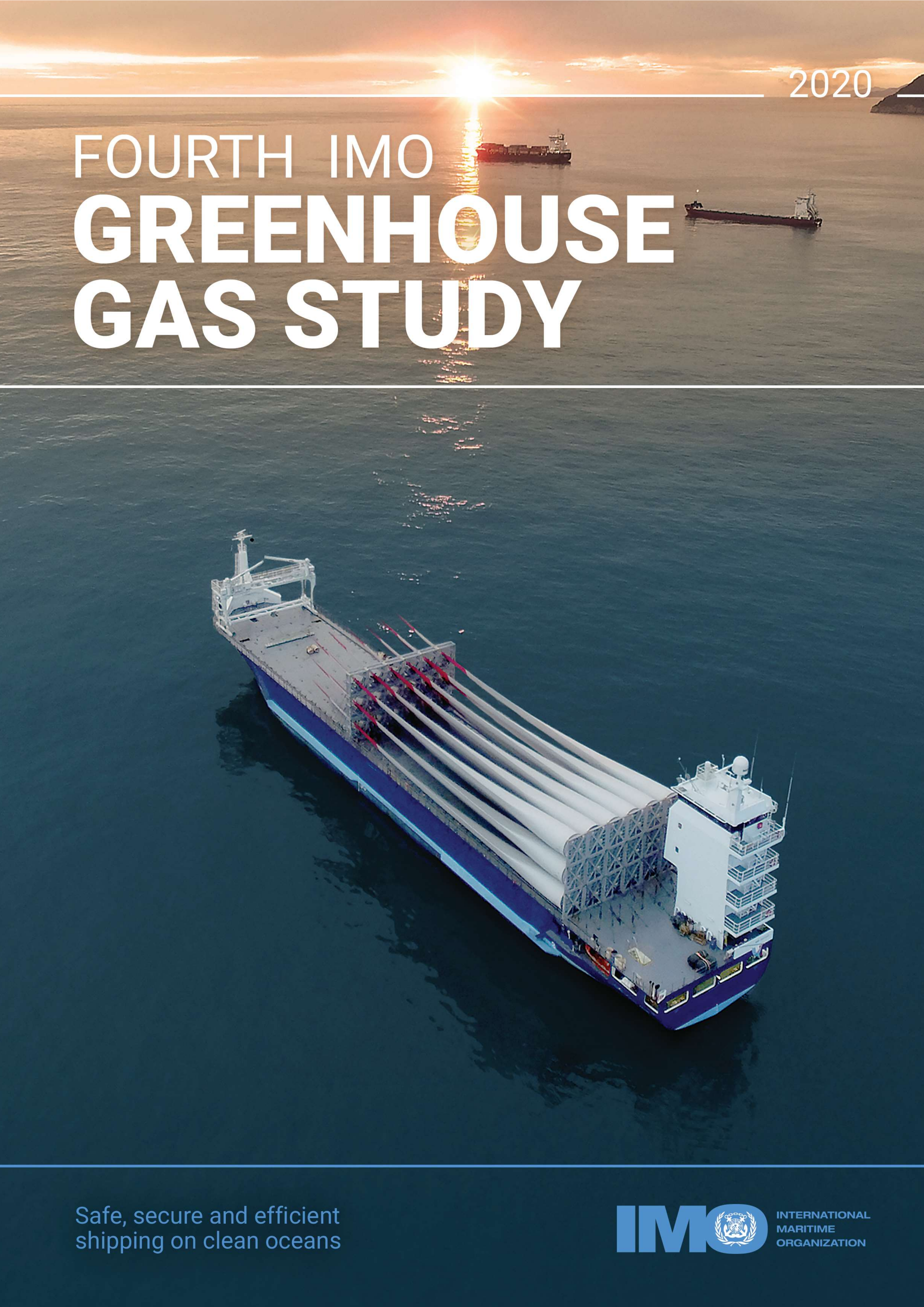

2020

FOURTH IMO
GREENHOUSE GAS STUDY

Safe, secure and efficient
shipping on clean oceans

INTERNATIONAL
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Fourth IMO GHG Study 2020

Executive Summary

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Further information on this study can be obtained from the contact person Jasper Faber (CE Delft).

