Fourth IMO GHG Study 2020

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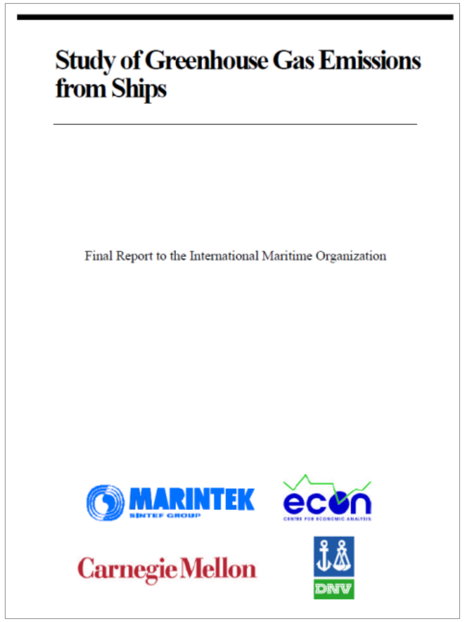
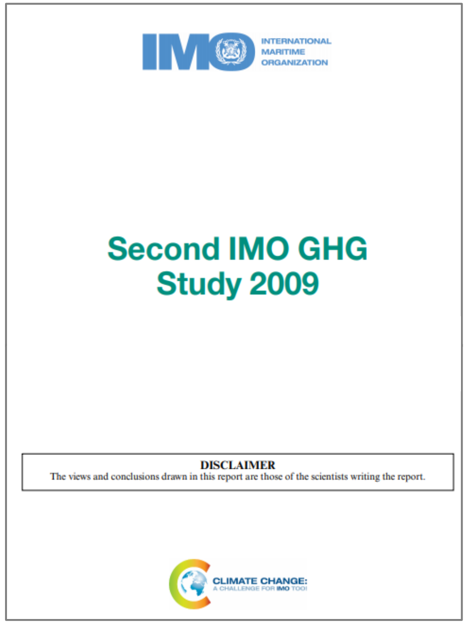
Contents

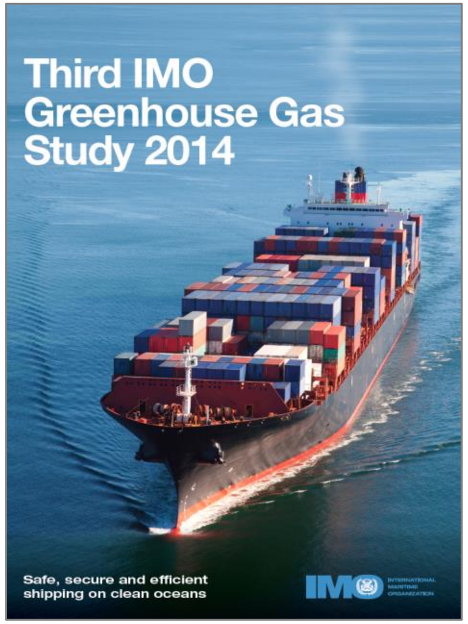
History

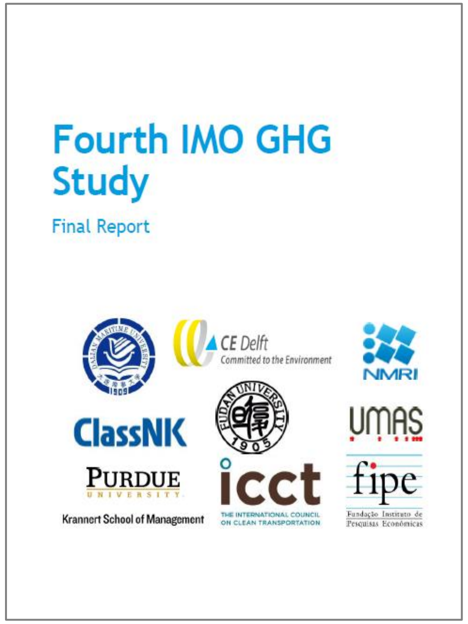
Comparison with previous reports

Reports	Published	Estimated Emissions	Int'l Shipping % of Global CO2 emissions	Future Scenario	2050 BAU Projection
First	2000	1996	1.8% (1996)	-	-
Second	2009	1990 – 2007	2.7% (2007)	2007 – 2050	200 – 300%
Third	2014	2007 – 2012	2.2% (2012)	2012 – 2050	50 – 250%
Fourth	2020	2012 – 2018	2.5% (2018)	2018 – 2050	90 – 130%









Introduction

Objective

- To develop an accurate estimate of historical emissions of international shipping and state-of-the-art projections of future emissions
  - Inventory of GHG emissions from international shipping 2012 – 2018
  - Scenarios of future international shipping emissions 2018 – 2050

Scope

- Global emissions of GHGs and relevant substances from ships of 100 GT and above engaged in both domestic and international voyages
  - 6 GHGs : CO_2, CH_4, N_2O, HFCs, PFCs, SF_6
    - CO_2-eq : 100-year GWPs (CO_2 – 1, CH_4 – 28, N_2O – 265) from IPCC AR5
  - Relevant substances : NO_x, NMVOCs, CO, PM, SO_x, BC

Emissions Inventory

Methodology

Bottom-up : Vessel's operation activity

1. Fuel-based (CO2, SOx, BC)

$$EM_i = FC_i \cdot EF_f$$

EM_i : Hourly emissions (g pollutant/h)
FC_i : Hourly fuel consumption (g fuel/h)
EF_f : Fuel-based emission factor (g pollutant/g fuel)

2. Energy-based (NOx, CH4, CO, N2O, PM, NMVOC)

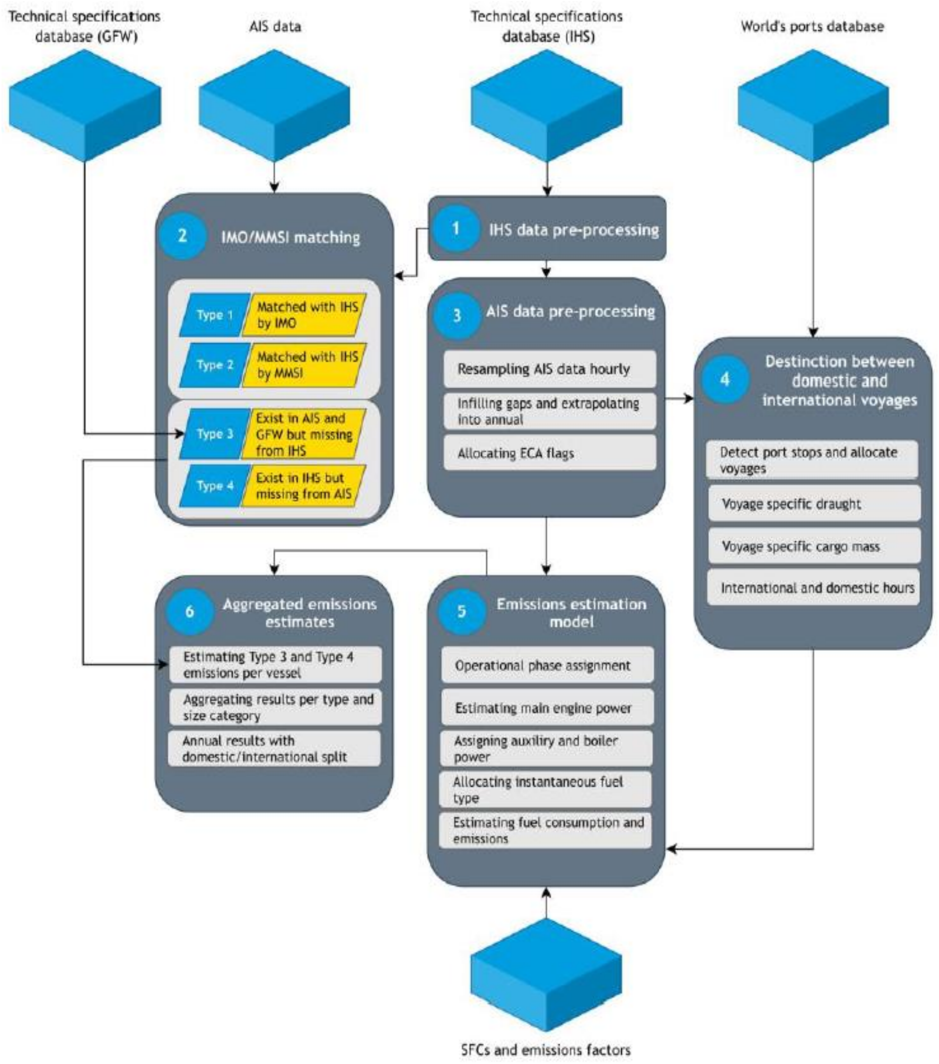
$$EM_i = W_i \cdot EF_e$$

EM_i : Hourly emissions (g pollutant / h)
W_i : Engine/Boiler power output (kW)
EF_e : Energy-based emission factor (g pollutant/kWh)

