, der før som udgangspunkt har brugt 1,0 % fuelolie, er begyndt at bruge marin dieselolie (MDO) / marin gasolie (MGO), når de sejler inden for SECA. Skiftet i brændstoftype har medført et fald i den beregnede BC-emission, idet BC -emissionsfaktorerne for MDO / MGO er mindre end BC-emissionsfaktorerne for 1,0 % fuelolie.

SO_2-emissionsreduktionerne fra 2012 til 2016 er tydeligt synlige for SECA-områderne vist på de rumlige emissionsfordelinger i figur DS 2. For BC er emissionsreduktionerne mindre tydelige, men de kan dog også ses på figuren. For NO_x derimod, er der ikke nogle tydelige forskelle på de rumlige emissionsfordelinger for 2012 og 2016.

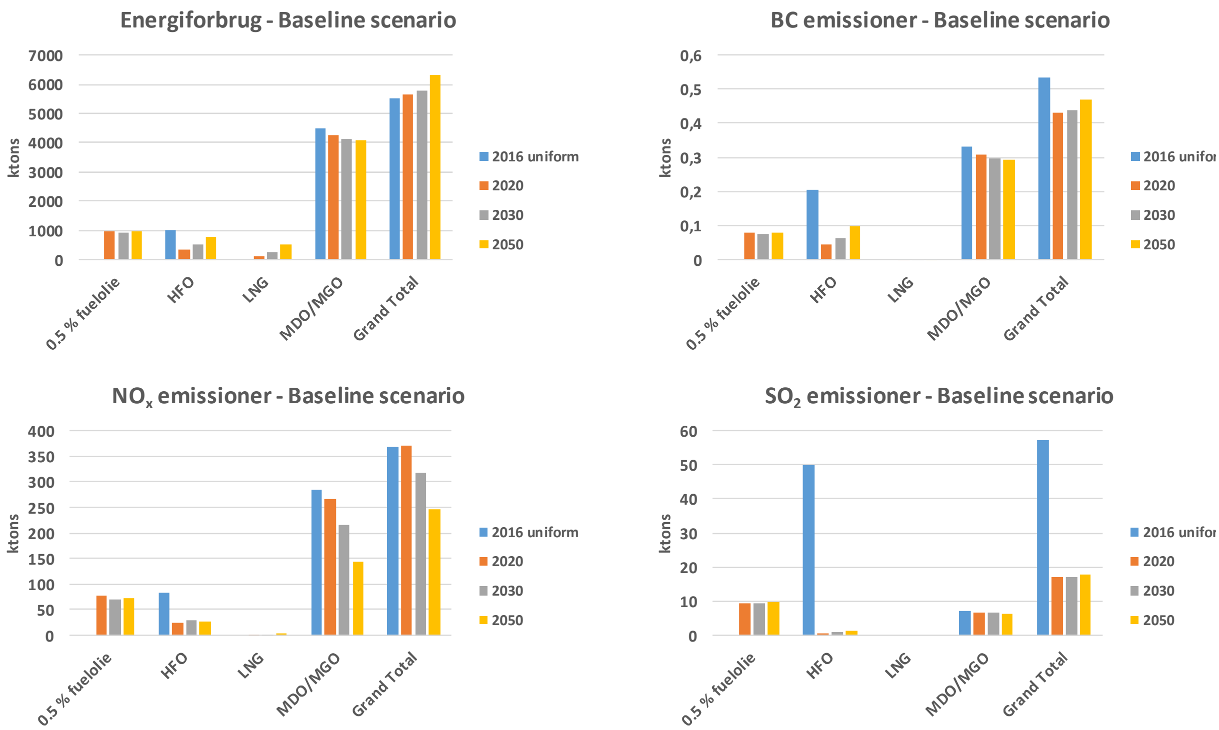


Figur DS 2 Rumligt fordelte BC, NO_x og SO_2 emissioner for alle skibe i 2012 og 2016.

I Baseline scenariet for prognoseårene 2020*[2030, 2050]* beregnes følgende totalresultater for energiforbrug: 5.7*[5.8, 6.3]* Mtons; SO_2: 17*[17, 18]* ktons; NO_x: 371*[318, 247]* ktons og BC: 0.43*[0.44, 0.47]* ktons.

De fremskrevne Baseline emissionsresultater vurderes bedst ved at forklare emissionsudviklingen fra de nutidige emissioner beregnet ud fra de konsoliderede (femårsvægtede) skibsaktivitetsdata og det ensartede gittersystem, der bruges til at fremskrive skibsaktiviteterne, samt emissionsfaktorer for 2016 (den såkaldte ensartet gitterfordelte 2016 opgørelse).

Følgende forskelle mellem de ensartet gitterfordelte 2016 resultater og Baseline BAU resultaterne i prognoseårene 2020, 2030 og 2050 (procentforskelle i parentes) er beregnet for energiforbrug (+3 %, +5 %, +14 %), BC (-19 %, -18 %, -12 %), SO_2 (-70 %, -70 %, -69 %) og NO_x (+1 %, -14 %, -33 %).

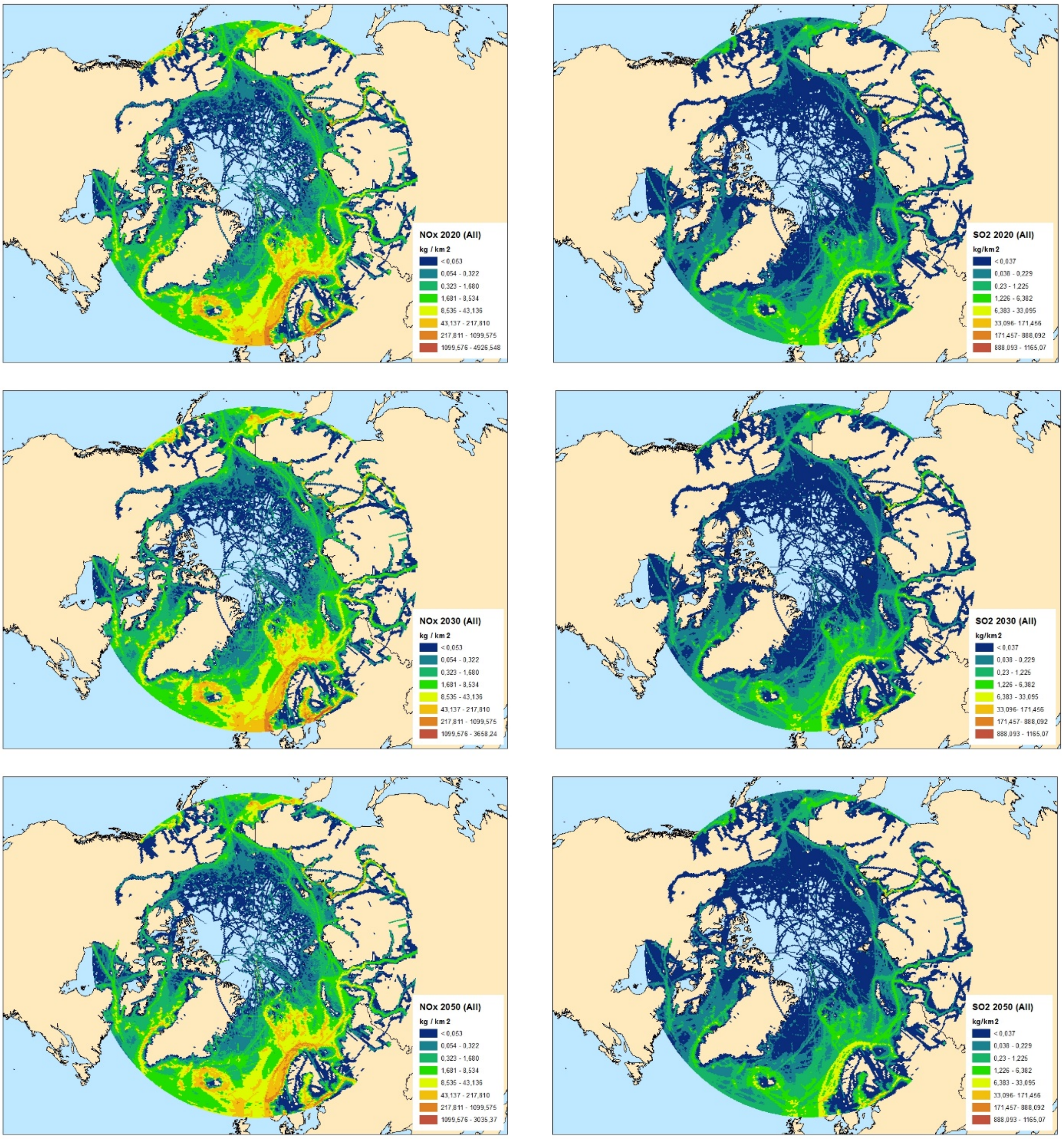


Figur DS 3 Totaler for energiforbrug (massebasis), NO_x, SO_2 og BC emissioner beregnet for 2016 (ensartet gitterfordelt) og for 2020, 2030 og 2050 i Baseline scenariet.

NO_x-emissionerne falder igennem prognoseperioden (Figur DS 3 og DS 4) pga. et fald i emissionsfaktorerne. Emissionsreduktionerne er mest markante indenfor SECA-området i Nordsøen / Østersøen (Figur DS 4), hvor nye motorer, installeret ombord i skibe fra 1.1.2021, skal overholde IMO's (International Maritime Organization) Tier III NO_x-emissionskrav.

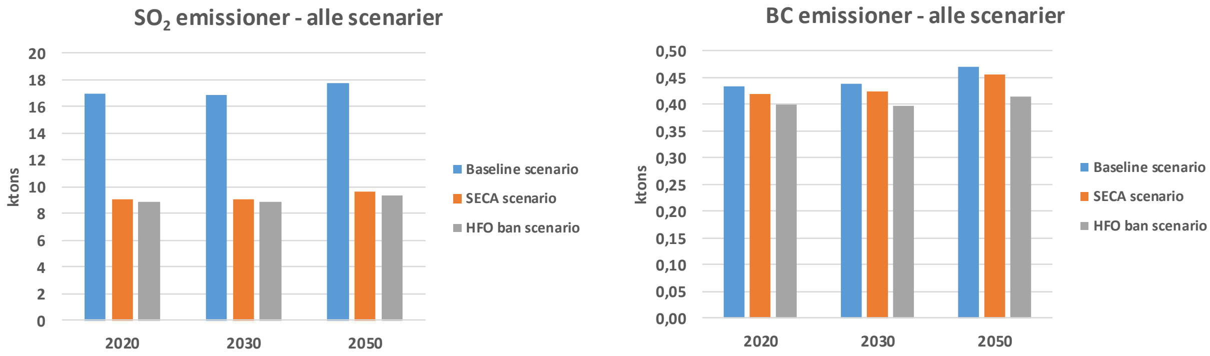
Hovedårsagen til SO_2- og BC-emissionsreduktionerne fra 2016 (ensartet gitterfordelt) til 2020 er skiftet i brændstoftype fra HFO med et svovlindhold på 2.45 % i 2016 til 0.5 % fuelolie i 2020 og de dermed faldende emissionsfaktorer.

På trods af stigningen i det samlede brændstofforbrug fra 2020 og fremefter, er de samlede emissioner af SO_2 næsten stabile i prognoseperioden på grund af den stigende mængde HFO, der anvendes i kombination med EGCS (figur ES 3 og ES 4). Også det gradvist øgede LNG-brændstofforbrug antaget i baseline scenariet spiller en vigtig rolle i emissionsforklaringen for SO_2. Udledningen af BC stiger noget på grund af de højere BC-emissionsfaktorer for HFO i kombination med EGCS sammenlignet med emissionsfaktorerne for det brændstof, der udskiftes (MDO / MGO inden for SECA, 0,5 % fuelolie uden for SECA).



Figur DS 4 Rumligt fordelte NO_x- og SO_2-emissioner for alle skibe i 2020, 2030 og 2050 beregnet i Baseline BAU scenariet.

I SECA-scenariet for prognoseårene 2020*[2030, 2050]*, beregnes følgende totalresultater for energiforbrug: 5.7*[5.8, 6.3]* Mtons; SO_2: 9.0*[9.1, 9.6]* ktons; NO_x: 371*[318, 247]* ktons og BC: 0.42*[0.42, 0.46]* ktons. I HFO forbud-scenariet for prognoseårene 2020*[2030, 2050]*, bliver totalresultaterne for energiforbrug: 5.7*[5.8, 6.3]* Mtons: SO_2: 8.9*[8.9, 9.3]* ktons; NO_x: 371*[318, 247]* ktons og BC: 0.40*[0.40, 0.41]* ktons.

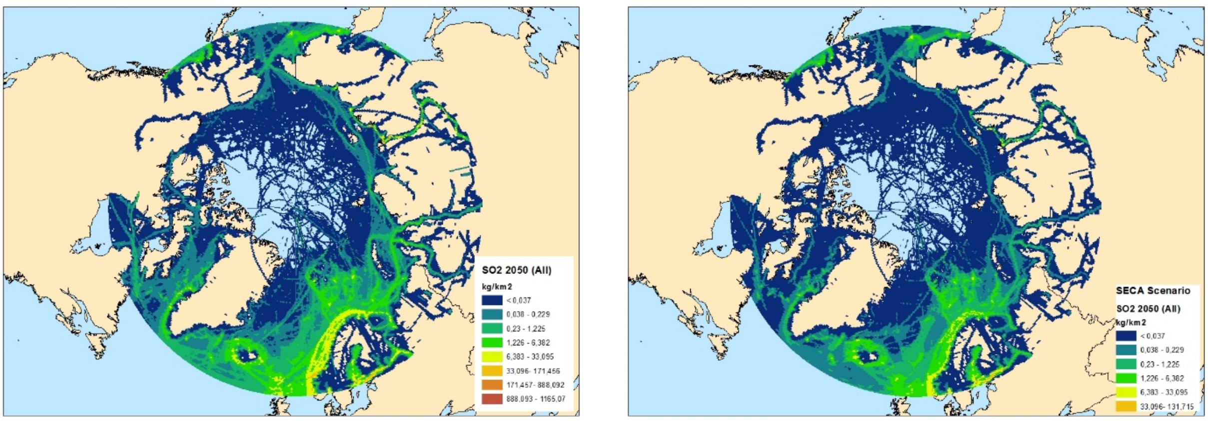


Figur DS 5 Totaler for energiforbrug (massebasis), NO_x, SO_2 og BC emissioner beregnet i Baseline, SECA og HFO forbud BAU scenarierne.

Det totale energiforbrug og NO_x-emissionerne er de samme for Baseline, SECA og HFO forbud-scenarierne, dels fordi faktorerne for specifikt energiforbrug og NO_x er ens for HFO og MDO / MGO, og dels fordi LNG-andelene af det samlede energiforbrug er ens i alle tre scenarier.

I alle scenarieårene bliver de beregnede SO_2-emissioner for SECA og HFO forbud-scenarierne kun omtrent halvt så store som de beregnede emissioner for Baseline-scenariet (Figurerne DS 5 og DS 6). I SECA-scenariet bruges HFO kun af skibe med EGCS, og mængden af 0,5 % fuelolie uden for SECA, der ikke erstattes af LNG, bliver erstattet af MGO / MDO. I HFO forbud-scenariet bliver al HFO, der ikke erstattes af LNG, erstattet af MGO / MDO.

For BC i 2020*[2030, 2050]*, bliver de beregnede emissioner for HFO forbud- og SECA-scenarierne henholdsvis 8 %*[9 %, 12 %]* og 3 %*[3 %, 3 %]* mindre end emissionerne beregnet i Baseline-scenariet. Bortset fra LNG, hvor de samme andele af brændstofforbruget er antaget i alle scenarier, anvendes kun MDO / MGO-brændstof i HFO forbud-scenariet med en sammenhørende lav BC-emissionsfaktor. I SECA-scenariet bruges HFO brændstof i kombination med EGCS med en relativt højere BC-emissionsfaktor. I SECA-scenariet er BC-emissionerne fra MDO / MGO, der erstatter 0,5 % fuelolie, imidlertid mindre end emissionerne fra den mængde 0,5 % fuelolie, der anvendes i baseline-scenariet, på grund af BC-emissionsfaktorernes niveau.



Figur DS 5 Rumligt fordelte SO_2-emissioner for alle skibe i 2020, 2030 og 2050 beregnet i Baseline og SECA BAU scenarierne.

I den forrige emissionsopgørelse for det arktiske område, udført af Winther et al. (2014), blev emissionsresultater beregnet for det historiske år 2012 og prognoseårene 2020, 2030 og 2050.

Ændringerne fra den forrige til den nye undersøgelse for 2012*[2020, 2030, 2050]* opgøres til -3 %*[8 %, 7 %, 5 %]* for sejlet antal km, -5 %*[23 %, 22 %, 20 %]* for energiforbrug, -7 %*[-44 %, -44 %, -46 %]* for SO_2, 4 %*[23 %, 24 %, 18 %]* for NO_x og -55 %*[-73 %, -74 %, -75 %]* for BC.

Der er flere årsåger til de ovennævnte ændringer i resultaterne. De vigtigste kvalitative forklaringer angives i det følgende.

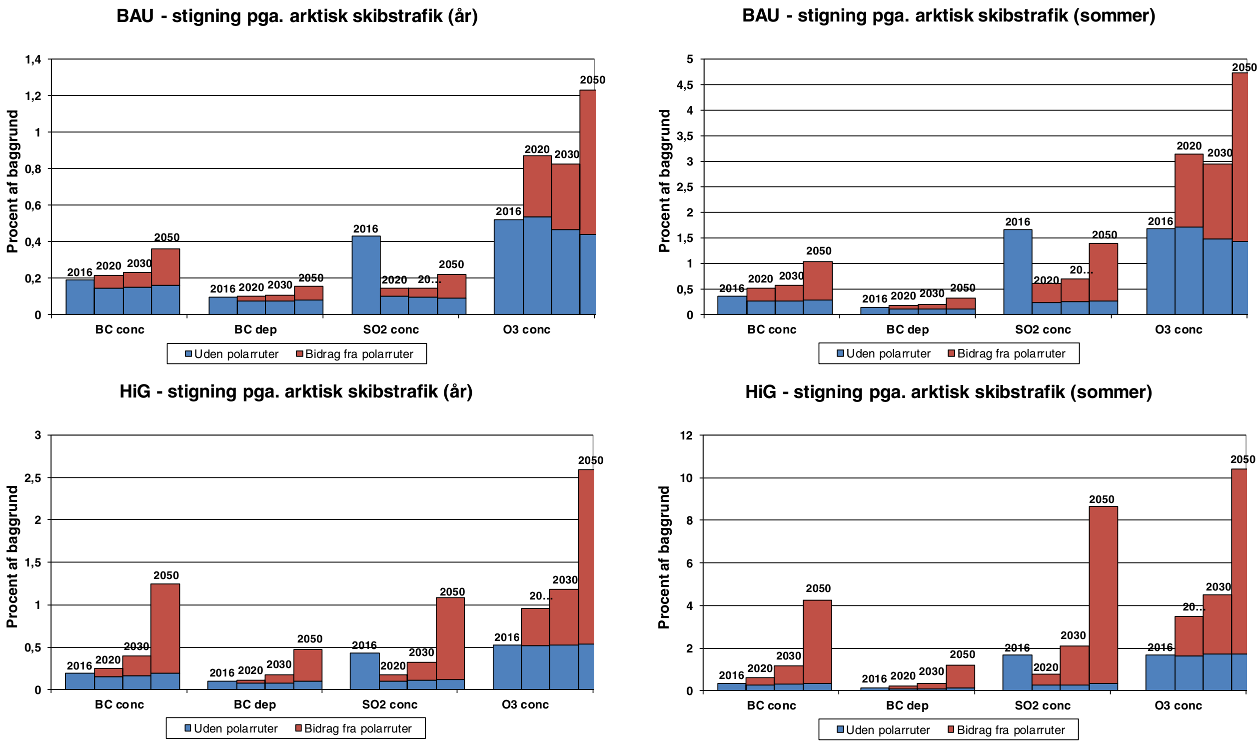
I den tidligere opgørelse, var vækstraterne for trafikken baseret på skibsaktivitetsdata for 2012. I den nuværende opgørelse, er trafikvæksten baseret på konsoliderede femårs-vægtede trafikdata. Dette ændrer følgelig skibsaktivitetsfordelingen per skibstype og -størrelse og påvirker især det samlede brændstofforbrug og NO_x-emissionerne.

For SO_2 skyldes emissionsændringerne mellem den foregående og den nuværende opgørelse hovedsageligt justeringer i svovlindholdet for MDO / MGO som input til emissionsberegningerne i den nuværende opgørelse. Indførelsen af LNG som brændstof i den nuværende opgørelse, giver også emissionsændringer, hvor forøgelsen af mængden af forbrugt LNG i scenarieårene påvirker SO_2- og BC-emissionerne i faldende retning.

For BC skyldes de største emissionsændringer mellem den foregående og den nuværende emissionsopgørelse ændringer i emissionsfaktorerne. På den måde er BC-emissionsfaktoren i den tidligere opgørelse ændret fra 0,35 g / kg brændstof uanset brændstoftype til et sæt af meget lavere emissionsfaktorer i den nuværende opgørelse for brændstoftyperne MDO / MGO, 2,5 % HFO og 0,5 % fuelolie. På trods af at der sker en opjustering af BC-emissionen i den nuværende opgørelse, pga. relativt lave motorbelastninger, bliver den aggregerede BC-emissionsfaktor i den nuværende opgørelse 0,15 g / kg brændstof for hele området i 2012.

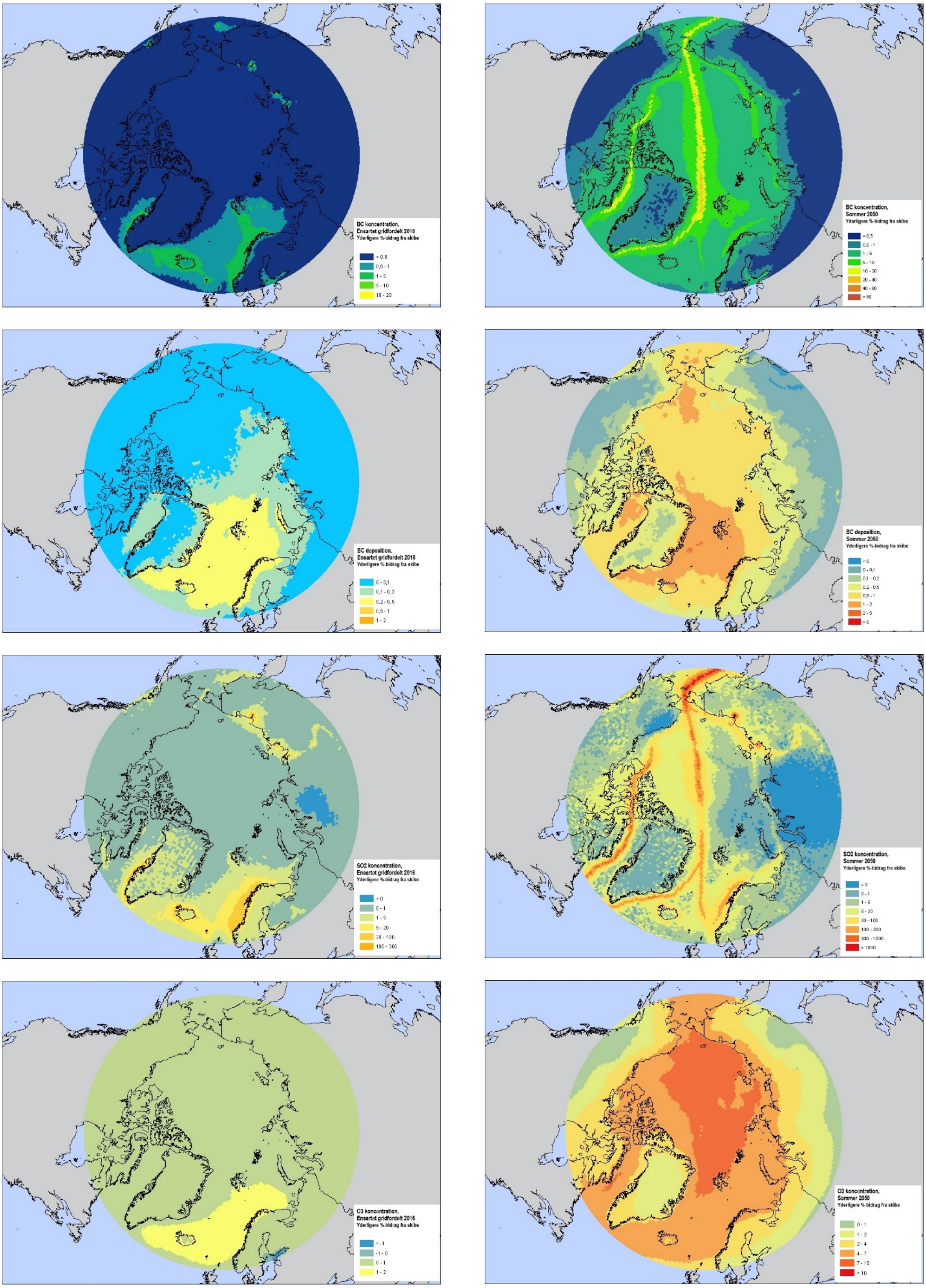
Emissionsfaktorerne i dette projekt stemmer godt overens med målekonklusionerne fra det internationale projekt vedrørende BC emissioner fra skibe, koordineret af the International Council of Clean Transport ICCT (2016), samt litteraturstudier udført af Lack and Corbett (2012) and Lack (2016). Et velkendt problem for BC er dog manglen på måledata for skibsmotorer, og derfor skal de beregnede emissionsresultater vurderes med forsigtighed. Nye BC-emissionsdata vil blive grundigt vurderet til brug for skibsemissionsopgørelser i fremtiden.

De gennemsnitlige stigninger i overfladekoncentrationen af BC, SO_2 og O_3 og BC-depositionen ligger på et lavt niveau for Baseline-scenarierne for BAU og HiG-trafikvækst, når bidraget for polarruter ikke medtages (Figur DS 6). Når bidraget for polarruter medtages, bliver stigningerne i overfladekoncentrationerne og BC-depositionen markant højere. Både med og uden polarruters bidrag bliver stigningerne i koncentrationer og BC-deposition meget større i sommerperioden. For polarruters bidrag alene om sommeren beregnes gennemsnitlige stigninger for BCcon*[BCdep, SO_2, O_3]* på 0.8 % *[0.2 %, 1.1 %, 3.3 %]* og 3.9 % *[1.1 %, 8.3 %, 8.7 %]*, for hhv. BAU og HiG-trafikvækst i 2050. For polarruters bidrag alene beregnes som årsgennemsnit stigninger for BCcon*[BCdep, SO_2, O_3]* på 0.2 % *[0.1 %, 0.1 %, 0.8 %]* og 1.0 % *[0.4 %, 1.0 %, 2.1 %]*, for hhv. BAU og HiG-trafikvækst i 2050.



Figur DS 6 Stigning i BC deposition og BC, SO_2 og O_3 overfladekoncentrationer for skibstrafik i 2016 (ensartet gitterfordelt), 2020, 2030 og 2050 (hele året og sommerperioden), beregnet som procentdele af baggrund.

De rumligt fordelte gennemsnitlige koncentrations- og depositionsbidrag for skibe er også lave i den største del af opgørelsesområdet i 2016 (ensartet grid-fordelt 2016, Figur DS 7). Det yderligere bidrag til BC-koncentrationen for skibe bliver op til 5 % omkring Island, og i visse geografiske områder beregnes ekstra koncentrationer af SO_2 på mellem 20-100 %. I sommerperioden i 2050, bliver de beregnede ekstra koncentrationsbidrag fra skibe langs polarruterne meget synlige for BC (20-40 %) og SO_2 (300-1000 %). BC-depositionen og O_3-koncentrationen bliver størst over hhv. oceanet øst for Grønland (1-2 %) og i det højarktiske område (7-10 %).



Figur DS 7 Rumligt fordelte stigninger i BC depositionen og BC, SO_2 og O_3 overfladekoncentrationerne for skibstrafik i 2016 (ensartet gitterfordelt, hele året) og 2050 (sommerperioden), beregnet som procentdele af baggrund.

1 Introduction

Navigation is one of the most important local sources of emissions in the Arctic area. Navigation emissions are characterized by the fact that the air pollutants formed during ship engine combustion are being injected directly into the Arctic environment along the vessels route at low vessel chimney heights. Hence, the emission deposition from vessels sailing in the Arctic area become relatively large compared to the total emissions emitted by these vessels (e.g. Corbett et al., 2010; Winther et al., 2014). In this respect, the emissions of black carbon (BC) are of particular interest. It is well known that BC has global warming properties due to its ability to absorb light over reflective surfaces, e.g. snow covered surfaces and due to its darkening effect when deposited to snow and ice surfaces (e.g. Quinn et al., 2008; Flanner, 2007, 2009).

In a previous project “Emissions from shipping in the Arctic”, carried out by DCE – Danish Centre for Environment and Energy at the Institute for Science and Technology at Aarhus University with financial support from the Danish Cooperation for Environment in the Arctic (DANCEA), a spatial distributed emission inventory for ships in the Arctic area above 58.95N was made for the year 2012 based on satellite AIS data, ship engine power functions and technology stratified emission factors (Winther et al., 2014). Emission projections and emission concentration and deposition calculations were also made for the years 2020, 2030 and 2050 and further calculations were also made by combining the baseline projected emissions with additional ship emissions estimated for polar diversion routes due to the possible extent of polar sea ice in the future.

The objective of the present project “Emissions from shipping in the Arctic from 2012-2016 and updated emission projections until 2050” is to extend the current emission model to cover the historical years 2012-2016 for the use of monitoring of the ship emission development in the Arctic area. A further goal is to carry out updated and improved emission projections for the years 2020, 2030 and 2050 by using the more robust five year weighted historical data for ship traffic, updated traffic growth rates, updated emission factors for BC in particular, emission factor adjustments for ship engine load, and by making assumptions for fuel type usage and the deployment of EGCS (Exhaust Gas Cleaning System) for SO_x scrubbing in the projection years. For historical and projected emissions, the project purpose is also to model the concentration and the deposition of the emissions.

In addition to the Baseline emission projections, the project aims are also to make scenario projections for a SECA scenario and a HFO ban scenario. In the SECA scenario, the existing SECA zones (i.e. America and North Sea / Baltic Sea SECA’s) are expanded to cover the entire inventory area above 58.95N. In the HFO ban scenario, no use of HFO by ships is allowed in the inventory area at all. Updated ship emission estimations along polar diversion routes are also made in the project.

A map of the inventory area (above 58.95N) is shown in Figure 1.1 with mark ups of the parts of the current SECAs for America and the North Sea / Baltic Sea also covered by the inventory area.

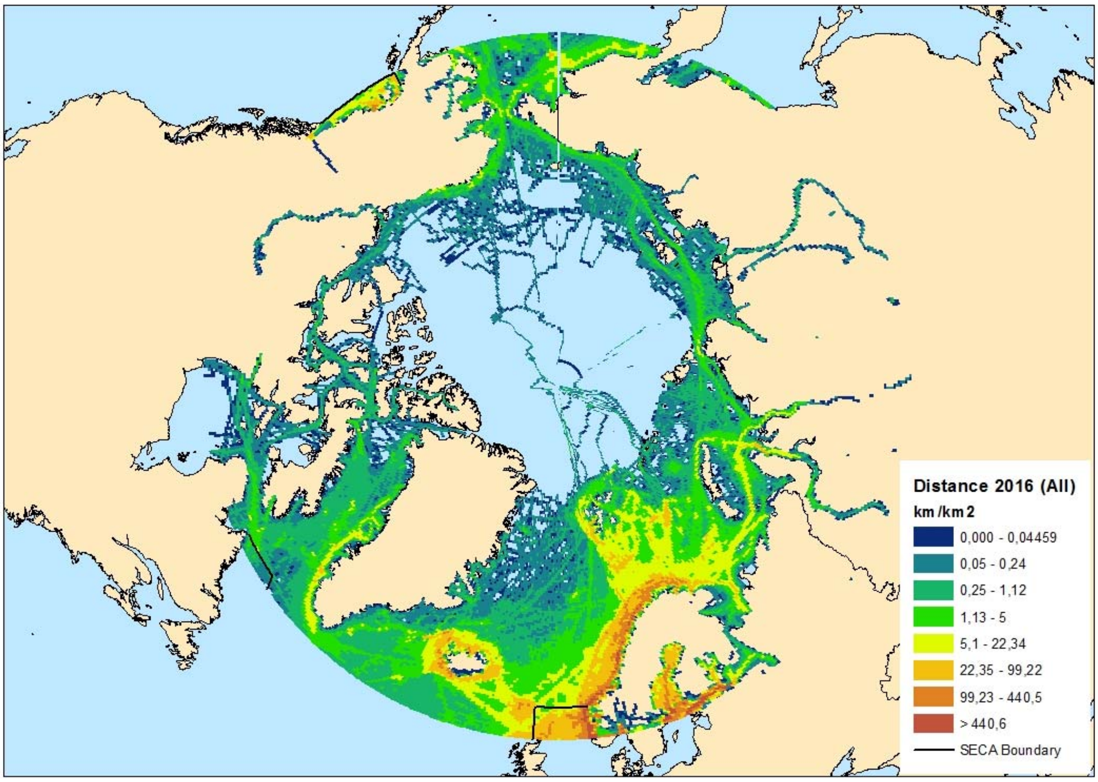


Figure 1.1 Map of the inventory area (above 58.95N) with mark ups of the parts of the current SECAs for America and the North Sea/Baltic Sea also covered by the inventory area.

The full list of emission components estimated in the project are the short lived climate pollutants and their precursors SO_2, NO_x, CO, NMVOC, PM, BC and OC (organic carbon) and the greenhouse gases CO_2, CH_4 and N_2O. In the main report, focus will be on the inventory results for fuel consumption, SO_2, NO_x and BC. Results for the remaining emission components are shown in the report annex.

The ship traffic projections are, in this project, made on the basis of ship type specific traffic scaling factors established by Corbett et al. (2010) for the Arctic. The business as usual (BAU) traffic scenario derived from Corbett et al. (2010). BAU traffic growth rates are regarded as the central traffic scenario in this project and the emission projection results based on BAU will be given in great details in this report.

Scenario calculations are also made in the project based on high growth (HiG) traffic rates proposed by Corbett et al. (2010). The HiG based emission results will be shortly summarized in the report and greater details are shown in the report annex. However, HiG results for the concentration and the deposition of emissions will be shown in more details in the report in order to predict the environmental effects in a worst case scenario.

Chapter 2 presents the 2012-2016 input ship activity data for the Arctic area above 58.95 N, based on terrestrial and satellite AIS data processed by the Danish Maritime Authority (DMA) into grid cells and stratified according to ship categories and ship length intervals, as well as average sailing speed and distance. Chapter 2 also presents the forecast ship activity data established by scaling the five-year weighted and uniform gridded historical ship activity data with traffic growth data derived from the Corbett scenarios.

Chapter 3 shortly summarizes the estimation of ship engine power from input activity data and the derivation of ship energy efficiency improvements based on IMO's (International Maritime Organization) Energy Efficiency Design Index (EEDI) figures. Chapter 4 describes the assumptions behind the Baseline, SECA and HFO emission scenarios in terms of fuel type usage (HFO, MDO/MGO and penetration of LNG) and the deployment of EGCS. The emission factors and engine load emission adjustment factors are documented in Chapter 5 along with fuel sulphur content for the fuel types included in the inventories.

Chapter 6 explains the calculation method, and emission inventory results are explained in Chapter 7 for the historical years 2012-2016 as well as results for the projection years 2020, 2030 and 2050 calculated in the Baseline, SECA and HFO ban scenarios. Results are also shown on GIS maps in Chapter 7. In Chapter 8 the emission concentration and deposition results are shown and discussed for the historical years and the Baseline scenario years.

This project is funded by the Danish Environmental Protection Agency as part of the environmental support program DANCEA (Danish Cooperation for Environment in the Arctic). The results will be a part of the Danish input for AMAP (Arctic Monitoring and Assessment Program) in the Arctic Council.

Daniel Lack, Air Quality and Climate Consulting, must be thanked for providing engine load specific data for BC emissions used in this study. Also many thanks to Jens Peter Hansen, Alfa Laval, for discussions related to EGCS emission reduction rates and to Per Winther Kristensen, Danish Shipping, Palle Kristensen, DMA and Michael Prehn, Danish Maritime, for providing views on global EGCS deployment rates for shipping in the forecast years.

2 Ship activity data

The present study covers the maritime area north of 58.95N comprising also parts of the American emission control area (ECA)[1] and the North Sea / Baltic Sea ECAs[2].

Ship activity data for the years 2012-2016 are shown in Section 2.1. Section 2.2 presents activity data for the consolidated base year (weighted average of 2012-2016 activity data) and ship type specific traffic growth data for the years 2020, 2030 and 2050. Section 2.2 also presents the ship activity data for the years 2020, 2030 and 2050 produced by scaling the base year activity data with traffic growth data.

2.1 Activity data for 2012-2016

The AIS data for the Arctic area north of 58.95N, provided by the Danish Maritime Authority (DMA) in the project, are received from terrestrial base stations and from satellites equipped with AIS receivers. The data represent the years 2012-2016 with only minor gaps measured in hours here and there. The high intensive traffic areas; i.e. the coasts of Norway, Iceland, Faroe Islands and the Baltic Sea are all covered by terrestrial base stations and receivers. AIS data down-sampled to six minutes from these areas are available through HELCOM - the Baltic Marine Environment Protection Commission[3].

Outside these areas, the AIS data are gathered from satellites. DMA has access to two, sometimes three polar orbital satellites[4]. These satellites orbit the earth once every 90 minutes in a height of approximately 700 km. The area north of 75N will be visible to a single satellite at any given moment. In the area between 58N and 75N, AIS signals from given ships are picked up at least every two hours; however, in some satellite orbits the detection rate can go down to 20 minutes.

The AIS data have been further processed using the software tool IWRAP[5]. Using AIS data, IWRAP can be used to set up a model that can estimate the expected number of ship collisions and groundings in a given area. The IWRAP software has been thoroughly tested around the world and is recommended by IMO to be used when assessing the risks of a given waterway (IMO, 2010).