Foreword by the Secretary-General, Mr. Kitack Lim

The *Fourth IMO GHG Study 2020* is the first IMO greenhouse gas study published since the adoption in April 2018 of the *Initial IMO Strategy on reduction of GHG emissions from ships*. This landmark strategy is aimed at enhancing IMO's contribution to global efforts to combat climate change by addressing GHG emissions from international shipping.

The Initial Strategy provides the high-level international policy framework setting out a clear pathway to reduce GHG emissions from ships; envisages to phase out GHG emissions from international shipping as soon as possible in this century; and also identifies levels of ambition related to a 2008 emission baseline: reduce CO_2 emissions per transport work (carbon intensity) by at least 40% by 2030 and reduce the total annual GHG emissions by at least 50% by 2050.

The most recent estimates included in this *Fourth IMO GHG Study 2020* show that GHG emissions of total shipping have increased from 977 million tonnes in 2012 to 1,076 million tonnes in 2018 (9.6% increase) mostly due to a continuous increase of global maritime trade. The share of shipping emissions in global anthropogenic GHG emissions has increased from 2.76% in 2012 to 2.89% in 2018.

For the first time, the *Fourth IMO GHG Study 2020* includes estimates of carbon intensity, and outlines that overall carbon intensity, as an average across international shipping, was approximately 20 to 30% better in 2018 than in 2008 (baseline year in the Initial Strategy).

Based on various long-term economic and energy scenarios (not taking into account long-term effects of the COVID-19 pandemic), and without any additional measures, the Study describes that shipping emissions are projected to increase from about 90% of 2008 emissions in 2018 to 90-130% of 2008 emissions by 2050.

The Study demonstrates that whilst further improvement of the carbon intensity of shipping can be achieved, it will be difficult to achieve IMO's 2050 GHG reduction ambition only through energy-saving technologies and speed reduction of ships. Therefore, under all projected scenarios, in 2050, a large share of the total amount of CO_2 reduction will have to come from the use of low-carbon alternative fuels.

I am convinced that IMO is best placed to continue to develop a robust international regulatory framework for shipping that will enable the global uptake of alternative low-carbon and zero-carbon fuels.

When MEPC 75 approved the Study in November 2019, many delegations commended the scientific quality of the *Fourth IMO GHG Study 2020*, delivered by the international consortium of world-renowned experts under the auspices of IMO, which will greatly assist IMO in evidence-based decision making on further GHG reduction measures.

I extend my thanks to the thirteen members of the Steering Committee of IMO Member States for their dedication and support in overseeing this important Study, that is, Belgium, Brazil, Canada, China, Denmark, Japan, Liberia, the Netherlands, Norway, Panama, Republic of Korea, Singapore, Turkey and United States, supported by experts from twelve different countries undertaking an external review of quality assurance and quality control (QA/QC) issues. I would also like to express my profound appreciation to the Governments of Australia, Canada, Denmark, France, Japan, the Netherlands, Norway, the Republic of Korea, the United Arab Emirates and the United Kingdom for their financial contributions, without which the Study would not have been possible.

The decarbonization of shipping is one of the biggest challenges faced by shipping industry, and I trust that the *Fourth IMO GHG Study 2020* will constitute a solid scientific reference to those supporting this effort, in particular IMO's Marine Environment Protection Committee, but also industry, research institutions and all other stakeholders involved in this voyage together with IMO.

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List of abbreviations and definitions

AB	Auxiliary Boiler
AE	Auxiliary Engine
AER	Annual Efficiency Ratio in gram CO_2/Dwt/nm)
AFFF	Aqueous Film Forming Foam
AIS	Automatic Identification System
ALB	Available Lower Berth
BAU	Business As Usual
BC	Black Carbon
BOG	Boil Off Gas
BU	Bottom-Up
CAPEX	Capital Expenditures
CBM	Cubic Metre
CCS	Carbon Capture and Storage
cDIST	Cargo-distance, an efficiency metric similar to the AER in which the capacity can be expressed in TEU, cubic metre or other relevant parameters appropriate for certain ship types, in gram CO_2/capacity/nm
CF	Correction Factor
CH_4	Methane
CII	Carbon Intensity Indicator
CMD	Continuous Monitoring Dataset
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DIST	CO_2 emissions per distance travelled, in kilogram CO_2/nautical mile
DWT	Deadweight Tonnage
EC	European Commission
ECA	Emission Control Area
EEA	European Environment Agency
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator in gram CO_2/tonne cargo/nm
EEPI	Energy Efficiency Performance Indicator
EF_e	Energy-Based Emission Factors
EF_f	Fuel-Based Emission Factors
EGR	Exhaust Gas Recirculation
EIV	Estimated Index Value
EU MRV	EU Monitoring, Reporting and Verification of CO_2 emissions