Top-down : Fuel sales statistics

- **Fuel sales data from IEA**

Fuel sales for marine sectors x EF for each fuel type



Emissions Inventory

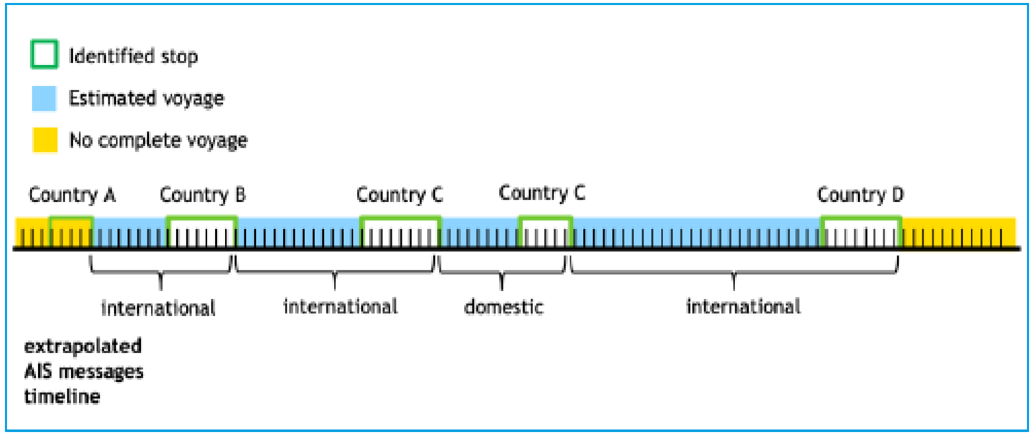
- **Split between domestic and international shipping**

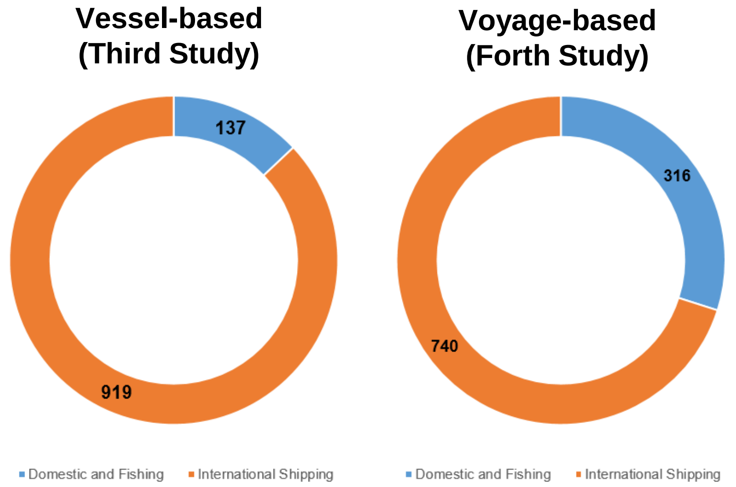
  - **Voyage-based Int'l shipping**
    - **Voyage-based allocation is newly taken from 4th GHG Study**
    - **International emissions as those which occurred on a voyage between two ports in different countries = based on Actual ship's voyage**

  - **Vessel-based Int'l shipping**
    - **Vessel-based allocation is taken from 3th GHG Study**
    - **International emissions as shipping between ports of different countries = based on ship's registered navigation area**

  *** Same ship may frequently be engaged in both international and domestic shipping operations**

Figure 10 – Allocation of international and domestic nature of shipping according to voyage-based method





Emissions Inventory

Shipping GHG emission 2012 – 2018

- Total shipping : 977 million tCO2e in 2012 to 1,076 million tCO2e in 2018 (9.6% increase)
  - Total shipping : Domestic + International + Fishing

Shipping CO2 emission 2012 – 2018

- Total shipping : 962 million tCO2 in 2012 to 1,056 million tCO2 in 2018 (9.3% increase)
  - Total shipping : Domestic + International + Fishing
- Voyage-based Int'l shipping : 701 million tCO2 in 2012 to 740 million tCO2 in 2018 (5.6% increase)
- Vessel-based Int'l shipping : 848 million tCO2 in 2012 to 919 million tCO2 in 2018 (8.4% increase)

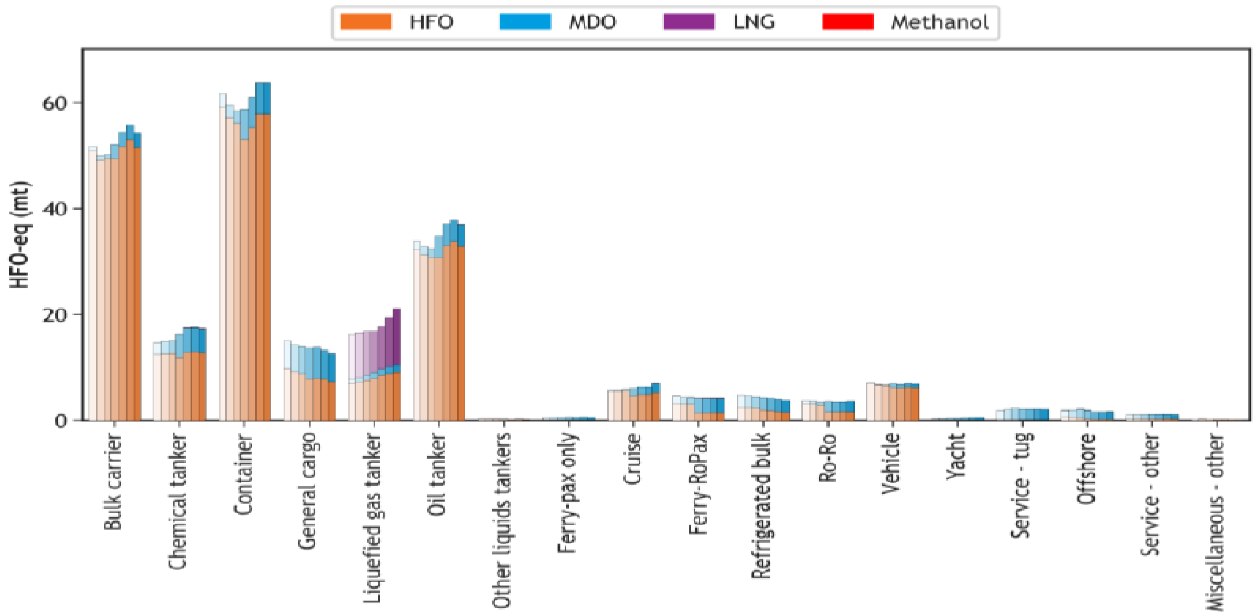
Year	Global CO2 emissions (million tonnes)	Total Shipping CO2 (million tonnes)	Total Shipping % of Global	Voyage-based Int'l Shipping CO2 (million tonnes)	Voyage-based Int'l shipping % of Global	Vessel-based Int'l Shipping CO2 (million tonnes)	Vessel-based Int'l Shipping % of Global
2012	34,793	962	2.76%	701	2.01%	848	2.44%
2013	34,959	957	2.74%	684	1.96%	837	2.39%
2014	35,225	964	2.74%	681	1.93%	846	2.37%
2015	35,239	991	2.81%	700	1.99%	859	2.44%
2016	35,380	1,026	2.90%	727	2.05%	894	2.53%
2017	35,810	1,064	2.97%	746	2.08%	929	2.59%
2018	**36,573**	**1,056**	**2.89%**	**740**	**2.02%**	**919**	**2.51%**

Emissions Inventory

HFO-eq fuel consumption per ship type

- **Dominant Ship Types : Containers, Bulk carriers and Oil tankers**
- **Dominant Fuel Type : HFO (79% of total fuel consumption in 2018)**
  - However, during the period of 2012 – 2018, a significant change in the fuel mix has occurred
  - Share changed during 2012 – 2018 : HFO 7% ↓, MDO 6% ↑, LNG 0.9% ↑
  - Methanol was used 130,000 tonnes in 2018 and became the fourth most significant fuel