Apart from its original purpose, IWRAP also offers a number of statistical functions and these are being used in the present project. Firstly, the ships are classified into 14 ship types and 16 ship lengths (LPP: length between perpendiculars) categories (intervals of 25 m), by using the static part of the AIS data (IMO number, ship type and ship size) together with a detailed ship type table. The ship types have mainly been chosen with regard to their cargo and

[1] American ECA: south of 60N extending up to 200 nautical miles from coasts of the United States, Canada and the French territories.
[2] North Sea / Baltic Sea ECA: Outer boundaries are the North Sea south of 62N and east of 4W and the English Channel east of 5W and north of 48°30'N.
[3] http://www.helcom.fi
[4] A Norwegian government satellite and commercial satellites from exactEarth and ORBCOMM.
[5] IALA Waterway Risk Assessment Programme. Developed by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), and the software company Gatehouse. http://iala-aism.org/wiki/iwrap.

hull shape. The sea area has been divided into grid cells with the same height and width measured in degrees, a 0.5° longitude x 0.225° latitude grid, and on a monthly resolution.

Table 2.1 shows the vessel types included in this study from DMA data and the assumed engine type, fuel type by origin, and engine life time for the vessels.

Table 2.1 Engine type, default fuel type and assumed engine life time for the vessel types included in this study.

Vessel type, V	Engine type, k	Default fuel type, f	Engine life time, LT
Crude oil tanker	Slow speed (2-stroke)	HFO	30
Oil products & chemical tanker	Slow speed (2-stroke)	HFO	30
Ro-ro passenger ship	Medium/High speed (4-stroke)[a]	HFO, MDO/MGO[b]	30/10[a]
Gas tanker	Slow speed (2-stroke)	HFO	30
Container ship	Slow speed (2-stroke)	HFO	30
General cargo ship	Slow speed (2-stroke)	HFO	30
Bulk carrier	Slow speed (2-stroke)	HFO	30
Ro-ro cargo ship	Medium/High speed (4-stroke) [a]	HFO, MDO/MGO[b]	30/10[a]
Passenger ship	Medium/High speed (4-stroke) [a]	HFO, MDO/MGO[b]	30/10[a]
Fast ferry	Medium/High speed (4-stroke) [a]	HFO, MDO/MGO[b]	30/10[a]
Support ship	Medium/High speed (4-stroke) [a]	HFO, MDO/MGO[b]	30/10[a]
Fishing ship	Medium speed (4-stroke)		20
Other ship	Medium/High speed (4-stroke) [a]	HFO, MDO/MGO[b]	30/10[a]

a) High speed engines and life time = 10 years for design power < 1000 kW.

b) MDO/MGO for design power < 4000 kW.

HFO: Heavy Fuel Oil, MDO/MGO: Marine Diesel Oil/Marine Gas Oil.

In order to comply with the 0.1 % fuel sulphur limits for HFO in SECA's, which entered into force from 1.1.2015, a limited number of Exhaust Gas Cleaning Systems (EGCS) for SO_x scrubbing has been installed on board ships globally until now. The preferred choice from ship owners/charterers has, however, been to switch fuel from HFO to MDO/MGO - or a similar "SECA fuel" type[6] - instead of using HFO and EGCS. The market share of the so-called "SECA fuels" is small, but yet unknown. Consequently, in this project for 2015 and 2016 we assume that the fuel type being used is MDO/MGO inside SECA's and HFO outside SECA's for ships using HFO by origin.

The ship length (LPP) categories given in DMA data are shown in Table 2.2.

Tabel 2.2 Ship length categories (LPP) used in this study.

LPP interval (m)→	<= 50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	225-250	250-275	275-300	> 300

IWRAP orders all the AIS data according to the ship id and time and calculates the distance, course and speed sailed in each grid cell. By aggregation, the output prepared by DMA for the emission inventories is a list of geographic cells per month with information of total sailed distances stratified into the different ship types/LPP/average speed combinations that have been recorded in the individual cells.

The total distances sailed in 2012-2016 per ship type and ship length interval in the inventory area are shown in Table 2.3.

[6] The so-called SECA fuels are blend products with a maximum fuel sulphur content of 0.1 %, which does not meet the fuel specifications for MDO or MGO.

Table 2.3 Total sailing distance (km x 10^3) per ship type and LPP interval for the inventory area in the years 2012-2016.

Year	LPP interval (m)→	<= 50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	225-250	250-275	275-300	> 300	Total
2012	Crude oil tanker	0	1	0	0	0	57	26	6	595	707	25	21	1439
2012	Oil products & chemical tanker	496	278	1601	2406	2291	736	1680	40	540	569	139	3	10778
2012	Ro-ro passenger ship	1914	3134	2100	2047	1647	1719	1285	1355	0	0	0	0	15202
2012	Gas tanker	0	152	154	152	58	39	25	49	20	0	213	0	861
2012	Container ship	0	146	1199	709	1953	1352	253	216	34	9	11	2	5884
2012	General cargo ship	1228	5175	12330	7108	2226	1178	323	95	195	0	34	2	29893
2012	Bulk carrier	0	288	265	739	11	302	1315	121	1194	48	200	9	4493
2012	Ro-ro cargo ship	54	50	128	609	479	1098	636	154	1	33	0	0	3243
2012	Passenger ship	6205	687	502	374	346	355	627	230	94	245	374	24	10064
2012	Fast ferry	185	0	2	0	0	0	0	0	0	0	0	0	187
2012	Support ship	5830	1809	4431	675	90	258	0	1	0	0	0	1	13095
2012	Fishing ship	13863	12737	1436	901	47	0	0	0	0	0	0	0	28984
2012	Other ship	3256	1046	392	535	310	133	58	4	7	1	2	6	5751
	All vessels	33031	25504	24539	16257	9458	7228	6228	2270	2680	1614	998	68	129873
2013	Crude oil tanker	0	0	3	0	0	82	17	3	513	765	46	5	1435
2013	Oil products & chemical tanker	556	312	1373	2333	2337	864	1861	47	502	606	148	2	10940
2013	Ro-ro passenger ship	1549	2761	2012	2063	1260	1065	957	1061	0	0	0	0	12727
2013	Gas tanker	0	138	142	143	47	38	35	14	11	4	169	0	742
2013	Container ship	0	171	1033	656	1582	1556	193	237	29	1	15	6	5478
2013	General cargo ship	1254	4714	11181	6579	2512	1105	395	73	179	1	24	2	28020
2013	Bulk carrier	0	205	258	647	23	304	1474	140	1315	86	197	14	4663
2013	Ro-ro cargo ship	36	55	126	451	413	844	570	160	0	61	0	0	2716
2013	Passenger ship	5602	704	438	439	614	406	944	487	93	227	471	49	10475
2013	Fast ferry	196	0	1	0	0	0	0	0	0	0	0	0	197
2013	Support ship	5895	1992	4390	808	143	304	3	0	0	0	0	2	13537
2013	Fishing ship	15052	14007	1536	1175	47	0	0	0	0	0	0	0	31817
2013	Other ship	5765	1030	665	779	402	160	70	14	10	7	0	12	8915
	All vessels	35905	26089	23158	16072	9379	6728	6520	2235	2653	1757	1070	93	131661
2014	Crude oil tanker	0	0	0	0	0	145	36	4	546	758	50	14	1554
2014	Oil products & chemical tanker	628	513	1532	2747	2161	891	1954	26	331	617	198	11	11608
2014	Ro-ro passenger ship	1913	3491	2129	2386	1218	1161	918	1045	0	0	0	0	14261
2014	Gas tanker	0	114	124	156	53	152	31	13	7	0	195	8	855
2014	Container ship	40	138	1127	618	1431	1704	113	240	72	11	17	5	5516
2014	General cargo ship	1572	4833	11225	7278	3085	273	655	73	246	2	38	7	30287
2014	Bulk carrier	0	141	250	522	61	319	1783	141	1309	130	198	8	4860
2014	Ro-ro cargo ship	58	59	67	394	355	906	577	191	2	62	1	0	2671
2014	Passenger ship	6268	891	564	436	736	451	984	482	94	248	407	50	11610
2014	Fast ferry	262	0	7	0	0	0	0	0	0	0	2	0	271
2014	Support ship	7960	2479	5364	810	133	335	7	4	0	0	0	4	17098
2014	Fishing ship	18468	16731	2262	1143	76	0	0	0	0	0	0	0	38679
2014	Other ship	6604	1553	1341	851	438	216	82	9	35	14	4	14	11162
	All vessels	43773	30943	25992	17341	9747	7552	7139	2228	2642	1842	1111	120	150431
2015	Crude oil tanker	0	0	1	0	0	163	26	0	536	885	47	38	1695
2015	Oil products & chemical tanker	712	442	1749	3026	2328	825	2200	36	431	747	192	11	12699
2015	Ro-ro passenger ship	1998	3896	2621	2804	1495	1051	991	1114	0	0	0	0	15970
2015	Gas tanker	0	146	112	147	60	236	24	9	1	0	271	0	1006
2015	Container ship	12	162	1047	636	1537	1581	165	193	75	4	15	10	5436
2015	General cargo ship	1893	6022	11936	7629	3662	1542	842	130	201	5	24	8	33894

Continued…														
2015	Bulk carrier	0	162	144	614	109	351	1664	205	1328	84	157	51	4869
2015	Ro-ro cargo ship	67	67	66	515	311	837	591	237	4	58	0	0	2752
2015	Passenger ship	7490	1023	704	555	774	563	1337	484	132	222	435	100	13818
2015	Fast ferry	324	0	0	0	0	0	0	0	0	0	0	0	324
2015	Support ship	8561	2603	5438	861	144	371	4	0	0	0	0	1	17984
2015	Fishing ship	21362	20439	2959	1400	94	0	0	0	0	0	0	0	46254
2015	Other ship	6677	1899	1316	924	398	228	70	8	3	4	6	14	11546
	All vessels	49095	36860	28093	19110	10911	7748	7913	2417	2713	2008	1146	233	168247
2016	Crude oil tanker	0	0	0	0	0	219	23	0	568	1034	50	76	1970
2016	Oil products & chemical tanker	463	218	1667	2387	2109	651	2349	28	552	814	241	3	11480
2016	Ro-ro passenger ship	2323	4640	3511	3136	1540	1083	949	1144	0	0	0	0	18326
2016	Gas tanker	0	169	97	149	42	235	20	0	16	0	282	0	1010
2016	Container ship	1	166	946	561	1444	1616	182	194	74	9	22	20	5234
2016	General cargo ship	1347	6415	12552	6653	3363	1979	966	192	375	42	61	13	33958
2016	Bulk carrier	0	208	88	676	26	317	1491	163	1463	89	161	45	4727
2016	Ro-Ro cargo ship	81	59	69	616	336	750	569	232	0	62	0	0	2776
2016	Passenger ship	8685	1125	661	457	653	446	1307	578	142	243	441	115	14852
2016	Fast ferry	761	0	0	0	0	0	0	0	0	0	0	0	762
2016	Support ship	7910	1875	4269	802	83	327	23	0	0	0	0	0	15290
2016	Fishing ship	19759	15174	2415	821	73	0	0	0	0	0	0	0	38243
2016	Other ship	3862	922	558	697	425	260	40	40	23	2	1	1	6831
	All vessels	45193	30971	26833	16955	10095	7883	7919	2571	3212	2295	1260	273	155458

Figure 2.1 shows the share of total sailing distance per ship type in 2016. For convenience, the tanker category in Figure 1 adds up the distance sum of crude oil, oil products, chemical and gas tankers. Likewise the passenger ship category consists of ro-ro passenger ships, passenger ships (not ro-ro) and fast ferries.

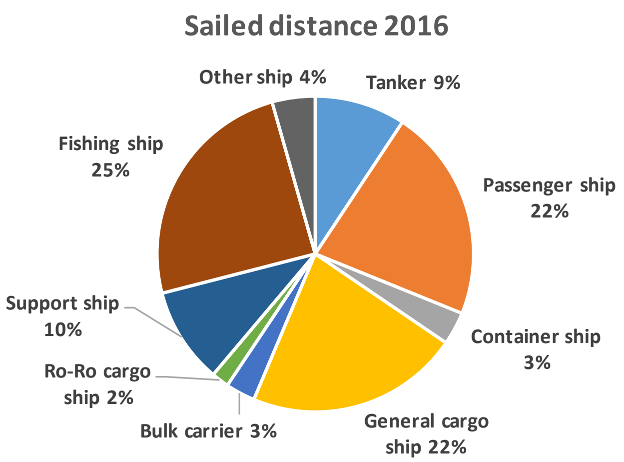
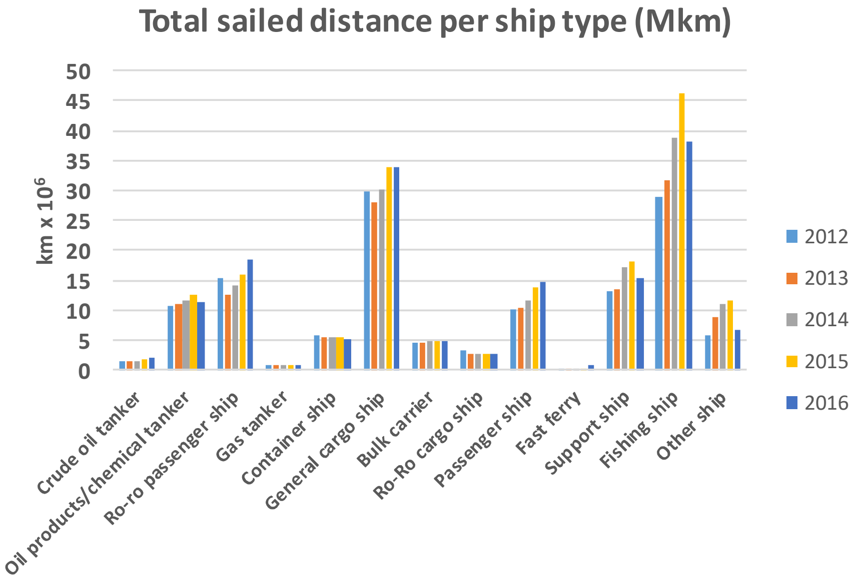


Figure 2.1 Ship type share of total sailing distance in 2016.

Figure 2.2 shows the distance sailed per ship type in 2012-2016 (upper figure) and total distance sailed per month 2012-2016 (lower figure). Please note the different scales on the two graphs.



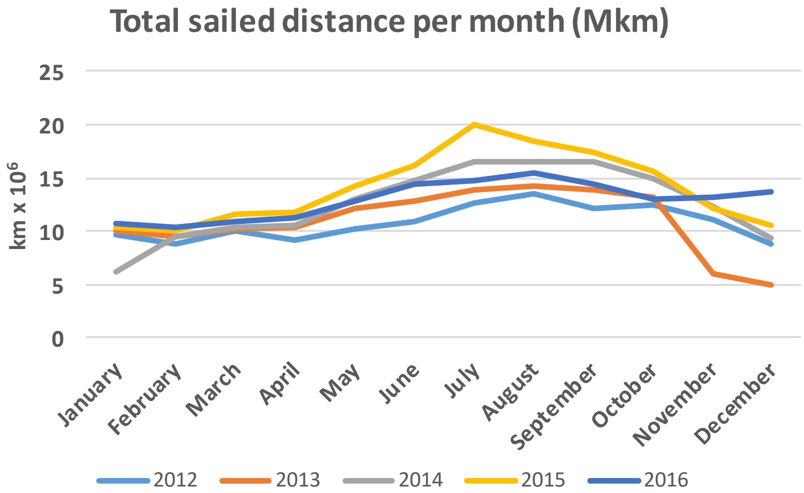


Figure 2.2 Distance sailed per ship type in 2012-2016 (upper figure) and total distance sailed per month 2012-2016 (lower figure).

Most of the sailed distance in the area is done by fishing ships, general cargo, passenger ships, support ships and tankers (Figure 2.1, for 2016). For fishing vessels, the transport development per month is variable, whereas for the remaining most busy ship categories, the traffic maximum is reached during the warmest months of the year (not shown).

Figure 2.3 shows the total spatial distribution of ship traffic for all ships in 2016 based on the AIS dataset.

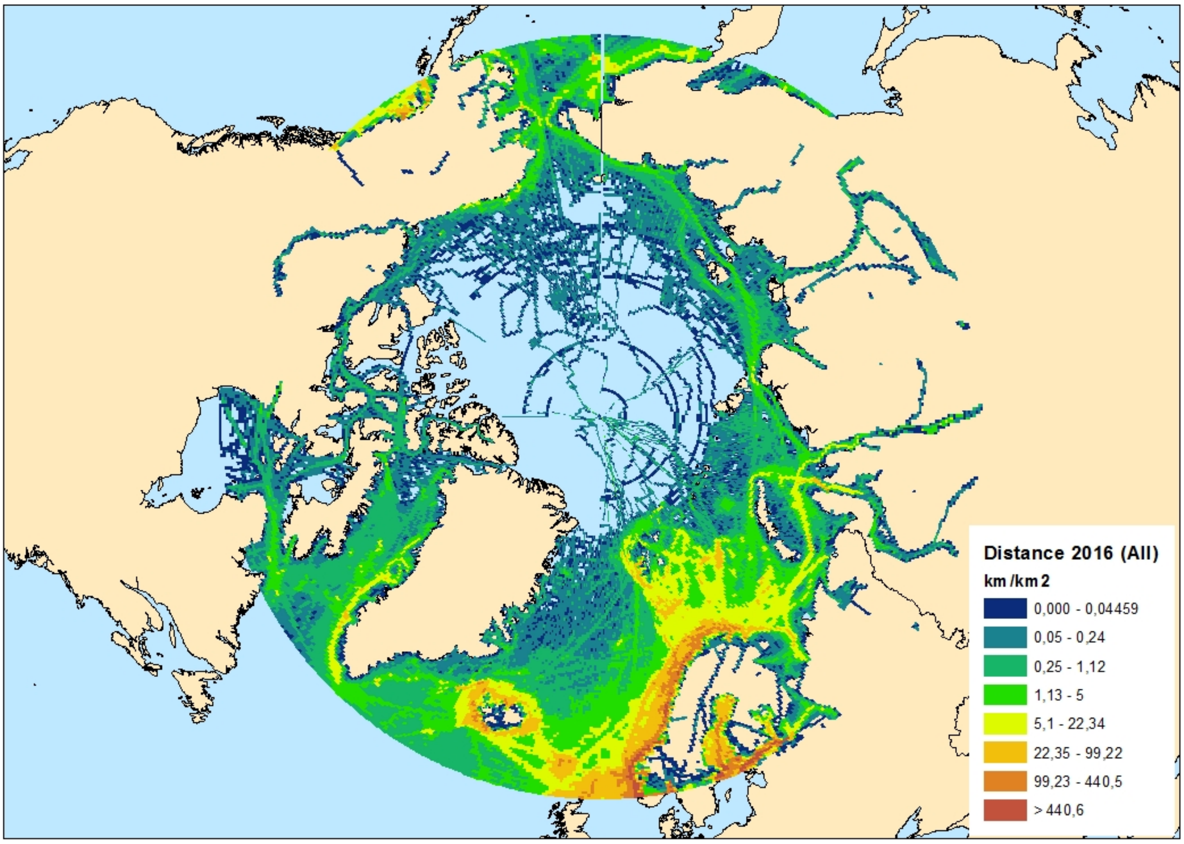


Figure 2.3 Spatial distribution of ship traffic for all ships in 2016.

2.2 Activity data projections for 2020, 2030 and 2050

A consolidated ship activity data set is created in this project based on the five-year ship activity data provided by DMA. The consolidated traffic weighted ship activity data are used in order to obtain a more robust basis for the projection of ship activity data, thus avoiding inexpedient temporal and spatial specific fluctuations in traffic records, and in order to achieve a uniform grid cell reference system for the emission projection calculations. Due to the nature of data processing in DMA, the grid cell references differ from year to year in DMA data.

To obtain uniform distance sailed and kWh's produced by main engines and auxiliary engines, the grid cell specific share of the year x month x ship type x LPP x speed value combination in DMA data (stratified data record), projected into the appropriate uniform grid cell, is summed up for this specific uniform grid cell and stratified data record combination. The uniform grid cell sum is subsequently divided by five (the number of inventory years in DMA historical data).

Uniform main engine loads are obtained by weighing the main engine load for each stratified data record with the share of produced main engine kWh's projected into the appropriate uniform grid cell, and subsequently divide by the sum of produced main engine kWh's being projected into the uniform grid cell. A general description of the calculation of the stratified main engine loads is given in Chapter 3.

The total sailing distances per ship type and LPP interval calculated for the consolidated ship activity data is shown in Table 2.4.

Table 2.4 Total sailing distance (km x 10^3) per ship type and LPP interval for the inventory area in the consolidated ship activity data set weighted from 2012-2016 ship activity data.

LPP interval (m)→	<= 50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	225-250	250-275	275-300	> 300	Total
Crude oil tanker	0	0	1	0	0	133	25	3	552	830	43	31	1618
Oil products & chemical tanker	571	353	1584	2580	2245	793	2009	35	471	670	184	6	11501
Ro-ro passenger ship	1939	3584	2475	2487	1432	1216	1020	1144	0	0	0	0	15297
Gas tanker	0	144	126	149	52	140	27	17	11	1	226	2	895
Container ship	11	157	1070	636	1589	1562	181	216	57	7	16	8	5510
General cargo ship	1459	5432	11845	7049	2970	1415	636	113	239	10	36	6	31211
Bulk carrier	0	201	201	640	46	319	1545	154	1322	87	183	26	4722
Ro-ro cargo ship	59	58	91	517	379	887	589	195	2	55	0	0	2831
Passenger ship	6850	886	574	452	624	444	1040	452	111	237	425	68	12164
Fast ferry	346	0	2	0	0	0	0	0	0	0	0	0	348
Support ship	7231	2152	4779	791	119	319	7	1	0	0	0	2	15401
Fishing ship	17701	15818	2121	1088	67	0	0	0	0	0	0	0	36795
Other ship	5233	1290	854	757	395	200	64	15	16	6	3	10	8841
All vessels	41399	30073	25723	17147	9918	7428	7144	2344	2780	1903	1117	157	147134

The traffic scaling factors used in this study for traffic projections are derived from traffic growth factors in the Corbett et al. (2010) business as usual (BAU) scenario[7] by referring our study's ship types to the Corbett et al. (2010) ship types and by using modified Corbett traffic growth factors evolved from 2014. The year 2014 is chosen as the midpoint year for the 2012-2016 weighted ship activity data shown in Table 2.4.

The resulting BAU traffic scenario is regarded as the central traffic scenario in this project. High growth traffic scaling factors used to estimate high growth traffic levels in the projection years are in the same way derived from the high growth (HiG) scenario in Corbett et al. (2010). The HiG traffic scaling factors are shown in the annex of this report.

Table 2.5 shows the vessel type specific BAU traffic scaling factors between base year and the forecast years 2020, 2030 and 2050. The vessel type specific traffic scaling factors are used to estimate the traffic levels in the forecast years.

[7] The Corbett BAU scenario originates from the Second IMO GHG Study 2009 (Buhaug et al., 2009).

Table 2.5 BAU traffic scaling factors for the years 2020, 2030 and 2050 used in this study.

Vessel type	Traffic scaling factors			Vessel type
This study	2020	2030	2050	Corbett et al. (2010)
Crude oil tanker	1.30	1.71	2.62	Tanker
Oil products & chemical tanker	1.30	1.71	2.62	Tanker
Ro-ro passenger ship	1.04	1.14	1.43	Passenger vessels
Gas tanker	1.30	1.71	2.62	Tanker
Container ship	1.19	1.71	3.86	Container ship
General cargo ship	1.02	1.07	1.21	General cargo ship
Bulk carrier	1.09	1.29	1.85	Bulk ships
Ro-ro cargo ship	1.02	1.07	1.21	General cargo ship
Passenger ship	1.04	1.14	1.43	Passenger vessels
Fast ferry	1.04	1.14	1.43	Passenger vessels
Support ship	1.14	1.32	1.69	Offshore Service Vessels
Fishing ship	1	1	1	-
Other ship	1	1	1	-

The total sailing distances per ship type and LPP interval projected for the years 2020, 2030 and 2050 in the inventory area are shown in Table 2.6.

Table 2.6 Total sailing distance (km x 10^3) per ship type and ship length interval projected for the inventory area in 2020, 2030 and 2050.

Year	LPP interval (m)→	<= 50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	225-250	250-275	275-300	> 300	Total
2020	Crude oil tanker	0	0	1	0	0	173	33	3	717	1078	56	40	2103
	Oil products & chemical tanker	742	458	2059	3352	2917	1030	2610	46	612	871	239	8	14943
	Ro-ro passenger ship	2020	3733	2577	2591	1491	1266	1062	1191	0	0	0	0	15932
	Gas tanker	0	186	163	194	68	182	35	22	14	1	294	2	1163
	Container ship	13	187	1277	758	1895	1863	216	257	68	8	19	10	6571
	General cargo ship	1484	5527	12052	7173	3022	1440	647	115	244	10	37	6	31758
	Bulk carrier	0	219	219	696	50	347	1683	168	1439	95	199	28	5142
	Ro-ro cargo ship	60	59	93	526	386	902	599	198	2	56	0	0	2881
	Passenger ship	7134	923	598	471	650	463	1083	471	116	247	443	70	12668
	Fast ferry	360	0	2	0	0	0	0	0	0	0	0	0	362
	Support ship	8235	2450	5442	901	135	363	8	1	0	0	0	2	17538
	Fishing ship	17701	15818	2121	1088	67	0	0	0	0	0	0	0	36795
	Other ship	5233	1290	854	757	395	200	64	15	16	6	3	10	8841
	All vessels	42981	30850	27458	18508	11076	8230	8041	2488	3227	2372	1290	176	156698
2030	Crude oil tanker	0	0	1	0	0	228	44	4	944	1419	74	53	2768
	Oil products & chemical tanker	976	603	2709	4411	3840	1356	3435	60	806	1146	314	10	19667
	Ro-ro passenger ship	2217	4098	2829	2844	1637	1390	1166	1307	0	0	0	0	17488
	Gas tanker	0	245	215	255	89	240	47	29	19	1	387	3	1530
	Container ship	18	268	1833	1089	2722	2675	310	369	97	12	27	14	9436
	General cargo ship	1560	5809	12666	7538	3176	1514	680	120	256	11	39	7	33375
	Bulk carrier	0	258	259	823	59	410	1989	198	1701	112	235	33	6078
	Ro-ro cargo ship	63	62	98	553	405	948	629	208	2	59	0	0	3028
	Passenger ship	7831	1013	656	517	714	508	1189	517	127	271	486	77	13905
	Fast ferry	395	0	2	0	0	0	0	0	0	0	0	0	398
	Support ship	9560	2845	6317	1046	157	422	10	1	0	0	0	2	20360
	Fishing ship	17701	15818	2121	1088	67	0	0	0	0	0	0	0	36795
	Other ship	5233	1290	854	757	395	200	64	15	16	6	3	10	8841
	All vessels	45554	32309	30562	20922	13260	9890	9562	2831	3967	3037	1566	209	173669
2050	Crude oil tanker	0	1	2	0	0	349	67	7	1445	2173	114	82	4238
	Oil products & chemical tanker	1495	923	4149	6755	5879	2077	5260	92	1234	1756	481	15	30115
	Ro-ro passenger ship	2765	5110	3528	3546	2042	1733	1454	1631	0	0	0	0	21809
	Gas tanker	0	376	329	391	136	367	71	45	29	2	593	4	2343
	Container ship	41	604	4127	2452	6127	6022	699	832	219	27	62	32	21244
	General cargo ship	1771	6594	14379	8558	3605	1718	772	137	291	12	44	7	37888
	Bulk carrier	0	371	371	1182	85	589	2855	285	2442	161	337	47	8725
	Ro-ro cargo ship	72	70	111	628	460	1077	715	236	2	67	0	0	3437
	Passenger ship	9766	1263	818	645	890	633	1482	645	158	338	607	96	17341
	Fast ferry	493	0	3	0	0	0	0	0	0	0	1	0	496
	Support ship	12228	3639	8081	1338	201	539	13	2	0	0	0	3	26043
	Fishing ship	17701	15818	2121	1088	67	0	0	0	0	0	0	0	36795
	Other ship	5233	1290	854	757	395	200	64	15	16	6	3	10	8841
	All vessels	51564	36059	38874	27339	19887	15304	13452	3926	5835	4541	2240	296	219317

Figure 2.4 shows the total sailing distance per ship type in 2012, 2020, 2030 and 2050 using the figures from Table 1 and 3.

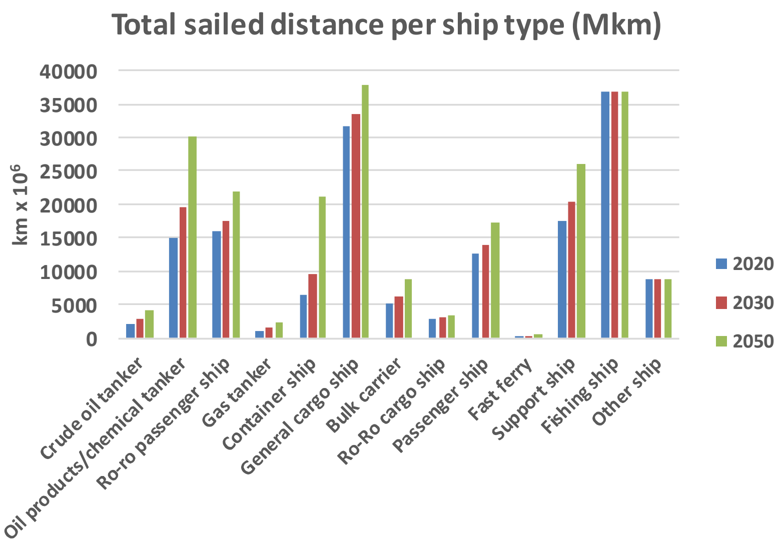


Figure 2.4 Total distance sailed per ship type projected for the years 2020, 2030 and 2050.

3 Ship engine power and adjustment for ship's Energy Efficiency Design Index (EEDI)

For all ship types, excluding fishing ships, main engine and auxiliary engine power, functions have been developed in our study by using the generic ship design model (SHIP-DESMO), see Kristensen (2012a and 2012b) and Kristensen and Lützen (2012). For each ship type, the ship LPP length and current vessel speed are used as input to predict the design power and the power needed for propulsion at the current vessel speed. For fishing ships the total installed power per LPP length is roughly estimated by Danish Fishermen's Association (Pers. Comm. Henrik Lund, 2013).

A precise prediction of power demand for fishing activities is difficult to obtain. The sailing speeds (and hence sailing distances) are generally low during direct fishing, and a low average sailing speed of 5.0 knots can also be derived from the AIS activity data in this work. On the other hand, low sailing speeds do not automatically imply low engine loads for fishing ships. Additional engine power is needed (which increases fuel consumption), either due to the nature of the fishing work (e.g. trawl fishing) or due to the power needed for the processing and packing of the fish catch at sea. Thus, in order to account for all activities in relation to fishing, an average engine load of 60 % of total installed power is assumed for the Arctic area as a whole (Pers. Comm. John Ingar Jenssen, COWI Tromsø, 2013).

A thorough explanation of the engine power expressions is given in Winther et al. (2014).

Ship EEDI (Energy Efficiency Design Index) fuel efficiencies are regulated by Marpol 83/78 Annex VI (Chapter 4) mandatory from 1 January 2013 for new built ships larger than 400 GT. EEDI is a design index value that expresses how much CO_2 is produced per work done (g CO_2/tonnes.nm).

Table 3.1 shows the EEDI reduction percentages per ship type used in our study for the years 2020, 2030 and 2050. For a more thorough description of the calculation of these reduction percentages, please see Winther et al. (2014) and Winther (2015).

Table 3.1 Aggregated EEDI reductions (%) per ship type used in this study.

Ship type	EEDI reduction %		
	2020	2030	2050
Crude oil tanker	2.33	11.00	28.66
Oil products & chemical tanker	1.86	8.76	22.84
Ro-ro passenger ship	0.33	5.67	18.67
Gas tanker	2.01	9.47	24.67
Container ship	2.02	9.53	24.83
General cargo ship	1.07	5.06	13.20
Bulk carrier	2.17	10.22	26.62
Ro-ro cargo ship	0.33	5.67	18.67
Passenger ship	0.33	5.67	18.67
Fast ferry	0.33	5.67	18.67
Support ship	0.33	5.67	18.67
Fishing ship	0.00	0.00	0.00
Other ship	0.33	5.67	18.67

4 Emission scenarios

This project includes a Baseline emission projection scenario and two additional SECA and HFO ban scenarios. The baseline scenario forms the basis for the SECA and HFO ban scenarios.

All three scenarios use the BAU traffic activity projections explained in Chapter 2.2 and further the scenarios assume an increasing amount of LNG fuel used as a substitution for HFO in the inventory area throughout the projection years. The scenarios use the "low case" LNG fuel share of total marine fuel consumption being 2 %, 4 % and 8 % in the years 2020, 2030 and 2050, respectively, as described in the IMO 3rd GHG study published by IMO (2015).

The baseline scenario assumes an increase in the use of EGCS for SO_2 emission abatement in the case of ships using HFO with a high content of sulphur. In the baseline scenario inside the existing SECA zones (i.e. America and North Sea / Baltic Sea SECA's) the fuel type switches from HFO to MDO / MGO for ships using HFO by origin (c.f. Table 2.1) and not having an EGCS installed (c.f. chapter 5.3.2). Outside the existing SECA's the latter ships use 0.5 % HFO.

In the SECA scenario, the existing SECA zones (i.e. America and North Sea / Baltic Sea SECA's) are expanded to cover the entire inventory area. The SECA scenario takes on board the baseline shares of LNG fuel consumption and EGCS installations. Further in the SECA scenario, the fuel is shifting from HFO to MDO / MGO outside the existing SECA's by ships using HFO by origin (c.f. Table 2.1) and not using EGCS. The emission impact of using EGCS is further assessed in a model run involving higher shares of EGCS installations on board ships.

In the HFO ban scenario, no use of HFO by ships is allowed at all in the inventory area. The HFO ban scenario includes the consumption of LNG as assumed in the baseline scenario. The remaining part of the HFO consumption not being substituted by LNG is assumed to switch to MGO / MDO in the entire inventory area.

4.1 Baseline scenario

In the Baseline scenario, a moderate increase in the use of LNG is assumed as well as the use of EGCS in combination with high sulphur HFO fuel.

4.1.1 Use of LNG

Our study use the "low case" LNG fuel share of total marine fuel consumption being 2 %, 4 % and 8 % in the years 2020, 2030 and 2050, respectively, as described in the IMO 3rd GHG study published by IMO (2015). This "low case" LNG fuel mix share is used also in the SECA and HFO ban scenarios (Chapter 4.2 and 4.3).

The forecasting of LNG fuel consumption by ships is regarded to be highly uncertain. In our project, the inclusion of the IMO "low case" LNG fuel consumption development as a basis for the scenario calculations was discussed with the Danish ship-owners association, called 'Danish Shipping' (pers. comm Per Winther Kristensen, 2017). Also the relevance of using the IMO

(2015) “high case” 2020, 2030 and 2050 LNG fuel mix shares of 10 %, 15 % and 25 %, respectively, was touched during these project discussions.

The general opinion from Danish Shipping was that LNG will not play an important role as a fuel for navigation in the future. Several limitations are associated with LNG as a fuel in the maritime sector such as LNG fuel supply infrastructure, the large size of LNG fuel tanks on board ships, and the escapes and losses of methane during daily operation that cause increasing environmental concerns for the shipping industry as such.

As a consequence, in our project it was decided to keep the IMO (2015) LNG “low case” fuel development as the LNG fuel mix basis in all scenario cases and not introduce further enhanced LNG fuel consumption developments in the scenario calculations.

4.1.2 Shares of ships with EGCS

In this project, projections of EGCS installed on board ships in 2020, 2030 and 2050 are made based on EGCS installation cost effectiveness (CE) functions from the IMO’s fuel availability study (IMO, 2016a), global ship fleet engine size data from Danish Shipping, general assumptions of average life time of ships and discussions made with Danish Shipping (pers. comm. Per Winther Kristensen), DMA (pers. comm. Palle Kristensen) and Danish Maritime (pers. comm. Michael Prehn).

IMO (2016a) finds the share of ships for which EGCS are cost-effective (CE) to use as a function of installed main engine power (>5 MW) for new build installations and retrofit installations during dry dock visits, respectively. The CE probability functions are based on economic considerations that include annualized capital and operational expenditures weighted up against saved fuel cost.

IMO (2016a) also points out other barriers for the installation of EGCS on board ships. These include regulatory barriers (discharge of wash water being constrained or prohibited), technical or operational barriers (space limitations on board ships, ship stability, Tier III compatibility), installation capacity in ship yards and other barriers (e.g. split incentive between owner/charterer)[8].

Danish Shipping and DMA believe global EGCS installation shares between 25 % and 30 % of the global fleet (>5 MW) in 2050 to be realistic, taking into consideration fuel price differences, fuel availability concerns and the demand for more climate-friendly fuels. Danish Maritime regards twice as high global EGCS installation shares to be more realistic.

Based on these inputs from the Danish stakeholders, we choose a global EGCS share between 25 % and 30 % (28 %) as end target for 2050 to include in the Baseline and SECA scenario, and the double (56 %) EGCS share as input for a “high share EGCS” model run included in the SECA scenario.

We combined the IMO (2016a) new build and retrofit CE probability curves (function of main engine size) with the main engine size distribution of the global fleet. For all ships, an assumed average lifetime of 30 years roughly

[8] In IMO (2016a), different barrier probability percentages and a few other sensitivity parameters are used in a set of sensitivity calculations.

gave the number of new build ships each year, and estimated dry dock visits every five year roughly gave the number of ships in dry dock visit each year.

This temporal (and engine size) distribution of new builds and dry dock visits enabled the calculation of the number of EGCS installations as new builds and retrofits per year in the years between 2016 and 2050, regardless of other barriers preventing EGCS installations to be made. Also regardless of other barriers, the installation-engine size distribution for the years 2020, 2030 and 2050, respectively, is the sum of the annually made installations per engine size in the preceding years (unadjusted EGCS distributions).

However, as previously explained, the share of EGCS installations in the global fleet (> 5 MW) is assumed to be 28 % for the baseline and 56 % for the high case EGCS model run for 2050. Hence, the unadjusted EGCS distributions for 2020, 2030 and 2050 are iteratively scaled in order to make the sum of EGCS installations match 28 % and 56 % of the global fleet in 2050[9]. Table 4.1 shows the calculated global number of ships with EGCS installed in 2020, 2030 and 2050, and percentage shares of global fleet derived from the simple EGCS installation estimation.

Table 4.1 Estimated number of ships with EGCS installed in 2020, 2030 and 2050, and shares of global fleet.