Figure 4 - International HFO-equivalent fuel consumption per ship type, according to the voyage-based allocation of international emissions

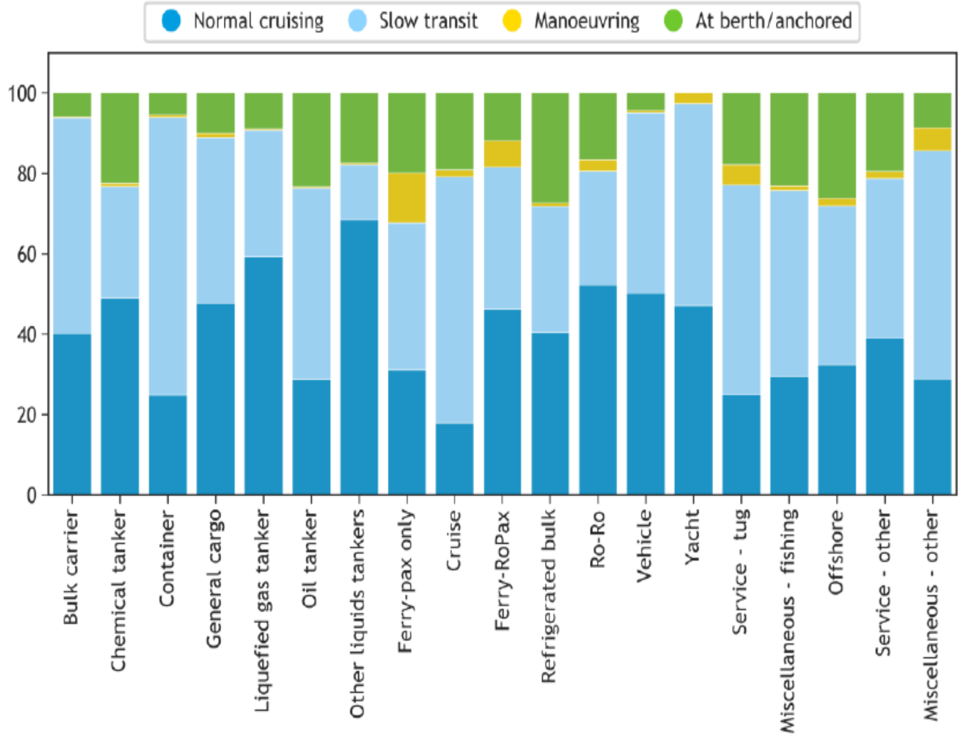


Emissions Inventory

GHG emissions per operational phase

- **Chemical tankers and Oil tankers**
  - **Relatively large emissions portion of phases at or near the port or terminal (20% more)**
- **Containers, Cruise ships and Oil tankers**
  - **Relatively small emissions portion of cruising due to dominance of slow cruising**
- **Liquefied gas and Oher liquids tankers**
  - **Relatively large emissions portion of cruising**

Figure 6 - Proportion of international GHG emissions (in CO_2e) by operational phase in 2018, according to the voyage-based allocation of emissions. Operational phases are assigned based on the vessel's speed over ground, distance from coast/port and main engine load (see Table 16).



Emissions Inventory

Operating Speed Trends

- Operating speeds remain key driver in emissions and are susceptible to market forces
  - Decoupling in the rate of increase in installed power and fuel consumption
    - Average ship sizes and installed power increased
    - Average fuel consumption increased, but lower rate than increase in average installed power
    - Decoupling is the consequence of continued reduction in operating speeds and the average number of days at sea

Figure 8 - Speed trends for the three highest emitting fleets aggregated (top left) and broken down for each ship type's size categories, which can be found in Section 2.2.1

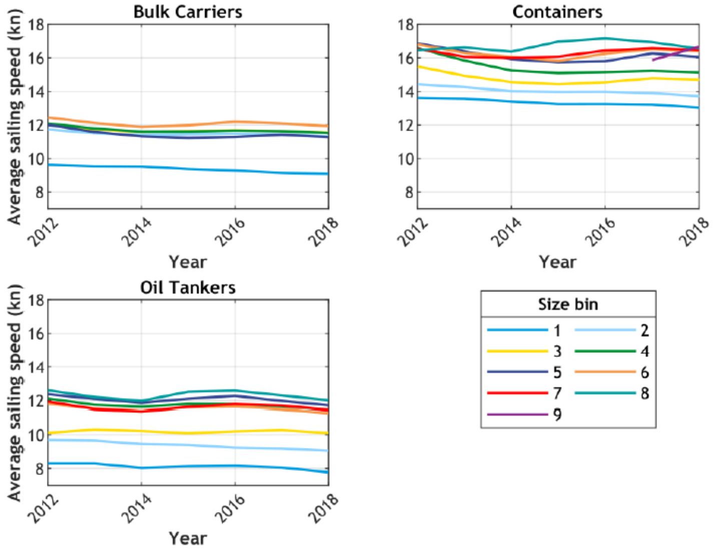


Table 8 - Updated vessel type and size categories

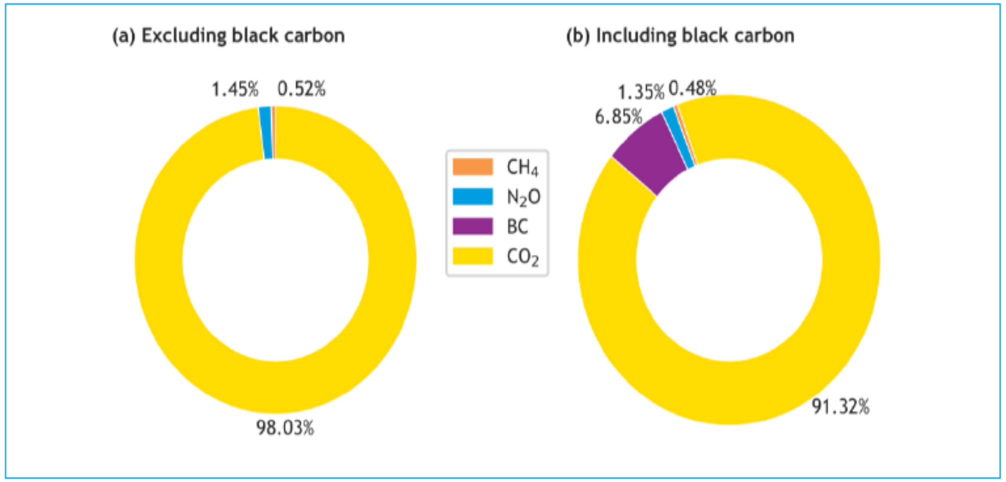
Type bin	IMO4 size bin	Capacity	Unit	IMO3 size bin
Bulk carrier	1	0-9,999	DWT	1
	2	10,000-34,999	DWT	2
	3	35,000-59,999	DWT	3
	4	60,000-99,999	DWT	4
	5	100,000-199,999	DWT	5
	6	200,000-+	DWT	6
Chemical tanker	1	0-4,999	DWT	1
	2	5,000-9,999	DWT	2
	3	10,000-19,999	DWT	3
	4	20,000-39,999	DWT	4
	5	40,000-+	DWT	4
Container	1	0-999	TEU	1
	2	1,000-1,999	TEU	2
	3	2,000-2,999	TEU	3
	4	3,000-4,999	TEU	4
	5	5,000-7,999	TEU	5
	6	8,000-11,999	TEU	6
	7	12,000-14,499	TEU	7
	8	14,500-19,999	TEU	8
	9	20,000-+	TEU	8
General cargo	1	0-4,999	DWT	1
	2	5,000-9,999	DWT	2
	3	10,000-19,999	DWT	3
	4	20,000-+	DWT	3
Liquefied gas tanker	1	0-49,999	CBM	1
	2	50,000-99,999	CBM	2
	3	100,000-199,999	CBM	2
	4	200,000-+	CBM	3
Oil tanker	1	0-4,999	DWT	1
	2	5,000-9,999	DWT	2
	3	10,000-19,999	DWT	3
	4	20,000-59,999	DWT	4
	5	60,000-79,999	DWT	5
	6	80,000-119,999	DWT	6
	7	120,000-199,999	DWT	7
	8	200,000-+	DWT	8

Emissions Inventory

Emissions both GHG and Air Pollutants

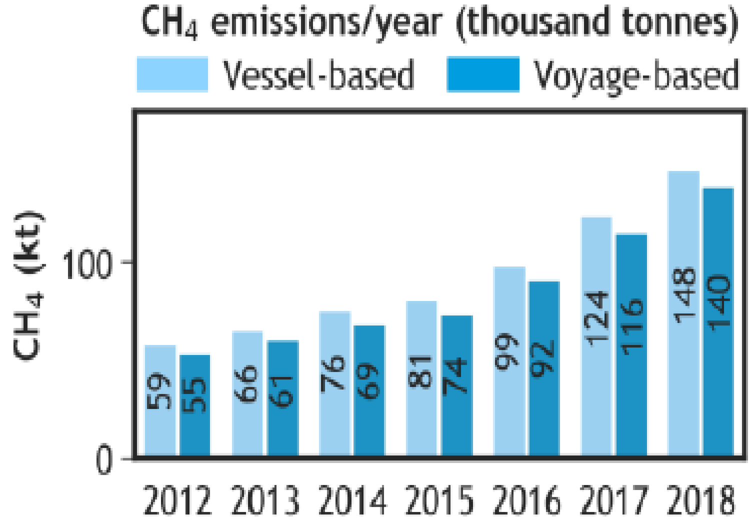
- **CH4 increased 150% over the period due to increase in consumption of LNG**
- **SOx and PM increased in spite of reduction in HFO and increase in MDO and LNG**
  - Average sulfur content increase in HFO exceeds sulfur content reduction by fuel change
- **NOx has lower increase rates due to Tier II and III regulations but the overall trend increased**

Figure 78 - Comparison of the contribution of individual species to voyage-based international greenhouse gas emissions (in CO_2e) in 2018, highlighting the impact the inclusion of black carbon has.



* 100-year GWPs : CO2 – 1, CH4 – 28, N2O – 265, BC – 900

Figure 9 - Emissions species trends, all species 2012-2018, showing both the estimates for voyage-based and vessel-based international shipping emissions



Carbon Intensity

Carbon Intensity of international shipping

- **4 metrics of carbon intensity**
  - Energy Efficiency Operational Indicator (EEOI, g CO2/t·nm)
  - Annual Efficiency Ratio (AER, g CO2/dwt·nm)
  - Distance (DIST, kg CO2/nm)
  - Time (TIME, tCO2/hr)
- **Analysis methodologies**
  - Allocation : Vessel-based and Voyage-based
  - Percentage changes : Overall (aggregated data) and Individual (regression fit)

Table 3 – Carbon intensity levels and percentage changes of international shipping (vessel-based)

Year	EEOI (gCO2/t/nm)					AER(gCO2/DWT/nm)					DIST(kgCO2/nm)					TIME(tCO2/hr)				
	Value	Variation vs 2008		Variation vs 2012		Value	Variation vs 2008		Variation vs 2012		Value	Variation vs 2008		Variation vs 2012		Value	Variation vs 2008		Variation vs 2012	
		overall	individual	overall	individual		overall	individual	overall	individual		overall	individual	overall	individual		overall	individual	overall	individual
2008	17,10	–	–	–	–	8,08	–	–	–	–	306,46	–	–	–	–	3,64	–	–	–	–
2012	13,16	-23,1%	-16,8%	–	–	7,06	-12,7%	-5,6%	–	–	362,65	18,3%	-5,6%	–	–	4,32	18,6%	-14,7%	–	–
2013	12,87	-24,7%	-18,3%	-2,2%	-2,0%	6,89	-14,8%	-7,1%	-2,4%	-1,7%	357,73	16,7%	-7,1%	-1,4%	-1,7%	4,18	14,6%	-18,1%	-3,3%	-4,2%
2014	12,34	-27,9%	-20,4%	-6,3%	-4,6%	6,71	-16,9%	-7,8%	-4,9%	-2,4%	360,44	17,6%	-7,7%	-0,6%	-2,4%	4,17	14,4%	-19,9%	-3,6%	-6,2%
2015	12,33	-27,9%	-19,0%	-6,3%	-2,8%	6,64	-17,8%	-6,5%	-5,9%	-1,3%	366,56	19,6%	-6,5%	1,1%	-1,3%	4,25	16,6%	-18,5%	-1,6%	-4,9%
2016	12,22	-28,6%	-18,7%	-7,2%	-2,5%	6,58	-18,6%	-6,4%	-6,8%	-1,4%	373,46	21,9%	-6,4%	3,0%	-1,4%	4,35	19,3%	-18,0%	0,6%	-4,4%
2017	11,87	-30,6%	-20,8%	-9,8%	-5,0%	6,43	-20,4%	-8,4%	-8,9%	-3,3%	370,97	21,0%	-8,4%	2,3%	-3,3%	4,31	18,2%	-20,4%	-0,3%	-7,0%
2018	11,67	-31,8%	-21,5%	-11,3%	-6,2%	6,31	-22,0%	-9,3%	-10,6%	-4,2%	376,81	23,0%	-9,3%	3,9%	-4,2%	4,34	19,1%	-22,2%	0,4%	-9,1%

Table 4 – Carbon intensity levels and percentage changes of international shipping (voyage-based)

Year	EEOI (gCO2/t/nm)					AER(gCO2/DWT/nm)					DIST(kgCO2/nm)					TIME(tCO2/hr)				
	Value	Variation vs 2008		Variation vs 2012		Value	Variation vs 2008		Variation vs 2012		Value	Variation vs 2008		Variation vs 2012		Value	Variation vs 2008		Variation vs 2012	
		overall	individual	overall	individual		overall	individual	overall	individual		overall	individual	overall	individual		overall	individual	overall	individual
2008	15,16	–	–	–	–	7,40	–	–	–	–	350,36	–	–	–	–	4,38	–	–	–	–
2012	12,19	-19,6%	-11,4%	–	–	6,61	-10,7%	-4,6%	–	–	387,01	10,5%	-4,6%	–	–	4,74	8,11%	-13,9%	–	–
2013	11,83	-22,0%	-13,6%	-3,0%	-2,6%	6,40	-13,5%	-6,6%	-3,2%	-2,2%	380,68	8,7%	-6,6%	-1,6%	-2,2%	4,57	4,13%	-17,6%	-3,7%	-4,5%
2014	11,29	-25,6%	-16,2%	-7,4%	-5,5%	6,20	-16,1%	-7,6%	-6,1%	-3,1%	382,09	9,1%	-7,6%	-1,3%	-3,1%	4,54	3,49%	-19,4%	-4,3%	-6,6%
2015	11,30	-25,5%	-14,5%	-7,3%	-3,7%	6,15	-16,9%	-6,2%	-6,9%	-2,0%	388,62	10,9%	-6,2%	0,4%	-2,0%	4,64	5,75%	-18,0%	-2,2%	-5,3%
2016	11,21	-26,1%	-14,0%	-8,1%	-3,2%	6,09	-17,7%	-5,9%	-7,8%	-1,8%	397,05	13,3%	-5,9%	2,6%	-1,8%	4,77	8,68%	-17,4%	0,5%	-4,7%
2017	10,88	-28,2%	-15,9%	-10,8%	-5,4%	5,96	-19,5%	-7,7%	-9,8%	-3,7%	399,38	14,0%	-7,7%	3,2%	-3,7%	4,79	9,21%	-19,7%	1,0%	-7,2%
2018	10,70	-29,4%	-17,2%	-12,3%	-7,0%	5,84	-21,0%	-8,9%	-11,5%	-4,8%	401,91	14,7%	-8,9%	3,8%	-4,9%	4,79	9,17%	-21,5%	1,0%	-9,3%

Carbon Intensity

Percentage changes of Overall Carbon Intensity

- **EEOI & AER kept decreasing (improving) between 2012 – 2018**
  - Reduction rate (voyage-based) : -29% (EEOI) and -21% (AER) in 2018 compared with 2008
- **DIST & TIME have increasing trend (worsening) between 2012 – 2018**
  - Reduction rate (voyage-based) : 15% (DIST) and 9% (TIME) in 2018 compared with 2008
  - Increasing average ship size = Increasing CO2 emissions
  - TIME has lower increasing trend due to speed reduction

Figure 13 – Percentage changes in overall carbon intensity of international shipping (vessel-based)