	No. of ships > 5 MW, year ultimo		
	2020	2030	2050
Baseline/SECA scenario	4069	5857	8357
High share EGCS (SECA scenario)	5361	11181	16581
	% share of global fleet > 5 MW, year ultimo		
	2020	2030	2050
Baseline/SECA scenarios	14	20	28
High share EGCS (SECA scenario)	18	38	56

Figure 4.1 shows the fraction of ships with EGCS installed as a function of the installed ship main engine power. These fractions are used as input for the emission calculations made in the project.

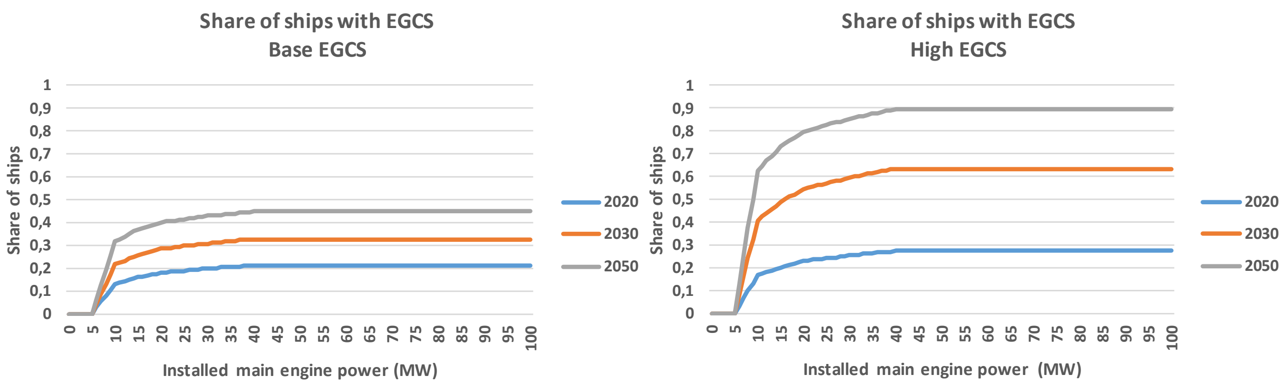


Figure 4.1 Share of ships with EGCS as a function of the installed ship main engine power.

[9] The scaling factor is interpreted as the additional barrier for EGCS installation as expected by the relevant stakeholders in shipping consulted in our project (c.f. above description of the "barrier probability factor", IMO (2016a)).

4.2 SECA scenario

In the SECA scenario, the existing SECA zones (i.e. America and North Sea / Baltic Sea SECA's) are expanded to cover the entire inventory area. The SECA scenario takes on board the shares of LNG fuel consumption of total fuel consumption and the shares of SO_x EGCS installations included in the Baseline scenario.

Further in the SECA scenario, the fuel is assumed to shift from HFO to MDO / MGO outside the existing SECA's by ships using HFO by origin (c.f. Table 2.1) and not having an EGCS installed. The emission impact of using EGCS is further assessed in a "high case EGCS" model run involving higher shares of EGCS installations on board ships.

4.3 HFO ban scenario

In the HFO ban scenario, use of HFO by ships is prohibited all across the inventory area. The HFO ban scenario includes the shares of LNG consumption of total fuel consumption as assumed in the baseline scenario. The remaining part of the HFO consumption by ships not being replaced by LNG, is assumed to be replaced by MGO / MDO for the entire inventory area.

5 Specific fuel consumption and emission factors

Generally, the specific fuel consumption and emission factors in g / kWh used to calculate the emissions from ships in this project are classified according to engine type, fuel type and engine production year.

MAN DIESEL & Turbo (2012) is the most prominent source for specific fuel consumption (sfc) and NO_x emission factors for slow- and medium-speed diesel engines used in the present study. With a global market share of 75 %, MAN Diesel & Turbo is by far the world's largest ship engine manufacturer. Hence in terms of representation, the emission factors from this source are well suited as input for inventory emission calculations comprising many ships.

For LNG, IMO (2015) is the source of sfc and emission factors.

5.1 Fuel

The standard curves for specific fuel consumption (sfc) factors on a fuel mass basis (g / kWh) related to the ISO 8178 test cycle are shown in Figure 5.1 for slow-, medium- and high-speed engines, as a function of engine production year. For engines produced until the mid-1990s, the sfc data come from the Danish TEMA 2000 model (Ministry of Transport, 2000). For newer engines, sfc data and expectations of sfc levels are provided by MAN Diesel & Turbo (2012). Slight energy efficiency improvements are expected for engines produced in the years between 2013 and 2016. For the years 2016+, the sfc values are expected to remain unchanged.

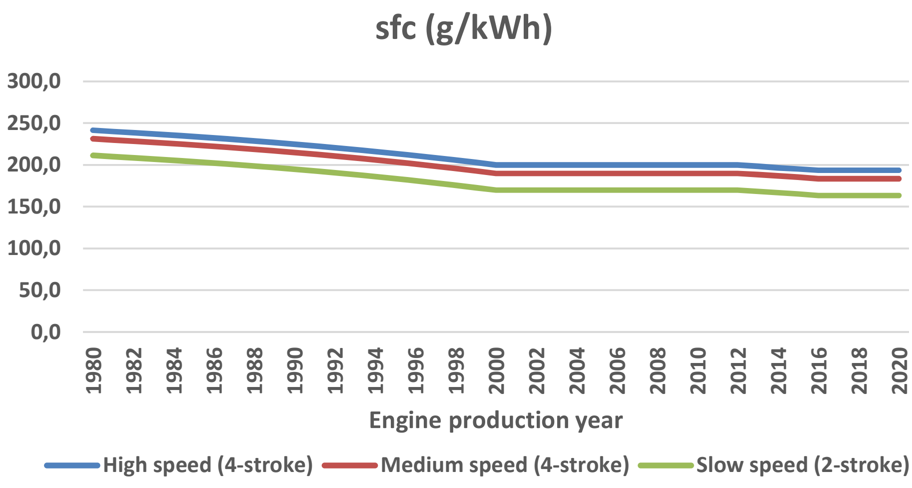


Figure 5.1 Specific fuel consumption for marine engines per engine production year (g/kWh).

Using the average engine life times, LT, listed in Table 2.1, by fuel mass the average sfc factors per vessel type, V, engine type, k, and inventory year, X, is calculated from:

$$sfc_{V,k,X} = \frac{\sum_{year=X}^{year=X-LT} sfc_{k,y}}{LT_{V,k}} \quad (1)$$

Where sfc = specific fuel consumption (g / kWh), X = inventory year, k = engine type, y = engine production year, LT = engine life time.

The calculation of specific fuel consumption (sfc) factors related to energy content of the fuel (MJ / kWh) is further stratified into fuel type, f. The following expression is used:

$$sfc_{V,k,f,X} = \frac{\sum_{year=X}^{year=X-LT} LHV_f \cdot sfc_{k,y} / 1000}{LT_{V,k}} \quad (2)$$

Where sfc = specific fuel consumption (MJ / kWh), LHV = Lower Heating Value (heavy fuel oil: 40.9 MJ / kg; diesel: 42.7 MJ / kg).

For LNG, a constant value of 166 g / kWh is used taken from IMO (2015).

5.2 NO_x

5.2.1 IMO emission regulations for NO_x

For seagoing vessels, NO_x emissions are regulated as explained in Marpol 73/78 Annex VI, formulated by IMO (International Maritime Organization), and further, amendments to MARPOL Annex VI has been agreed by IMO in October 2008. A three tiered emission regulation approach is considered, which comprises the following:

Tier I: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2000 and prior to 1 January 2011.

Tier II: Diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2011.

Tier III[10]: Diesel engines (> 130 kW) installed on a ship constructed on or after1 January 2016 operating in the North American ECA or the United States Carribean Sea ECA and diesel engines (> 130 kW) installed on a ship constructed on or after 1 January 2021 operating in the Baltic Sea and North Sea ECAs.

The NO_x emission limits for ship engines in relation to their rated engine speed (n) given in RPM (Revolutions Per Minute) are shown in Table 5.1.

Table 5.1 Tier I-III NO_x emission limits for ship engines (amendments to MARPOL Annex VI).

RPM	NO_x limit (g/kWh)		
	Tier I	Tier II	Tier III
N < 130	17	14.4	3.4
130 ≤ n < 2000	45 x n-0.2	44 x n-0.23	9 x n-0.2
N ≥ 2000	9.8	7.7	2

10 For ships operating in a designated NO_x Emission Control Area (NECA). Outside a NECA, Tier II limits apply.

Following the IMO emission regulations, the NO_x Tier I limits are also to be applied for existing engines with a power output higher than 5000 kW and a displacement per cylinder at or above 90 litres, installed on a ship constructed on, or after 1 January 1990 but prior to 1 January 2000.

5.2.2 NO_x emission factors

The NO_x emission factors (g / kWh) for slow- and medium-speed engines are provided by MAN DIESEL (2012). The data are shown in Figure 3 for the engine production years 1980-2020, together with NO_x emission factors for high-speed engines. The emission information for high-speed engines comes from the Danish TEMA2000 emission model (Ministry of Transport, 2000) by assuming that these engines produce 1 g less NO_x per kWh compared with medium speed engines. This assumption is used for future years also.

The increase in engine fuel efficiency up to 2000 caused the NO_x emission factors to increase. However, at the beginning of the 1990s (slow-speed engines) and by the end of the 1990s (medium-speed engines), NO_x emission performance is improved, mainly due to improved engine design. The emission improvements are of a sufficient size to enable the IMO Tier I NO_x emission requirements in 2000 to be met. For engines that have to be in compliance with Tier III emission standards in NECA areas, emission factors are estimated by reducing the Tier I emission factors (2000-2010) with 80 %, corresponding with the Tier III:Tier I percentage reduction from IMO limits.

The emission factors in Figure 5.2 on next page are shown for NECA areas as well as outside NECA. The present study includes the American ECA area above 60 degrees North that extends up to 200 nautical miles from coasts of the United States, Canada and the French territories, and the North Sea / Baltic Sea NECA area (ships constructed on or after 1.1.2021) within the boundaries of the North Sea / Baltic Sea SECA.

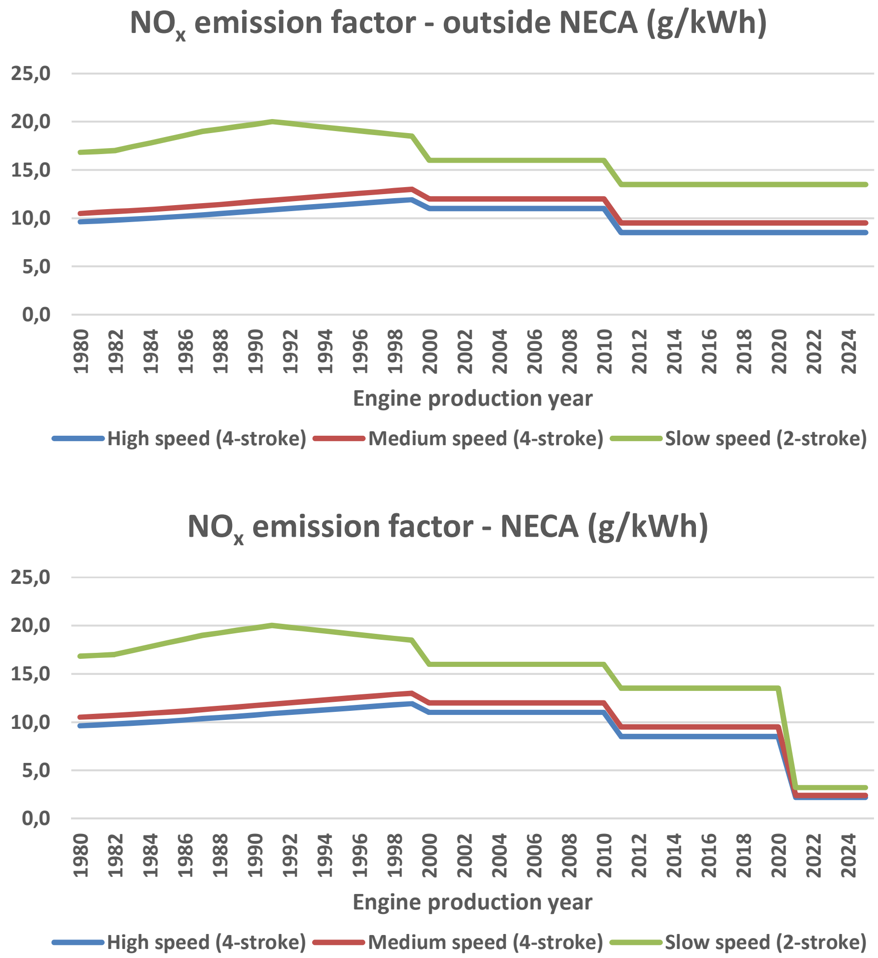


Figure 5.2 NO_x emission factors for marine engines per engine production year (g/kWh).

For LNG a constant value of 1.3 g / kWh is used taken from IMO (2015).

5.3 SO_2

5.3.1 Fuel sulphur regulations

Table 5.2 shows the current IMO fuel sulphur legislation in force (MARPOL Annex VI, Regulation 14 plus amendments), related to fuel oil used by ship engines. In sulphur emission control areas (SECA), the fuel sulphur limit for fuel oil was 1.5 % until 1 March 2010 for the Baltic Sea / North Sea and until 1 July 2010 for North America. By 1 January 2010 and 1 January 2015, the fuel sulphur limit was lowered to 1.0 % and 0.1 %, respectively, according to the legislation.

Outside the SECAs, the global fuel oil sulphur limit was 4.5 % until 1 January 2012. From 1 January 2012, the fuel sulphur limit was reduced to 3.5 %. From 1 January 2020, the fuel oil sulphur limit will be further reduced to 0.5 %.

Table 5.2 MARPOL Annex VI fuel sulphur regulations for heavy fuel oil used by ship engines.

Area	S %	Implementation date
SECA – Baltic sea/North Sea	1.5	Until 1.3.2010
SECA – America	1.5	Until 1.7.2010
SECA – Baltic sea/North Sea	1.0	From 1.3.2010
SECA – America	1.0	From 1.7.2010
All SECA's	0.1	1.1.2015
Outside SECA	4.5	Until 2012
Outside SECA	3.5	1.1.2012
Outside SECA	0.5	1.1.2020

5.3.2 Fuel sulphur content in the current inventory

HFO fuelled ships with EGCS

In the current inventory (Baseline and SECA scenarios), the ships with EGCS installed are assumed to continuously be using HFO with a fuel sulphur content of 2.45 % (Fs = 2.45 %), as monitored by IMO (2016b) for 2015. By assumption, the EGCS sulphur removal efficiency is equivalent to Fs = 0.1 %. EGCS systems are included in the emission projections from 2020 onwards (c.f. Chapter 4).

HFO fuelled ships without EGCS

Inside SECA's, the ships without EGCS using HFO by origin (historical years 2015/2016, and all scenario years) are assumed to shift fuel from HFO to MDO/MGO (c.f. Chapter 2). In 2012-2014, these ships are assumed to be using 1.0 % fuel oil inside SECA's.

Outside SECA's - in historical years as well as in Baseline forecast years – ships without EGCS continue to use HFO with Fs corresponding to the IMO monitoring levels for 2012-2015, 2.45 % for 2016-2019 and 0.5 % fuel oil from 2020 onwards (Tables 5.3 and 5.4). Outside SECA's, in the SECA and HFO ban scenarios, these ships are assumed to shift fuel from 0.5 % fuel oil to MDO/MGO.

MDO/MGO fuelled ships

For MDO/MGO, the fuel sulphur content used in the present inventory reduces from 0.14 % in 2012 to 0.08 % in 2015, as monitored by IMO (2016b). From 2015 onwards, the fuel sulphur content is kept at 0.08 % (Tables 5.3 and 5.4).

Table 5.3 Sulphur content of fuels used in the present inventory for 2012-2016.

Fuel/Area	2012	2013	2014	2015	2016
1.0 % fuel oil SECA	1	1	1	Fuel shift to MDO/MGO	
HFO outside SECA	2.51	2.43	2.46	2.45	2.45
MDO/MGO	0.14	0.13	0.12	0.08	0.08
non-SECA limit	3.5	3.5	3.5	3.5	3.5

Table 5.4 Fs and removal efficiency equivalent Fs eq. of fuels used in the present inventory for 2020, 2030 and 2050.

	Fuel/Area	Area	Fs (2020, 2030, 2050)	Comment
Baseline	HFO (with EGCS)	SECA	2.45 %	Fs eq. = 0.1 %
	HFO (with EGCS)	Non SECA	2.45 %	Fs eq. = 0.1 %
	Fuel oil (without EGCS)	SECA	(0.1 %)	Fuel shift to MDO/MGO
	Fuel oil (without EGCS)	Non SECA	0.5 %	-
	MDO/MGO		0.08 %	-
	LNG		0	-
SECA scenario	HFO (with EGCS)	SECA	2.45 %	Fs eq. = 0.1 %
	Fuel oil (without EGCS)	SECA	(0.1 %)	Fuel shift to MDO/MGO
	MDO/MGO	SECA	0.08	-
	LNG	SECA	0	-
HFO ban	MDO/MGO		0.08	-
	LNG		0	-

In order to obtain emission factors in g / kWh, the fuel sulphur percentages from the Tables 5.3 and 5.4 are inserted in the following expression:

$$EF\,(SO_2) = \frac{2 \cdot Fs \cdot sfc}{100} \quad (3)$$

Where EF = emission factor in g / kWh, Fs = fuel sulphur %, and sfc = specific fuel consumption in g / kWh. The sfc factor is taken from equation 1.

Equation 3 uses 2.0 kg SO_2 / kg S, the chemical relation between burned sulphur and generated SO_2 provided in EMEP / EEA (2016).

5.4 PM

The PM emissions for diesel fuelled ship engines are taken from IMO (2015) and rely on sfc and the fuel sulphur content, S%. PM emission factors in g / kWh for HFO and MDO / MGO, respectively, are calculated from the following expressions (4) and (5):

$$EF_{HFO,PM}\,(g\,/\,kWh) = 1.35 + (sfc \cdot 7 \cdot 0.02247 \cdot (S\%/100 - 0.0246)) \quad (4)$$

$$EF_{MDO,PM}\,(g\,/\,kWh) = 0.23 + (sfc \cdot 7 \cdot 0.02247 \cdot (S\%/100 - 0.0024)) \quad (5)$$

The sfc factor (g / kWh) is taken from equation 1.

For LNG, a constant value of 0.03 g / kWh is used taken from IMO (2015).

For EGCS, an average 60 % reduction of the PM emissions for HFO is assumed based on the available literature. Reduction rates of 60 % - 80 % are proposed by ICCT (2017) whereas average measured PM emission reduction rates by MST (2012) are around 45 %.

5.5 BC

The BC emission factors are regarded as very uncertain as indicated by the large variations in the emission factors published until now in the international literature (e.g. Lack & Corbett, 2012).

The BC emission factor of 0.35 g/kg fuel suggested by Corbett et al. (2010) regardless of fuel type was used in our previous Arctic emission inventory (Winther et al., 2014) and in numerous other inventory projects (e.g. Peters et al. (2011), Dalsøren et al. (2012), Ødemark et al. (2012) and Browse et al. (2013)). However, during the time after our previous inventory, the Corbett factor has been criticized for being too high and for disregarding fuel type as a parameter for BC emissions as well.

Fostered by the need for more knowledge in relation to maritime BC emissions, an international research project was initiated by the ICCT (International Council of Clean Transport) with participation from engine manufacturers, measurement laboratories, emission inventory compilers and policy experts[11] (e.g. ICCT, 2014). The research project was informed and guided by three workshops in order to obtain a solid understanding of the current state of knowledge on BC measurement and testing, emissions inventories, and control strategies for marine vessels, to work toward consensus on a standardized measurement and reporting approach for maritime BC emissions, and to solidify recommendations for marine BC measurement approaches, and to identify effective technological and operational strategies to control BC from marine engines.

Evidence presented at the third ICCT workshop suggests that shifting from conventional HFO to distillate fuels such as MGO can reduce BC emissions (ICCT, 2016). From the measurement results presented at the workshop, it was also concluded that the general BC emission levels for ship engines are much lower than the often cited Corbett factor of 0.35 g/kg fuel regardless of fuel type.

The workshop conclusions in terms of general BC emission levels and the size order of the BC emission factors for HFO and MDO are in good accordance with the fuel type specific measurement results for HFO (2.5 % S), IFO (Intermediate Fuel Oil; 0.5 % S)[12] and MDO (0.1 % S) made by Aakko-Saksa et al. (2016) and presented at the workshop. For all three fuel types tested, Aakko-Saksa et al. (2016) measure considerably lower BC emissions, and measure the smallest emissions from MDO and IFO compared to the emissions from 2.5 % HFO.

Findings by Lack and Corbett (2012) and Lack (2016) also support the size order of the BC emission factors measured by Aakko-Saksa (2016). Without attempting to quantify specific emission factors for BC, Lack (2016) concludes "Despite a range of values across 20 studies, the balance of evidence suggest that a shift from low quality high sulphur residual fuels to high quality low sulphur distillate fuels will result in a 50 % reduction in BC emissions".

[11] The research project was funded by the Climate and Clean Air Coalition (CCAC) and implemented jointly by the International Council on Clean Transportation (ICCT) and the United Nations Environment Program (UNEP).
[12] IFO (Intermediate Fuel Oil) is a fuel type, which is likely to be commercially available as a substitute for high sulphur HFO fuels, when the global 0.5 % fuel sulphur limits come into force in 2020.

Besides being in agreement with the general workshop measurement conclusions and the important BC emissions review work made by Lack and Corbett (2012) and Lack (2016), the Aakko-Saksa et al. (2016) study is well documented and peer reviewed work. In addition, Aakko-Saksa et al. (2016) report BC emission factors for the same fuel types (and similar fuel sulphur contents) that we include in the present study. All together, these are good reasons to select the BC emission factors from Aakko-Saksa et al. (2016) as input factors in the present emission inventory. However, due to the general uncertainty of BC emissions factors and the level of impact from the different factors that influences the emissions of BC from ship engines, additional measurement research is needed in this field. In this way, BC formation is influenced by many variables such as fuel properties (e.g. hydrogen / carbon ratio), fuel blend composition for lower sulphur hybrid fuels (residual and light fraction blends), engine type, engine IMO Tier standard and engine load (e.g. ICCT, 2016). Any new data arriving on BC emission factors will be carefully assessed in future shipping emission projects for possible inclusion in updated emission inventory calculations.

The emission factors from Aakko-Saksa et al. (2016) for 2.5 % HFO, 0.5 % IFO and 0.1 % MDO are shown in Table 5.5. The emission factors are measured on a lab engine with the filter smoke number (FSN) method and represent an engine load of 75 %. We use the measured 2.5 % HFO emission factor to represent the BC emissions for 2.45 % HFO in our project, and by assumption we let the same emission factor represent the emission factor for 1.0 % fuel oil. Further, the measured 0.5 % IFO emission factor represents 0.5 % fuel oil in our study.

Table 5.5 Emission factors for BC used in the present project.

Fuel type, measured	Fuel type, this study	EFBC (g/kg fuel)
HFO (Fs =2.5 %)	2.45 % HFO/1.0 % fuel oil	0.155
IFO (Fs = 0.5 %)	0.5 % fuel oil	0.065
MDO (Fs = 0.1 %)	MDO/MGO	0.056
	LNG	0.00155

For EGCS, due to the limited data available so far, BC reduction rates are still somewhat uncertain. An average 40 % reduction of the BC emissions for HFO is assumed (i.e. 0.093 g / kg fuel) based on the following sources. Reduction rates of 45 % - 50 % are proposed by ICCT (2015). Lack and Corbett (2012) suggest reduction rates between 40-70 % based on an extensive literature review, and Johnson et al. (2016) measured a BC reduction rate of 30 % on a large ocean going vessel.

For LNG, a BC emission factor of 0.00155 g / kg fuel (Table 5.5.) is used derived as 1 % of the BC emissions for HFO suggested by ICCT (2015).

The emission factors for BC in g / kg fuel are transformed into g / kWh by multiplying with sfc / 1000, as shown in expression (6).

Subsequently, the BC emission factor in g / kWh is found from:

$$EF_{BC}(g/kWh) = \frac{EF_{BC}(g/kgfuel) \cdot sfc}{1000} \quad (6)$$

5.6 CO, VOC, NMVOC and CH_4

For diesel engines, the emission factors of CO and VOC come from TEMA2000, and originates from the emission measurement programme carried out by Lloyds (1995). A split of VOC into NMVOC and CH_4 (3 % of VOC) is taken from EMEP / EEA (2009). For CO, substantial (linear) emission factor reductions are expected for the years between 2013 and 2016, due to energy efficiency improvements for new engines (MAN Diesel & Turbo, 2012).

For LNG, the emission factors come from IMO (2015).

The CO and VOC emission factors are given in the following Table 5.6.

Table 5.6 CO, VOC, NMVOC and CH_4 emission factors used in the present study.

	Year	Slow speed (g/kWh)	Medium speed (g/kWh)	High speed (g/kWh)	LNG (g/kWh)
CO	Until 2013	1.6	1.6	1.6	1.3
CO	2013-2016	1.4-0.8	1.4-0.8	1.4-0.8	1.3
VOC	All years	0.5	0.5	0.5	9.0
NMVOC	All years	0.485	0.485	0.485	0.5
CH4	All years	0.015	0.015	0.015	8.5

5.7 OC

The emission factors of OC used in the present study are taken from Corbett et al. (2010). The latter source use PM emission factor information taken from the second IMO GHG Study 2009 (Buhaug et al., 2009) and OC fractions of PM based on the findings from Lack et al. (2008, 2009).

Corbett et al. (2010) finds OC emission factors to be fuel sulphur dependent, and OC factors are found to vary between 1.07 and 0.39 g / kg fuel, for a sulphur content range between 2.7 % and 0.5 %, also based on Lack et al. (2008, 2009). In the present study, it is decided to use a factor of 1.07 g / kg fuel for 2.5 % HFO and 0.39 g OC / kg fuel for 0.5 % HFO and for MDO in general.

The emission factors for OC in g / kg fuel are transformed into g / kWh by multiplying with sfc / 1000, as shown in expression (5).

For LNG, no emissions are estimated for OC.

5.8 CO_2

The mass based CO_2 emission factor per fuel type shown in Table 5.7, is found as the product of the fuel type specific lower heating value (LHV) and the energy related CO_2 emission factor.

For LNG, the CO_2 emission factor of 2750 g / kg fuel is used taken from IMO (2015).

The CO_2 emission factors are given in the following Table 5.7.

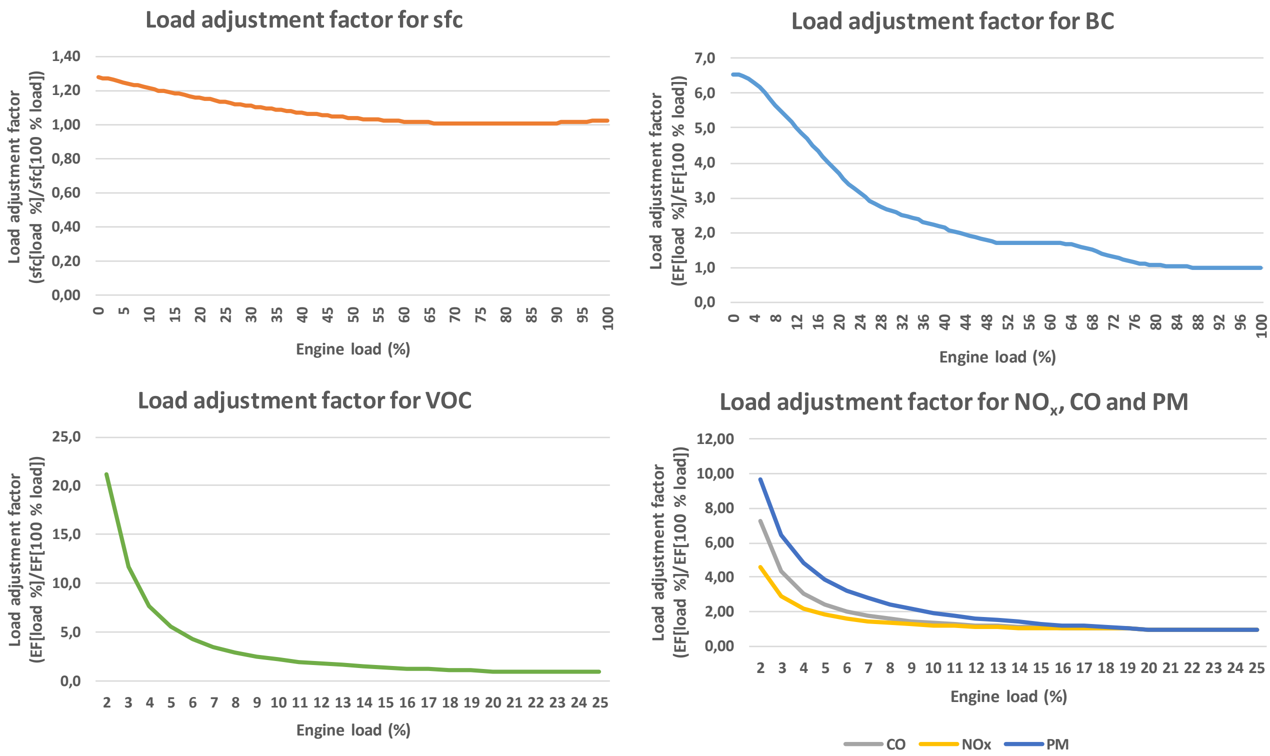
Table 5.7 CO_2 emission factors used in the present study.

Fuel type	LHV (MJ/kg)	$EFCO_2$ (g/MJ)	$EFCO_2$ (g/kg fuel)
HFO	40.9	78	3190
MDO/MGO	42.7	74	3160
LNG	47.9	57.4	2750

The emission factors for CO_2 in g / kg fuel are transformed into g / kWh by multiplying with sfc / 1000, as shown in expression (5).

5.9 Engine load adjustment factors

Specific fuel consumption (sfc) and emission factors are found to vary with engine load, and engine load adjustment factors, LAF, need to be established. For sfc and NO_x, N_2O, CO, VOC and PM engine load, adjustment functions are provided by IMO (2015) based on Starcrest (2014), see Figure 5.3. For BC, the engine load adjustment curve shown in Figure 5.3 is provided by Lack (2016) as published in Lack and Corbett (2012).



sfc: $0.455 \cdot (load(\%)/100)^2 - 0.71 \cdot (load(\%)/100) + 1.28$

VOC: $0.0667 \cdot (load(\%)/100)^{-1.5} + 0.3859$, load % ≥ 2

NO_x: $0.1255 \cdot (load(\%)/100)^{-1.5} + 10.4496$, load % ≥ 2

CO: $0.8378 \cdot (load(\%)/100)^{-1.0} + 0.1458$, load % ≥ 2

PM: $0.0059 \cdot (load(\%)/100)^{-1.5} + 0.2551$, load % ≥ 2

Figure 5.3 Load adjustment factor curves for sfc, BC, NOx, CO, VOC and PM.

The effective emission factor for the emission component i, EF_i, is calculated as the product of the base emission factor , $EF_{base,i}$ (described in the sections 5.2-5.8) and the load adjustment factor, LAF_i (Figure 5.3).

$$EF_i = EF_{base,i} \cdot LAF_i \quad (7)$$

The engine load is found for each data record in the traffic data provided by DMA (Section 2.1). The engine load is calculated as the ratio between main engine kW produced by the specific ship type / LPP class at the specific sailing speed and the design power for the specific ship type / LPP class (see Chapter 3).

For fuel consumption, the effective sfc factor is found using expression (7) also. The base specific fuel consumption factors, sfc_{base} are described in section 5.1 and the LAF factor is given in Figure 5.3.

5.10 Fuel related emission factors derived from inventory results

Based on the fuel and emission results presented in Chapter 7, fuel related emission factors are derived for 2012-2016 (Table 5.8) as well as for the projection years in the Baseline (Table 5.9), SECA (Table 5.10) and HFO ban (Table 5.11) scenarios. The emission factors for 2012-2016 and the Baseline scenario are broken down into SECA and Non SECA parts of the inventory area.

Table 5.8 Fuel related emission factors for 2012-2016.

Year	Area	Fuel type	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
			kTonnes	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
2012	SECA	1.0 % fuel oil	1602	20.00	3190	74.73	2.69	8.38	0.08	0.224	1.070	4.65	0.16
2012	SECA	MDO/MGO	397	2.80	3160	56.79	2.50	7.89	0.08	0.071	0.390	0.91	0.16
2012	Non SECA	HFO	857	50.20	3190	80.09	2.72	8.49	0.08	0.208	1.070	7.10	0.16
2012	Non SECA	MDO/MGO	1911	2.80	3160	57.11	2.45	7.81	0.07	0.074	0.390	0.97	0.16
2012	Grand Total		4768	17.10	3175	67.14	2.59	8.13	0.08	0.148	0.741	3.30	0.16
2013	SECA	1.0 % fuel oil	1530	20.00	3190	74.22	2.72	8.41	0.08	0.221	1.070	4.69	0.16
2013	SECA	MDO/MGO	431	2.60	3160	56.78	2.52	7.91	0.08	0.071	0.390	0.92	0.16
2013	Non SECA	HFO	970	48.60	3190	82.43	2.82	8.68	0.08	0.208	1.070	7.11	0.16
2013	Non SECA	MDO/MGO	2119	2.60	3160	57.22	2.47	7.83	0.07	0.074	0.390	0.96	0.16
2013	Grand Total		5050	16.71	3175	67.17	2.62	8.18	0.08	0.144	0.727	3.27	0.16
2014	SECA	1.0 % fuel oil	1568	20.00	3190	74.91	2.75	8.43	0.08	0.223	1.070	4.75	0.16
2014	SECA	MDO/MGO	529	2.40	3160	56.83	2.53	7.87	0.08	0.071	0.390	0.92	0.16
2014	Non SECA	HFO	1405	49.20	3190	86.37	2.87	8.79	0.09	0.187	1.070	7.33	0.16
2014	Non SECA	MDO/MGO	2786	2.40	3160	57.40	2.50	7.83	0.07	0.075	0.390	0.95	0.16
2014	Grand Total		6287	17.24	3174	68.19	2.65	8.20	0.08	0.137	0.711	3.32	0.16
2015	SECA	MDO/MGO	2141	1.60	3160	70.12	2.72	8.23	0.08	0.079	0.390	0.94	0.16
2015	Non SECA	HFO	1040	49.00	3190	82.66	2.92	8.73	0.09	0.220	1.070	7.27	0.16
2015	Non SECA	MDO/MGO	3401	1.60	3160	57.50	2.51	7.77	0.08	0.075	0.390	0.89	0.16
2015	Grand Total		6582	9.09	3165	65.58	2.64	8.07	0.08	0.099	0.497	1.92	0.16
2016	SECA	MDO/MGO	2238	1.60	3160	70.03	2.73	8.13	0.08	0.078	0.390	0.95	0.16
2016	Non SECA	HFO	928	49.00	3190	81.00	2.87	8.49	0.09	0.231	1.070	7.23	0.16
2016	Non SECA	MDO/MGO	2241	1.60	3160	57.51	2.51	7.66	0.08	0.074	0.390	0.90	0.16
2016	Grand Total		5407	9.74	3165	66.73	2.66	8.00	0.08	0.103	0.507	2.01	0.16

Table 5.9 Fuel related emission factors for the Baseline scenario.

Year	Area	Fuel type	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
			kTonnes	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
2020	SECA	HFO + EGCS	234	2.00	3190	69.84	2.66	7.55	0.08	0.128	1.070	2.66	0.15
		LNG	68	0.00	2750	7.83	54.22	7.83	51.21	0.001	0.000	0.18	0.11
		MDO/MGO	1851	1.60	3160	69.83	2.66	7.52	0.08	0.071	0.390	0.94	0.16
2020	Non SECA	0.5 % fuel oil	947	10.00	3190	81.85	2.82	7.95	0.08	0.082	1.070	4.42	0.16
		HFO + EGCS	110	2.00	3190	80.17	2.82	7.93	0.08	0.127	1.070	2.88	0.16
		LNG	45	0.00	2750	7.83	54.22	7.83	51.21	0.001	0.000	0.18	0.11
		MDO/MGO	2408	1.60	3160	57.41	2.56	7.26	0.08	0.074	0.390	0.93	0.16
	Grand Total		5664	3.00	3159	65.52	3.68	7.50	1.10	0.076	0.537	1.61	0.16
2030	SECA	HFO + EGCS	343	2.00	3190	50.68	2.76	6.37	0.08	0.127	1.070	2.78	0.15
		LNG	138	0.00	2750	7.83	54.22	7.83	51.21	0.001	0.000	0.18	0.11
		MDO/MGO	1769	1.60	3160	49.83	2.75	6.33	0.08	0.071	0.390	0.99	0.16
2030	Non SECA	0.5 % fuel oil	930	10.00	3190	76.49	2.92	6.71	0.09	0.081	1.070	4.71	0.16
		HFO + EGCS	163	2.00	3190	74.85	2.92	6.68	0.09	0.127	1.070	3.00	0.16
		LNG	93	0.00	2750	7.83	54.22	7.83	51.21	0.001	0.000	0.18	0.11
		MDO/MGO	2340	1.60	3160	54.29	2.64	6.09	0.08	0.074	0.390	0.97	0.16
	Grand Total		5775	2.92	3151	55.01	4.80	6.36	2.13	0.076	0.543	1.71	0.15
2050	SECA	HFO + EGCS	522	2.00	3190	15.72	2.82	4.50	0.08	0.127	1.070	2.87	0.15
		LNG	300	0.00	2750	7.83	54.22	7.83	51.21	0.001	0.000	0.18	0.11
		MDO/MGO	1751	1.60	3160	15.55	2.81	4.49	0.08	0.070	0.390	1.02	0.16
2050	Non SECA	0.5 % fuel oil	971	10.00	3190	74.32	2.98	4.73	0.09	0.080	1.070	4.88	0.16
		HFO + EGCS	248	2.00	3190	72.27	2.97	4.69	0.09	0.126	1.070	3.07	0.16
		LNG	205	0.00	2750	7.83	54.22	7.83	51.21	0.001	0.000	0.18	0.11
		MDO/MGO	2313	1.60	3160	50.74	2.68	4.29	0.08	0.074	0.390	0.98	0.16
	Grand Total		6310	2.81	3135	39.12	6.91	4.73	4.17	0.074	0.546	1.77	0.15

Table 5.10 Fuel related emission factors for the SECA scenario.