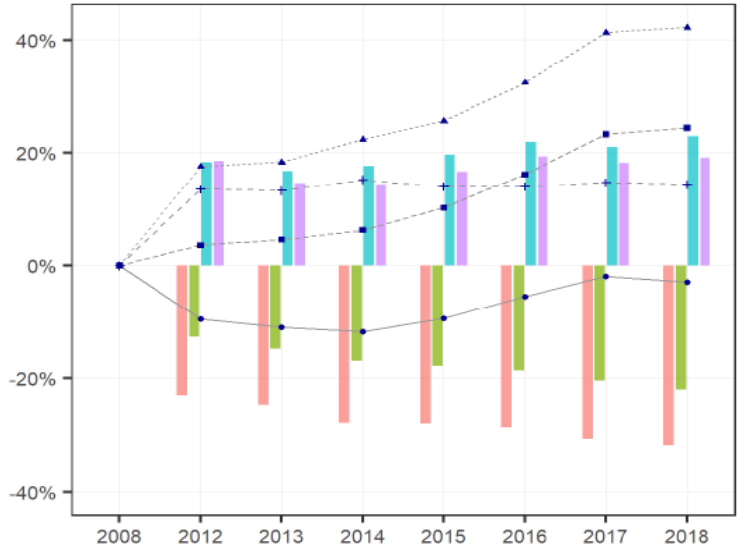
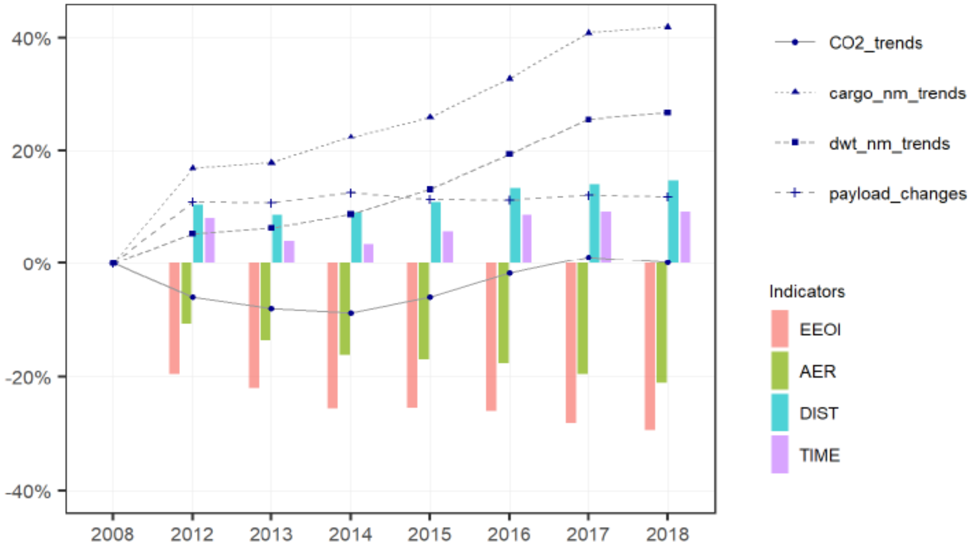


Figure 14 – Percentage changes in overall carbon intensity of international shipping (voyage-based)



Carbon Intensity

Percentage changes of Individual Carbon Intensity

- **EEOI & AER kept going down (improving) but narrowed down compared to overall carbon intensity**
  - Reduction rate (voyage-based) : -17% (EEOI) and -9% (AER) in 2018 compared with 2008
  - No contribution of scale economy
- **DIST & TIME kept going down (improving) between 2012 – 2018**
  - Reduction rate (voyage-based) : -9% (DIST) and -22% (TIME) in 2018 compared with 2008
  - TIME has larger improvement due to speed reduction

Figure 15 – Percentage changes in individual based carbon intensity of international shipping (vessel-based)

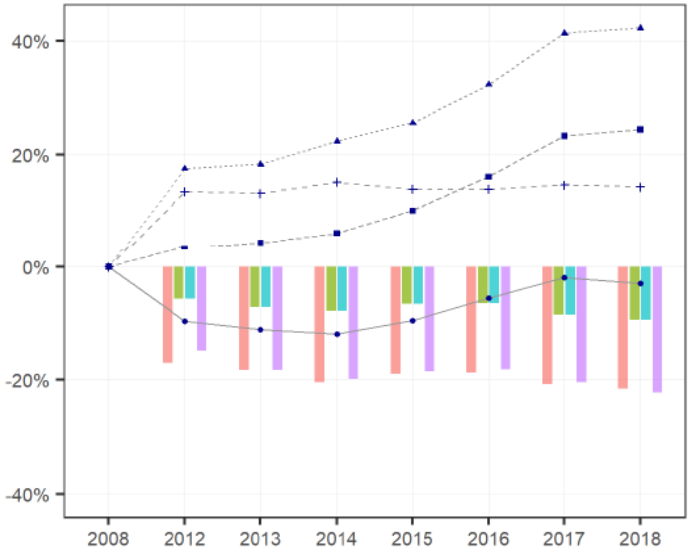
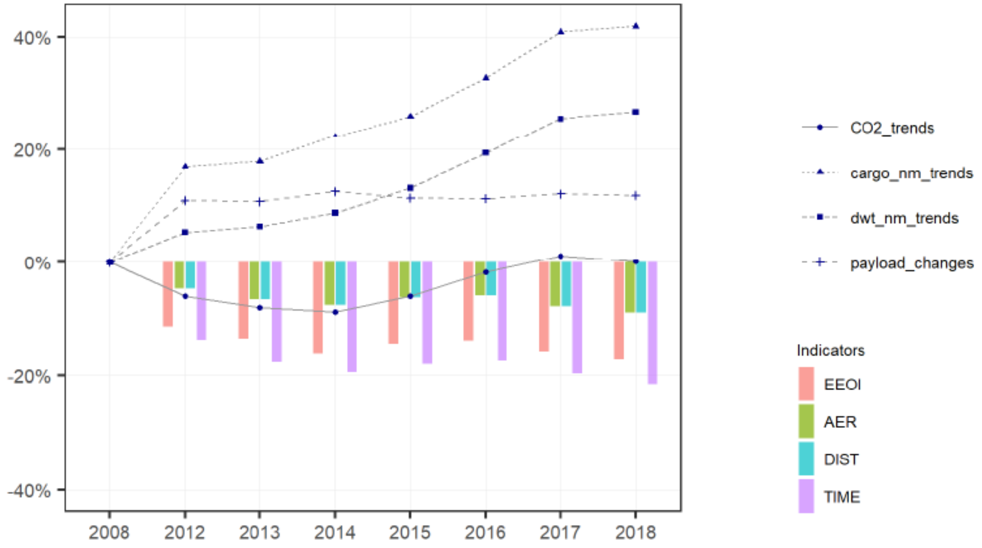


Figure 16 – Percentage changes in individual based carbon intensity of international shipping (voyage-based)



Carbon Intensity

Improvement trends of Carbon Intensity

Most improvement achieved before 2012

- Reduction rates in carbon intensity of international shipping indexed at 2008, at which time the shipping market was reaching its peak right before the long-lasting depression
- Taking 2012 as the reference year instead of 2008, reductions in carbon intensity narrowed down

Improvement slowed down since 2015

- Average annual percentage changes ranging from 1 to 2%
- Due to limit in speed reduction, payload utilization and technical improvements of existing ships

Table 66 - Carbon intensity levels and percentage changes of international shipping（Option 1）

Year	EEOI ($gCO_2/t.nm$)					AER($gCO_2/dwt.nm$)					DIST($kgCO_2/nm$)					TIME(tCO_2/hr)				
	Value	Variation vs 2008		Variation vs 2012		Value	Variation vs 2008		Variation vs 2012		Value	Variation vs 2008		Variation vs 2012		Value	Variation vs 2008		Variation vs 2012	
		overall	individual	overall	individual		overall	individual	overall	individual		overall	individual	overall	individual		overall	individual	overall	individual
2008	17.10	–	–	–	–	8.08	–	–	–	–	306.46	–	–	–	–	3.64	–	–	–	–
2012	13.16	-23.1%	-16.8%	–	–	7.06	-12.7%	-5.6%	–	–	362.65	18.3%	-5.6%	–	–	4.32	18.57%	-14.7%	–	–
2013	12.87	-24.7%	-18.3%	-2.2%	-2.0%	6.89	-14.8%	-7.1%	-2.4%	-1.7%	357.73	16.7%	-7.1%	-1.4%	-1.7%	4.18	14.61%	-18.1%	-3.3%	-4.2%
2014	12.34	-27.9%	-20.4%	-6.3%	-4.6%	6.71	-16.9%	-7.8%	-4.9%	-2.4%	360.44	17.6%	-7.7%	-0.6%	-2.4%	4.17	14.36%	-19.9%	-3.6%	-6.2%
2015	12.33	-27.9%	-19.0%	-6.3%	-2.8%	6.64	-17.8%	-6.5%	-5.9%	-1.3%	366.56	19.6%	-6.5%	1.1%	-1.3%	4.25	16.62%	-18.5%	-1.6%	-4.9%
2016	12.22	-28.6%	-18.7%	-7.2%	-2.5%	6.58	-18.6%	-6.4%	-6.8%	-1.4%	373.46	21.9%	-6.4%	3.0%	-1.4%	4.35	19.32%	-18.0%	0.6%	-4.4%
2017	11.87	-30.6%	-20.8%	-9.8%	-5.0%	6.43	-20.4%	-8.4%	-8.9%	-3.3%	370.97	21.0%	-8.4%	2.3%	-3.3%	4.31	18.20%	-20.4%	-0.3%	-7.0%
2018	11.67	-31.8%	-21.5%	-11.3%	-6.2%	6.31	-22.0%	-9.3%	-10.6%	-4.2%	376.81	23.0%	-9.3%	3.9%	-4.2%	4.34	19.06%	-22.2%	0.4%	-9.1%

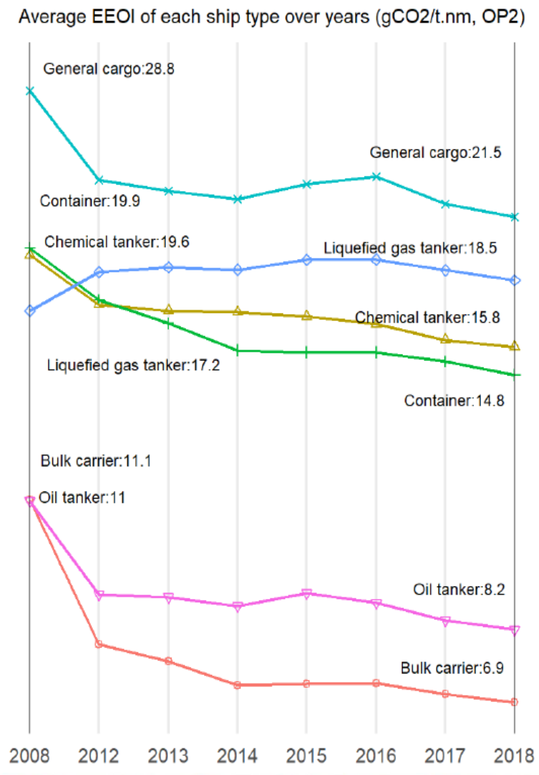
Table 67 - Carbon intensity levels and percentage changes of International shipping（Option 2）

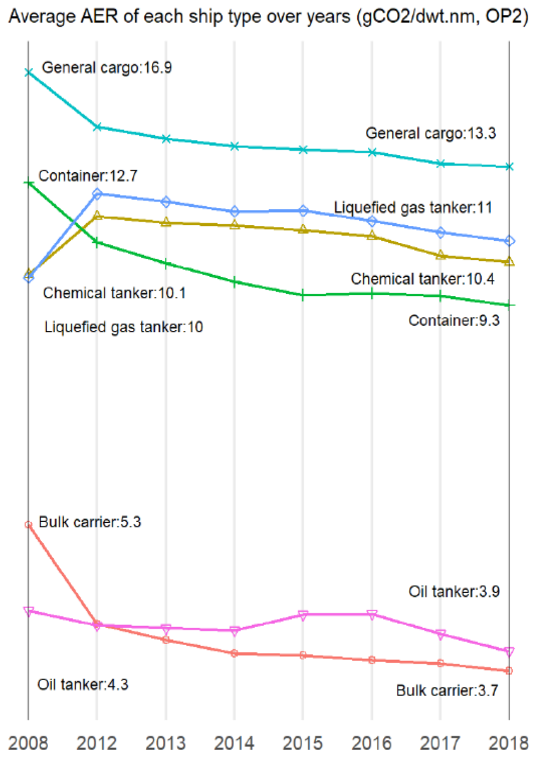
Year	EEOI ($gCO_2/t.nm$)					AER($gCO_2/dwt.nm$)					DIST($kgCO_2/nm$)					TIME(tCO_2/hr)				
	Value	Variation vs 2008		Variation vs 2012		Value	Variation vs 2008		Variation vs 2012		Value	Variation vs 2008		Variation vs 2012		Value	Variation vs 2008		Variation vs 2012	
		overall	individual	overall	individual		overall	individual	overall	individual		overall	individual	overall	individual		overall	individual	overall	individual
2008	15.16	–	–	–	–	7.40	–	–	–	–	350.36	–	–	–	–	4.38	–	–	–	–
2012	12.19	-19.6%	-11.4%	–	–	6.61	-10.7%	-4.6%	–	–	387.01	10.5%	-4.6%	–	–	4.74	8.11%	-13.9%	–	–
2013	11.83	-22.0%	-13.6%	-3.0%	-2.6%	6.40	-13.5%	-6.6%	-3.2%	-2.2%	380.68	8.7%	-6.6%	-1.6%	-2.2%	4.57	4.13%	-17.6%	-3.7%	-4.5%
2014	11.29	-25.6%	-16.2%	-7.4%	-5.5%	6.20	-16.1%	-7.6%	-6.1%	-3.1%	382.09	9.1%	-7.6%	-1.3%	-3.1%	4.54	3.49%	-19.4%	-4.3%	-6.6%
2015	11.30	-25.5%	-14.5%	-7.3%	-3.7%	6.15	-16.9%	-6.2%	-6.9%	-2.0%	388.62	10.9%	-6.2%	0.4%	-2.0%	4.64	5.75%	-18.0%	-2.2%	-5.3%
2016	11.21	-26.1%	-14.0%	-8.1%	-3.2%	6.09	-17.7%	-5.9%	-7.8%	-1.8%	397.05	13.3%	-5.9%	2.6%	-1.8%	4.77	8.68%	-17.4%	0.5%	-4.7%
2017	10.88	-28.2%	-15.9%	-10.8%	-5.4%	5.96	-19.5%	-7.7%	-9.8%	-3.7%	399.38	14.0%	-7.7%	3.2%	-3.7%	4.79	9.21%	-19.7%	1.0%	-7.2%
2018	10.70	-29.4%	-17.2%	-12.3%	-7.0%	5.84	-21.0%	-8.9%	-11.5%	-4.8%	401.91	14.7%	-8.9%	3.8%	-4.9%	4.79	9.17%	-21.5%	1.0%	-9.3%

Carbon Intensity

Carbon Intensity level of typical cargo ships

- Lowest carbon intensity levels achieved by bulk carriers, oil tankers and container ships
- Decreasing trend of carbon intensity performance of most ships between 2012 and 2018
  - Increasing average ship size in all ship types
  - Design efficiency in oil tankers, bulk carriers and chemical tankers
  - Speed reduction in bulk carriers, chemical tankers, container ships and oil tankers





Future Shipping Emissions

Method for projecting emissions from shipping

- Projecting transport work – non-energy products ➔ SSP
  - Historical relation between maritime transport work and economic parameters (per capita GDP, Population)
  - Projecting transport work based on long-term projections of GDP and Population

- Projecting transport work – energy products ➔ RCP
  - IPCC projections of energy consumption
  - Projecting transport work using energy consumption projections

- Making a detailed description of the fleet and its activity in the base year 2018

- Projecting future fleet composition and energy efficiency of ships

- Projecting shipping emissions

Non-coal dry bulk, containers, other unitized cargo, and chemicals (Relation between transport work and relevant drivers: Logistics, denoted by _L; Gravitation model, denoted by _G)	Coal dry bulk,-oil tankers and gas tankers
Long-term socio-economic scenarios	Long-term energy scenarios
SSP1 (Sustainability – Taking the Green Road)	RCP1.9 (1.5°C) in combination with SSP1, SSP2 and SSP5
SSP2 (Middle of the Road)	RCP2.6 (2°C, very low GHG emissions) in combination with SSP1, SSP2, SSP4 and SSP5
SSP3 (Regional Rivalry – A Rocky Road)	RCP3.4 (extensive carbon removal) in combination with SSP1, SS2, SSP3, SSP4 and SSP5
SSP4 (Inequality – A Road Divided)	RCP4.5 (2.4°C, medium-low mitigation or very low baseline) in combination with SSP1, SS2, SSP3, SSP4 and SSP5
SSP5 (Fossil-fueled Development – Taking the Highway)	RCP6.0 (2.8°Cmedium baseline, high mitigation in combination with SSP1, SS2, SSP3, SSP4 and SSP5
OECD long-term baseline projections	