Year	Fuel type	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
		kTonnes	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
2020	HFO + EGCS	344	2.00	3190	73.13	2.71	7.67	0.08	0.128	1.070	2.73	0.15
	LNG	113	0.00	2750	7.83	54.22	7.83	51.21	0.001	0.000	0.18	0.11
	MDO/MGO	5206	1.60	3160	66.28	2.64	7.48	0.08	0.072	0.390	0.95	0.16
	Total	5664	1.59	3153	65.52	3.68	7.50	1.10	0.074	0.424	1.04	0.16
2030	HFO + EGCS	506	2.00	3190	58.47	2.81	6.47	0.08	0.127	1.070	2.85	0.15
	LNG	231	0.00	2750	7.83	54.22	7.83	51.21	0.001	0.000	0.18	0.11
	MDO/MGO	5038	1.60	3160	56.82	2.73	6.29	0.08	0.071	0.390	0.99	0.16
	Total	5775	1.57	3146	55.01	4.80	6.36	2.13	0.074	0.434	1.12	0.15
2050	HFO + EGCS	770	2.00	3190	33.91	2.87	4.56	0.09	0.127	1.070	2.93	0.15
	LNG	505	0.00	2750	7.83	54.22	7.83	51.21	0.001	0.000	0.18	0.11
	MDO/MGO	5035	1.60	3160	43.06	2.78	4.44	0.08	0.071	0.390	1.02	0.16
	Total	6310	1.52	3131	39.12	6.91	4.73	4.17	0.072	0.442	1.18	0.15

Table 5.11 Fuel related emission factors for HFO ban scenario.

Year	Area	Fuel type	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
			kTonnes	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
2020		LNG	113	0.00	2750	7.83	54.22	7.83	51.21	0.001	0.000	0.18	0.11
		MDO/MGO	5551	1.60	3160	66.70	2.64	7.49	0.08	0.072	0.390	0.95	0.16
		Total	5664	1.57	3152	65.52	3.68	7.50	1.10	0.070	0.382	0.93	0.16
2030		LNG	231	0.00	2750	7.83	54.22	7.83	51.21	0.001	0.000	0.18	0.11
		MDO/MGO	5544	1.60	3160	56.97	2.74	6.30	0.08	0.072	0.390	0.99	0.16
		Total	5775	1.54	3143	55.01	4.80	6.36	2.13	0.069	0.374	0.96	0.15
2050		LNG	505	0.00	2750	7.83	54.22	7.83	51.21	0.001	0.000	0.18	0.11
		MDO/MGO	5805	1.60	3160	41.84	2.80	4.46	0.08	0.071	0.390	1.02	0.16
		Total	6310	1.47	3127	39.12	6.91	4.73	4.17	0.066	0.359	0.95	0.15

6 Calculation method

For each inventory year, X, and for each combination of ship type, engine type, fuel type and LPP length interval, the work produced by the ship engine during the sailing distance, D, and the vessel average speed, V, is calculated as:

$$W_{S,f,k,l}(X) = P_{S,f,k,l} \cdot (100 - EEDIf_S(X))/100 \cdot D_{S,l}(X)/V_{S,l} \quad (8)$$

Where W = Engine work produced in kWh, S = ship type, f = fuel type, k = engine type, l = LPP length interval, P = Engine power in kW, D = Distance in NM and V = Vessel average speed in knots provided by DMA (Section 2.1), and EEDIf = Energy Efficiency Design Index factor (Table 3.1).

The engine power is estimated with the SHIP-DESMO model (Kristensen, 2012) by using ship type, LPP and vessel average speed as input parameters (Chapter 3).

The fuel consumption and the emissions are calculated as:

$$E_{S,i}(X) = \sum_{f,k,l} W_{S,f,k,l}(X) \cdot EF_{i,f,k}(X) \cdot LAF_i \quad (9)$$

EF_i = Fuel consumption or emission factor in g / kWh and LAF = engine load adjustment factor (Section 5.9).

7 Fuel consumption and emission results

7.1 Results for 2012-2016

Table 7.1 shows the sailed distance, engine kWh's produced, total fuel consumption (by mass and energy), BC, NO_x and SO_2 emission results per ship type for the inventory area in 2012-2016. The calculated emission results for CO, VOC, OC, CO_2, CH_4 and N_2O can be seen in the annex section of this report.

Table 7.1 Results per ship type calculated for the inventory area in 2012-2016.

Year	Vessel type	Distance km x 10^6	Power kWh x 10^6	Fuel kTonnes	Fuel TJ	SO_2 Tonnes	NO_x Tonnes	BC Tonnes
2012	Bulk carrier	4.49	1027	193	7876	7358	18080	39
2012	Container ship	5.88	1178	223	9118	6393	20818	47
2012	Crude oil tanker	1.44	541	102	4166	2530	9560	22
2012	Fast ferry	0.19	8	2	70	5	87	0
2012	Fishing ship	28.98	9644	1985	84763	5558	113382	150
2012	Gas tanker	0.86	194	36	1484	1415	3415	6
2012	General cargo ship	29.89	2224	430	17588	13621	39598	106
2012	Oil products & chemical tanker	10.78	1904	357	14621	11907	33706	72
2012	Other ship	5.75	633	131	5427	3957	7510	17
2012	Passenger ship	10.06	1749	366	15118	9687	20752	66
2012	Ro-ro cargo ship	3.24	755	158	6469	3398	8954	31
2012	Ro-ro passenger ship	15.20	2928	624	25625	14183	35023	135
2012	Support ship	13.09	774	162	6843	1531	9222	16
2012	Grand Total	129.87	23558	4768	199168	81542	320105	708
2013	Bulk carrier	4.66	1066	200	8176	7642	18687	42
2013	Container ship	5.48	1089	206	8415	5961	19130	45
2013	Crude oil tanker	1.44	520	98	4006	2600	9143	21
2013	Fast ferry	0.20	16	3	136	8	165	0
2013	Fishing ship	31.82	10744	2197	93830	5713	125851	166
2013	Gas tanker	0.74	156	29	1191	1065	2732	5
2013	General cargo ship	28.02	2580	491	20072	16730	45629	112
2013	Oil products & chemical tanker	10.94	2016	376	15388	13037	35542	77
2013	Other ship	8.91	601	125	5222	2593	7181	17
2013	Passenger ship	10.47	2358	491	20217	12015	27939	90
2013	Ro-ro cargo ship	2.72	648	135	5535	2800	7665	28
2013	Ro-ro passenger ship	12.73	2489	524	21532	12521	29634	107
2013	Support ship	13.54	846	176	7432	1689	9951	18
2013	Grand Total	131.66	25129	5050	211151	84373	339249	727
2014	Bulk carrier	4.86	1127	210	8600	8094	19709	46
2014	Container ship	5.52	1062	200	8176	5811	18562	45
2014	Crude oil tanker	1.55	549	103	4201	2850	9569	22
2014	Fast ferry	0.27	21	4	183	33	232	0
2014	Fishing ship	38.68	14220	2890	123388	6935	165904	218
2014	Gas tanker	0.85	205	38	1549	1347	3557	6
2014	General cargo ship	30.29	3719	697	28508	26237	65201	149
2014	Oil products & chemical tanker	11.61	3407	624	25520	24828	59238	108
2014	Other ship	11.16	809	167	6989	3833	9736	22
2014	Passenger ship	11.61	2265	469	19349	11103	26723	85
2014	Ro-ro cargo ship	2.67	626	130	5332	2677	7379	28
2014	Ro-ro passenger ship	14.26	2615	546	22485	12669	31042	109
2014	Support ship	17.10	1011	209	8838	2004	11887	20

Continued								
2014	Grand Total	150.43	31636	6287	263118	108423	428740	859
2015	Bulk carrier	4.87	1081	201	8352	6227	18645	34
2015	Container ship	5.44	1017	191	8017	3465	17606	25
2015	Crude oil tanker	1.70	579	108	4556	1434	10045	13
2015	Fast ferry	0.32	11	2	91	3	115	0
2015	Fishing ship	46.25	17387	3510	149885	5616	201976	265
2015	Gas tanker	1.01	251	46	1918	1321	4315	6
2015	General cargo ship	33.89	2627	502	21034	11216	46094	85
2015	Oil products & chemical tanker	12.70	2592	476	19854	13174	44843	64
2015	Other ship	11.55	730	151	6337	2597	8691	17
2015	Passenger ship	13.82	2543	524	22161	6773	29917	55
2015	Ro-ro cargo ship	2.75	624	129	5513	451	7337	11
2015	Ro-ro passenger ship	15.97	2607	544	23047	5999	30879	60
2015	Support ship	17.98	958	198	8400	1564	11172	19
2015	Grand Total	168.25	33006	6582	279165	59842	431636	652
2016	Bulk carrier	4.73	1083	199	8296	6137	18466	33
2016	Container ship	5.23	1008	188	7895	3513	17312	25
2016	Crude oil tanker	1.97	680	125	5286	2101	11661	16
2016	Fast ferry	0.76	33	7	283	11	353	0
2016	Fishing ship	38.24	12100	2427	103635	3883	139903	183
2016	Gas tanker	1.01	258	47	1957	1389	4398	6
2016	General cargo ship	33.96	2806	532	22299	11379	48467	87
2016	Oil products & chemical tanker	11.48	1996	366	15355	7522	34165	47
2016	Other ship	6.83	441	91	3836	1443	5110	12
2016	Passenger ship	14.85	2610	534	22593	6677	30479	55
2016	Ro-ro cargo ship	2.78	642	132	5606	611	7484	11
2016	Ro-ro passenger ship	18.33	2855	591	25031	6667	33668	65
2016	Support ship	15.29	821	168	7152	1328	9352	16
2016	Grand Total	155.46	27335	5407	229223	52660	360819	556

Table 7.2 shows the sailed distance, engine kWh's produced, total fuel consumption (by mass and energy), BC, NO_x and SO_2 emission results calculated for the inventory area in 2012-2016 and grouped according to fuel type and sea area (SECA / Non SECA). The calculated emission results for CO, VOC, OC, CO_2, CH_4 and N_2O can be seen in the annex section of this report.

Table 7.2 Results per fuel type and sea area (SECA/Non SECA) calculated for the inventory area in 2012-2016.

Year	Area	Fuel type	Distance km x 10^6	Power kWh x 10^6	Fuel kTonnes	Fuel TJ	SO_2 Tonnes	NO_x Tonnes	BC Tonnes
2012	SECA	1.0 % fuel oil	44	7984	1602	65522	32040	119722	359
2012	SECA	MDO/MGO	19	1925	397	16962	1112	22558	28
2012	Non SECA	HFO	27	4366	857	35065	43038	68667	178
2012	Non SECA	MDO/MGO	39	9283	1911	81621	5352	109158	142
2012	Grand Total		130	23558	4768	199168	81542	320105	708
2013	SECA	1.0 % fuel oil	39	7670	1530	62589	30606	113574	338
2013	SECA	MDO/MGO	21	2102	431	18409	1121	24478	30
2013	Non SECA	HFO	30	4999	970	39669	47137	79945	202
2013	Non SECA	MDO/MGO	42	10358	2119	90484	5510	121251	157
2013	Grand Total		132	25129	5050	211151	84373	339249	727
2014	SECA	1.0 % fuel oil	42	7913	1568	64119	31354	117439	350
2014	SECA	MDO/MGO	24	2595	529	22590	1270	30067	37
2014	Non SECA	HFO	31	7429	1405	57454	69113	121331	263
2014	Non SECA	MDO/MGO	53	13699	2786	118956	6686	159902	208
2014	Grand Total		150	31636	6287	263118	108423	428740	859
2015	SECA	MDO/MGO	71	10770	2141	91410	3425	150113	168
2015	Non SECA	HFO	36	5409	1040	42549	50976	85992	229
2015	Non SECA	MDO/MGO	62	16827	3401	145206	5441	195531	255
2015	Grand Total		168	33006	6582	279165	59842	431636	652
2016	SECA	MDO/MGO	73	11347	2238	95578	3581	156763	175
2016	Non SECA	HFO	34	4826	928	37973	45493	75204	214
2016	Non SECA	MDO/MGO	49	11162	2241	95672	3585	128852	167
2016	Grand Total		155	27335	5407	229223	52660	360819	556

In general terms, the combination of LPP length, ship speed, sailing distance, specific fuel consumption and the related emission factors determines the total fuel consumption and emissions for each ship type (Figure 7.2) and the totals for the whole area (Figure 7.1).

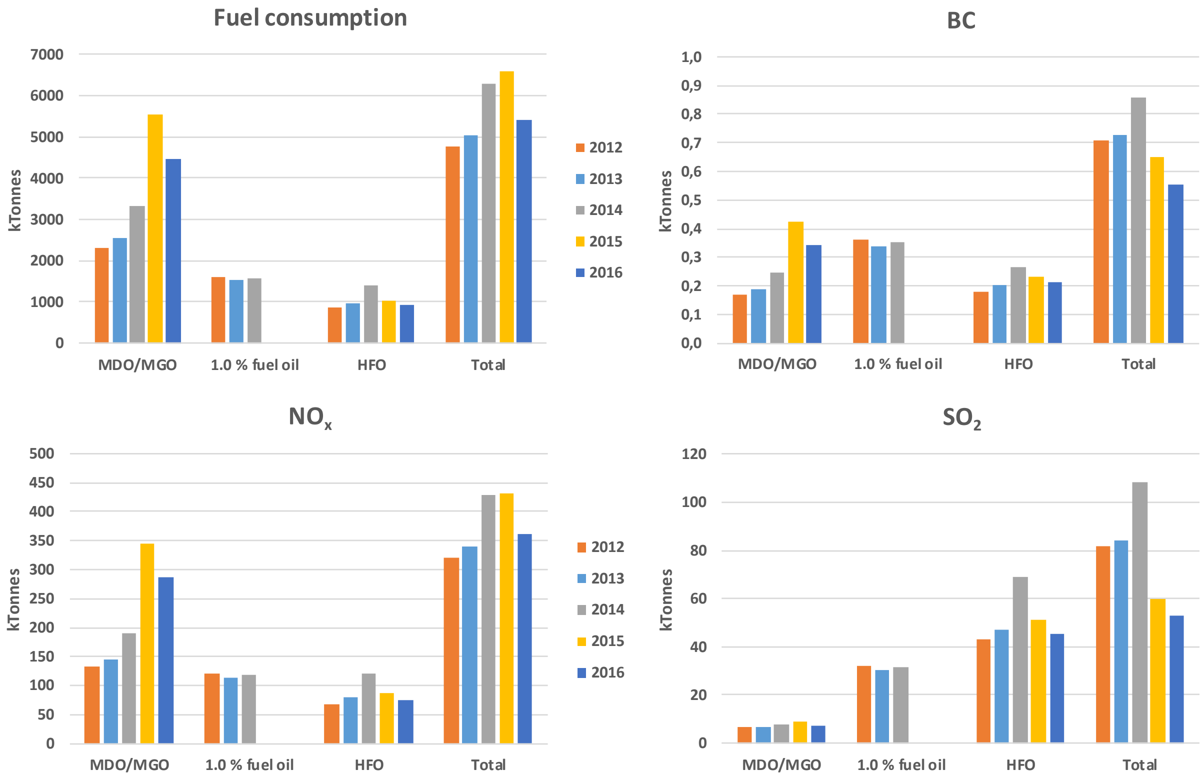


Figure 7.1 Total fuel consumption (by mass), NO_x, SO_2 and BC emissions in 2012-2016.

For the years 2012-2016, the NO_x emissions levels are quite similar to the fuel consumption levels (Figure 7.1). In 2015 and 2016, the calculated SO_2 emissions drop significantly caused by the fuel switch from 1.0 % fuel oil to MDO / MGO inside SECA's as explained in Chapter 2.1. The latter fuel switch also brings significant BC emission reductions due to the lower emission factors for MDO / MGO compared to 1.0 % fuel oil (Chapter 5.5).

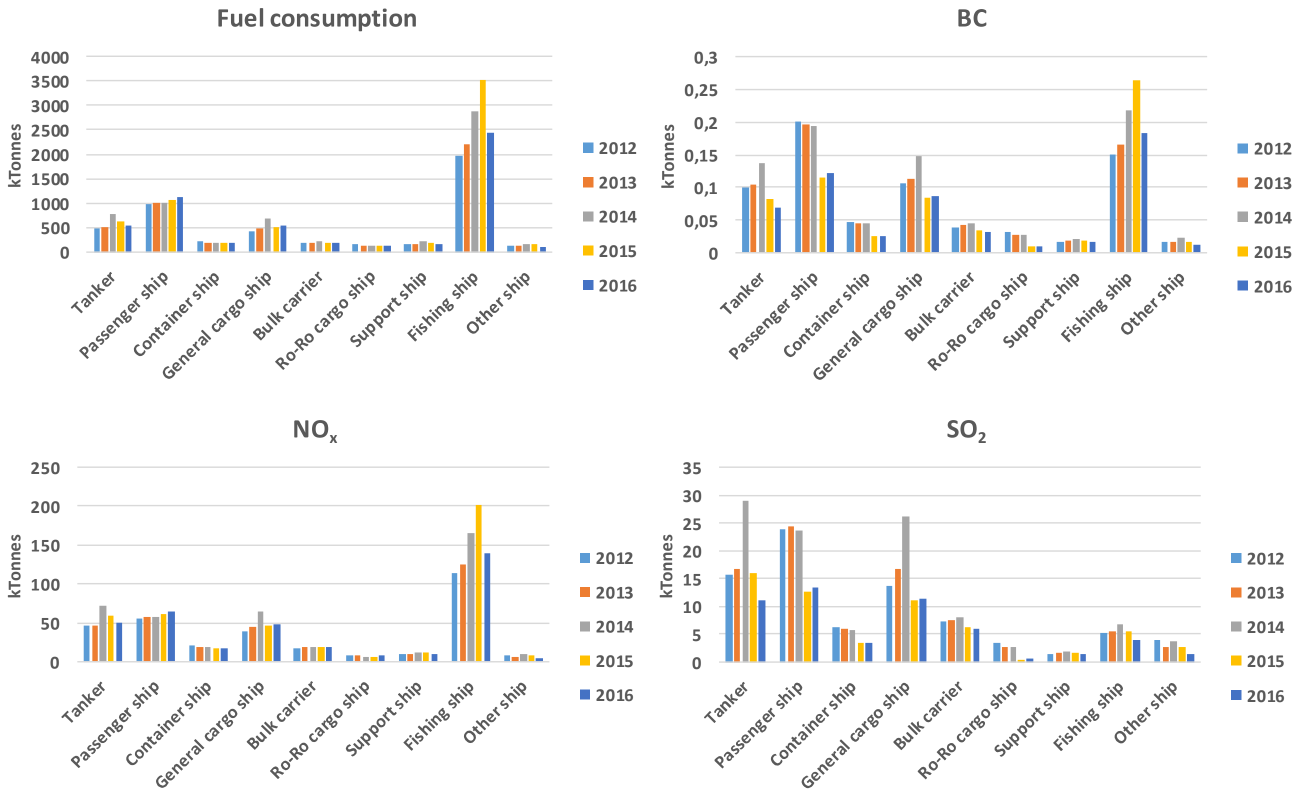


Figure 7.2 Fuel consumption (by mass), NO_x, SO_2 and BC emissions per ship type in 2012-2016.

Per ship type in the latest historical year 2016, the largest shares (percentage values in brackets, Figure 7.3) of fuel consumption (by mass), BC, NO_x and SO_2 are calculated for fishing ships (45 %, 33 %, 39 %, 7 %) followed by passenger ships (21 %, 22 %, 18 %, 25 %), general cargo (10 %, 16 %, 13 %, 22 %), tankers (10 %, 12 %, 14 %, 21 %), bulk carriers (4 %, 6 %, 5 %, 12 %) and container ships (3 %, 4 %, 5 %, 7 %)[13].

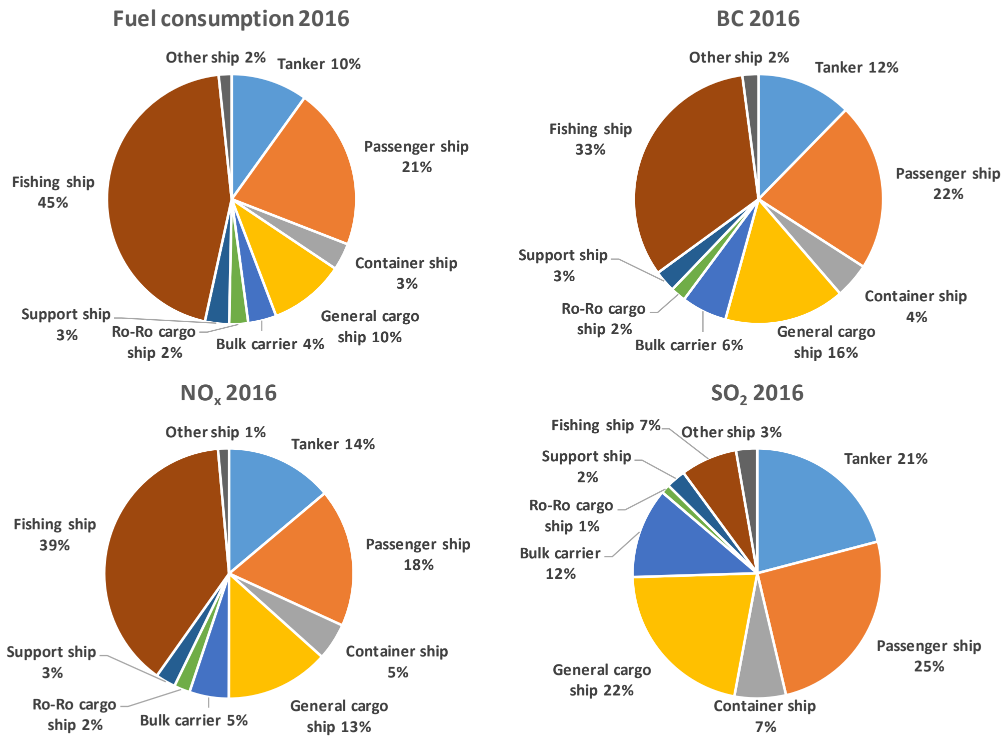


Figure 7.3 Shares of fuel consumption (by mass) and NO_x, SO_2 and BC emissions per ship type in 2016.

Figure 7.4 shows the spatial distribution of BC, NO_x and SO_2 emissions for all ships in 2012 and 2016.

The SO_2 emission reductions in the SECAs from 2012 to 2016 are clearly visible from Figure 7.4. Hence, the 2016 emissions are only one tenth of the 2012 emissions due to the stricter fuel sulphur regulations in SECA's from 1 January 2015 causing the before mentioned fuel switch from 1.0 % fuel oil to MDO / MGO by ships using HFO by origin (Table 7.2). Although less visible, BC emission reductions in the SECAs also appear from Figure 7.4; in 2016 the BC emissions are less than half of the emissions calculated for 2012 (Table 7.2). For NO_x, there are no clear visual differences in the emissions distributions shown for 2012 and 2016 in Figure 7.4. From 2012 to 2016, the NO_x emissions increase by 13 % for the whole area (Table 7.2).

[13] Tankers comprise the ship categories crude oil, oil products as well as chemical and gas tankers. The passenger ship category consists of ro-ro passenger ships, passenger ships (not ro-ro) and fast ferries.

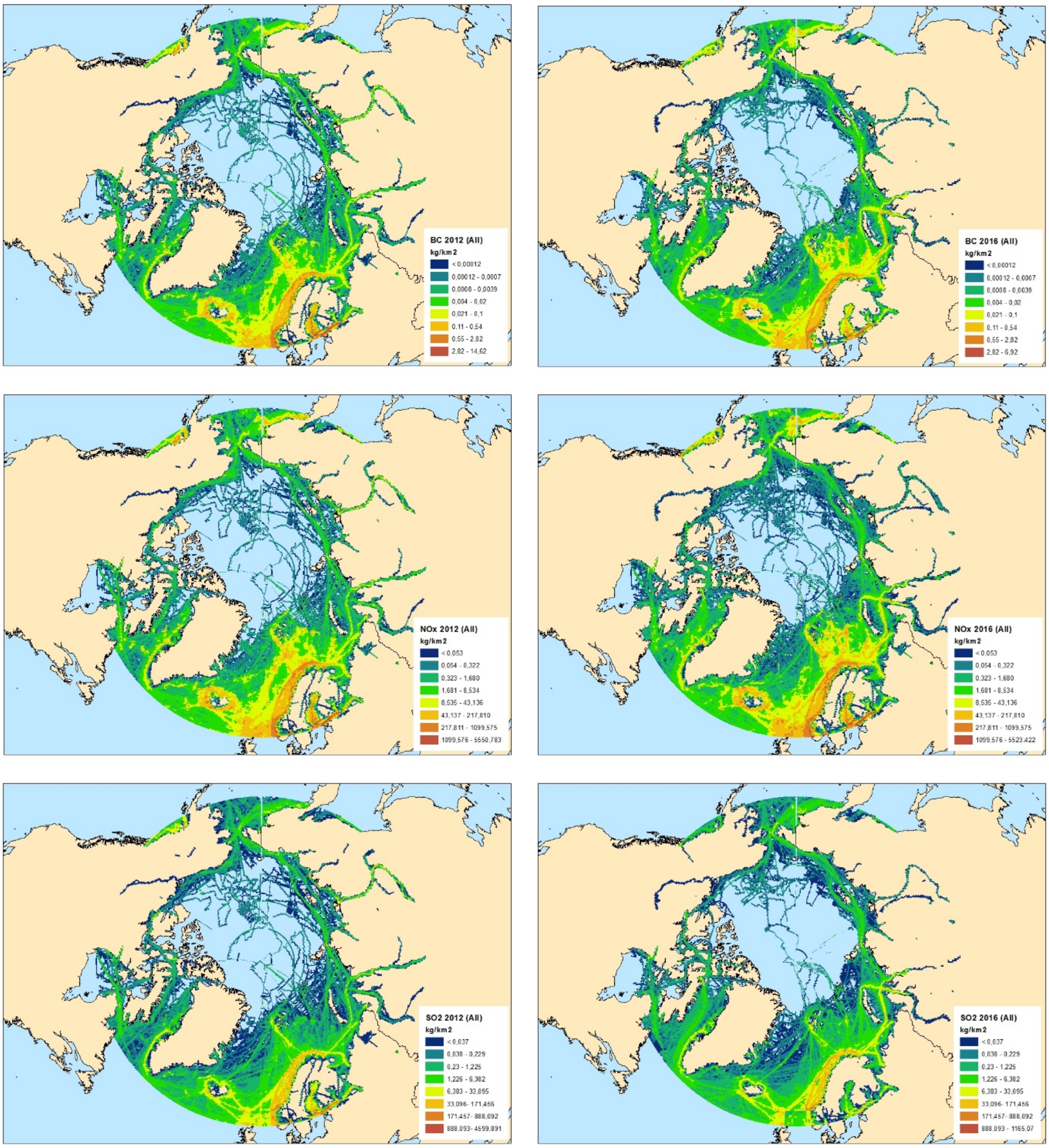


Figure 7.4 Spatial distribution of BC, NO_x and SO_2 emissions for all ships in 2012 and 2016.

7.2 Results for 2016 in uniform grid

In order to make the most correct assessment of the emissions calculated in the scenarios for the years 2020, 2030 and 2050, comparisons need to be made for today's emissions calculated by using the consolidated (five-year weighted average) ship activity data and the uniform grid system used to project the ship activity data in the scenarios (section 2.2), and emission factors for 2016. This five-year ship activity weighted and uniform gridded 2016 inventory is referred to as the uniform gridded 2016 inventory.

Table 7.3 shows the sailed distance, engine kWh's produced, total fuel consumption (by mass and energy), BC, NO_x and SO_2 emission results for the uniform gridded 2016 inventory. The results are grouped according to fuel type and sea area (SECA / Non SECA). The calculated results for the emissions of CO, VOC, OC, CO_2, CH_4 and N_2O can be seen in the annex section of this report.

Table 7.3 Results per fuel type and sea area (SECA/Non SECA) calculated for the uniform gridded 2016 inventory.

Year	Area	Fuel type	Distance	Power	Fuel	Fuel	SO_2	NO_x	BC
			km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	Tonnes	Tonnes
2016 uniform	SECA	MDO/MGO	66	10490	2052	87633	3284	143539	150
2016 uniform	Non SECA	HFO	49	12224	2452	104720	3924	141006	182
2016 uniform	Non SECA	MDO/MGO	32	5392	1018	41623	49866	83815	203
2016 uniform	Grand Total		147	28106	5522	233976	57074	368359	535

Compared with the original 2016 inventory results (Table 7.2), the uniform gridded 2016 results (Table 7.3) for sailed distance, engine kWh's produced, fuel consumption (by mass), SO_2, NO_x and BC, change by -5 %, 3 %, 2 %, 8 %, 2 % and -4 %, respectively. The differences occur from the shift between the five-year weighted and actual 2016 ship activity data and engine loads.

7.3 Results for Baseline scenario

Table 7.4 shows the sailed distance, engine kWh's produced, total fuel consumption (by mass and energy), BC, NO_x and SO_2 emission results per ship type for the Baseline BAU scenario in 2020, 2030 and 2050. The calculated results for the emissions of CO, VOC, OC, CO_2, CH_4 and N_2O can be seen in the annex section of this report.

Table 7.4 Results per ship type calculated for the inventory area in the Baseline BAU scenario for 2020, 2030 and 2050.

Year	Vessel type	Distance km x 10^6	Power kWh x 10^6	Fuel kTonnes	Fuel TJ	SO_2 Tonnes	NO_x Tonnes	BC Tonnes
2020	Bulk carrier	5.14	1153	204	8529	1212	17886	17
2020	Container ship	6.57	1257	224	9454	875	19532	18
2020	Crude oil tanker	2.10	732	130	5495	426	11346	10
2020	Fast ferry	0.36	18	4	154	6	178	0
2020	Fishing ship	36.80	12819	2512	107254	4019	144795	190
2020	Gas tanker	1.16	272	47	1982	259	4222	3
2020	General cargo ship	31.76	2818	509	21377	2575	43934	44
2020	Oil products & chemical tanker	14.94	3058	538	22525	3026	47464	38
2020	Other ship	8.84	643	127	5351	564	6913	9
2020	Passenger ship	12.67	2409	475	20075	1563	26161	35
2020	Ro-ro cargo ship	2.88	673	132	5632	255	7286	10
2020	Ro-ro passenger ship	15.93	2823	563	23846	1693	30768	45
2020	Support ship	17.54	1003	199	8441	503	10640	13
2020	Grand total	156.70	29679	5664	240115	16976	371126	432
2030	Bulk carrier	6.08	1250	214	8966	1157	15133	17
2030	Container ship	9.44	1667	287	12122	1051	18661	23
2030	Crude oil tanker	2.77	878	150	6374	456	9575	12
2030	Fast ferry	0.40	19	4	157	6	138	0
2030	Fishing ship	36.80	12819	2432	103837	3891	128782	184
2030	Gas tanker	1.53	331	56	2338	272	3957	3
2030	General cargo ship	33.38	2824	491	20749	2309	33065	42
2030	Oil products & chemical tanker	19.67	3776	641	26966	3415	44841	45
2030	Other ship	8.84	610	117	4935	487	5401	8
2030	Passenger ship	13.91	2512	478	20251	1463	20509	35
2030	Ro-ro cargo ship	3.03	672	127	5435	238	5043	9
2030	Ro-ro passenger ship	17.49	2946	567	24042	1620	23689	46
2030	Support ship	20.36	1103	212	9035	519	8877	14
2030	Grand total	173.67	31406	5775	245208	16883	317669	438
2050	Bulk carrier	8.73	1466	246	10430	1150	12303	19
2050	Container ship	21.24	3115	526	22404	1761	18504	41
2050	Crude oil tanker	4.24	1077	181	7736	484	5487	14
2050	Fast ferry	0.50	21	4	168	7	127	0
2050	Fishing ship	36.80	12819	2394	102232	3831	110735	181
2050	Gas tanker	2.34	421	70	2959	286	3324	4
2050	General cargo ship	37.89	2887	493	21008	2059	20527	40
2050	Oil products & chemical tanker	30.12	5010	836	35490	4100	39234	55
2050	Other ship	8.84	528	99	4221	376	3690	7
2050	Passenger ship	17.34	2718	506	21563	1380	11898	37
2050	Ro-ro cargo ship	3.44	663	123	5266	216	1713	9
2050	Ro-ro passenger ship	21.81	3192	600	25589	1573	12449	48
2050	Support ship	26.04	1218	231	9867	534	6880	15
2050	Grand total	219.32	35135	6310	268933	17757	246870	470

Table 7.5 shows the sailed distance, engine kWh's produced, total fuel consumption (by mass and energy) and BC, NO_x and SO_2 emissions calculated for the Baseline BAU scenario in 2020, 2030 and 2050 and grouped according to fuel type and area (SECA / Non SECA). All HFO is used in combination with an EGCS. The emission results for CO, VOC, OC, CO_2, CH_4 and N_2O are shown in the annex section of this report.

Table 7.5 Results per fuel type and sea area (SECA/Non SECA) calculated for the inventory area in the Baseline BAU scenario for 2020, 2030 and 2050.

Year	Area	Fuel type	Distance	Power	Fuel	Fuel	SO_2	NO_x	BC
			km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	Tonnes	Tonnes
2020	SECA	HFO + EGCS	3.7	1223	234	9589	469	16372	30
		LNG	1.9	411	68	3265	0	534	0
		MDO/MGO	66.3	9729	1851	79049	2962	129280	131
	Non SECA	0.5 % fuel oil	31.3	5169	947	38744	9473	77537	78
		HFO + EGCS	1.9	593	110	4495	220	8811	14
		LNG	1.4	272	45	2161	0	353	0
		MDO/MGO	50.2	12283	2408	102812	3852	138238	179
	Grand Total		156.7	29679	5664	240115	16976	371126	432
2030	SECA	HFO + EGCS	6.1	1858	343	14011	685	17362	44
		LNG	4.2	832	138	6619	0	1082	0
		MDO/MGO	71.2	9644	1769	75527	2830	88143	125
	Non SECA	0.5 % fuel oil	33.8	5276	930	38030	9298	71126	76
		HFO + EGCS	3.2	913	163	6664	326	12197	21
		LNG	3.1	559	93	4446	0	727	0
		MDO/MGO	52.0	12324	2340	99912	3744	127033	173
	Grand Total		173.7	31406	5775	245208	16883	317669	438
2050	SECA	HFO + EGCS	11.8	2903	522	21362	1045	8209	66
		LNG	10.8	1806	300	14361	0	2348	0
		MDO/MGO	84.7	9757	1751	74751	2801	27223	123
	Non SECA	0.5 % fuel oil	41.4	5644	971	39733	9715	72201	78
		HFO + EGCS	6.3	1418	248	10131	495	17901	31
		LNG	8.0	1235	205	9820	0	1605	0
		MDO/MGO	56.2	12372	2313	98775	3701	117383	171
	Grand Total		219.3	35135	6310	268933	17757	246870	470

Derived from Table 7.3 and Table 7.5, the following percentage changes between the uniform 2016 results and the Baseline BAU results for the forecast years 2020, 2030, 2050, respectively (results in brackets) are calculated for fuel consumption (+3 %, +5 %, +14 %), BC (-19 %, -18 %, -12 %), SO_2 (-70 %, -70 %, -69 %) and NO_x (+1 %, -14 %, -33 %).

The percentage changes between the uniform 2016 results and the Baseline HiG results for the forecast years 2020*[2030, 2050]* becomes +6 %*[+13 %, +37 %]* for fuel consumption, -17 %*[-11 %, 6 %]* for BC, -69 %*[-67 %, -61 %]* for SO_2 and +4 %*[-7 %, -21 %]* for NO_x[14].

The most convenient way to assess the emission results calculated in the Baseline BAU scenario is to explain the emission development per fuel type from the uniform 2016 base year to the scenario projection years.

[14]The percentage changes between the historical 2016 results and the Baseline BAU results for the forecast years 2020*[2030, 2050]* becomes +5 %*[+7 %, +17 %]* for fuel consumption, -22 %*[-21 %, -15 %]* for BC, -68 %*[-68 %, -66 %]* for SO_2 and +3 %*[-12 %, -32 %]* for NO_x. The percentage changes between the historical 2016 results and the Baseline HiG results for the forecast years 2020*[2030, 2050]* becomes +8 %*[+15 %, +40 %]* for fuel consumption, -20 %*[-15 %, 2 %]* for BC, -66 %*[-65 %, -57 %]* for SO_2 and +6 %*[-5 %, -19 %]* for NO_x.

The totals for fuel consumption, BC, SO_2 and NO_x emission are shown per fuel type in Figure 7.5 for 2016 uniform, 2020, 2030 and 2050. Figure 7.6 shows the spatial distribution of NO_x and SO_2 emissions for 2020, 2030 and 2050.

The total fuel consumption increases in the forecast period due to the projected ship traffic growth in the calculations. On the other hand, the envisaged ship energy efficiency improvements included in the calculations have dampened fuel growth somewhat during the period; the (5-year averagely weighted) total ship traffic for the uniform 2016 inventory increase by 49 % until 2050, whereas fuel consumption increase by 14 %.

Since the total fuel consumption increase during the period, the NO_x emission reductions (Figures 7.5 and 7.6) are hence driven by the decrease in NO_x emission factors during the period (c.f. Tables 5.8 and 5.9). The spatial NO_x emission reductions are most significant for the North Sea / Baltic Sea ECAs (Figure 7.6) where new engines installed on board ships from 1 January 2021 must comply with the most stringent Tier III NO_x emission standards.

For SO_2 and BC, the major reason for the emission reductions from uniform 2016 to 2020 shown on Figure 7.5 (SO_2 and BC) and the Figures 7.4 and 7.6 (SO_2) is the reduction of the HFO fuel sulphur content from 2.45 % in 2016 to 0.5 % in 2020 and the consequently reduced emission factors (c.f. Tables 5.8 and 5.9).

For SO_2 from 2020 onwards, different reasons explain the almost stable SO_2 emissions during the forecast years, compared to the increase in fuel consumption. The increasing amount of HFO being used in combination with an EGCS (corresponding to Fs = 0.1 %; see chapter 5.3.2) gradually reduces the emissions related to HFO consumption. Also, the gradually increased LNG fuel consumption assumed in the Baseline scenario plays an important role in the emission explanation for SO_2 due to zero SO_2 emissions from this fuel type.

The major reasons for the calculated BC emission increase from 2020 onwards are due to the increase in fuel consumption of HFO being scrubbed during the forecast period and the BC emission factor levels. The BC emission factor for 2.45 % HFO fuel in combination with an EGCS (0.093 g / kg fuel, before load adjustment) is higher than the emission factors for the 0.5 % fuel oil (0.065 g / kg fuel, before load adjustment) being replaced outside SECA's and the MDO / MGO fuel (0.053 g / kg fuel, before load adjustment) being replaced inside SECA's (see Chapter 5.5).

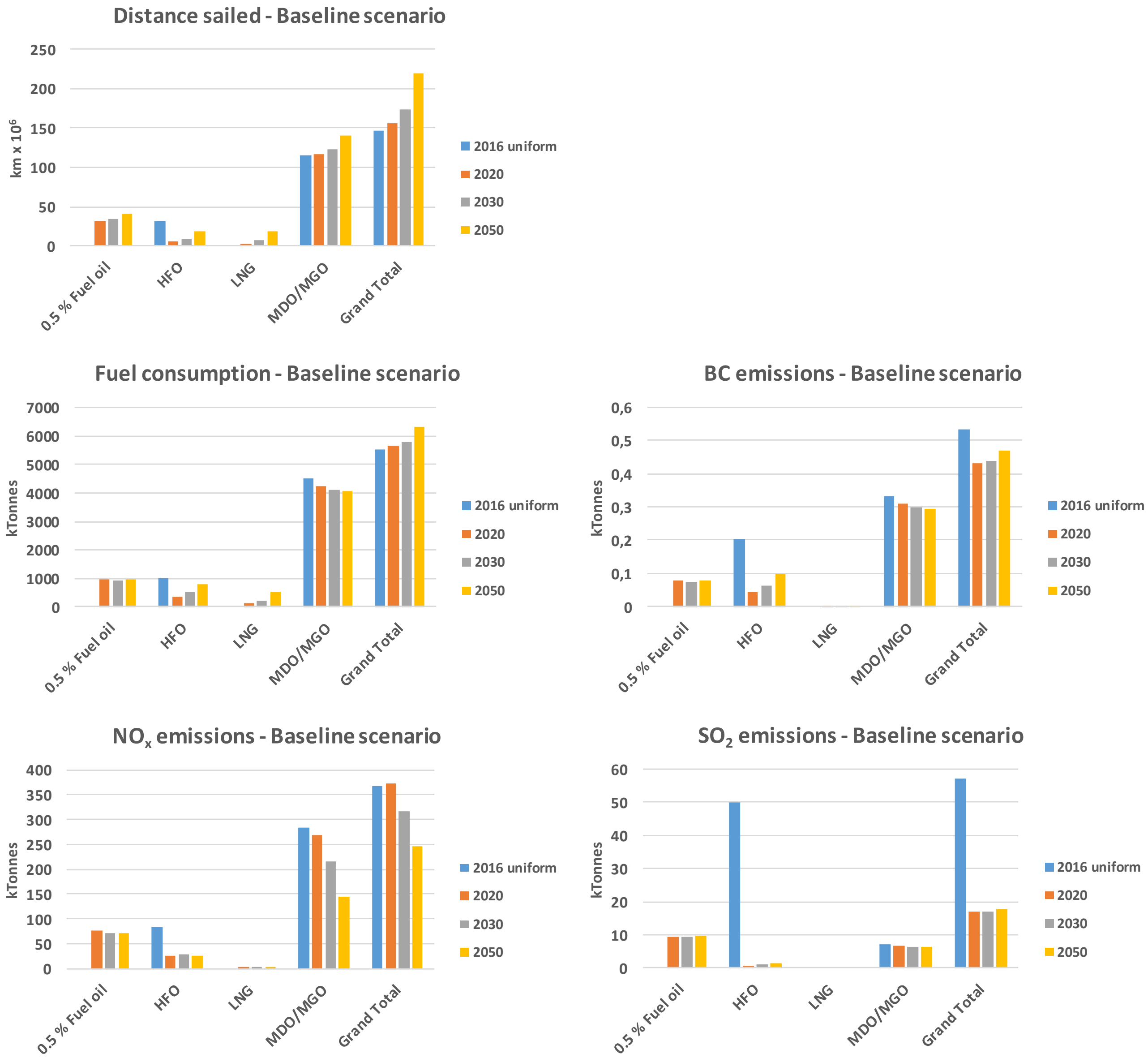


Figure 7.5 Total fuel consumption (by mass), NO_x, SO_2 and BC emissions calculated in the Baseline BAU scenario.

In order to assess the impact on atmospheric concentrations of pollutants and BC deposition due to additional ship traffic in the Arctic diverted from current shipping routes (Chapter 8), because of a possible extent of polar sea ice in the future, scenario estimates of CO_2 (proxy for fuel consumption), BC, NO_x and SO_2 for diversion traffic are made based on the Business-As-Usual (BAU) and High Growth (HiG) scenario emission results for the diversion routes[15] from Corbett et al. (2010). The latter diversion route sub results are drawn out for the area north of 58.95N by accessing the gridded data made publically available online (http://coast.cms.udel.edu/ArcticShipping/) by Corbett et al. (2010). Subsequently, the diversion route fuel consumption is found as the CO_2 emissions for the diversion routes divided by the fuel related emission factor for CO_2 from Corbett et al. (2010), and fuel consumptions are further modified by taking into account today's expectations of the future energy efficiency changes of the ships (EEDI and sfc; see Chapter 3 and 5.1). Next, the

[15] In Corbett et al. (2010), BAU diversion traffic are 1 %, 1 % and 1.8 % of global shipping in the forecast years 2020, 2030 and 2050, respectively. HiG growth diversion traffic are 1 %, 2 % and 5 % of global shipping in the forecast years 2020, 2030 and 2050, respectively.

emissions are found as the product of the diversion route fuel consumption and the emission factors from the Baseline results.

Table 7.6 shows the estimated emissions of CO_2, SO_2, NO_x and BC for the polar diversion routes in 2020, 2030 and 2050 for BAU and HiG traffic growth.

Tabel 7.6 Estimated emissions of CO_2, SO_2, NO_x and BC for the polar diversion routes in 2020, 2030 and 2050 for BAU and HiG traffic growth.

			BAU traffic growth			HiG traffic growth		
	Unit		2020	2030	2050	2020	2030	2050
Diversion routes	Tonnes	SO_2	8028	8715	18424	10367	25133	94474
	Tonnes	NO_x	141117	127620	185217	182516	369086	949073
	Tonnes	BC	130	148	336	170	433	1737
	kTonnes	CO_2	5243	6052	14131	6775	17451	72296
Additional contribution from diversion	%	SO_2	47	52	104	61	149	532
	%	NO_x	38	40	75	49	116	384
	%	BC	30	34	71	39	99	370
	%	CO_2	29	33	71	38	96	365

The additional percentage of emissions from ship traffic on Arctic diversion routes based on BAU diversion traffic for the forecast years 2020*[2030, 2050]* becomes +29 %*[+33 %, +71 %]* for CO_2, +30 %*[+34 %, +71 %]* for BC, +47 %*[+52 %, +104 %]* for SO_2 and +38 %*[+40 %, +75 %]* for NO_x.

The additional percentage of emissions from ship traffic on Arctic diversion routes based on HiG diversion traffic for the forecast years 2020*[2030, 2050]* becomes +38 %*[+96 %, +365 %]* for CO_2, +39 %*[+99 %, +370 %]* for BC, +61 %*[+149 %, +532 %]* for SO_2 and +49 %*[+116 %, +384 %]* for NO_x.

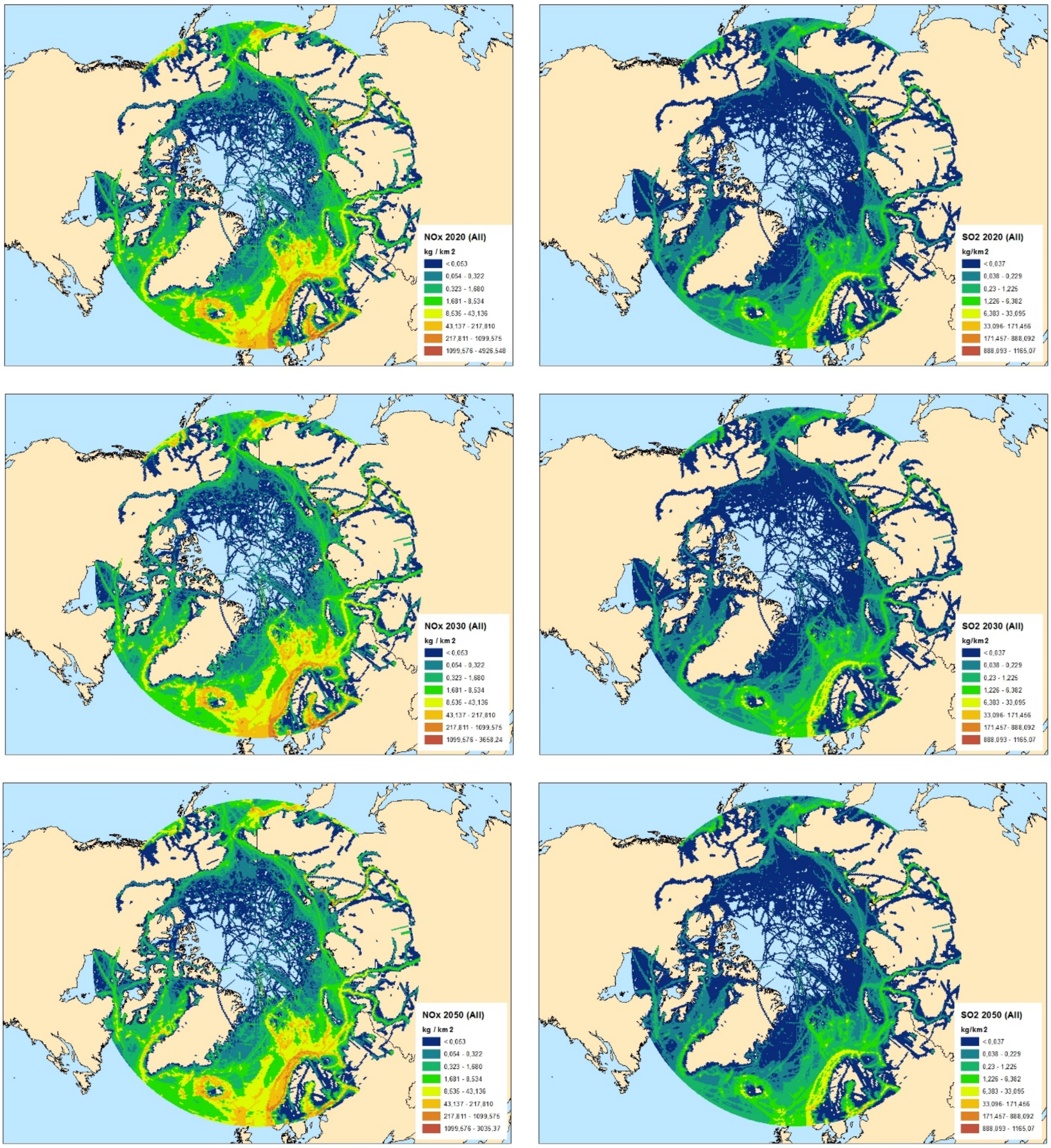


Figure 7.6 Spatial distribution of NO_x and SO_2 emissions for all ships in 2020, 2030 and 2050 calculated in the Baseline BAU scenario.

7.4 Results for SECA scenario

In the SECA scenario, the existing SECAs (i.e. America and North Sea / Baltic Sea SECA's) are expanded to cover the entire inventory area. The SECA scenario takes on board the shares of LNG fuel consumption of total fuel consumption and the share of EGCS installed globally on board ships with main engines > 5 MW (28 % in 2050) as included in the Baseline scenario (section 4.1.2).

Table 7.7 shows the sailed distance, engine kWh's produced, total fuel consumption (by mass and energy), BC, NO_x and SO_2 emission results per ship type for the SECA BAU scenario in 2020, 2030 and 2050. The calculated results for the emissions of CO, VOC, OC, CO_2, CH_4 and N_2O can be seen in the annex section of this report.

Table 7.7 Results per ship type calculated for the inventory area in the SECA BAU scenario for 2020, 2030 and 2050.

Year	Vessel type	Distance km x 10^6	Power kWh x 10^6	Fuel kTonnes	Fuel TJ	SO_2 Tonnes	NO_x Tonnes	BC Tonnes
2020	Bulk carrier	5.14	1153	204	8720	324	17886	15
2020	Container ship	6.57	1257	224	9565	357	19532	17
2020	Crude oil tanker	2.10	732	130	5542	208	11346	10
2020	Fast ferry	0.36	18	4	154	6	178	0
2020	Fishing ship	36.80	12819	2512	107254	4019	144795	190
2020	Gas tanker	1.16	272	47	2021	75	4222	3
2020	General cargo ship	31.76	2818	509	21758	798	43934	41
2020	Oil products & chemical tanker	14.94	3058	538	22993	841	47464	35
2020	Other ship	8.84	643	127	5428	201	6913	8
2020	Passenger ship	12.67	2409	475	20246	763	26161	33
2020	Ro-ro cargo ship	2.88	673	132	5641	211	7286	10
2020	Ro-ro passenger ship	15.93	2823	563	24016	900	30768	44
2020	Support ship	17.54	1003	199	8481	316	10640	13
2020	Grand total	156.70	29679	5664	241820	9019	371126	418
2030	Bulk carrier	6.08	1250	214	9143	330	15133	16
2030	Container ship	9.44	1667	287	12252	446	18661	22
2030	Crude oil tanker	2.77	878	150	6421	236	9575	11
2030	Fast ferry	0.40	19	4	157	6	138	0
2030	Fishing ship	36.80	12819	2432	103837	3891	128782	184
2030	Gas tanker	1.53	331	56	2378	86	3957	3
2030	General cargo ship	33.38	2824	491	21084	747	33065	39
2030	Oil products & chemical tanker	19.67	3776	641	27490	971	44841	41
2030	Other ship	8.84	610	117	5000	183	5401	8
2030	Passenger ship	13.91	2512	478	20403	754	20509	34
2030	Ro-ro cargo ship	3.03	672	127	5444	198	5043	9
2030	Ro-ro passenger ship	17.49	2946	567	24199	888	23689	44
2030	Support ship	20.36	1103	212	9074	336	8877	14
2030	Grand total	173.67	31406	5775	246882	9073	317669	424
2050	Bulk carrier	8.73	1466	246	10599	360	12303	18
2050	Container ship	21.24	3115	526	22615	775	18504	40
2050	Crude oil tanker	4.24	1077	181	7781	271	5487	14
2050	Fast ferry	0.50	21	4	168	6	127	0
2050	Fishing ship	36.80	12819	2394	102232	3831	110735	181
2050	Gas tanker	2.34	421	70	2998	102	3324	4
2050	General cargo ship	37.89	2887	493	21299	702	20527	37
2050	Oil products & chemical tanker	30.12	5010	836	36114	1188	39234	51
2050	Other ship	8.84	528	99	4270	151	3690	6
2050	Passenger ship	17.34	2718	506	21694	767	11898	36
2050	Ro-ro cargo ship	3.44	663	123	5273	182	1713	9
2050	Ro-ro passenger ship	21.81	3192	600	25734	899	12449	46
2050	Support ship	26.04	1218	231	9904	363	6880	15
2050	Grand total	219.32	35135	6310	270682	9597	246870	455

Table 7.8 shows the sailed distance, engine kWh's produced, total fuel consumption (by mass and energy) and BC, NO_x and SO_2 emissions calculated for the SECA BAU scenario in 2020, 2030 and 2050 and grouped according to fuel type. All HFO is used in combination with an EGCS. Emission results for CO, VOC, OC, CO_2, CH_4 and N_2O are shown in the annex section of this report.

Table 7.8 Results per fuel type and sea area (SECA/Non SECA) calculated for the inventory area in the SECA BAU scenario for 2020, 2030 and 2050.

Year	Fuel type	Distance km x 10^6	Power kWh x 10^6	Fuel kTonnes	Fuel TJ	SO_2 Tonnes	NO_x Tonnes	BC Tonnes
2020	HFO + EGCS	5.6	1816	344	14084	689	25184	44
	LNG	3.3	682	113	5426	0	887	0
	MDO/MGO	147.8	27181	5206	222310	8330	345055	374
	Total	156.7	29679	5664	241820	9019	371126	418
2030	HFO + EGCS	9.3	2771	506	20675	1011	29558	64
	LNG	7.4	1392	231	11065	0	1809	0
	MDO/MGO	157.0	27244	5038	215142	8062	286301	360
	Total	173.7	31406	5775	246882	9073	317669	424
2050	HFO + EGCS	18.2	4321	770	31493	1540	26109	97
	LNG	18.8	3041	505	24180	0	3953	1
	MDO/MGO	182.3	27773	5035	215008	8057	216807	357
	Total	219.3	35135	6310	270682	9597	246870	455

The most convenient way to assess the emission results calculated in the SECA scenario is to explain the emission development per fuel type from the uniform 2016 base year to the scenario projection years.

Derived from the results in Table 7.3 and Table 7.8, the following percentage changes between the uniform 2016 results and the SECA BAU results for the forecast years 2020, 2030, 2050, respectively (results in brackets) are calculated for fuel consumption(+3 %, +5 %, +14 %), BC(-22 %, -21 %, -15 %), SO_2 (-84 %, -84 %, -83 %) and NO_x (+1 %, -14 %, -33 %).

The percentage changes between the uniform 2016 results and the SECA HiG results for the forecast years 2020*[2030, 2050]* becomes +6 %*[+13 %, +37 %]* for fuel consumption, -20 %*[-14 %, 3 %]* for BC, -84 %*[-83 %, -80 %]* for SO_2 and +4 %*[-7 %, -21 %]* for NO_x[16].

The totals for fuel consumption, BC, SO_2 and NO_x emission are shown per fuel type in Figure 7.7 for 2016 uniform, 2020, 2030 and 2050.

The fuel consumption and NO_x emission totals calculated for the SECA scenario (Table 7.8) equal the results obtained in the Baseline scenario (Table 7.5). The main reason for this is that the engine specific fuel consumption and NO_x emission factors are unaffected by the fuel switch from HFO to MDO / MDO, and also the same shares of LNG of total fuel consumption per forecast year are assumed in both scenarios.

[16] The percentage changes between the historical 2016 results and the SECA BAU results for the forecast years 2020*[2030, 2050]* become +5 %*[+7 %, +17 %]* for fuel consumption, -25 %*[-24 %, -18 %]* for BC, -83 %*[-83 %, -82 %]* for SO_2 and +3 %*[-12 %, -32 %]* for NO_x. The percentage changes between the historical 2016 results and the SECA HiG results for the forecast years 2020*[2030, 2050]* become +8 %*[+15 %, +40 %]* for fuel consumption, -23 %*[-18 %, -1 %]* for BC, -82 %*[-81 %, -78 %]* for SO_2 and +6 %*[-5 %, -19 %]* for NO_x.

For SO_2 and BC, the major reason for the emission reductions from uniform 2016 to 2020 shown on Figure 7.7, is the fuel switch from HFO to MDO / MGO outside the existing SECAs by ships using HFO by origin and not using EGCS. Thereby the emission factors are consequently reduced (c.f. Tables 5.8 and 5.10).

For SO_2 and BC from 2020 onwards, the emissions increases are somewhat smaller during the forecast years, compared to the increase in fuel consumption. This is mainly due to the gradually increased fuel consumption assumed in the scenario for LNG, for which zero SO_2 emissions and insignificant BC emissions occur during combustion (Table 7.8).

For BC, however, the emission benefits obtained from LNG usage is partly set off by the increasing use of EGCS and the associated emission factor levels. The effective BC emission factor for 2.45 % HFO fuel in combination with EGCS is higher than the emission factors for the 0.5 % fuel oil being replaced outside the existing SECA's and the MDO / MGO fuel being replaced inside the existing SECA's (see Chapter 5.5).

A further description of the fuel consumption and emission results for the SECA scenario is given in Chapter 7.6, involving cross comparisons with the Baseline and HFO ban scenario results.

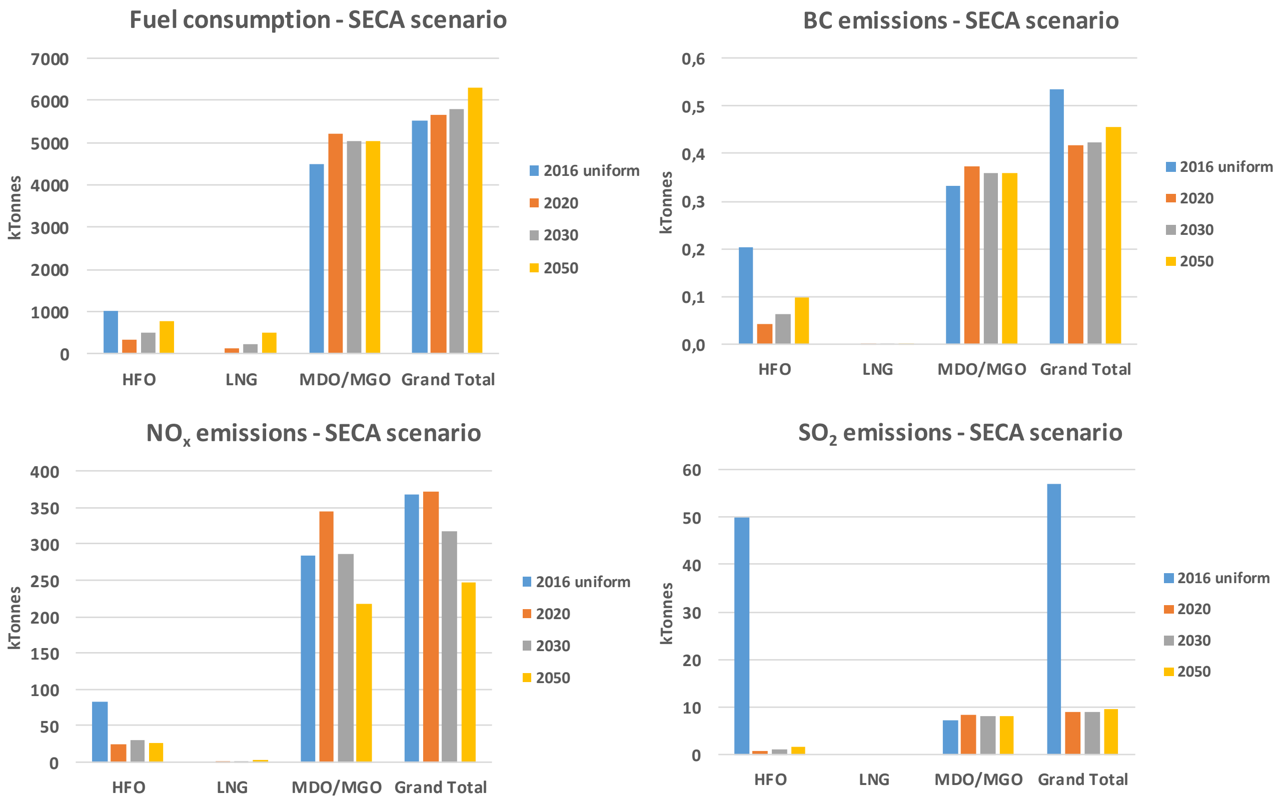


Figure 7.7 Total fuel consumption (by mass), NO_x, SO_2 and BC emissions calculated in the SECA BAU scenario.

For the SECA scenario, a "high case EGCS" calculation has been made by assuming a double share of EGCS in 2050 (56 %) installed globally on board ships with main engines > 5 MW as explained in section 4.1.2. Table 7.9 shows the sailed distance, engine kWh's produced, total fuel consumption (by mass and energy) and BC, NO_x and SO_2 emissions calculated for the SECA scenario in 2020, 2030 and 2050. The results are grouped according to fuel type.

Table 7.9 Results for high case EGCS model run assuming a double share of EGCS installed globally on board ships with main engines > 5 MW.

Year	Fuel type	Distance km x 10^6	Power kWh x 10^6	Fuel kTonnes	Fuel TJ	SO_2 Tonnes	NO_x Tonnes	BC Tonnes
2020	HFO + EGCS	6.5	2117	401	16421	803	29344	51
	LNG	3.3	682	113	5426	0	887	0
	MDO/MGO	146.9	26880	5149	219871	8239	340895	369
	Total	156.7	29679	5664	241717	9042	371126	421
2030	HFO + EGCS	17.7	5295	967	39533	1933	56422	123
	LNG	7.4	1392	231	11065	0	1809	0
	MDO/MGO	148.5	24719	4577	195455	7324	259437	327
	Total	173.7	31406	5775	246052	9257	317669	450
2050	HFO + EGCS	36.0	8575	1529	62521	3057	51759	193
	LNG	18.8	3041	505	24180	0	3953	1
	MDO/MGO	164.5	23518	4277	182615	6843	191158	303
	Total	219.3	35135	6310	269316	9900	246870	497

Figure 7.8 shows the fuel type specific results for the baseline EGCS shares assumed in the SECA (and Baseline) scenario and the high EGCS shares used in the “high case EGCS” model run. Results are only shown for MDO / MGO and HFO given that fuel consumption and emissions related to LNG usage remain unchanged in the two calculation situations.

As predicted by the calculation assumptions, the total fuel consumption of HFO increases with the number of EGCS installed in a given projection year and the total fuel consumption of MDO / MGO correspondingly decreases (Tables 7.8-7.9 and Figure 7.8). The NO_x emissions display the same trend. The fuel consumption and NO_x emission totals are equal for the two model runs; the engine specific fuel consumption and NO_x emission factors in both cases are unaffected by fuel type and the EGCS is assumed to have no impact on fuel consumption and NO_x emissions.

The BC and SO_2 emission differences between the baseline and high EGCS share model runs are rather small. For the high EGCS model run, the total emissions of BC*[SO_2]* increase by 1 %*[0 %]*, 6 %*[2 %]* and 9 %*[3 %]* in 2020, 2030 and 2050, respectively, compared with the emissions obtained using the baseline shares of EGCS installed. Due to the general uncertainties related to BC emission factors and BC scrubber reduction rates, as explained in Section 5.5, the calculated results for BC emissions must be regarded with care.

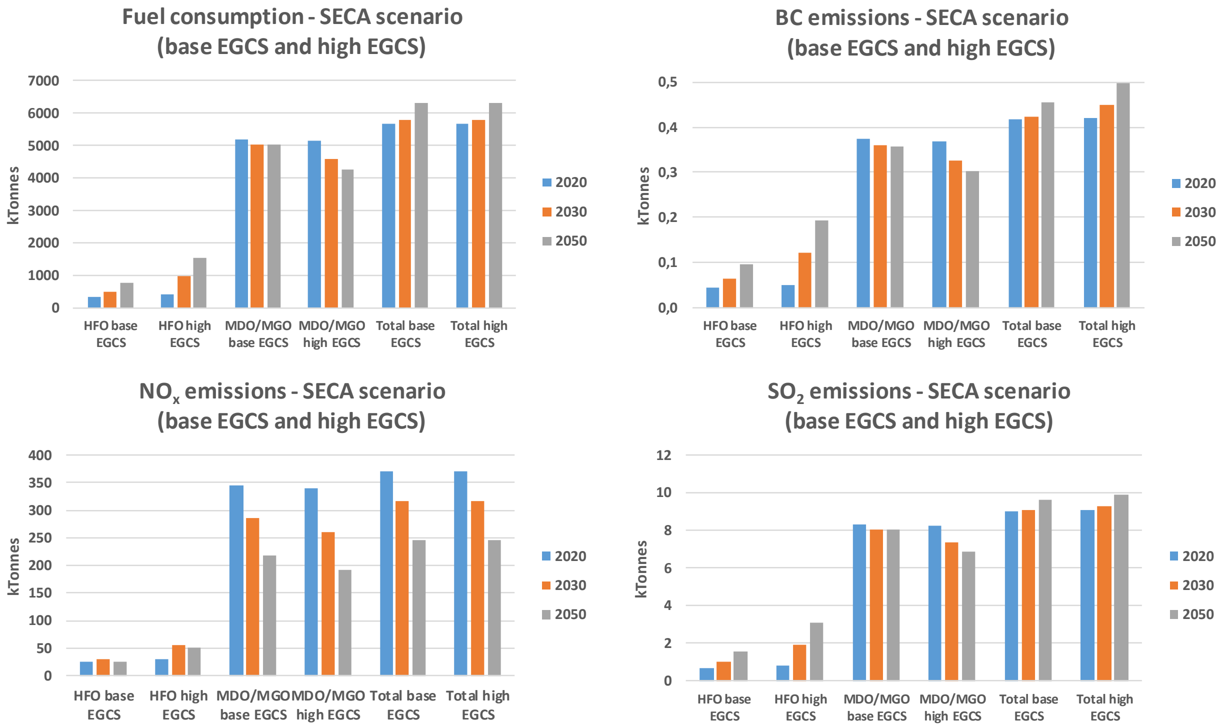


Figure 7.8 Total fuel consumption (by mass), NO_x, SO_2 and BC emissions calculated in the baseline and high EGCS model runs.

7.5 Results for HFO ban scenario

In the HFO ban scenario, use of HFO by ships is prohibited all across the inventory area. The HFO ban scenario includes the shares of LNG consumption of total fuel consumption as assumed in the baseline scenario. The remaining part of the HFO consumption by ships not being replaced by LNG, is assumed to be replaced by MGO / MDO for the entire inventory area.

Table 7.10 shows the sailed distance, engine kWh's produced, total fuel consumption (by mass and energy), BC, NO_x and SO_2 emission results per ship type for the HFO ban BAU scenario in 2020, 2030 and 2050. The calculated results for the emissions of CO, VOC, OC, CO_2, CH_4 and N_2O can be seen in the annex section of this report.

Table 7.10 Results per ship type calculated for the inventory area in the HFO ban BAU scenario for 2020, 2030 and 2050.

Year	Vessel type	Distance km x 10^6	Power kWh x 10^6	Fuel kTonnes	Fuel TJ	SO_2 Tonnes	NO_x Tonnes	BC Tonnes
2020	Bulk carrier	5.14	1153	204	8766	313	17886	14
2020	Container ship	6.57	1257	224	9623	344	19532	15
2020	Crude oil tanker	2.10	732	130	5580	200	11346	9
2020	Fast ferry	0.36	18	4	155	6	178	0
2020	Fishing ship	36.80	12819	2512	107254	4019	144795	190
2020	Gas tanker	1.16	272	47	2032	73	4222	2
2020	General cargo ship	31.76	2818	509	21835	781	43934	38
2020	Oil products & chemical tanker	14.94	3058	538	23066	825	47464	33
2020	Other ship	8.84	643	127	5439	199	6913	8
2020	Passenger ship	12.67	2409	475	20372	735	26161	30
2020	Ro-ro cargo ship	2.88	673	132	5675	203	7286	9
2020	Ro-ro passenger ship	15.93	2823	563	24157	869	30768	39
2020	Support ship	17.54	1003	199	8486	315	10640	13
2020	Grand total	156.70	29679	5664	242440	8881	371126	399
2030	Bulk carrier	6.08	1250	214	9211	315	15133	14
2030	Container ship	9.44	1667	287	12355	423	18661	19
2030	Crude oil tanker	2.77	878	150	6484	222	9575	10
2030	Fast ferry	0.40	19	4	157	6	138	0
2030	Fishing ship	36.80	12819	2432	103837	3891	128782	184
2030	Gas tanker	1.53	331	56	2395	82	3957	3
2030	General cargo ship	33.38	2824	491	21185	725	33065	35
2030	Oil products & chemical tanker	19.67	3776	641	27611	945	44841	38
2030	Other ship	8.84	610	117	5014	180	5401	7
2030	Passenger ship	13.91	2512	478	20576	716	20509	29
2030	Ro-ro cargo ship	3.03	672	127	5490	188	5043	8
2030	Ro-ro passenger ship	17.49	2946	567	24394	844	23689	38
2030	Support ship	20.36	1103	212	9082	335	8877	13
2030	Grand total	173.67	31406	5775	247792	8870	317669	397
2050	Bulk carrier	8.73	1466	246	10703	337	12303	15
2050	Container ship	21.24	3115	526	22859	721	18504	32
2050	Crude oil tanker	4.24	1077	181	7883	248	5487	11
2050	Fast ferry	0.50	21	4	168	6	127	0
2050	Fishing ship	36.80	12819	2394	102232	3831	110735	181
2050	Gas tanker	2.34	421	70	3026	95	3324	3
2050	General cargo ship	37.89	2887	493	21420	675	20527	33
2050	Oil products & chemical tanker	30.12	5010	836	36311	1145	39234	45
2050	Other ship	8.84	528	99	4285	148	3690	6
2050	Passenger ship	17.34	2718	506	21932	714	11898	29
2050	Ro-ro cargo ship	3.44	663	123	5332	169	1713	7
2050	Ro-ro passenger ship	21.81	3192	600	26003	839	12449	38
2050	Support ship	26.04	1218	231	9915	360	6880	14
2050	Grand total	219.32	35135	6310	272068	9289	246870	414

Table 7.11 shows the sailed distance, engine kWh's produced, total fuel consumption (by mass and energy) and BC, NO_x and SO_2 emissions calculated for the HFO ban BAU scenario in 2020, 2030 and 2050 and grouped according to fuel type. The emission results for CO, VOC, OC, CO_2, CH_4 and N_2O are shown in the annex section of this report.

Table 7.11 Results per fuel type and sea area (SECA/Non SECA) calculated for the inventory area in the HFO ban BAU scenario for 2020, 2030 and 2050.

Year	Fuel type	Distance km x 10^6	Power kWh x 10^6	Fuel kTonnes	Fuel TJ	SO_2 Tonnes	NO_x Tonnes	BC Tonnes
2020	LNG	3.3	682	113	5426	0	887	0
	MDO/MGO	153.4	28996	5551	237014	8881	370239	399
	Total	156.7	29679	5664	242440	8881	371126	399
2030	LNG	7.4	1392	231	11065	0	1809	0
	MDO/MGO	166.3	30014	5544	236727	8870	315860	397
	Total	173.7	31406	5775	247792	8870	317669	397
2050	LNG	18.8	3041	505	24180	0	3953	1
	MDO/MGO	200.5	32094	5805	247887	9289	242917	413
	Total	219.3	35135	6310	272068	9289	246870	414

The most convenient way to assess the emission results calculated in the HFO ban scenario is to explain the emission development per fuel type from the uniform 2016 base year to the scenario projection years.

Derived from the results in Table 7.3 and Table 7.11, the following percentage changes between the uniform 2016 results and the HFO ban BAU results for the forecast years 2020, 2030, 2050, respectively (results in brackets) are calculated for fuel consumption(+3 %, +5 %, +14 %), BC(-25 %, -26 %, -23 %), SO_2 (-84 %, -84 %, -84 %) and NO_x (+1 %, -14 %, -33 %).

The percentage changes between the uniform 2016 results and the HFO ban HiG results for the forecast years 2020*[2030, 2050]* becomes +6 %*[+13 %, +37 %]* for fuel consumption, -20 %*[-14 %, +3 %]* for BC, -84 %*[-83 %, -80 %]* for SO_2 and +4 %*[-7 %, -21 %]* for NO_x[17].

The totals for fuel consumption, BC, SO_2 and NO_x emissions are shown per fuel type in Figure 7.9 for uniform 2016, 2020, 2030 and 2050.

The fuel consumption and NO_x emission totals calculated for the HFO ban scenario (Table 7.11) equals the results obtained in the Baseline scenario (Table 7.5) for the same reasons as previously explained for the SECA scenario.

For SO_2 and BC, the emission reductions from uniform 2016 to 2020 (shown in Figure 7.9) are due to the complete fuel switch from HFO to MDO / MGO outside the existing SECAs by ships using HFO by origin. In this case, the input emission factors are significantly smaller (c.f. Tables 5.8 and 5.11).

For SO_2 and BC from 2020 onwards, the emissions increases are somewhat smaller during the forecast years, compared to the increase in fuel consumption. This is due to the gradually increased fuel consumption assumed in the

[17] The percentage changes between the historical 2016 results and the HFO ban BAU results for the forecast years 2020*[2030, 2050]* become +5 %*[+7 %, +17 %]* for fuel consumption, -28 %*[-29 %, -26 %]* for BC, -83 %*[-83 %, -82 %]* for SO_2 and +3 %*[-12 %, -32 %]* for NO_x. The percentage changes between the historical 2016 results and the HFO ban HiG results for the forecast years 2020*[2030, 2050]* become +8 %*[+15 %, +40 %]* for fuel consumption, -26 %*[-23 %, -11 %]* for BC, -83 %*[-82 %, -79 %]* for SO_2 and +6 %*[-5 %, -19 %]* for NO_x.

scenario for LNG, for which zero SO_2 emissions and insignificant BC emissions occur during combustion (Table 7.11).

A further description of the fuel consumption and emission results for the HFO ban scenario is given in Chapter 7.6, involving cross comparisons with the Baseline and SECA scenario results.

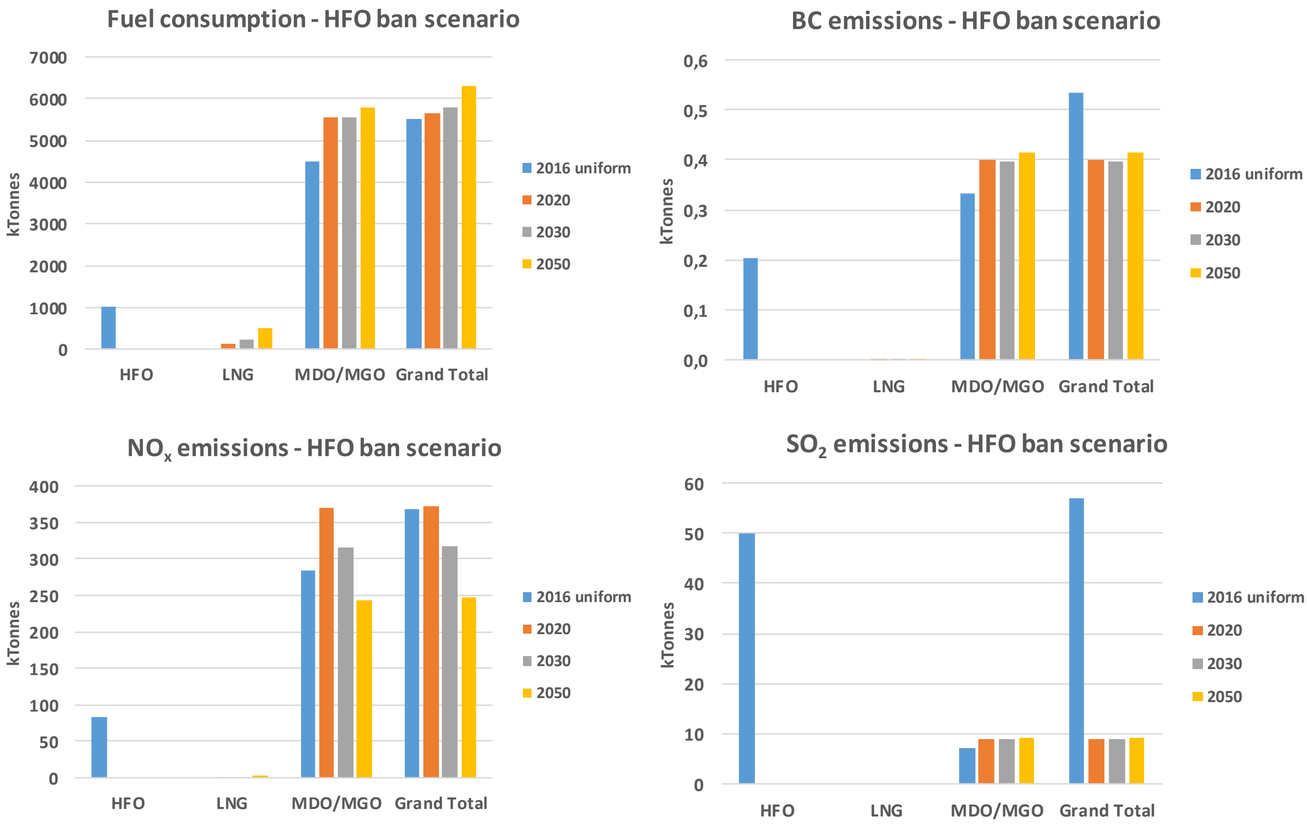


Figure 7.9 Total fuel consumption (by mass), NO_x, SO_2 and BC emissions calculated in the HFO ban BAU scenario.