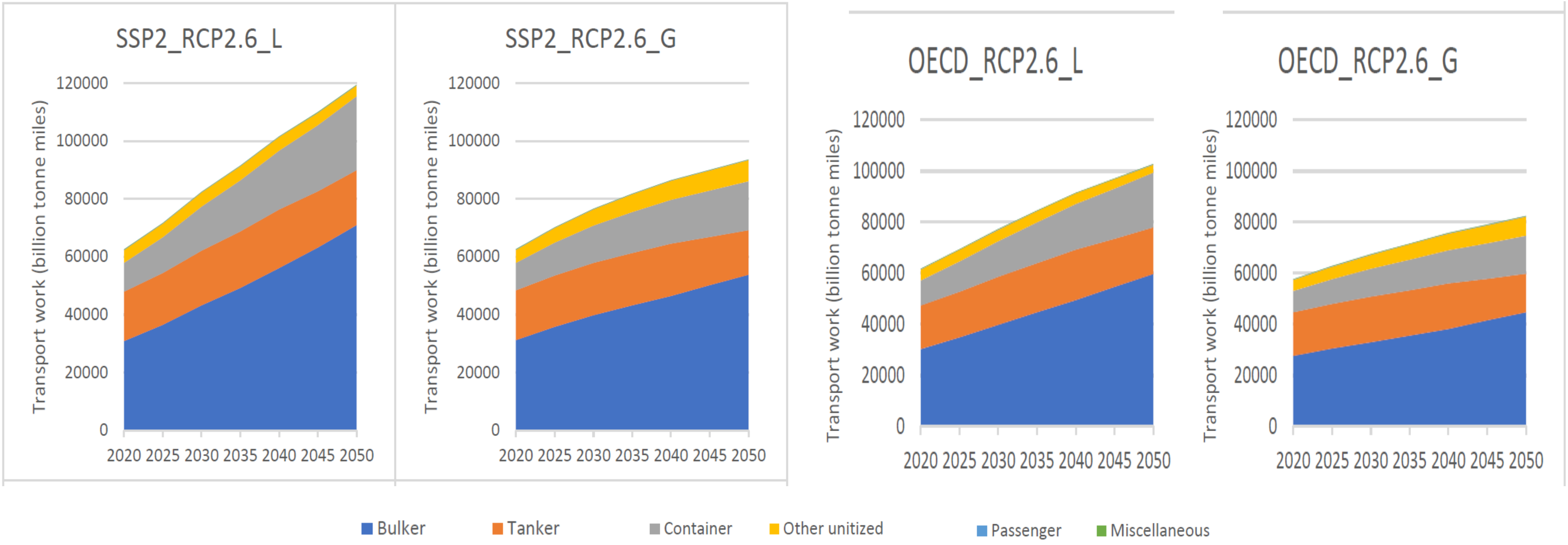
Source: (Van Vuuren, et al., 2011b), (Riahi, et al., 2017) Making sense of climate change scenarios: Senses Toolkit

SSP: Shared Socio-Economic Pathway
RCP: Representative Concentration Pathway

Future Shipping Emissions

Transport work projections

- Aggregate transport work increase by 40 – 100% in scenario SSP2 / OECD and RCP 2.6
  - Logistics analysis (75 – 100%) higher than gravitation model (40 – 60%)



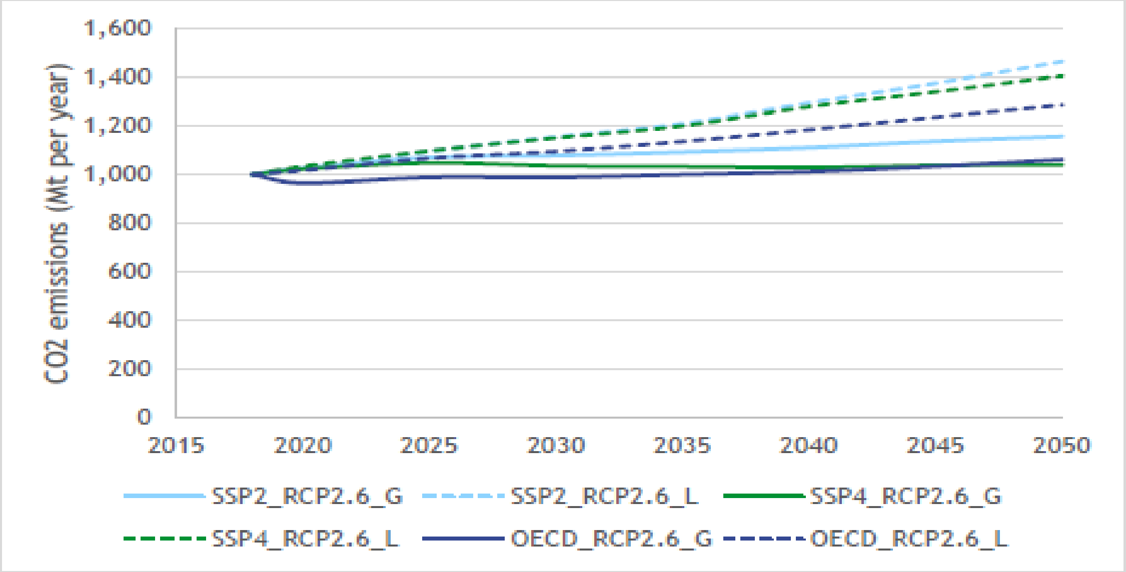
- L : logistics analysis – analyses relation between global transport work and its drivers over the longest period available and projects the relation further using a logistics curve
- G : Gravitation model – derives from Newton's law of universal gravitation (proportional to product of two masses and inversely proportional to the square of the distance)
  - Country imports from a specific exporters are taken as proportional to the product of the two countries' GDP and inversely proportional to the square of the distance

Future Shipping Emissions

Emission Projections

- **BAU (Business As Usual)**
  - no adoption of new regulations that have an impact on energy efficiency or carbon intensity
- **Shipping emissions increase from 1,000MtCO_2 in 2018 to 1,000 – 1,500MtCO_2 in 2050**
  - Emissions projected to increase 90% in 2018 and 90 – 130% by 2050 compared to 2008
  - By 2050, increase of 0 – 50% of 2018 levels and 90 – 130% of 2008 levels
  - Increased by transport demand growth in spite of further efficiency improvement

Figure 26 – BAU scenarios GDP growth in line with recent projections, energy transition in line with 2 degrees target