7.6 Results for all scenarios

Table 7.12 summarizes the totals for sailed distance, engine kWh's produced, fuel consumption (by mass and energy) and BC, NO_x and SO_2 emissions for the Baseline, SECA and HFO ban BAU scenarios in 2020, 2030 and 2050. Table 7.12 also shows the percentage change in results for the SECA and HFO ban BAU scenarios compared with the Baseline BAU results.

Table 7.12 Summary of results for the Baseline, SECA and HFO ban BAU scenarios in 2020, 2030 and 2050, and % change between Baseline and SECA/HFO ban scenario results.

	Scenario	Year	Distance km x 10^6	Power kWh x 10^6	Fuel kTonnes	Fuel TJ	SO_2 Tonnes	NO_x Tonnes	BC Tonnes
Total	Baseline	2020	156.7	29679	5664	240115	16976	371126	432
		2030	173.7	31406	5775	245208	16883	317669	438
		2050	219.3	35135	6310	268933	17757	246870	470
	SECA	2020	156.7	29679	5664	241820	9019	371126	418
		2030	173.7	31406	5775	246882	9073	317669	424
		2050	219.32	35135	6310	270682	9597	246870	455
	HFO ban	2020	156.70	29679	5664	242440	8881	371126	399
		2030	173.67	31406	5775	247792	8870	317669	397
		2050	219.32	35135	6310	272068	9289	246870	414
% change	Baseline	2020	0	0	0	0	0	0	0
		2030	0	0	0	0	0	0	0
		2050	0	0	0	0	0	0	0
	SECA	2020	0	0	0	1	-47	0	-3
		2030	0	0	0	1	-46	0	-3
		2050	0	0	0	1	-46	0	-3
	HFO ban	2020	0	0	0	1	-48	0	-8
		2030	0	0	0	1	-47	0	-9
		2050	0	0	0	1	-48	0	-12

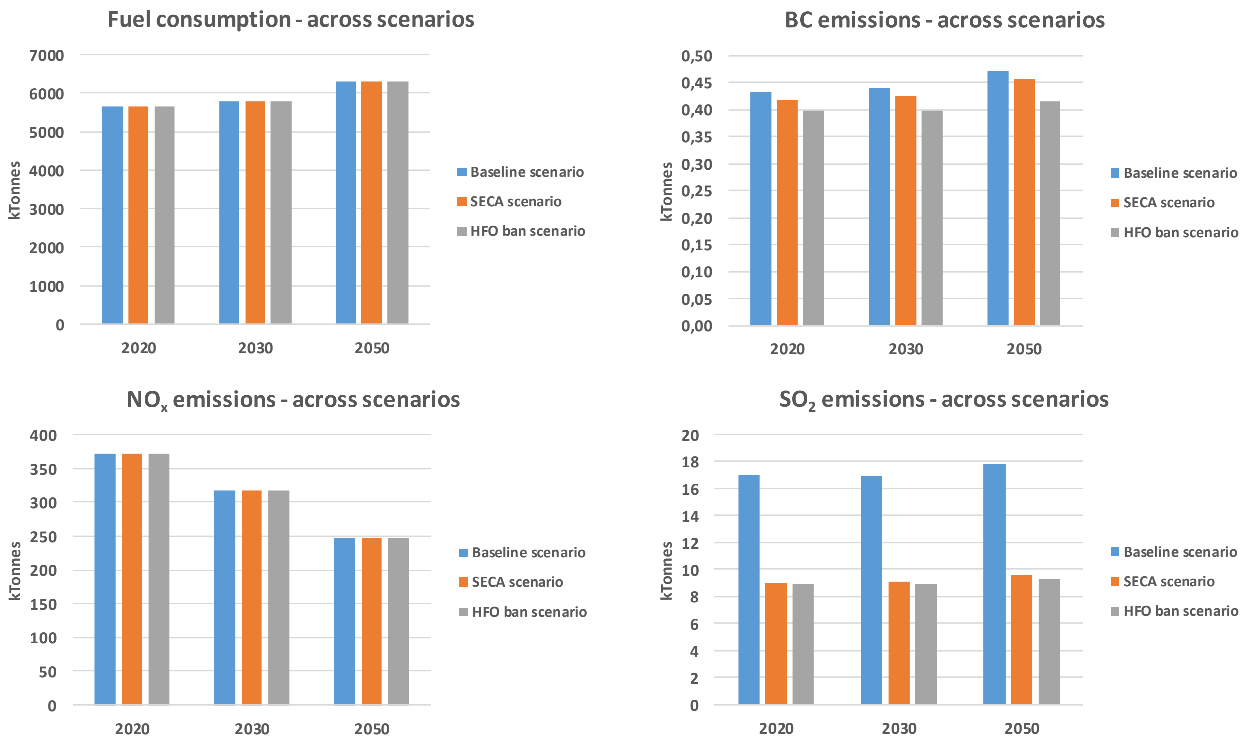


Figure 7.10 Total fuel consumption (by mass), NO_x, SO_2 and BC emissions calculated in the Baseline, SECA and HFO ban BAU scenarios.

The fuel consumption and NO_x emission totals calculated for the SECA and HFO ban scenario equal the results obtained in the Baseline scenario (Table 7.12). The main reason for this is that the engine specific fuel consumption and

NO_x emission factors are unaffected by the fuel switch from HFO to MDO / MDO, and also the same shares of LNG of total fuel consumption per forecast year is assumed in both scenarios.

In all scenario years for SO_2, the calculated emissions for the SECA and HFO ban scenarios are almost half of the emissions calculated for the Baseline scenario (Table 7.12). These emission differences are also visible from the spatially distributed total SO_2 emissions for the Baseline and SECA scenarios in 2050 (Figure 7.11). In the SECA scenario, HFO is only used by ships with EGCS, with a sulphur removal efficiency equivalent Fs = 0.1 (Table 5.4). The 0.5 % fuel oil used outside the original SECA area and not being replaced by LNG, is being replaced by MDO / MGO (Fs = 0.08) according to the scenario definitions explained in section 4.1. In the HFO ban scenario, all HFO consumption by ships not being replaced by LNG is replaced by MGO / MDO) according to the scenario definitions explained in section 4.2.

For BC in 2020*[2030, 2050]*, the HFO ban and SECA emissions are 8 %*[9 %, 12 %]* and 3 %*[3%, 3 %]* smaller, respectively, than the Baseline results (Table 7.12). Apart from LNG with similar fuel consumption shares assumed in all three cases, in the HFO ban scenario, only the fuel type MDO / MGO with the smallest BC emission factor (0.053 g / kg fuel, before load adjustment) is used. In the Baseline and SECA scenarios similar shares of EGCS are used with a higher BC emission factor (0.093 g / kg fuel, before load adjustment). However, in the SECA scenario, the BC emissions from MDO / MGO fuel that replaces 0.5 % fuel oil are smaller due to the level of the BC emission factors.

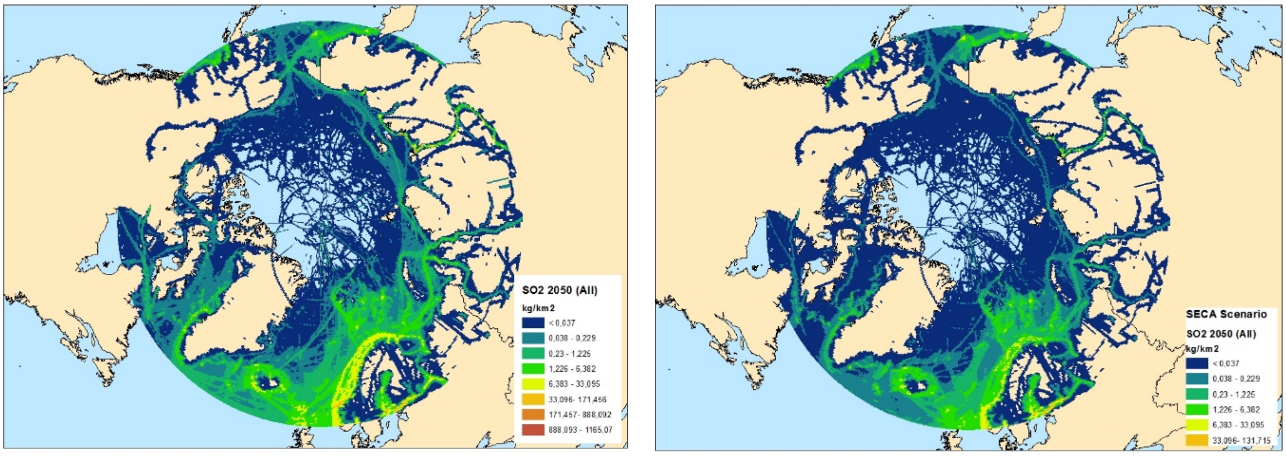


Figure 7.11 Spatial distribution of SO_2 emissions for all ships in 2050 calculated in the Baseline and SECA scenarios.

7.7 Results for previous inventory

In the previous ship emission inventory for the Arctic area, results were calculated for the historical year 2012 and Baseline scenario results were calculated for the projection years 2020, 2030 and 2050. The ship activity data projections were developed by using the BAU traffic growth rates from Corbett et al. (2010) evolved from 2012.

Table 7.13 shows the results for sailed distance, total fuel consumption (by mass), BC, NO_x and SO_2 emissions calculated for the current and the previous inventory for the years 2012, 2020, 2030 and 2050. The percentage changes in the results between the current and previous inventory are also shown in Table 7.13.

The inventory changes for 2012*[2020, 2030, 2050]* become -3 %*[8 %, 7 %, 5 %]*, -5 %*[23 %, 22 %, 20 %]*, -7 %*[-44 %, -44 %, -46 %]*, 4 %*[23 %, 24 %, 18 %]* and -55 %*[-73 %, -74 %, -75 %]*, respectively, for sailed distance, total fuel consumption, SO_2, NO_x and BC.

Table 7.13 Summary of results for the current and the previous inventory for 2012 and for Baseline BAU 2020, 2030 and 2050 projection results, and % change between the current and previous inventory results.

	Year	Distance	Fuel	SO_2	NO_x	BC
		km x 10^6	kTonnes	Tonnes	Tonnes	Tonnes
Current inventory	2012	130	4768	81542	320105	708
	2020	157	5664	16976	371126	432
	2030	174	5775	16883	317669	438
	2050	219	6310	17757	246870	470
Previous inventory	2012	134	4528	87944	307942	1585
	2020	146	4615	30102	301052	1615
	2030	162	4731	30408	256250	1656
	2050	209	5271	32863	208361	1845
% change	2012	-3	5	-7	4	-55
	2020	8	23	-44	23	-73
	2030	7	22	-44	24	-74
	2050	5	20	-46	18	-75

There are multiple reasons for the above listed changes in results. The most important qualitative explanations are given in the following.

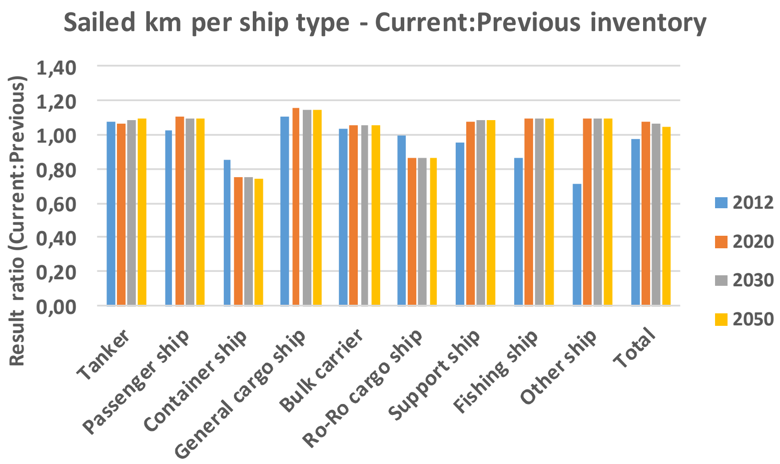
In terms of traffic input data, the ship activity data for 2012 were updated by DMA in the current inventory. Further, the ship traffic projections are now based on consolidated five-year weighted traffic data with 2014 as the starting year point for the calculation of traffic growth rates instead of using 2012 traffic data in the previous inventory. As a result, the ship activity distribution by ship type (Figure 7.12) and ship sizes have changed and impact the total fuel consumption and NO_x emissions to the most extent.

For SO_2, the emission changes between the previous and the current inventory are predominantly ruled by the differences in fuel sulphur content for MDO/MGO. In the previous inventory for 2012, the sulphur content for MDO/MGO was set to 0.5 %, and was kept at this level for MDO/MGO fuel used outside SECA's in the projection years. The current inventory uses instead a MDO/MGO fuel sulphur content of 0.14 % in 2012, and for the projection years a fuel sulphur content of 0.08 % is used.

Also, the introduction of LNG fuel consumption in the current inventory has an impact on the inventory results and the increasing amount of LNG fuel used in the projection years in particular brings down the total emission estimates of SO_2 and BC.

For BC, the most important emission changes originates from the changes in emission factors (section 5.5). Along this line, the emission factor of 0.35 g/kg fuel used in the previous inventory regardless of fuel type has been changed in the current inventory to the much lower emission factors for MDO/MGO, 2.5 % HFO and 0.5 % fuel oil (Table 5.5).

Reversely, the current inventory adjusts the specific fuel consumption and emission factors upwards for the variations in ship engine loads. This adjustment in particular influences the BC emissions at the engine loads that can be derived from the input traffic data (section 5.9). The engine load adjusted BC emission factors are on average approximately 40 % higher than the unadjusted emission factors shown in Table 5.5.



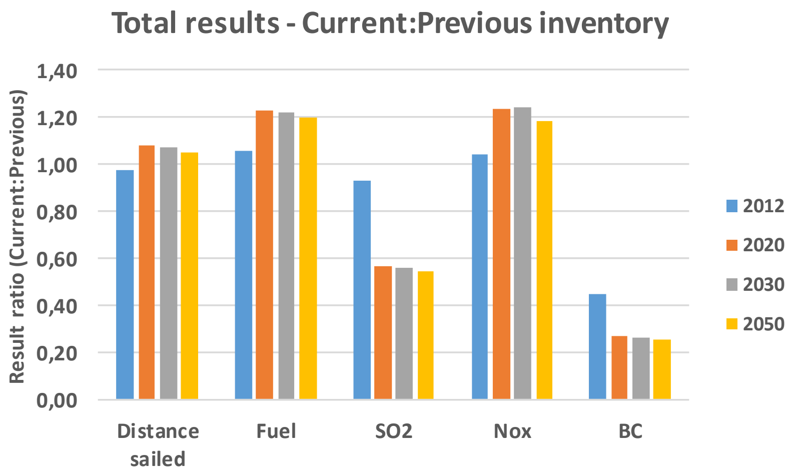


Figure 7.12 Ratios of results for sailed km per ship type (upper figure) and total distance, fuel consumption, SO_2, NO_x and BC emissions (lower fugure) between current and previous inventory for the years 2012, 2020, 2030 and 2050.

Table 7.14 shows the estimated emissions of CO_2, SO_2, NO_x and BC for the polar diversion routes in 2020, 2030 and 2050 for the current and previous inventory at BAU traffic growth. The percentage change between the current and the previous inventory results is also shown in Table 7.14.

The inventory changes for the forecast years 2020*[2030, 2050]* become -2 %*[-3 %, -4 %]* for CO_2, -78 %*[-78 %, -79 %]* for BC, -57 %*[-60 %, -64 %]* for SO_2 and +26 %*[-2 %, -40 %]* for NO_x.

The reason for the differences in diversion route emission results between the current and the previous inventory rely on differences in the emission factors used. In the previous inventory, emission factors from Corbett et al. (2010) were used to multiply the estimated fuel consumption for the diversion route. In the current inventory, up-to-date emission factors from the present project are used instead.

Tabel 7.14 Emission results for polar diversion routes for the current and the previous inventory for 2020, 2030 and 2050, and % change between the current and previous inventory results.

Diversion routes	Unit		2020	2030	2050
Current inventory	Tonnes	SO_2	8028	8715	18424
	Tonnes	NO_x	141117	127620	185217
	Tonnes	BC	130	148	336
	kTonnes	CO_2	5243	6052	14131
Previous inventory	Tonnes	SO_2	18630	21670	51410
	Tonnes	NO_x	111870	130120	308680
	Tonnes	BC	580	680	1610
	kTonnes	CO_2	5341	6213	14738
% change	%	SO_2	-57	-60	-64
	%	NO_x	26	-2	-40
	%	BC	-78	-78	-79
	%	CO_2	-2	-3	-4

8 Results for concentration and deposition of emissions

The transport and transformation of BC and other air pollutants in the Arctic originating from anthropogenic and natural sources outside the Arctic (referred to as "background emissions" in the following) and the emissions from Arctic shipping have been determined by using the Danish Eulerian Hemispheric Model (DEHM), see e.g. Christensen (1997) and Brandt et al. (2012). DEHM has been widely used to describe the transport of pollutants into Arctic (Christensen, 1997; Christensen et al., 2004; Skov et al., 2006; Hole et al., 2009), and has been used in many assessments in the Arctic Monitoring and Assessment Programme (AMAP 2006, 2011). DEHM is a 3D chemical transport model and in this study the model has been set up with a horizontal resolution of 150 km at 60N and a nested grid of 50 km resolution for the Arctic. The vertical model resolution has been defined on an irregular grid with 29 layers up to approximately 15 km reflecting the structure of the atmosphere. For further detail of the model system, see Brandt et al. (2012).

All the model runs made in this project are two years model runs using meteorological data for 2008 and 2009 obtained from the weather forecast model PSU / NCAR (Pennsylvania State University / National Center for Atmospheric Research) Mesoscale Model version 5 (MM5) modelling subsystem (see Grell et al., 1995) driven by global meteorological data from the National Centers for Environmental Prediction (NCEP) as input.

The basic background model run with DEHM calculates the atmospheric concentrations and depositions of pollutants based on the emissions for the latest historical year (2008 / 2009). The input emissions come from the global anthropogenic RCP (Representative Concentration Pathways) model (Larmarque et al., 2010) and the EMEP (European Monitoring and Evaluation Program) emission inventories for Europe (Mareckova et al., 2008). Furthermore emissions from biomass burning from the GFEDv3 (Global Fire Emissions Database version 3) model (van der Werf et al., 2010) have been used.

In the basic model run, the emissions from RCP and EMEP include ship emissions, and ship emissions are set to zero north of 60N. The model runs, including Arctic ship emissions are then constructed by adding the historical (or scenario projection year specific) Arctic ship emissions to the basis run emissions and then run the DEHM model with exactly the same model setup. The difference between the model runs, including Arctic ship emissions and the basic run is only explained by the extra emission contributions from Arctic navigation.

The Arctic ships emissions inventories used as input for the concentration and deposition results shown in this chapter are the uniform gridded 2016 inventory and the Baseline emission projections for both BAU and HiG traffic growth. All projection model runs for concentration and deposition of emissions are made in two versions, with and without Arctic traffic diverted from current shipping routes, as explained in Chapter 7.3. It must be mentioned that the DEHM model runs with the future ships emission inventories do not take into account the influence of a changed future Arctic climate, e.g. the reduced sea-ice cover influence on dry deposition of BC or the photolysis rates, which will have an influence on the ozone chemistry, due to the changed albedo. This adds some uncertainty to the estimated future air pollution levels in the Arctic.

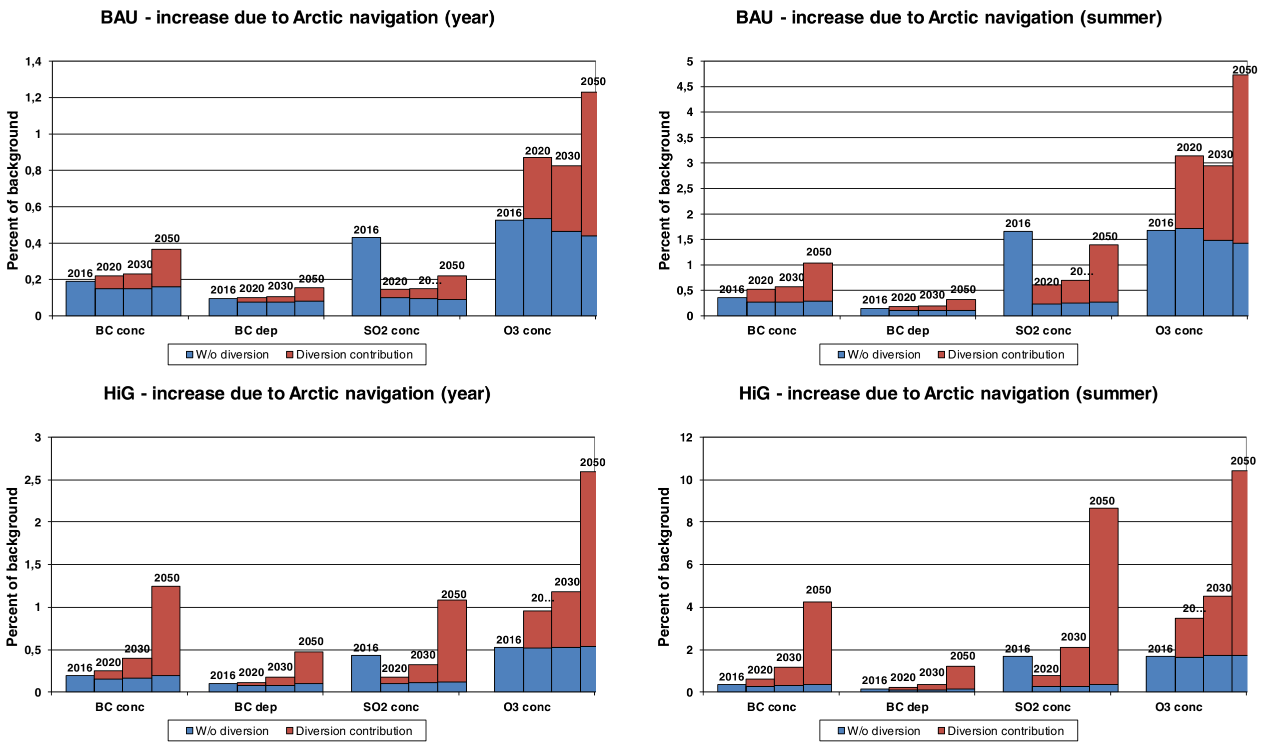


Figure 8.1 Increase of BC deposition and BC, SO_2 and O_3 surface concentrations in 2016 (uniform gridded), 2020, 2030 and 2050 (whole year and summertime average) due to Arctic navigation, as percentage of background.

For all DEHM model runs, Figure 8.1 shows the yearly average and summertime percentage increase of the surface mean concentrations of BC, SO_2 and O_3 and the mean deposition of BC for the inventory area (north of 58.95N) due to navigation, relative to the basic model run (c.f. model run approach explained above). The BC and SO_2 surface concentrations caused by navigation and the direct navigation emissions explained in Chapter 7.2 and 7.3 display a similar trend.

The average surface concentration and BC deposition increases from navigation (Figure 8.1) remain on low levels for the baseline scenarios without diversion traffic included. For the projection scenarios with additional diversion traffic, the forecasted increases in surface concentration and BC deposition become far more pronounced. In both cases, with or without diversion traffic, the surface concentration / deposition increases become significantly higher during summertime. Solely for diversion traffic, the summertime average surface concentration / deposition percentage increases for BCcon*[BCdep, SO_2, O_3]* become 0.8 % *[0.2 %, 1.1 %, 3.3 %]* and 3.9 % *[1.1 %, 8.3 %, 8.7 %]*, respectively, for BAU and HiG in 2050. And solely for diversion traffic, the yearly average surface concentration / deposition percentage increases for BCcon*[BCdep, SO_2, O_3]* become 0.2 % *[0.1 %, 0.1 %, 0.8 %]* and 1.0 % *[0.4 %, 1.0 %, 2.1 %]*, respectively, for BAU and HiG in 2050.

Apart from a larger sea area becoming navigable during summertime, and the presence of additional diversion traffic, the following reasons further explain the elevated summer surface concentration levels. Ships are one of the major SO_2 (and BC) emission sources in this area, and SO_2 emission factors are high, although fuel sulphur content declines in the future. Further, it is known that non-Arctic SO_2 emissions are placed outside the Polar Front, especially in the summertime, which prevent the near surface transport of air masses into the Arctic. Furthermore, SO_2 gets oxidized to SO_4^{2-} due to the large amount of sunlight radiation before it reaches the Arctic area. Also, the photo chemical reactions that transform O_3 precursors as NO_x and VOC into O_3, are enhanced in the summertime in the Arctic due to the presence of midnight sun or sunlight during many hours of the day and due to the high albedo of the sea ice and snow, which increase the photolysis rates (as previously explained), concurrent with the increased emissions due to the Arctic diversion traffic.

Figure 8.2 depicts the spatial distribution of the BC, SO_2 and O_3 surface concentrations and BC deposition values from Figure 8.1, based on our inventory results and background emissions.

Also the spatially distributed average navigation contributions are low in most of the inventory area in 2016. The additional contribution to BC surface concentrations, however, reach up to 5 % mainly around Iceland, and high SO_2 additional contributions (20-100 %) are calculated in some sea areas due to reasons explained earlier. In 2050, during summertime, the additional contributions from navigation (mainly from diverted traffic) becomes very visible for BC (20-40 %) and SO_2 (300-1000 %) along the Arctic diversion routes, while the BC deposition (1-2 %) and the O_3 concentration (7-10 %) become highest over the oceans east of Greenland and in High Arctic, respectively. The main reasons for the higher O_3 surface concentrations are higher concentrations of O_3 precursors like NO_x and VOC, together with long daylight and high albedo of sea ice and snow. As mentioned above, the calculated increase in O_3 surface concentrations do not take into account the reduced sea ice cover in 2050 and its influence on the photolysis rates.

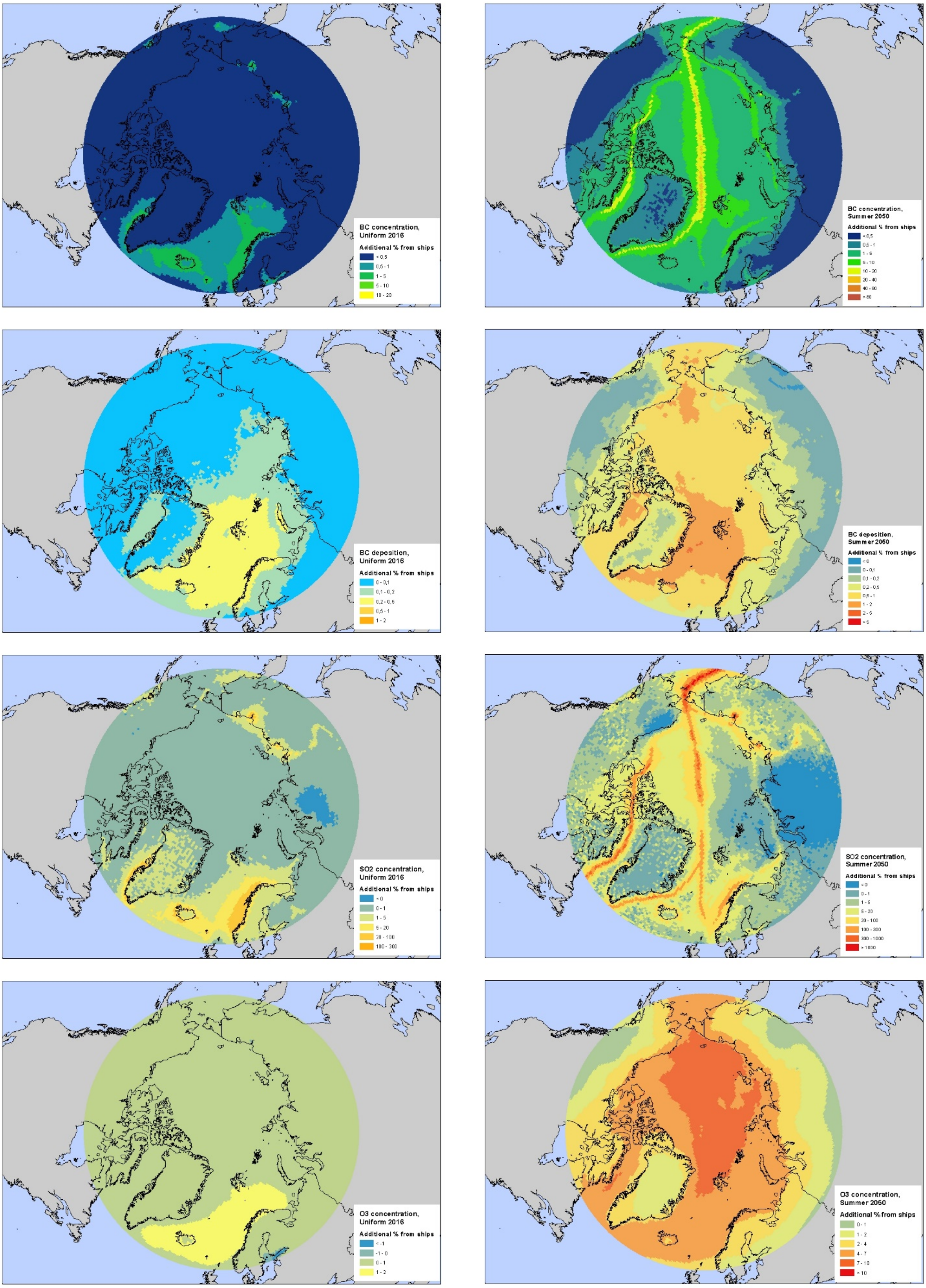


Figure 8.2 Spatial distribution of the increase of BC deposition and BC, SO_2 and O_3 surface concentrations in 2016 (uniform gridded, whole year) and 2050 (summertime) due to Arctic navigation, as percentage of background.

In the previous ship emission inventory, for the Arctic area concentration and deposition results were calculated for the historical year 2012 and BAU Baseline scenario results were calculated for the projection years 2020, 2030 and 2050. The Baseline scenario results were based on emission inventories using as traffic data input the BAU ship activity data projections from Corbett et al. (2010) evolved from 2012.

Due to the changes in traffic input data, emission factors and assumptions made for fuel type usage etc. as discussed in Chapter 7.7, the emission concentration and depositions also reduce significantly in the current inventory compared with the previous inventory, in both cases with or without diversion traffic.

Calculated for the diversion traffic alone in 2050, the summertime average surface concentration / deposition percentage decreases for BCcon*[BCdep, SO_2, O_3]* become 79 % *[79 %, 72 %, 30 %]* during summertime and 79 % *[79 %, 72 %, 29 %]* for the yearly average.

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Appendix

Annexes for Chapter 2

HiG growth traffic scaling factors for the years 2020, 2030 and 2050 used in this study.

Vessel type		1		Vessel type
This study	2020	2030	2050	Corbett et al. (2010)
Crude oil tanker	1.36	1.92	3.31	Tanker
Oil products & chemical tanker	1.36	1.92	3.31	Tanker
Ro-ro passenger ship	1.10	1.29	1.81	Passenger vessels
Gas tanker	1.36	1.92	3.31	Tanker
Container ship	1.32	2.20	6.60	Container ship
General cargo ship	1.07	1.20	1.55	General cargo ship
Bulk carrier	1.14	1.45	2.35	Bulk ships
Ro-ro cargo ship	1.07	1.20	1.55	General cargo ship
Passenger ship	1.10	1.29	1.81	Passenger vessels
Fast ferry	1.10	1.29	1.81	Passenger vessels
Support ship	1.20	1.48	2.14	Offshore Service Vessels
Fishing ship	1	1	1	-
Other ship	1	1	1	-

Annexes for Chapter 7 related to calculated results for the years 2012-2016

Results per ship type calculated for the inventory area in 2012-2016.

Year	Vessel type	Distance km x 10^6	Power kWh x 10^6	Fuel kTonnes	Fuel TJ	SO_2 Tonnes	CO_2 kTonnes	NO_x Tonnes	VOC Tonnes	CO Tonnes	CH_4 Tonnes	BC Tonnes	OC Tonnes	PM Tonnes	N_2O Tonnes
2012	Bulk carrier	4.49	1027	193	7876	7358	614	18080	526	1669	16	39	206	1233	30
2012	Container ship	5.88	1178	223	9118	6393	711	20818	617	1942	19	47	239	1262	35
2012	Crude oil tanker	1.44	541	102	4166	2530	325	9560	284	892	9	22	109	549	16
2012	Fast ferry	0.19	8	2	70	5	5	87	4	13	0	0	1	2	0
2012	Fishing ship	28.98	9644	1985	84763	5558	6272	113382	4822	15431	145	150	774	1911	312
2012	Gas tanker	0.86	194	36	1484	1415	116	3415	100	317	3	6	39	235	6
2012	General cargo ship	29.89	2224	430	17588	13621	1372	39598	1211	3769	36	106	460	2515	66
2012	Oil products & chemical tanker	10.78	1904	357	14621	11907	1140	33706	1006	3153	30	72	383	2174	56
2012	Other ship	5.75	633	131	5427	3957	415	7510	359	1087	11	17	108	595	21
2012	Passenger ship	10.06	1749	366	15118	9687	1166	20752	929	2913	28	66	341	1611	57
2012	Ro-ro cargo ship	3.24	755	158	6469	3398	504	8954	397	1246	12	31	167	691	25
2012	Ro-ro passenger ship	15.20	2928	624	25625	14183	1987	35023	1606	4964	48	135	622	2666	96
2012	Support ship	13.09	774	162	6843	1531	511	9222	467	1369	14	16	84	316	26
2012	Grand Total	129.87	23558	4768	199168	81542	15141	320105	12329	38763	370	708	3532	15762	746
2013	Bulk carrier	4.66	1066	200	8176	7642	638	18687	555	1742	17	42	214	1289	31
2013	Container ship	5.48	1089	206	8415	5961	656	19130	575	1797	17	45	220	1177	32
2013	Crude oil tanker	1.44	520	98	4006	2600	312	9143	276	860	8	21	105	544	15
2013	Fast ferry	0.20	16	3	136	8	10	165	8	25	0	0	1	3	1
2013	Fishing ship	31.82	10744	2197	93830	5713	6943	125851	5372	17119	161	166	857	2098	345
2013	Gas tanker	0.74	156	29	1191	1065	93	2732	81	254	2	5	31	184	5
2013	General cargo ship	28.02	2580	491	20072	16730	1566	45629	1411	4361	42	112	525	3021	76
2013	Oil products & chemical tanker	10.94	2016	376	15388	13037	1200	35542	1085	3364	33	77	403	2358	59
2013	Other ship	8.91	601	125	5222	2593	396	7181	380	1093	11	17	89	450	20
2013	Passenger ship	10.47	2358	491	20217	12015	1563	27939	1269	3939	38	90	471	2150	77
2013	Ro-ro cargo ship	2.72	648	135	5535	2800	431	7665	343	1069	10	28	142	587	21
2013	Ro-ro passenger ship	12.73	2489	524	21532	12521	1669	29634	1359	4185	41	107	520	2308	81
2013	Support ship	13.54	846	176	7432	1689	556	9951	505	1482	15	18	92	355	28
2013	Grand Total	131.66	25129	5050	211151	84373	16034	339249	13217	41289	397	727	3670	16524	791
2014	Bulk carrier	4.86	1127	210	8600	8094	671	19709	607	1859	18	46	225	1385	33
2014	Container ship	5.52	1062	200	8176	5811	638	18562	570	1754	17	45	214	1159	31
2014	Crude oil tanker	1.55	549	103	4201	2850	328	9569	291	901	9	22	110	585	16

Continued															
2014	Fast ferry	0.27	21	4	183	33	14	232	12	35	0	0	2	7	1
2014	Fishing ship	38.68	14220	2890	123388	6935	9131	165904	7110	22468	213	218	1127	2735	454
2014	Gas tanker	0.85	205	38	1549	1347	121	3557	106	330	3	6	41	239	6
2014	General cargo ship	30.29	3719	697	28508	26237	2224	65201	2027	6223	61	149	746	4549	109
2014	Oil products & chemical tanker	11.61	3407	624	25520	24828	1991	59238	1779	5530	53	108	668	4207	99
2014	Other ship	11.16	809	167	6989	3833	531	9736	528	1485	16	22	122	652	27
2014	Passenger ship	11.61	2265	469	19349	11103	1494	26723	1227	3768	37	85	441	2018	73
2014	Ro-ro cargo ship	2.67	626	130	5332	2677	415	7379	333	1030	10	28	138	569	20
2014	Ro-ro passenger ship	14.26	2615	546	22485	12669	1741	31042	1435	4377	43	109	533	2377	85
2014	Support ship	17.10	1011	209	8838	2004	660	11887	629	1785	19	20	108	421	34
2014	Grand Total	150.43	31636	6287	263118	108423	19957	428740	16654	51545	500	859	4473	20902	988
2015	Bulk carrier	4.87	1081	201	8352	6227	638	18645	568	1741	17	34	163	995	31
2015	Container ship	5.44	1017	191	8017	3465	604	17606	544	1658	16	25	120	617	29
2015	Crude oil tanker	1.70	579	108	4556	1434	341	10045	313	950	9	13	60	281	17
2015	Fast ferry	0.32	11	2	91	3	7	115	6	17	0	0	1	2	0
2015	Fishing ship	46.25	17387	3510	149885	5616	11091	201976	8693	27123	261	265	1369	3131	552
2015	Gas tanker	1.01	251	46	1918	1321	146	4315	130	400	4	6	36	215	7
2015	General cargo ship	33.89	2627	502	21034	11216	1592	46094	1507	4492	45	85	345	1934	77
2015	Oil products & chemical tanker	12.70	2592	476	19854	13174	1512	44843	1382	4211	41	64	364	2190	75
2015	Other ship	11.55	730	151	6337	2597	477	8691	473	1311	14	17	93	455	24
2015	Passenger ship	13.82	2543	524	22161	6773	1660	29917	1382	4184	41	55	290	1199	82
2015	Ro-ro cargo ship	2.75	624	129	5513	451	409	7337	334	1016	10	11	54	145	20
2015	Ro-ro passenger ship	15.97	2607	544	23047	5999	1723	30879	1447	4341	43	60	286	1104	84
2015	Support ship	17.98	958	198	8400	1564	626	11172	601	1670	18	19	95	353	32
2015	Grand Total	168.25	33006	6582	279165	59842	20828	431636	17379	53115	521	652	3274	12621	1031
2016	Bulk carrier	4.73	1083	199	8296	6137	634	18466	563	1703	17	33	161	986	31
2016	Container ship	5.23	1008	188	7895	3513	595	17312	545	1626	16	25	119	629	29
2016	Crude oil tanker	1.97	680	125	5286	2101	398	11661	364	1090	11	16	76	388	20
2016	Fast ferry	0.76	33	7	283	11	21	353	17	49	1	0	3	6	1
2016	Fishing ship	38.24	12100	2427	103635	3883	7669	139903	6050	18554	182	183	947	2183	382
2016	Gas tanker	1.01	258	47	1957	1389	149	4398	133	404	4	6	37	227	7
2016	General cargo ship	33.96	2806	532	22299	11379	1686	48467	1564	4633	47	87	358	1963	81
2016	Oil products & chemical tanker	11.48	1996	366	15355	7522	1160	34165	1061	3180	32	47	242	1323	57
2016	Other ship	6.83	441	91	3836	1443	288	5110	270	751	8	12	54	254	14
2016	Passenger ship	14.85	2610	534	22593	6677	1692	30479	1412	4203	42	55	292	1197	84

Continued

2016	Ro-ro cargo ship	2.78	642	132	5606	611	416	7484	339	1019	10	11	57	167	20
2016	Ro-ro passenger ship	18.33	2855	591	25031	6667	1872	33668	1586	4676	48	65	313	1228	92
2016	Support ship	15.29	821	168	7152	1328	533	9352	491	1358	15	16	81	298	27
2016	Grand Total	155.46	27335	5407	229223	52660	17114	360819	14394	43246	432	556	2740	10848	845

Results per fuel type and sea area (SECA/Non SECA) calculated for the inventory area in 2012-2016.

Year	Area	Fuel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
			km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2012	SECA	HFO	44	7984	1602	65522	32040	5111	119722	4315	13420	129	359	1714	7445	249
2012	SECA	MDO/MGO	19	1925	397	16962	1112	1255	22558	994	3134	30	28	155	385	63
2012	Non SECA	HFO	27	4366	857	35065	43038	2735	68667	2330	7278	70	178	917	6085	134
2012	Non SECA	MDO/MGO	39	9283	1911	81621	5352	6040	109158	4690	14931	141	142	745	1846	301
2012	Grand Total		130	23558	4768	199168	81542	15141	320105	12329	38763	370	708	3532	15762	746
2013	SECA	HFO	39	7670	1530	62589	30606	4882	113574	4167	12876	125	338	1637	7181	238
2013	SECA	MDO/MGO	21	2102	431	18409	1121	1362	24478	1088	3409	33	30	168	415	68
2013	Non SECA	HFO	30	4999	970	39669	47137	3094	79945	2732	8419	82	202	1038	6899	152
2013	Non SECA	MDO/MGO	42	10358	2119	90484	5510	6696	121251	5230	16585	157	157	826	2028	334
2013	Grand Total		132	25129	5050	211151	84373	16034	339249	13217	41289	397	727	3670	16524	791
2014	SECA	HFO	42	7913	1568	64119	31354	5001	117439	4317	13218	130	350	1677	7451	243
2014	SECA	MDO/MGO	24	2595	529	22590	1270	1672	30067	1339	4162	40	37	206	504	83
2014	Non SECA	HFO	31	7429	1405	57454	69113	4481	121331	4035	12346	121	263	1503	10299	222
2014	Non SECA	MDO/MGO	53	13699	2786	118956	6686	8803	159902	6963	21820	209	208	1086	2648	439
2014	Grand Total		150	31636	6287	263118	108423	19957	428740	16654	51545	500	859	4473	20902	988
2015	SECA	MDO/MGO	71	10770	2141	91410	3425	6764	150113	5813	17619	174	168	835	2009	333
2015	Non SECA	HFO	36	5409	1040	42549	50976	3319	85992	3040	9081	91	229	1113	7568	163
2015	Non SECA	MDO/MGO	62	16827	3401	145206	5441	10745	195531	8527	26416	256	255	1326	3043	535
2015	Grand Total		168	33006	6582	279165	59842	20828	431636	17379	53115	521	652	3274	12621	1031
2016	SECA	MDO/MGO	73	11347	2238	95578	3581	7073	156763	6109	18203	183	175	873	2119	348
2016	Non SECA	HFO	34	4826	928	37973	45493	2962	75204	2663	7886	80	214	993	6711	144
2016	Non SECA	MDO/MGO	49	11162	2241	95672	3585	7080	128852	5621	17156	169	167	874	2018	352
2016	Grand Total		155	27335	5407	229223	52660	17114	360819	14394	43246	432	556	2740	10848	845

Results per fuel type and sea area (SECA/Non SECA) calculated for the uniform gridded 2016 inventory.

Year	Area	Fuel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
			km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2016 uniform	SECA	MDO/MGO	66	10490	2052	87633	3284	6485	143539	5309	16208	159	150	800	1921	318
2016 uniform	Non SECA	HFO	49	12224	2452	104720	3924	7749	141006	6127	18745	184	182	956	2207	386
2016 uniform	Non SECA	MDO/MGO	32	5392	1018	41623	49866	3247	83815	2791	8464	84	203	1089	7343	159
2016 uniform	Grand Total		147	28106	5522	233976	57074	17481	368359	14228	43417	427	535	2846	11471	862

Annexes for Chapter 7 related to calculated results for business as usual (BAU) traffic growth

Results per ship type calculated for the inventory area in the Baseline BAU scenario for 2020, 2030 and 2050.

Year	Vessel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
		km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2020	Bulk carrier	5.14	1153	204	8529	1212	646	17886	1009	1646	445	17	166	635	31
2020	Container ship	6.57	1257	224	9454	875	708	19532	1109	1807	488	18	148	510	34
2020	Crude oil tanker	2.10	732	130	5495	426	410	11346	640	1043	283	10	81	266	20
2020	Fast ferry	0.36	18	4	154	6	11	178	10	23	1	0	1	4	1
2020	Fishing ship	36.80	12819	2512	107254	4019	7937	144795	6410	18289	192	190	980	2327	395
2020	Gas tanker	1.16	272	47	1982	259	150	4222	236	388	103	3	37	140	7
2020	General cargo ship	31.76	2818	509	21377	2575	1607	43934	2528	4120	1108	44	363	1351	77
2020	Oil products & chemical tanker	14.94	3058	538	22525	3026	1699	47464	2668	4374	1171	38	406	1572	83
2020	Other ship	8.84	643	127	5351	564	402	6913	485	925	144	9	82	259	20
2020	Passenger ship	12.67	2409	475	20075	1563	1500	26161	2040	3438	856	35	291	793	73
2020	Ro-ro cargo ship	2.88	673	132	5632	255	416	7286	610	960	281	10	66	155	20
2020	Ro-ro passenger ship	15.93	2823	563	23846	1693	1777	30768	2468	4068	1073	45	329	863	86
2020	Support ship	17.54	1003	199	8441	503	628	10640	605	1382	94	13	94	254	31
2020	Grand total	156.70	29679	5664	240115	16976	17890	371126	20818	42461	6241	432	3043	9128	879
2030	Bulk carrier	6.08	1250	214	8966	1157	672	15133	1486	1471	874	17	169	670	32
2030	Container ship	9.44	1667	287	12122	1051	900	18661	1995	1973	1172	23	191	684	43
2030	Crude oil tanker	2.77	878	150	6374	456	472	9575	1043	1031	615	12	96	324	23
2030	Fast ferry	0.40	19	4	157	6	12	138	10	18	1	0	1	4	1
2030	Fishing ship	36.80	12819	2432	103837	3891	7684	128782	6410	14870	192	184	948	2347	382
2030	Gas tanker	1.53	331	56	2338	272	175	3957	389	388	227	3	42	164	9
2030	General cargo ship	33.38	2824	491	20749	2309	1544	33065	3432	3397	2010	42	341	1321	74
2030	Oil products & chemical tanker	19.67	3776	641	26966	3415	2014	44841	4470	4450	2620	45	474	1922	98
2030	Other ship	8.84	610	117	4935	487	369	5401	567	710	245	8	74	241	18
2030	Passenger ship	13.91	2512	478	20251	1463	1504	20509	2850	2946	1614	35	297	834	73
2030	Ro-ro cargo ship	3.03	672	127	5435	238	399	5043	838	790	509	9	66	163	19
2030	Ro-ro passenger ship	17.49	2946	567	24042	1620	1780	23689	3482	3494	2027	46	339	922	85
2030	Support ship	20.36	1103	212	9035	519	670	8877	739	1217	177	14	99	277	33

Continued															
2030	Grand total	173.67	31406	5775	245208	16883	18197	317669	27711	36755	12284	438	3138	9873	891
2050	Bulk carrier	8.73	1466	246	10430	1150	768	12303	2554	1285	1835	19	185	731	37
2050	Container ship	21.24	3115	526	22404	1761	1639	18504	5457	2744	3918	41	348	1258	78
2050	Crude oil tanker	4.24	1077	181	7736	484	565	5487	1877	942	1351	14	116	394	27
2050	Fast ferry	0.50	21	4	168	7	12	127	11	17	1	0	2	4	1
2050	Fishing ship	36.80	12819	2394	102232	3831	7565	110735	6410	10255	192	181	934	2356	376
2050	Gas tanker	2.34	421	70	2959	286	217	3324	725	368	519	4	49	191	11
2050	General cargo ship	37.89	2887	493	21008	2059	1536	20527	5122	2578	3672	40	320	1253	73
2050	Oil products & chemical tanker	30.12	5010	836	35490	4100	2605	39234	8684	4394	6225	55	589	2438	126
2050	Other ship	8.84	528	99	4221	376	312	3690	653	464	375	7	60	196	15
2050	Passenger ship	17.34	2718	506	21563	1380	1582	11898	4448	2373	3109	37	313	880	76
2050	Ro-ro cargo ship	3.44	663	123	5266	216	382	1713	1219	584	894	9	66	166	18
2050	Ro-ro passenger ship	21.81	3192	600	25589	1573	1871	12449	5484	2812	3906	48	361	992	89
2050	Support ship	26.04	1218	231	9867	534	730	6880	958	1018	339	15	106	297	36
2050	Grand total	219.32	35135	6310	268933	17757	19785	246870	43601	29835	26337	470	3448	11158	962

Results per ship type calculated for the inventory area in the SECA BAU scenario for 2020, 2030 and 2050.

Year	Vessel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
		km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2020	Bulk carrier	5.14	1153	204	8720	324	643	17886	1009	1646	445	15	94	258	31
2020	Container ship	6.57	1257	224	9565	357	706	19532	1109	1807	488	17	106	290	34
2020	Crude oil tanker	2.10	732	130	5542	208	409	11346	640	1043	283	10	63	174	20
2020	Fast ferry	0.36	18	4	154	6	11	178	10	23	1	0	1	3	1
2020	Fishing ship	36.80	12819	2512	107254	4019	7937	144795	6410	18289	192	190	980	2327	395
2020	Gas tanker	1.16	272	47	2021	75	149	4222	236	388	103	3	22	61	7
2020	General cargo ship	31.76	2818	509	21758	798	1601	43934	2528	4120	1108	41	219	597	77
2020	Oil products & chemical tanker	14.94	3058	538	22993	841	1691	47464	2668	4374	1171	35	229	632	83
2020	Other ship	8.84	643	127	5428	201	401	6913	485	925	144	8	53	125	20
2020	Passenger ship	12.67	2409	475	20246	763	1497	26161	2040	3438	856	33	227	512	73
2020	Ro-ro cargo ship	2.88	673	132	5641	211	416	7286	610	960	281	10	62	139	20
2020	Ro-ro passenger ship	15.93	2823	563	24016	900	1774	30768	2468	4068	1073	44	265	589	86
2020	Support ship	17.54	1003	199	8481	316	627	10640	605	1382	94	13	79	186	31
2020	Grand total	156.70	29679	5664	241820	9019	17861	371126	20818	42461	6241	418	2399	5894	879
2030	Bulk carrier	6.08	1250	214	9143	330	670	15133	1486	1471	874	16	103	297	32
2030	Container ship	9.44	1667	287	12252	446	898	18661	1995	1973	1172	22	142	410	43
2030	Crude oil tanker	2.77	878	150	6421	236	472	9575	1043	1031	615	11	78	226	23
2030	Fast ferry	0.40	19	4	157	6	12	138	10	18	1	0	1	4	1
2030	Fishing ship	36.80	12819	2432	103837	3891	7684	128782	6410	14870	192	184	948	2347	382
2030	Gas tanker	1.53	331	56	2378	86	174	3957	389	388	227	3	27	78	9
2030	General cargo ship	33.38	2824	491	21084	747	1539	33065	3432	3397	2010	39	215	615	74
2030	Oil products & chemical tanker	19.67	3776	641	27490	971	2005	44841	4470	4450	2620	41	276	803	98
2030	Other ship	8.84	610	117	5000	183	368	5401	567	710	245	8	49	121	18
2030	Passenger ship	13.91	2512	478	20403	754	1501	20509	2850	2946	1614	34	240	569	73
2030	Ro-ro cargo ship	3.03	672	127	5444	198	399	5043	838	790	509	9	63	148	19
2030	Ro-ro passenger ship	17.49	2946	567	24199	888	1778	23689	3482	3494	2027	44	280	653	85
2030	Support ship	20.36	1103	212	9074	336	670	8877	739	1217	177	14	84	207	33
2030	Grand total	173.67	31406	5775	246882	9073	18168	317669	27711	36755	12284	424	2506	6477	891
2050	Bulk carrier	8.73	1466	246	10599	360	766	12303	2554	1285	1835	18	121	364	37

Continued															
2050	Container ship	21.24	3115	526	22615	775	1635	18504	5457	2744	3918	40	268	798	78
2050	Crude oil tanker	4.24	1077	181	7781	271	564	5487	1877	942	1351	14	99	296	27
2050	Fast ferry	0.50	21	4	168	6	12	127	11	17	1	0	2	4	1
2050	Fishing ship	36.80	12819	2394	102232	3831	7565	110735	6410	10255	192	181	934	2356	376
2050	Gas tanker	2.34	421	70	2998	102	216	3324	725	368	519	4	34	103	11
2050	General cargo ship	37.89	2887	493	21299	702	1531	20527	5122	2578	3672	37	210	621	73
2050	Oil products & chemical tanker	30.12	5010	836	36114	1188	2595	39234	8684	4394	6225	51	353	1062	126
2050	Other ship	8.84	528	99	4270	151	312	3690	653	464	375	6	42	106	15
2050	Passenger ship	17.34	2718	506	21694	767	1579	11898	4448	2373	3109	36	264	644	76
2050	Ro-ro cargo ship	3.44	663	123	5273	182	382	1713	1219	584	894	9	63	153	18
2050	Ro-ro passenger ship	21.81	3192	600	25734	899	1869	12449	5484	2812	3906	46	306	737	89
2050	Support ship	26.04	1218	231	9904	363	729	6880	958	1018	339	15	92	229	36
2050	Grand total	219.32	35135	6310	270682	9597	19755	246870	43601	29835	26337	455	2788	7472	962

Results per ship type calculated for the inventory area in the HFO ban BAU scenario for 2020, 2030 and 2050.

Year	Vessel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
		km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2020	Bulk carrier	5.14	1153	204	8766	313	642	17886	1009	1646	445	14	76	208	31
2020	Container ship	6.57	1257	224	9623	344	705	19532	1109	1807	488	15	84	227	34
2020	Crude oil tanker	2.10	732	130	5580	200	409	11346	640	1043	283	9	49	132	20
2020	Fast ferry	0.36	18	4	155	6	11	178	10	23	1	0	1	3	1
2020	Fishing ship	36.80	12819	2512	107254	4019	7937	144795	6410	18289	192	190	980	2327	395
2020	Gas tanker	1.16	272	47	2032	73	149	4222	236	388	103	2	18	49	7
2020	General cargo ship	31.76	2818	509	21835	781	1599	43934	2528	4120	1108	38	190	512	77
2020	Oil products & chemical tanker	14.94	3058	538	23066	825	1689	47464	2668	4374	1171	33	201	551	83
2020	Other ship	8.84	643	127	5439	199	400	6913	485	925	144	8	49	114	20
2020	Passenger ship	12.67	2409	475	20372	735	1495	26161	2040	3438	856	30	179	400	73
2020	Ro-ro cargo ship	2.88	673	132	5675	203	416	7286	610	960	281	9	50	109	20
2020	Ro-ro passenger ship	15.93	2823	563	24157	869	1772	30768	2468	4068	1073	39	212	466	86
2020	Support ship	17.54	1003	199	8486	315	627	10640	605	1382	94	13	77	181	31
2020	Grand total	156.70	29679	5664	242440	8881	17851	371126	20818	42461	6241	399	2165	5280	879
2030	Bulk carrier	6.08	1250	214	9211	315	668	15133	1486	1471	874	14	77	220	32
2030	Container ship	9.44	1667	287	12355	423	896	18661	1995	1973	1172	19	103	294	43
2030	Crude oil tanker	2.77	878	150	6484	222	470	9575	1043	1031	615	10	54	154	23
2030	Fast ferry	0.40	19	4	157	6	12	138	10	18	1	0	1	3	1
2030	Fishing ship	36.80	12819	2432	103837	3891	7684	128782	6410	14870	192	184	948	2347	382
2030	Gas tanker	1.53	331	56	2395	82	174	3957	389	388	227	3	20	58	9
2030	General cargo ship	33.38	2824	491	21185	725	1537	33065	3432	3397	2010	35	177	500	74
2030	Oil products & chemical tanker	19.67	3776	641	27611	945	2003	44841	4470	4450	2620	38	230	664	98
2030	Other ship	8.84	610	117	5014	180	367	5401	567	710	245	7	44	107	18
2030	Passenger ship	13.91	2512	478	20576	716	1498	20509	2850	2946	1614	29	174	410	73
2030	Ro-ro cargo ship	3.03	672	127	5490	188	398	5043	838	790	509	8	46	106	19
2030	Ro-ro passenger ship	17.49	2946	567	24394	844	1774	23689	3482	3494	2027	38	206	476	85
2030	Support ship	20.36	1103	212	9082	335	670	8877	739	1217	177	13	82	200	33
2030	Grand total	173.67	31406	5775	247792	8870	18153	317669	27711	36755	12284	397	2162	5540	891
2050	Bulk carrier	8.73	1466	246	10703	337	764	12303	2554	1285	1835	15	82	244	37

Continued															
2050	Container ship	21.24	3115	526	22859	721	1631	18504	5457	2744	3918	32	176	518	78
2050	Crude oil tanker	4.24	1077	181	7883	248	563	5487	1877	942	1351	11	61	179	27
2050	Fast ferry	0.50	21	4	168	6	12	127	11	17	1	0	2	4	1
2050	Fishing ship	36.80	12819	2394	102232	3831	7565	110735	6410	10255	192	181	934	2356	376
2050	Gas tanker	2.34	421	70	3026	95	216	3324	725	368	519	3	23	70	11
2050	General cargo ship	37.89	2887	493	21420	675	1529	20527	5122	2578	3672	33	165	483	73
2050	Oil products & chemical tanker	30.12	5010	836	36311	1145	2591	39234	8684	4394	6225	45	279	833	126
2050	Other ship	8.84	528	99	4285	148	311	3690	653	464	375	6	36	90	15
2050	Passenger ship	17.34	2718	506	21932	714	1575	11898	4448	2373	3109	29	174	423	76
2050	Ro-ro cargo ship	3.44	663	123	5332	169	381	1713	1219	584	894	7	41	99	18
2050	Ro-ro passenger ship	21.81	3192	600	26003	839	1864	12449	5484	2812	3906	38	204	490	89
2050	Support ship	26.04	1218	231	9915	360	729	6880	958	1018	339	14	88	219	36
2050	Grand total	219.32	35135	6310	272068	9289	19732	246870	43601	29835	26337	414	2264	6006	962

Results per fuel type and sea area (SECA/Non SECA) calculated for the inventory area in the Baseline BAU scenario for 2020, 2030 and 2050.

Year	Area	Fuel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
			km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2020	SECA	HFO + EGCS	3.7	1223	234	9589	469	748	16372	623	1769	19	30	251	623	36
		LNG	1.9	411	68	3265	0	187	534	3695	534	3490	0	0	12	7
		MDO/MGO	66.3	9729	1851	79049	2962	5850	129280	4918	13919	148	131	722	1747	287
2020	Non SECA	0.5 % fuel oil	31.3	5169	947	38744	9473	3022	77537	2667	7534	80	78	1014	4189	148
		HFO +EGCS	1.9	593	110	4495	220	351	8811	310	872	9	14	118	317	17
		LNG	1.4	272	45	2161	0	124	353	2446	353	2310	0	0	8	5
		MDO/MGO	50.2	12283	2408	102812	3852	7608	138238	6158	17480	185	179	939	2232	379
	Grand Total		156.7	29679	5664	240115	16976	17890	371126	20818	42461	6241	432	3043	9128	879
2020	All	0.5 % fuel oil	31.3	5169	947	38744	9473	3022	77537	2667	7534	80	78	1014	4189	148
		HFO +EGCS	5.6	1816	344	14084	689	1099	25184	933	2641	28	44	368	940	53
		LNG	3.3	682	113	5426	0	312	887	6142	887	5801	0	0	20	12
		MDO/MGO	116.5	22012	4259	181861	6814	13458	267518	11076	31399	332	310	1661	3978	666
2020	All	Grand Total	156.7	29679	5664	240115	16976	17890	371126	20818	42461	6241	432	3043	9128	879
2020	SECA		71.9	11363	2154	91903	3431	6785	146187	9236	16222	3656	161	973	2382	331
	Non SECA		84.8	18316	3510	148212	13545	11105	224939	11582	26239	2585	271	2070	6746	548
2020	Grand Total		156.7	29679	5664	240115	16976	17890	371126	20818	42461	6241	432	3043	9128	879
2030	SECA	HFO + EGCS	6.1	1858	343	14011	685	1093	17362	945	2183	28	44	367	952	53
		LNG	4.2	832	138	6619	0	380	1082	7492	1082	7076	0	0	25	15
		MDO/MGO	71.2	9644	1769	75527	2830	5589	88143	4871	11189	146	125	690	1752	275
2030	Non SECA	0.5 % fuel oil	33.8	5276	930	38030	9298	2966	71126	2715	6241	81	76	995	4380	145
		HFO + EGCS	3.2	913	163	6664	326	520	12197	476	1089	14	21	174	489	25
		LNG	3.1	559	93	4446	0	255	727	5032	727	4752	0	0	17	10
		MDO/MGO	52.0	12324	2340	99912	3744	7393	127033	6180	14243	185	173	913	2258	368
	Grand Total		173.7	31406	5775	245208	16883	18197	317669	27711	36755	12284	438	3138	9873	891
2030	All	0.5 % fuel oil	33.8	5276	930	38030	9298	2966	71126	2715	6241	81	76	995	4380	145
		HFO +EGCS	9.3	2771	506	20675	1011	1613	29558	1421	3272	43	64	541	1440	78
		LNG	7.4	1392	231	11065	0	635	1809	12524	1809	11829	0	0	42	25
		MDO/MGO	123.2	21968	4109	175439	6574	12982	215176	11051	25432	332	298	1602	4011	643

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2030	All	Grand Total	173.7	31406	5775	245208	16883	18197	317669	27711	36755	12284	438	3138	9873	891
2030	SECA		81.5	12334	2250	96157	3515	7062	106587	13308	14455	7251	169	1056	2729	343
	Non SECA		92.1	19072	3525	149051	13368	11135	211082	14403	22300	5034	270	2082	7144	549
2030	Grand Total		173.7	31406	5775	245208	16883	18197	317669	27711	36755	12284	438	3138	9873	891
2050	SECA	HFO + EGCS	11.8	2903	522	21362	1045	1666	8209	1475	2351	44	66	559	1498	81
		LNG	10.8	1806	300	14361	0	824	2348	16255	2348	15352	0	0	54	33
		MDO/MGO	84.7	9757	1751	74751	2801	5532	27223	4924	7862	148	123	683	1789	272
2050	Non SECA	0.5 % fuel oil	41.4	5644	971	39733	9715	3099	72201	2893	4593	87	78	1039	4744	152
		HFO + EGCS	6.3	1418	248	10131	495	790	17901	735	1162	22	31	265	759	38
		LNG	8.0	1235	205	9820	0	564	1605	11114	1605	10497	0	0	37	23
		MDO/MGO	56.2	12372	2313	98775	3701	7309	117383	6205	9914	186	171	902	2276	364
	Grand Total		219.3	35135	6310	268933	17757	19785	246870	43601	29835	26337	470	3448	11158	962
2050	All	0.5 % fuel oil	41.4	5644	971	39733	9715	3099	72201	2893	4593	87	78	1039	4744	152
		HFO +EGCS	18.2	4321	770	31493	1540	2456	26109	2210	3513	66	97	824	2257	119
		LNG	18.8	3041	505	24180	0	1388	3953	27369	3953	25850	1	0	91	56
		MDO/MGO	140.9	22130	4064	173526	6502	12841	144606	11129	17776	334	294	1585	4065	636
2050	All	Grand Total	219.3	35135	6310	268933	17757	19785	246870	43601	29835	26337	470	3448	11158	962
2050	SECA		107.3	14467	2573	110474	3846	8022	37780	22654	12561	15544	189	1242	3341	386
	Non SECA		112.0	20668	3737	158459	13911	11763	209090	20947	17275	10792	280	2207	7817	577
2050	Grand Total		219.3	35135	6310	268933	17757	19785	246870	43601	29835	26337	470	3448	11158	962

Results per fuel type and sea area (SECA/Non SECA) calculated for the inventory area in the SECA BAU scenario for 2020, 2030 and 2050.

Year	Area	Fuel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
			km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2020	SECA	HFO + EGCS	3.7	1223	234	9589	469	748	16372	623	1769	19	30	251	623	36
		LNG	1.9	411	68	3265	0	187	534	3695	534	3490	0	0	12	7
		MDO/MGO	66.3	9729	1851	79049	2962	5850	129280	4918	13919	148	131	722	1747	287
2020	Non SECA	HFO + EGCS	1.9	593	110	4495	220	351	8811	310	872	9	14	118	317	17
		LNG	1.4	272	45	2161	0	124	353	2446	353	2310	0	0	8	5
		MDO/MGO	81.5	17452	3355	143261	5368	10601	215775	8825	25013	265	242	1308	3187	526
	Grand Total		156.7	29679	5664	241820	9019	17861	371126	20818	42461	6241	418	2399	5894	879
2020	All	HFO + EGCS	5.6	1816	344	14084	689	1099	25184	933	2641	28	44	368	940	53
		LNG	3.3	682	113	5426	0	312	887	6142	887	5801	0	0	20	12
		MDO/MGO	147.8	27181	5206	222310	8330	16451	345055	13743	38933	412	374	2030	4934	814
2020	All	Grand Total	156.7	29679	5664	241820	9019	17861	371126	20818	42461	6241	418	2399	5894	879
2020	SECA		71.9	11363	2154	91903	3431	6785	146187	9236	16222	3656	161	973	2382	331
	Non SECA		84.8	18316	3510	149917	5588	11076	224939	11582	26239	2585	256	1426	3512	548
2020	Grand Total		156.7	29679	5664	241820	9019	17861	371126	20818	42461	6241	418	2399	5894	879
2030	SECA	HFO + EGCS	6.1	1858	343	14011	685	1093	17362	945	2183	28	44	367	952	53
		LNG	4.2	832	138	6619	0	380	1082	7492	1082	7076	0	0	25	15
		MDO/MGO	71.2	9644	1769	75527	2830	5589	88143	4871	11189	146	125	690	1752	275
2030	Non SECA	HFO + EGCS	3.2	913	163	6664	326	520	12197	476	1089	14	21	174	489	25
		LNG	3.1	559	93	4446	0	255	727	5032	727	4752	0	0	17	10
		MDO/MGO	85.8	17600	3270	139615	5231	10332	198159	8895	20485	267	235	1275	3243	513
	Grand Total		173.7	31406	5775	246882	9073	18168	317669	27711	36755	12284	424	2506	6477	891
2030	All	HFO + EGCS	9.3	2771	506	20675	1011	1613	29558	1421	3272	43	64	541	1440	78
		LNG	7.4	1392	231	11065	0	635	1809	12524	1809	11829	0	0	42	25
		MDO/MGO	157.0	27244	5038	215142	8062	15921	286301	13766	31674	413	360	1965	4995	788
2030	All	Grand Total	173.7	31406	5775	246882	9073	18168	317669	27711	36755	12284	424	2506	6477	891
2030	SECA		81.5	12334	2250	96157	3515	7062	106587	13308	14455	7251	169	1056	2729	343
	Non SECA		92.1	19072	3525	150725	5557	11107	211082	14403	22300	5034	256	1450	3748	549
2030	Grand Total		173.7	31406	5775	246882	9073	18168	317669	27711	36755	12284	424	2506	6477	891

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2050	SECA	HFO + EGCS	11.8	2903	522	21362	1045	1666	8209	1475	2351	44	66	559	1498	81
		LNG	10.8	1806	300	14361	0	824	2348	16255	2348	15352	0	0	54	33
		MDO/MGO	84.7	9757	1751	74751	2801	5532	27223	4924	7862	148	123	683	1789	272
2050	Non SECA	HFO + EGCS	6.3	1418	248	10131	495	790	17901	735	1162	22	31	265	759	38
		LNG	8.0	1235	205	9820	0	564	1605	11114	1605	10497	0	0	37	23
		MDO/MGO	97.6	18016	3285	140257	5256	10379	189584	9098	14507	273	235	1281	3335	516
	Grand Total		219.3	35135	6310	270682	9597	19755	246870	43601	29835	26337	455	2788	7472	962
2050	All	HFO + EGCS	18.2	4321	770	31493	1540	2456	26109	2210	3513	66	97	824	2257	119
		LNG	18.8	3041	505	24180	0	1388	3953	27369	3953	25850	1	0	91	56
		MDO/MGO	182.3	27773	5035	215008	8057	15911	216807	14022	22369	421	357	1964	5124	788
2050	All	Grand Total	219.3	35135	6310	270682	9597	19755	246870	43601	29835	26337	455	2788	7472	962
2050	SECA		107.3	14467	2573	110474	3846	8022	37780	22654	12561	15544	189	1242	3341	386
	Non SECA		112.0	20668	3737	160207	5751	11733	209090	20947	17275	10792	266	1546	4131	577
2050	Grand Total		219.3	35135	6310	270682	9597	19755	246870	43601	29835	26337	455	2788	7472	962

Results per fuel type and sea area (SECA/Non SECA) calculated for the inventory area in the HFO ban BAU scenario for 2020, 2030 and 2050.

Year	Area	Fuel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
			km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2020	SECA	LNG	1.9	411	68	3265	0	187	534	3695	534	3490	0	0	12	7
		MDO/MGO	70.0	10952	2086	89060	3337	6590	145653	5541	15689	166	148	813	2008	323
2020	Non SECA	LNG	1.4	272	45	2161	0	124	353	2446	353	2310	0	0	8	5
		MDO/MGO	83.4	18044	3465	147954	5544	10949	224586	9136	25885	274	250	1351	3317	543
	Grand Total		156.7	29679	5664	242440	8881	17851	371126	20818	42461	6241	399	2165	5345	879
2020	All	LNG	3.3	682	113	5426	0	312	887	6142	887	5801	0	0	20	12
		MDO/MGO	153.4	28996	5551	237014	8881	17539	370239	14676	41574	440	399	2165	5325	867
2020	All	Grand Total	156.7	29679	5664	242440	8881	17851	371126	20818	42461	6241	399	2165	5345	879
2020	SECA		71.9	11363	2154	92325	3337	6778	146187	9236	16222	3656	148	813	2020	331
	Non SECA		84.8	18316	3510	150115	5544	11073	224939	11582	26239	2585	250	1351	3325	548
2020	Grand Total		156.7	29679	5664	242440	8881	17851	371126	20818	42461	6241	399	2165	5345	879
2030	SECA	LNG	4.2	832	138	6619	0	380	1082	7492	1082	7076	0	0	25	15
		MDO/MGO	77.3	11501	2111	90155	3378	6671	105504	5816	13373	174	150	823	2173	328
2030	Non SECA	LNG	3.1	559	93	4446	0	255	727	5032	727	4752	0	0	17	10
		MDO/MGO	89.0	18513	3433	146572	5492	10846	210355	9371	21573	281	247	1339	3452	538
	Grand Total		173.7	31406	5775	247792	8870	18153	317669	27711	36755	12284	397	2162	5667	891
2030	All	LNG	7.4	1392	231	11065	0	635	1809	12524	1809	11829	0	0	42	25
		MDO/MGO	166.3	30014	5544	236727	8870	17518	315860	15187	34946	456	397	2162	5625	866
2030	All	Grand Total	173.7	31406	5775	247792	8870	18153	317669	27711	36755	12284	397	2162	5667	891
2030	SECA		81.5	12334	2250	96774	3378	7051	106587	13308	14455	7251	150	823	2198	343
	Non SECA		92.1	19072	3525	151018	5492	11102	211082	14403	22300	5034	247	1339	3469	549
2030	Grand Total		173.7	31406	5775	247792	8870	18153	317669	27711	36755	12284	397	2162	5667	891
2050	SECA	LNG	10.8	1806	300	14361	0	824	2348	16255	2348	15352	0	0	54	33
		MDO/MGO	96.5	12661	2273	97053	3637	7182	35432	6399	10213	192	161	886	2435	353
2050	Non SECA	LNG	8.0	1235	205	9820	0	564	1605	11114	1605	10497	0	0	37	23
		MDO/MGO	104.0	19433	3532	150834	5652	11162	207485	9833	15669	295	252	1378	3655	554
	Grand Total		219.3	35135	6310	272068	9289	19732	246870	43601	29835	26337	414	2264	6181	962
2050	All	LNG	18.8	3041	505	24180	0	1388	3953	27369	3953	25850	1	0	91	56

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		MDO/MGO	200.5	32094	5805	247887	9289	18344	242917	16232	25882	487	413	2264	6090	907
2050	All	Grand Total	219.3	35135	6310	272068	9289	19732	246870	43601	29835	26337	414	2264	6181	962
2050	SECA		107.3	14467	2573	111414	3637	8006	37780	22654	12561	15544	161	886	2489	386
	Non SECA		112.0	20668	3737	160653	5652	11725	209090	20947	17275	10792	253	1378	3692	577
2050	Grand Total		219.3	35135	6310	272068	9289	19732	246870	43601	29835	26337	414	2264	6181	962

Results per fuel type and sea area (SECA/Non SECA) calculated for the inventory area in the High scrub BAU scenario for 2020, 2030 and 2050.

Year	Area	Fuel type	Distance km x 10^6	Power kWh x 10^6	Fuel kTonnes	Fuel TJ	SO_2 Tonnes	CO_2 kTonnes	NO_x Tonnes	VOC Tonnes	CO Tonnes	CH_4 Tonnes	BC Tonnes	OC Tonnes	PM Tonnes	N_2O Tonnes
2020	SECA	HFO + EGCS	4.3	1427	274	11189	547	873	19092	727	2064	22	35	293	383	42
		LNG	1.9	411	68	3265	0	187	534	3695	534	3490	0	0	12	7
		MDO/MGO	65.7	9525	1812	77379	2899	5726	126561	4814	13624	144	128	707	1749	281
2020	Non SECA	HFO + EGCS	2.2	690	128	5232	256	408	10252	361	1015	11	16	137	224	20
		LNG	1.4	272	45	2161	0	124	353	2446	353	2310	0	0	8	5
		MDO/MGO	81.2	17354	3337	142492	5339	10544	214334	8775	24870	263	241	1301	3187	524
	Grand Total		156.7	29679	5664	241717	9042	17863	371126	20818	42461	6241	421	2438	5563	879
2020	All	HFO + EGCS	6.5	2117	401	16421	803	1281	29344	1088	3079	33	51	430	607	62
		LNG	3.3	682	113	5426	0	312	887	6142	887	5801	0	0	20	12
		MDO/MGO	146.9	26880	5149	219871	8239	16270	340895	13589	38495	408	369	2008	4936	805
2020	All	Grand Total	156.7	29679	5664	241717	9042	17863	371126	20818	42461	6241	421	2438	5563	879
2020	SECA		71.9	11363	2154	91832	3447	6786	146187	9236	16222	3656	163	999	2144	331
	Non SECA		84.8	18316	3510	149885	5595	11077	224939	11582	26239	2585	257	1438	3419	548
2020	Grand Total		156.7	29679	5664	241717	9042	17863	371126	20818	42461	6241	421	2438	5563	879
2030	SECA	HFO + EGCS	11.6	3557	656	26841	1313	2094	33213	1810	4182	54	84	702	990	101
		LNG	4.2	832	138	6619	0	380	1082	7492	1082	7076	0	0	25	15
		MDO/MGO	65.7	7944	1455	62133	2328	4598	72292	4006	9191	120	102	567	1503	226
2030	Non SECA	HFO + EGCS	6.1	1738	310	12692	621	990	23210	906	2074	27	39	332	578	48
		LNG	3.1	559	93	4446	0	255	727	5032	727	4752	0	0	17	10
		MDO/MGO	82.9	16775	3122	133322	4996	9866	187146	8465	19500	254	224	1218	3116	490
	Grand Total		173.7	31406	5775	246052	9257	18182	317669	27711	36755	12284	450	2819	6229	891
2030	All	HFO + EGCS	17.7	5295	967	39533	1933	3084	56422	2716	6255	81	123	1034	1568	149
		LNG	7.4	1392	231	11065	0	635	1809	12524	1809	11829	0	0	42	25
		MDO/MGO	148.5	24719	4577	195455	7324	14464	259437	12471	28691	374	327	1785	4619	717
2030	All	Grand Total	173.7	31406	5775	246052	9257	18182	317669	27711	36755	12284	450	2819	6229	891
2030	SECA		81.5	12334	2250	95593	3641	7071	106587	13308	14455	7251	186	1270	2518	343
	Non SECA		92.1	19072	3525	150459	5616	11111	211082	14403	22300	5034	264	1550	3711	549
2030	Grand Total		173.7	31406	5775	246052	9257	18182	317669	27711	36755	12284	450	2819	6229	891

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2050	SECA	HFO + EGCS	23.5	5767	1038	42446	2076	3311	16300	2930	4670	88	132	1110	1641	160
		LNG	10.8	1806	300	14361	0	824	2348	16255	2348	15352	0	0	54	33
		MDO/MGO	73.1	6894	1235	52740	1976	3903	19132	3469	5543	104	86	482	1324	193
2050	Non SECA	HFO + EGCS	12.6	2809	491	20075	982	1566	35458	1456	2302	44	62	525	944	76
		LNG	8.0	1235	205	9820	0	564	1605	11114	1605	10497	0	0	37	23
		MDO/MGO	91.4	16625	3042	129875	4867	9611	172026	8377	13367	251	217	1186	3106	478
	Grand Total		219.3	35135	6310	269316	9900	19778	246870	43601	29835	26337	497	3304	7106	962
2050	All	HFO + EGCS	36.0	8575	1529	62521	3057	4877	51759	4386	6973	132	193	1636	2585	236
		LNG	18.8	3041	505	24180	0	1388	3953	27369	3953	25850	1	0	91	56
		MDO/MGO	164.5	23518	4277	182615	6843	13514	191158	11845	18910	355	303	1668	4430	670
2050	All	Grand Total	219.3	35135	6310	269316	9900	19778	246870	43601	29835	26337	497	3304	7106	962
2050	SECA		107.3	14467	2573	109546	4052	8038	37780	22654	12561	15544	218	1592	3018	386
	Non SECA		112.0	20668	3737	159770	5848	11740	209090	20947	17275	10792	279	1711	4088	577
2050	Grand Total		219.3	35135	6310	269316	9900	19778	246870	43601	29835	26337	497	3304	7106	962

Annexes for Chapter 7 related to calculated results for high traffic growth (HiG)

Results per ship type calculated for the inventory area in the Baseline HiG scenario for 2020, 2030 and 2050.