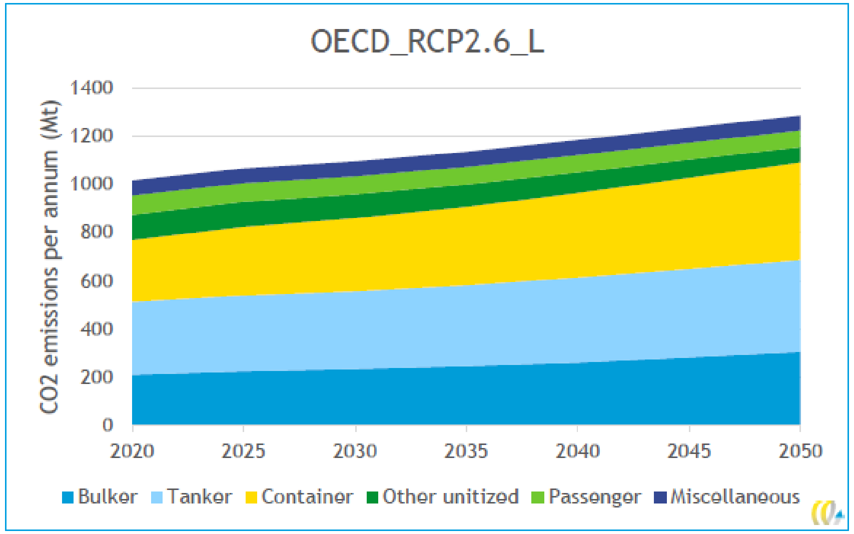


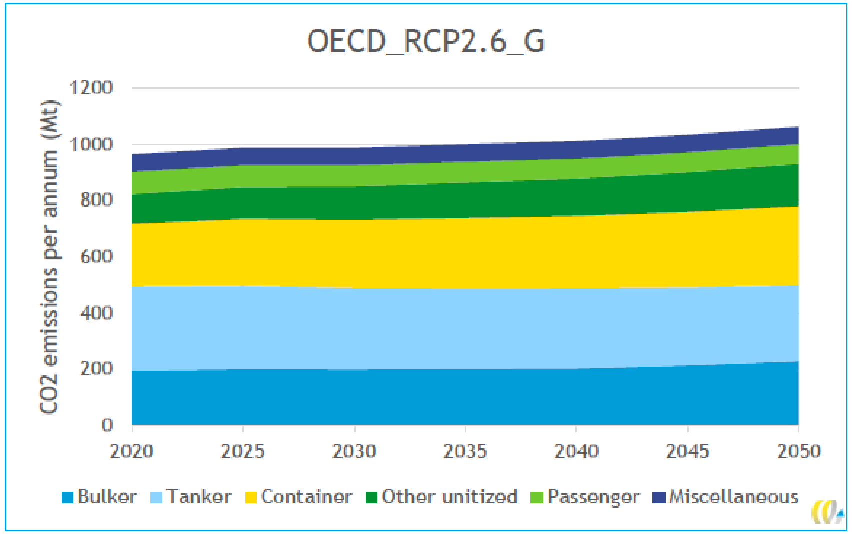
Future Shipping Emissions

Emission Projections per ship types

- **Bulkers increase by 10 – 50%**
  - **Reduction in coal transport is offset by an increase in other dry bulk transport work**
- **Tankers increase by 30% (L) or decrease by 10% (G)**
  - **Chemicals and gas transport increases, even when crude oil transport work decrease**
- **Containers increase by 20 – 70%**
  - **Increase in transport work of 70 – 140% and efficiency by increase in ship sizes**

Figure 170 - Emission projections per ship type





Future Shipping Emissions

Marginal abatement cost curve (MACC)

- Relationship between the total reduction of GHG emissions and the cost efficiency for individual abatement measures
- Assessed abatement potential and costs of 44 technologies
- Methodology : $C_j = K_j + S_j - E_j$
  - C_j : change of annual cost of technology $_j$ (USD/year)
  - K_j : annualized CAPEX (USD/year)
  - S_j : Incremental operating costs related to use of technology (USD/year)
  - E_j : fuel expenditure savings from technology $_j$ (USD/year)

Future Shipping Emissions

Table 75 - Penetration rates of technologies

Category	Group	Technology	Penetration rates (% of ships applying a technology) 2018	Scenario 1 2030	Scenario 1 2050	Scenario 2 2030	Scenario 2 2050
Energy Saving Technologies	Group 1 Main engine improvements	Main Engine Tuning	75.0%	100%	100%	80.0%	100%
		Common-rail	2.0%	56.0%		7.0%	32.0%
		Electronic engine control	1.0%	55.0%		6.0%	31.0%
	Group 2 Auxiliary systems	Frequency converters	12.5%	66.5%	100%	17.5%	42.5%
		Speed control of pumps and fans	50.0%	100%		55.0%	80.0%
	Group 3 Steam plant improvements	Steam plant operation improvements	(75.0%)	(100%)	(100%)	(80.0%)	(100%)
	Group 4 Waste heat recovery	Waste heat recovery	12.5%	66.5%	100%	17.5%	42.5%
		Exhaust gas boilers on auxiliary engines	12.5%	66.5%	100%	17.5%	42.5%
	Group 5 Propeller improvements	Propeller-rudder upgrade	12.5%	66.5%	100%	17.5%	42.5%
		Propeller upgrade (nozzle, tip winglet)					
		Propeller boss cap fins	10.0%	64.0%		15.0%	40.0%
		Contra-rotating propeller	12.5%	66.5%		17.5%	42.5%
	Group 6 Propeller maintenance	Propeller performance monitoring	12.5%	66.5%	100%	17.5%	42.5%
		Propeller polishing	75.0%	100%		80.0%	100%
	Group 7 Air lubrication	Air lubrication	(0.0%)	(100%)	(100%)	(5.0%)	(30%)
	Group 8 Hull coating	Low-friction hull coating	12.5%	66.5%	100%	17.5%	42.5%

Category	Group	Technology	Penetration rates (% of ships applying a technology) 2018	Scenario 1 2030	Scenario 1 2050	Scenario 2 2030	Scenario 2 2050
Energy Saving Technologies	Group 9 Hull maintenance	Hull performance monitoring	12.5%	66.5%	100%	17.5%	42.5%
		Hull brushing					
		Hull hydro-blasting					
		Dry-dock full blast (old ships)	50.0%	100%	100%	55.0%	80.0%
	Group 10 Optimization water flow hull openings	Optimization water flow hull openings	12.5%	66.5%	100%	17.5%	42.5%
	Group 11 Super light ship	Super light ship	(0.0%)	(100%)	(100%)	(5.0%)	(30%)
Renewable Energy	Group 12 Reduced auxiliary power demand	Reduced auxiliary power demand (low energy lighting etc.)	50.0%	100%	100%	55.0%	80%
	Group 13 Wind power	Towing kite	(0.0%)	(100%)	(100%)	(5.0%)	(30%)
		Wind power (fixed sails or wings)					
		Wind engine (Flettner rotor)					
	Group 14 Solar panels	Solar panels	(0.0%)	(100%)	(100%)	(5.0%)	(30%)
Alternative Fuel	Group 15A Use of alternative fuel with carbons	LNG+ICE	1.0%	55.0%	0.0%	1.5%	20.0%
		LNG+FC, Methanol + ICE, Ethanol + ICE	0.0%	54.0%		0.05%	
	Group 15B Use of alternative fuel without carbons	Use of alternative fuel: i.e. Hydrogen, Ammonia and etc.	0.0%	0.1%	100%	0.05%	20.0%
Speed Reduction	Group 16 Speed reduction	Speed reduction by 10%	(0.0%)	(100%)	(100%)	(100%)	(100%)

Future Shipping Emissions

Marginal abatement cost curve (MACC)

Reduction Potentials

- **CO_2 reduction without alternative fuel : 9 – 23% in 2030 and 17 – 36% in 2050**
- **USD -119/tCO_2 < MAC value > USD 105/tCO_2**

*** Solar panels (USD 1,186 in 2030 or USD 1,048 in 2050)**

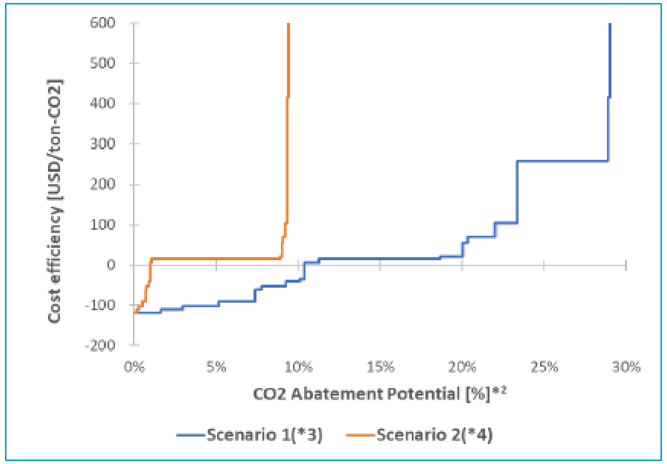
Alternative Fuel with carbon

- **In 2030, 6% of the total CO_2 reduction by alternative fuel with carbon**
- **MAC value > USD 250/tCO_2 for alternative fuel with carbon**

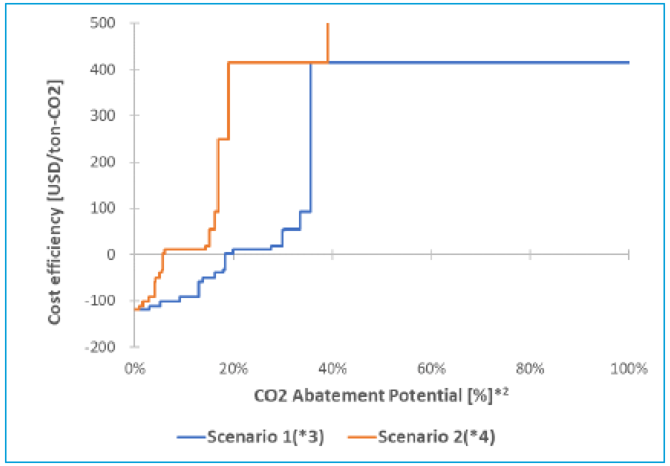
Alternative Fuel with zero-carbon

- **In 2050, 64% of the total CO_2 reduction by alternative fuel without carbon**
- **MAC value > USD 410/tCO_2 for alternative fuel without carbon**

Marginal abatement cost curve for 2030



Marginal abatement cost curve for 2050



Providing the **best services,**
Creating a **better world**

Thank you

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