Year	Vessel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
		km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2020	Bulk carrier	5.40	1211	215	8961	1275	679	18811	1050	1730	457	17	174	667	33
2020	Container ship	7.29	1394	249	10482	972	785	21679	1217	2004	529	20	164	566	38
2020	Crude oil tanker	2.21	768	137	5768	448	431	11922	665	1095	290	11	85	279	21
2020	Fast ferry	0.38	19	4	162	7	12	187	10	24	1	0	2	4	1
2020	Fishing ship	36.80	12819	2512	107254	4019	7937	144795	6410	18289	192	190	980	2327	395
2020	Gas tanker	1.22	286	50	2081	272	157	4436	245	407	106	3	38	148	8
2020	General cargo ship	33.39	2963	535	22471	2710	1690	46231	2631	4331	1139	47	382	1422	81
2020	Oil products & chemical tanker	15.69	3210	564	23643	3180	1783	49875	2773	4592	1201	40	426	1652	87
2020	Other ship	8.84	643	127	5350	564	402	6916	482	925	141	9	82	259	20
2020	Passenger ship	13.32	2533	500	21111	1645	1578	27534	2125	3616	880	37	307	835	77
2020	Ro-ro cargo ship	3.03	708	139	5920	268	438	7667	635	1009	289	10	69	163	21
2020	Ro-ro passenger ship	16.76	2969	592	25077	1782	1869	32384	2570	4278	1103	48	347	909	90
2020	Support ship	18.43	1054	209	8871	529	660	11185	634	1452	97	14	99	267	33
2020	Grand total	162.75	30577	5831	247152	17670	18419	383623	21447	43751	6426	445	3155	9497	905
2030	Bulk carrier	6.84	1406	240	10080	1307	757	17091	1621	1654	933	19	191	757	37
2030	Container ship	12.12	2140	368	15559	1356	1157	24060	2484	2532	1428	30	246	882	56
2030	Crude oil tanker	3.11	985	169	7151	514	531	10790	1136	1156	655	13	108	366	26
2030	Fast ferry	0.45	22	4	177	7	13	155	11	21	1	0	2	4	1
2030	Fishing ship	36.80	12819	2432	103837	3891	7684	128782	6410	14870	192	184	948	2347	382
2030	Gas tanker	1.72	371	62	2623	307	196	4459	423	435	242	4	47	185	10
2030	General cargo ship	37.54	3175	553	23321	2608	1738	37333	3743	3818	2145	47	385	1491	83
2030	Oil products & chemical tanker	22.08	4239	719	30253	3850	2262	50538	4867	4993	2790	51	534	2167	110
2030	Other ship	8.84	610	117	4933	489	369	5412	555	709	232	8	74	241	18
2030	Passenger ship	15.63	2822	537	22753	1651	1691	23122	3110	3309	1721	40	336	941	82
2030	Ro-ro cargo ship	3.41	756	143	6110	269	449	5691	913	888	543	11	75	184	22
2030	Ro-ro passenger ship	19.66	3309	637	27012	1829	2002	26710	3796	3924	2161	52	383	1040	96
2030	Support ship	22.86	1238	238	10145	583	753	9976	820	1366	190	16	112	312	37

Continued

2030	Grand total	191.03	33892	6220	263954	18661	19602	344119	29888	39674	13233	474	3441	10918	960
2050	Bulk carrier	11.09	1863	313	13228	1487	979	15858	3018	1619	2104	25	240	944	47
2050	Container ship	36.34	5327	900	38247	3063	2809	32065	8678	4655	6048	72	604	2186	134
2050	Crude oil tanker	5.36	1361	229	9756	622	715	7019	2205	1181	1540	18	149	505	34
2050	Fast ferry	0.63	26	5	213	8	16	161	14	21	1	0	2	5	1
2050	Fishing ship	36.80	12819	2394	102232	3831	7565	110735	6410	10255	192	181	934	2356	376
2050	Gas tanker	2.96	532	88	3731	367	275	4258	852	461	592	5	63	245	13
2050	General cargo ship	48.29	3678	628	26723	2668	1961	26518	6070	3259	4223	51	415	1622	93
2050	Oil products & chemical tanker	38.06	6331	1056	44754	5268	3299	50268	10204	5508	7097	71	757	3130	159
2050	Other ship	8.84	528	99	4217	381	313	3715	616	462	339	7	61	199	15
2050	Passenger ship	22.00	3443	642	27312	1777	2010	15218	5255	2984	3560	47	404	1132	97
2050	Ro-ro cargo ship	4.38	844	156	6699	280	488	2198	1441	737	1028	11	85	215	23
2050	Ro-ro passenger ship	27.67	4042	761	32409	2026	2378	15916	6470	3534	4471	62	465	1276	113
2050	Support ship	33.01	1543	293	12500	682	925	8744	1174	1288	389	19	135	379	46
2050	Grand total	275.43	42336	7567	322021	22460	23733	292673	52406	35964	31585	570	4312	14193	1153

Results per ship type calculated for the inventory area in the SECA HiG scenario for 2020, 2030 and 2050.

Year	Vessel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
		km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2020	Bulk carrier	5.40	1211	215	9161	340	675	18811	1050	1730	457	16	99	272	33
2020	Container ship	7.29	1394	249	10606	396	783	21679	1217	2004	529	19	117	322	38
2020	Crude oil tanker	2.21	768	137	5817	219	430	11922	665	1095	290	10	66	183	21
2020	Fast ferry	0.38	19	4	162	6	12	187	10	24	1	0	1	4	1
2020	Fishing ship	36.80	12819	2512	107254	4019	7937	144795	6410	18289	192	190	980	2327	395
2020	Gas tanker	1.22	286	50	2122	79	156	4436	245	407	106	3	23	64	8
2020	General cargo ship	33.39	2963	535	22872	840	1683	46231	2631	4331	1139	43	231	628	81
2020	Oil products & chemical tanker	15.69	3210	564	24136	884	1775	49875	2773	4592	1201	37	240	664	87
2020	Other ship	8.84	643	127	5428	202	401	6916	482	925	141	8	53	125	20
2020	Passenger ship	13.32	2533	500	21292	803	1575	27534	2125	3616	880	35	238	539	77
2020	Ro-ro cargo ship	3.03	708	139	5930	222	438	7667	635	1009	289	10	66	146	21
2020	Ro-ro passenger ship	16.76	2969	592	25256	948	1866	32384	2570	4278	1103	46	279	620	90
2020	Support ship	18.43	1054	209	8913	333	659	11185	634	1452	97	14	83	196	33
2020	Grand total	162.75	30577	5831	248948	9289	18389	383623	21447	43751	6426	430	2476	6089	905
2030	Bulk carrier	6.84	1406	240	10280	373	754	17091	1621	1654	933	18	116	336	37
2030	Container ship	12.12	2140	368	15727	575	1154	24060	2484	2532	1428	28	183	529	56
2030	Crude oil tanker	3.11	985	169	7204	266	530	10790	1136	1156	655	13	88	254	26
2030	Fast ferry	0.45	22	4	177	7	13	155	11	21	1	0	2	4	1
2030	Fishing ship	36.80	12819	2432	103837	3891	7684	128782	6410	14870	192	184	948	2347	382
2030	Gas tanker	1.72	371	62	2668	97	196	4459	423	435	242	3	30	88	10
2030	General cargo ship	37.54	3175	553	23699	844	1732	37333	3743	3818	2145	44	243	694	83
2030	Oil products & chemical tanker	22.08	4239	719	30843	1095	2252	50538	4867	4993	2790	46	311	904	110
2030	Other ship	8.84	610	117	4999	183	368	5412	555	709	232	8	49	121	18
2030	Passenger ship	15.63	2822	537	22925	851	1688	23122	3110	3309	1721	38	271	641	82
2030	Ro-ro cargo ship	3.41	756	143	6119	224	449	5691	913	888	543	10	71	167	22
2030	Ro-ro passenger ship	19.66	3309	637	27189	1002	1999	26710	3796	3924	2161	50	316	737	96
2030	Support ship	22.86	1238	238	10189	378	752	9976	820	1366	190	15	95	233	37
2030	Grand total	191.03	33892	6220	265856	9786	19570	344119	29888	39674	13233	458	2723	7055	960
2050	Bulk carrier	11.09	1863	313	13446	466	975	15858	3018	1619	2104	23	157	469	47

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2050	Container ship	36.34	5327	900	38615	1347	2803	32065	8678	4655	6048	69	465	1385	134
2050	Crude oil tanker	5.36	1361	229	9814	348	714	7019	2205	1181	1540	18	127	379	34
2050	Fast ferry	0.63	26	5	213	8	16	161	14	21	1	0	2	5	1
2050	Fishing ship	36.80	12819	2394	102232	3831	7565	110735	6410	10255	192	181	934	2356	376
2050	Gas tanker	2.96	532	88	3782	131	274	4258	852	461	592	5	43	132	13
2050	General cargo ship	48.29	3678	628	27100	910	1955	26518	6070	3259	4223	48	272	803	93
2050	Oil products & chemical tanker	38.06	6331	1056	45556	1527	3285	50268	10204	5508	7097	65	454	1361	159
2050	Other ship	8.84	528	99	4266	152	312	3715	616	462	339	6	42	106	15
2050	Passenger ship	22.00	3443	642	27481	986	2007	15218	5255	2984	3560	46	340	827	97
2050	Ro-ro cargo ship	4.38	844	156	6709	235	488	2198	1441	737	1028	11	82	198	23
2050	Ro-ro passenger ship	27.67	4042	761	32595	1157	2375	15916	6470	3534	4471	60	394	947	113
2050	Support ship	33.01	1543	293	12547	461	924	8744	1174	1288	389	19	117	292	46
2050	Grand total	275.43	42336	7567	324356	11559	23693	292673	52406	35964	31585	551	3430	9260	1153

Results per ship type calculated for the inventory area in the HFO ban HiG scenario for 2020, 2030 and 2050.

Year	Vessel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
		km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2020	Bulk carrier	5.40	1211	215	9209	330	675	18811	1050	1730	457	14	80	218	33
2020	Container ship	7.29	1394	249	10670	382	782	21679	1217	2004	529	17	93	252	38
2020	Crude oil tanker	2.21	768	137	5858	210	429	11922	665	1095	290	9	51	138	21
2020	Fast ferry	0.38	19	4	163	6	12	187	10	24	1	0	1	4	1
2020	Fishing ship	36.80	12819	2512	107254	4019	7937	144795	6410	18289	192	190	980	2327	395
2020	Gas tanker	1.22	286	50	2133	76	156	4436	245	407	106	3	19	51	8
2020	General cargo ship	33.39	2963	535	22953	822	1682	46231	2631	4331	1139	40	200	539	81
2020	Oil products & chemical tanker	15.69	3210	564	24212	867	1774	49875	2773	4592	1201	34	211	579	87
2020	Other ship	8.84	643	127	5439	199	400	6916	482	925	141	8	49	114	20
2020	Passenger ship	13.32	2533	500	21424	773	1572	27534	2125	3616	880	31	188	421	77
2020	Ro-ro cargo ship	3.03	708	139	5966	214	437	7667	635	1009	289	9	52	114	21
2020	Ro-ro passenger ship	16.76	2969	592	25404	915	1863	32384	2570	4278	1103	41	223	490	90
2020	Support ship	18.43	1054	209	8918	331	659	11185	634	1452	97	13	81	191	33
2020	Grand total	162.75	30577	5831	249603	9143	18378	383623	21447	43751	6426	410	2229	5440	905
2030	Bulk carrier	6.84	1406	240	10357	356	752	17091	1621	1654	933	15	87	248	37
2030	Container ship	12.12	2140	368	15860	545	1152	24060	2484	2532	1428	24	133	378	56
2030	Crude oil tanker	3.11	985	169	7275	250	528	10790	1136	1156	655	11	61	174	26
2030	Fast ferry	0.45	22	4	177	7	13	155	11	21	1	0	2	4	1
2030	Fishing ship	36.80	12819	2432	103837	3891	7684	128782	6410	14870	192	184	948	2347	382
2030	Gas tanker	1.72	371	62	2687	92	195	4459	423	435	242	3	23	65	10
2030	General cargo ship	37.54	3175	553	23814	819	1730	37333	3743	3818	2145	40	200	565	83
2030	Oil products & chemical tanker	22.08	4239	719	30980	1065	2250	50538	4867	4993	2790	42	260	749	110
2030	Other ship	8.84	610	117	5012	180	367	5412	555	709	232	7	44	108	18
2030	Passenger ship	15.63	2822	537	23121	807	1685	23122	3110	3309	1721	33	197	462	82
2030	Ro-ro cargo ship	3.41	756	143	6171	213	448	5691	913	888	543	9	52	120	22
2030	Ro-ro passenger ship	19.66	3309	637	27410	953	1996	26710	3796	3924	2161	43	232	537	96
2030	Support ship	22.86	1238	238	10197	376	752	9976	820	1366	190	15	92	224	37
2030	Grand total	191.03	33892	6220	266898	9554	19553	344119	29888	39674	13233	426	2329	5980	960
2050	Bulk carrier	11.09	1863	313	13581	436	973	15858	3018	1619	2104	19	106	314	47

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2050	Container ship	36.34	5327	900	39038	1253	2796	32065	8678	4655	6048	55	305	899	134
2050	Crude oil tanker	5.36	1361	229	9945	319	712	7019	2205	1181	1540	14	78	229	34
2050	Fast ferry	0.63	26	5	214	8	16	161	14	21	1	0	2	5	1
2050	Fishing ship	36.80	12819	2394	102232	3831	7565	110735	6410	10255	192	181	934	2356	376
2050	Gas tanker	2.96	532	88	3818	123	273	4258	852	461	592	4	30	90	13
2050	General cargo ship	48.29	3678	628	27256	875	1952	26518	6070	3259	4223	42	213	623	93
2050	Oil products & chemical tanker	38.06	6331	1056	45809	1471	3281	50268	10204	5508	7097	58	358	1067	159
2050	Other ship	8.84	528	99	4281	149	312	3715	616	462	339	6	36	91	15
2050	Passenger ship	22.00	3443	642	27787	918	2002	15218	5255	2984	3560	37	224	542	97
2050	Ro-ro cargo ship	4.38	844	156	6785	219	486	2198	1441	737	1028	9	53	127	23
2050	Ro-ro passenger ship	27.67	4042	761	32942	1080	2369	15916	6470	3534	4471	49	263	628	113
2050	Support ship	33.01	1543	293	12562	458	924	8744	1174	1288	389	18	112	278	46
2050	Grand total	275.43	42336	7567	326249	11138	23661	292673	52406	35964	31585	493	2715	7248	1153

Results per fuel type and sea area (SECA/Non SECA) calculated for the inventory area in the Baseline HiG scenario for 2020, 2030 and 2050.

Year	Area	Fuel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
			km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2020	SECA	HFO + EGCS	3.9	1294	248	10143	496	791	17346	659	1872	20	32	265	659	38
		LNG	2.0	423	70	3366	0	193	550	3810	550	3598	0	0	13	8
		MDO/MGO	69.5	10185	1937	82712	3099	6121	135628	5149	14573	154	137	755	1829	301
2020	Non SECA	0.5 % fuel oil	33.0	5445	998	40810	9978	3183	81746	2809	7936	84	82	1068	4414	156
		HFO + EGCS	2.0	625	116	4739	232	370	9299	327	919	10	15	124	334	18
		LNG	1.5	279	46	2221	0	127	363	2513	363	2374	0	0	8	5
		MDO/MGO	50.9	12324	2416	103161	3866	7634	138691	6180	17537	185	179	942	2239	380
	Grand Total		162.8	30577	5831	247152	17670	18419	383623	21447	43751	6426	445	3155	9497	905
2020	All	0.5 % fuel oil	33.0	5445	998	40810	9978	3183	81746	2809	7936	84	82	1068	4414	156
		HFO + EGCS	5.9	1919	364	14883	728	1161	26645	986	2792	30	46	389	994	56
		LNG	3.4	703	117	5586	0	321	913	6323	913	5972	0	0	21	13
		MDO/MGO	120.4	22510	4353	185873	6965	13755	274318	11328	32110	340	316	1698	4068	681
2020	All	Grand Total	162.8	30577	5831	247152	17670	18419	383623	21447	43751	6426	445	3155	9497	905
2020	SECA		75.3	11902	2255	96221	3595	7105	153524	9617	16995	3772	169	1021	2501	347
	Non SECA		87.4	18674	3576	150931	14075	11314	230099	11829	26756	2653	276	2134	6996	559
	Grand Total		162.8	30577	5831	247152	17670	18419	383623	21447	43751	6426	445	3155	9497	905
2030	SECA	HFO + EGCS	7.0	2135	393	16085	787	1255	20018	1086	2509	33	50	421	1095	61
		LNG	4.6	899	149	7151	0	411	1169	8094	1169	7645	0	0	27	16
		MDO/MGO	79.8	10787	1976	84362	3161	6243	99118	5449	12519	163	139	771	1961	307
2030	Non SECA	0.5 % fuel oil	38.6	5998	1057	43215	10566	3371	80998	3085	7094	93	86	1131	4982	165
		HFO + EGCS	3.7	1041	186	7594	371	592	13930	542	1241	16	24	199	557	29
		LNG	3.4	599	100	4767	0	274	779	5395	779	5096	0	0	18	11
		MDO/MGO	54.0	12431	2360	100780	3776	7458	128107	6235	14362	187	175	920	2278	371
	Grand Total		191.0	33892	6220	263954	18661	19602	344119	29888	39674	13233	474	3441	10918	960
2030	All	0.5 % fuel oil	38.6	5998	1057	43215	10566	3371	80998	3085	7094	93	86	1131	4982	165
		HFO + EGCS	10.7	3176	579	23679	1158	1847	33948	1628	3750	49	74	619	1652	89
		LNG	8.0	1499	249	11918	0	684	1949	13490	1949	12741	0	0	45	27
		MDO/MGO	133.8	23218	4336	185142	6937	13701	227225	11685	26881	351	314	1691	4239	678
2030	All	Grand Total	191.0	33892	6220	263954	18661	19602	344119	29888	39674	13233	474	3441	10918	960

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	SECA		91.4	13822	2518	107598	3948	7908	120305	14630	16197	7841	190	1191	3083	384
	Non SECA		99.6	20070	3702	156355	14714	11694	223814	15258	23477	5391	284	2250	7835	576
	Grand Total		191.0	33892	6220	263954	18661	19602	344119	29888	39674	13233	474	3441	10918	960
2050	SECA	HFO + EGCS	16.6	4003	718	29351	1435	2289	11419	2034	3241	61	91	768	2072	111
		LNG	13.0	2182	362	17349	0	996	2836	19637	2836	18547	0	0	65	40
		MDO/MGO	109.5	12602	2252	96143	3603	7115	35575	6361	10156	191	158	878	2313	350
2050	Non SECA	0.5 % fuel oil	56.2	7548	1298	53076	12977	4140	96920	3866	6140	116	104	1389	6350	203
		HFO + EGCS	8.7	1913	334	13656	668	1065	24278	991	1568	30	42	357	1026	52
		LNG	9.7	1465	243	11647	0	669	1904	13183	1904	12451	0	0	44	27
		MDO/MGO	61.7	12623	2361	100799	3777	7459	119741	6335	10119	190	174	921	2322	371
	Grand Total		275.4	42336	7567	322021	22460	23733	292673	52406	35964	31585	570	4312	14193	1153
2050	All	0.5 % fuel oil	56.2	7548	1298	53076	12977	4140	96920	3866	6140	116	104	1389	6350	203
		HFO + EGCS	25.3	5916	1052	43007	2103	3355	35697	3024	4809	91	133	1125	3098	162
		LNG	22.7	3647	605	28996	0	1665	4741	32820	4741	30997	1	0	109	67
		MDO/MGO	171.2	25225	4612	196942	7380	14574	155316	12696	20275	381	332	1799	4636	721
2050	All	Grand Total	275.4	42336	7567	322021	22460	23733	292673	52406	35964	31585	570	4312	14193	1153
	SECA		139.2	18786	3331	142843	5038	10400	49830	28032	16233	18799	249	1646	4451	500
	Non SECA		136.3	23550	4235	179178	17422	13333	242843	24375	19731	12787	320	2666	9742	652
	Grand Total		275.4	42336	7567	322021	22460	23733	292673	52406	35964	31585	570	4312	14193	1153

Results per fuel type and sea area (SECA/Non SECA) calculated for the inventory area in the SECA HiG scenario for 2020, 2030 and 2050.

Year	Area	Fuel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
			km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2020	SECA	HFO + EGCS	3.9	1294	248	10143	496	791	17346	659	1872	20	32	265	659	38
		LNG	2.0	423	70	3366	0	193	550	3810	550	3598	0	0	13	8
		MDO/MGO	69.5	10185	1937	82712	3099	6121	135628	5149	14573	154	137	755	1829	301
2020	Non SECA	HFO + EGCS	2.0	625	116	4739	232	370	9299	327	919	10	15	124	334	18
		LNG	1.5	279	46	2221	0	127	363	2513	363	2374	0	0	8	5
		MDO/MGO	83.9	17770	3414	145767	5462	10787	220437	8989	25474	270	246	1331	3246	535
	Grand Total		162.8	30577	5831	248948	9289	18389	383623	21447	43751	6426	430	2476	6089	905
2020	All	HFO + EGCS	5.9	1919	364	14883	728	1161	26645	986	2792	30	46	389	994	56
		LNG	3.4	703	117	5586	0	321	913	6323	913	5972	0	0	21	13
		MDO/MGO	153.4	27955	5351	228479	8561	16907	356065	14138	40046	424	383	2087	5075	836
2020	All	Grand Total	162.8	30577	5831	248948	9289	18389	383623	21447	43751	6426	430	2476	6089	905
2020	SECA		75.3	11902	2255	96221	3595	7105	153524	9617	16995	3772	169	1021	2501	347
	Non SECA		87.4	18674	3576	152727	5694	11284	230099	11829	26756	2653	261	1455	3589	559
	Grand Total		162.8	30577	5831	248948	9289	18389	383623	21447	43751	6426	430	2476	6089	905
2030	SECA	HFO + EGCS	7.0	2135	393	16085	787	1255	20018	1086	2509	33	50	421	1095	61
		LNG	4.6	899	149	7151	0	411	1169	8094	1169	7645	0	0	27	16
		MDO/MGO	79.8	10787	1976	84362	3161	6243	99118	5449	12519	163	139	771	1961	307
2030	Non SECA	HFO + EGCS	3.7	1041	186	7594	371	592	13930	542	1241	16	24	199	557	29
		LNG	3.4	599	100	4767	0	274	779	5395	779	5096	0	0	18	11
		MDO/MGO	92.6	18429	3417	145897	5467	10796	209104	9321	21457	280	245	1333	3398	536
	Grand Total		191.0	33892	6220	265856	9786	19570	344119	29888	39674	13233	458	2723	7055	960
2030	All	HFO + EGCS	10.7	3176	579	23679	1158	1847	33948	1628	3750	49	74	619	1652	89
		LNG	8.0	1499	249	11918	0	684	1949	13490	1949	12741	0	0	45	27
		MDO/MGO	172.3	29217	5392	230258	8628	17039	308222	14770	33976	443	384	2103	5358	843
2030	All	Grand Total	191.0	33892	6220	265856	9786	19570	344119	29888	39674	13233	458	2723	7055	960
	SECA		91.4	13822	2518	107598	3948	7908	120305	14630	16197	7841	190	1191	3083	384
	Non SECA		99.6	20070	3702	158257	5838	11662	223814	15258	23477	5391	268	1531	3973	576
	Grand Total		191.0	33892	6220	265856	9786	19570	344119	29888	39674	13233	458	2723	7055	960

Continued

2050	SECA	HFO + EGCS	16.6	4003	718	29351	1435	2289	11419	2034	3241	61	91	768	2072	111
		LNG	13.0	2182	362	17349	0	996	2836	19637	2836	18547	0	0	65	40
		MDO/MGO	109.5	12602	2252	96143	3603	7115	35575	6361	10156	191	158	878	2313	350
2050	Non SECA	HFO +EGCS	8.7	1913	334	13656	668	1065	24278	991	1568	30	42	357	1026	52
		LNG	9.7	1465	243	11647	0	669	1904	13183	1904	12451	0	0	44	27
		MDO/MGO	117.9	20172	3658	156211	5853	11560	216661	10201	16259	306	259	1427	3740	574
	Grand Total		275.4	42336	7567	324356	11559	23693	292673	52406	35964	31585	551	3430	9260	1153
2050	All	HFO +EGCS	25.3	5916	1052	43007	2103	3355	35697	3024	4809	91	133	1125	3098	162
		LNG	22.7	3647	605	28996	0	1665	4741	32820	4741	30997	1	0	109	67
		MDO/MGO	227.4	32773	5910	252354	9456	18674	252236	16562	26415	497	416	2305	6053	924
2050	All	Grand Total	275.4	42336	7567	324356	11559	23693	292673	52406	35964	31585	551	3430	9260	1153
	SECA		139.2	18786	3331	142843	5038	10400	49830	28032	16233	18799	249	1646	4451	500
	Non SECA		136.3	23550	4235	181514	6521	13293	242843	24375	19731	12787	301	1784	4810	652
	Grand Total		275.4	42336	7567	324356	11559	23693	292673	52406	35964	31585	551	3430	9260	1153

Results per fuel type and sea area (SECA/Non SECA) calculated for the inventory area in the HFO ban HiG scenario for 2020, 2030 and 2050.

Year	Area	Fuel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
			km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2020	SECA	LNG	2.0	423	70	3366	0	193	550	3810	550	3598	0	0	13	8
		MDO/MGO	73.4	11479	2185	93302	3496	6904	152973	5808	16445	174	155	852	2057	339
2020	Non SECA	LNG	1.5	279	46	2221	0	127	363	2513	363	2374	0	0	8	5
		MDO/MGO	85.9	18395	3530	150715	5647	11153	229736	9316	26393	279	255	1377	3362	553
	Grand Total		162.8	30577	5831	249603	9143	18378	383623	21447	43751	6426	410	2229	5440	905
2020	All	LNG	3.4	703	117	5586	0	321	913	6323	913	5972	0	0	21	13
		MDO/MGO	159.3	29874	5715	244016	9143	18057	382709	15124	42838	454	410	2229	5419	892
2020	All	Grand Total	162.8	30577	5831	249603	9143	18378	383623	21447	43751	6426	410	2229	5440	905
2020	SECA		75.3	11902	2255	96668	3496	7098	153524	9617	16995	3772	155	852	2070	347
	Non SECA		87.4	18674	3576	152935	5647	11280	230099	11829	26756	2653	255	1377	3370	559
2020	Grand Total		162.8	30577	5831	249603	9143	18378	383623	21447	43751	6426	410	2229	5440	905
2030	SECA	LNG	4.6	899	149	7151	0	411	1169	8094	1169	7645	0	0	27	16
		MDO/MGO	86.8	12923	2369	101155	3790	7485	119136	6536	15028	196	168	924	2343	367
2030	Non SECA	LNG	3.4	599	100	4767	0	274	779	5395	779	5096	0	0	18	11
		MDO/MGO	96.3	19470	3602	153825	5764	11383	223034	9863	22698	296	258	1405	3592	565
	Grand Total		191.0	33892	6220	266898	9554	19553	344119	29888	39674	13233	426	2329	5980	960
2030	All	LNG	8.0	1499	249	11918	0	684	1949	13490	1949	12741	0	0	45	27
		MDO/MGO	183.1	32393	5971	254980	9554	18868	342170	16398	37726	492	426	2329	5935	932
2030	All	Grand Total	191.0	33892	6220	266898	9554	19553	344119	29888	39674	13233	426	2329	5980	960
2030	SECA		91.4	13822	2518	108306	3790	7896	120305	14630	16197	7841	168	924	2370	384
	Non SECA		99.6	20070	3702	158592	5764	11657	223814	15258	23477	5391	258	1405	3610	576
2030	Grand Total		191.0	33892	6220	266898	9554	19553	344119	29888	39674	13233	426	2329	5980	960
2050	SECA	LNG	13.0	2182	362	17349	0	996	2836	19637	2836	18547	0	0	65	40
		MDO/MGO	126.1	16605	2969	126786	4751	9382	46993	8395	13397	252	210	1158	3039	460
2050	Non SECA	LNG	9.7	1465	243	11647	0	669	1904	13183	1904	12451	0	0	44	27
		MDO/MGO	126.6	22085	3992	170468	6388	12615	240939	11192	17827	336	283	1557	4099	626
	Grand Total		275.4	42336	7567	326249	11138	23661	292673	52406	35964	31585	493	2715	7248	1153
2050	All	LNG	22.7	3647	605	28996	0	1665	4741	32820	4741	30997	1	0	109	67

Continued																
		MDO/MGO	252.7	38690	6961	297253	11138	21997	287933	19587	31224	588	492	2715	7139	1086
2050	All	Grand Total	275.4	42336	7567	326249	11138	23661	292673	52406	35964	31585	493	2715	7248	1153
2050	SECA		139.2	18786	3331	144135	4751	10378	49830	28032	16233	18799	210	1158	3105	500
	Non SECA		136.3	23550	4235	182115	6388	13283	242843	24375	19731	12787	283	1557	4143	652
2050	Grand Total		275.4	42336	7567	326249	11138	23661	292673	52406	35964	31585	493	2715	7248	1153

Results per fuel type and sea area (SECA/Non SECA) calculated for the inventory area in the High scrub HiG scenario for 2020, 2030 and 2050.

Year	Area	Fuel type	Distance	Power	Fuel	Fuel	SO_2	CO_2	NO_x	VOC	CO	CH_4	BC	OC	PM	N_2O
			km x 10^6	kWh x 10^6	kTonnes	TJ	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2020	SECA	HFO + EGCS	4.5	1510	289	11836	579	923	20227	769	2184	23	37	310	405	45
		LNG	2.0	423	70	3366	0	193	550	3810	550	3598	0	0	13	8
		MDO/MGO	68.9	9969	1896	80945	3033	5990	132746	5039	14260	151	134	739	1831	294
2020	Non SECA	HFO + EGCS	2.3	728	135	5516	270	430	10819	381	1070	11	17	144	236	21
		LNG	1.5	279	46	2221	0	127	363	2513	363	2374	0	0	8	5
		MDO/MGO	83.6	17668	3395	144956	5432	10727	218917	8935	25323	268	245	1324	3245	533
	Grand Total		162.8	30577	5831	248839	9313	18391	383623	21447	43751	6426	433	2517	5739	905
2020	All	HFO + EGCS	6.9	2237	424	17352	849	1353	31046	1150	3254	34	54	454	641	66
		LNG	3.4	703	117	5586	0	321	913	6323	913	5972	0	0	21	13
		MDO/MGO	152.5	27637	5290	225901	8465	16717	351664	13974	39583	419	379	2063	5076	827
2020	All	Grand Total	162.8	30577	5831	248839	9313	18391	383623	21447	43751	6426	433	2517	5739	905
2020	SECA		75.3	11902	2255	96147	3612	7106	153524	9617	16995	3772	171	1049	2249	347
	Non SECA		87.4	18674	3576	152693	5701	11284	230099	11829	26756	2653	262	1468	3490	559
2020	Grand Total		162.8	30577	5831	248839	9313	18391	383623	21447	43751	6426	433	2517	5739	905
2030	SECA	HFO + EGCS	13.4	4088	753	30813	1507	2403	38291	2080	4805	62	96	806	1139	116
		LNG	4.6	899	149	7151	0	411	1169	8094	1169	7645	0	0	27	16
		MDO/MGO	73.4	8834	1616	68986	2585	5105	80845	4456	10223	134	113	630	1673	251
2030	Non SECA	HFO + EGCS	7.0	1982	354	14461	707	1128	26507	1032	2363	31	45	378	659	55
		LNG	3.4	599	100	4767	0	274	779	5395	779	5096	0	0	18	11
		MDO/MGO	89.2	17488	3249	138727	5198	10266	196528	8830	20334	265	233	1267	3253	510
	Grand Total		191.0	33892	6220	264905	9997	19586	344119	29888	39674	13233	487	3082	6770	960
2030	All	HFO + EGCS	20.4	6070	1107	45274	2214	3531	64797	3112	7169	93	141	1184	1798	171
		LNG	8.0	1499	249	11918	0	684	1949	13490	1949	12741	0	0	45	27
		MDO/MGO	162.6	26323	4864	207713	7783	15371	277373	13286	30557	399	346	1897	4927	761
2030	All	Grand Total	191.0	33892	6220	264905	9997	19586	344119	29888	39674	13233	487	3082	6770	960
2030	SECA		91.4	13822	2518	106950	4092	7919	120305	14630	16197	7841	209	1436	2839	384
	Non SECA		99.6	20070	3702	157955	5905	11667	223814	15258	23477	5391	278	1645	3931	576
2030	Grand Total		191.0	33892	6220	264905	9997	19586	344119	29888	39674	13233	487	3082	6770	960

Continued																
2050	SECA	HFO + EGCS	32.9	7951	1426	58312	2851	4548	22672	4039	6438	121	181	1526	2269	220
		LNG	13.0	2182	362	17349	0	996	2836	19637	2836	18547	0	0	65	40
		MDO/MGO	93.2	8654	1543	65907	2470	4877	24322	4355	6959	131	107	602	1668	241
2050	Non SECA	HFO + EGCS	17.3	3791	662	27058	1323	2111	48087	1963	3106	59	84	708	1276	103
		LNG	9.7	1465	243	11647	0	669	1904	13183	1904	12451	0	0	44	27
		MDO/MGO	109.3	18294	3331	142219	5329	10524	192852	9229	14721	277	235	1299	3431	523
	Grand Total		275.4	42336	7567	322492	11973	23725	292673	52406	35964	31585	607	4134	8753	1153
2050	All	HFO + EGCS	50.2	11742	2087	85370	4175	6659	70759	6003	9544	180	265	2233	3545	323
		LNG	22.7	3647	605	28996	0	1665	4741	32820	4741	30997	1	0	109	67
		MDO/MGO	202.6	26948	4874	208126	7799	15401	217173	13584	21680	408	342	1901	5099	764
2050	All	Grand Total	275.4	42336	7567	322492	11973	23725	292673	52406	35964	31585	607	4134	8753	1153
2050	SECA		139.2	18786	3331	141568	5321	10422	49830	28032	16233	18799	288	2127	4003	500
	Non SECA		136.3	23550	4235	180924	6652	13303	242843	24375	19731	12787	319	2007	4750	652
2050	Grand Total		275.4	42336	7567	322492	11973	23725	292673	52406	35964	31585	607	4134	8753	1153

EMISSIONS FROM SHIPPING IN THE ARCTIC FROM 2012-2016 AND EMISSION PROJECTIONS FOR 2020, 2030 AND 2050

This report presents results for spatial distributed emission inventories for the Arctic area above 58.95N from 2012-2016 based on satellite AIS data, ship engine power functions and technology stratified emission factors. Emission projection results for 2020, 2030 and 2050 are also presented for a Baseline scenario and for a SECA and a HFO ban scenario.

The full list of emission components estimated in the project are the short lived climate forcers SO_2, NOx, CO, NMVOC, PM, BC and OC and the greenhouse gases CO_2, CH_4 and N_2O. For 2012 *[2013, 2014, 2015, 2016]* the following total results are calculated for fuel consumption: 4.8 *[5.1, 6.3, 6.6, 5.4]* MTonnes; SO_2: 82 *[84, 108, 60, 53]* kTonnes; NOx: 320 *[339, 429, 432, 361]* kTonnes and BC: 0.71 *[0.73, 0.86, 0.65, 0.56]* kTonnes. In the Baseline scenario for the forecast years 2020 *[2030, 2050]* the following total results are calculated for fuel consumption: 5.7 *[5.8, 6.3]* MTonnes; SO_2: 17 *[17, 18]* kTonnes; NOx: 371 *[318, 247]* kTonnes and BC: 0.43 *[0.44, 0.47]* kTonnes. In all scenario years the calculated SO_2 emissions for the SECA and HFO ban scenarios are almost half of the emissions calculated for the Baseline scenario. For BC in 2020 *[2030, 2050]* the HFO ban and SECA emissions are 8 % *[9 %, 12 %]* and 3 % *[3%, 3 %]* smaller, respectively, than the Baseline results.

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