FOC	Fuel Oil Consumption
FSN	Filter Smoke Number
GDP	Gross Domestic Product
GFW	Global Fishing Watch
GHG	Greenhouse Gas
GPS	Global Positioning System
GT	Gross Tonnes
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Heavy Fuel Oil
HSD	High-Speed Diesel
ICE	Internal Combustion Engine
IEA	International Energy Agency
IHS	Information Handling Services
IHSF	IHS Fairplay (a data provider)
IMO	International Maritime Organization
IMO DCS	IMO Data collection system
IMO3	Third IMO GHG Study 2014
IMO4	Fourth IMO GHG Study (this study)
IPCC	Intergovernmental Panel on Climate Change
kt	Kilo Tonnes
ktoe	Kilo Tonnes of Oil Equivalent
kW	Kilo Watt
kWh	Kilo Watt-hour
LBSI	Lean Burn Spark-Ignited
LLF	Low Load Factor
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LSHFO	Low Sulfur Heavy Fuel Oil
MACC	Marginal Abatement Cost Curve
MAE	Mean Absolute Error
MCR	Maximum Continuous Rating
MDO	Marine Diesel Oil
ME	Main Engine
MEPC	Marine Environment Protection Committee
MGO	Marine Gas Oil
MMSI	Maritime Mobile Service Identity
MS	Medium-Speed
MSD	Medium-Speed Diesel
N_2O	Nitrous Oxide
NECA	NO_x Emission Control Area
NF_3	Nitrogen Trifluoride

NG	Natural Gas
nm	Nautical Mile
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
OPEX	Operational Expenditures
pax	Passengers
PFC	Perfluorocarbon
PM	Particulate matter
QA	Quality Assurance
QC	Quality Control
RCP	Representative Concentration Pathway
ro-pax	Roll-On/Roll-Off/Passengers
Ro-Ro	Roll-On/Roll-Off
RPM	Revolutions Per Minute
SCR	Selective Catalytic Reduction
SECA	SO_x Emission Control Area
SEEMP	Ship Energy Efficiency Management Plan
SF_6	Sulfur Hexafluoride
SFC	Specific Fuel Consumption
SOG	Speed Over Ground
SOLAS convention	International Convention for the Safety of Life at Sea
SO_x	Sulfur Oxides
SS	Slow-Speed
SSD	Slow-Speed Diesel
SSP	Shared Socio-Economic Pathway
STEAM	Ship Traffic Emission Assessment Model
TEU	Twenty-foot Equivalent Units
TIME	CO_2 emissions per hour underway, in tonne CO_2/hour
UMAS	University Maritime Advisory Services
UNCTAD	United Nations Conference on Trade and Development
UNFCCC	United Nations Framework Convention on Climate Change
UNSD	United Nations Statistics Division
USD	US Dollar
VBP	Vessel Boarding Program
VLSFO	Very Low Sulphur Fuel Oil
VOC	Volatile Organic Compounds
WERS	Waste Energy Recovery Systems
WHB	Waste Heat Boiler
WTO	World Trade Organization

Acknowledgements

The consortium thanks the Steering Committee and the expert reviewers of the *Fourth IMO Greenhouse Gas Study 2020* for their helpful review and comments. The consortium acknowledges and thanks the following organizations for their invaluable data contributions to this study: BIMCO, exactEarth, the International Energy Agency (IEA), IHS Maritime, Maersk, Stockholm Environment Institute and the World Shipping Council. In the course of its efforts, the consortium gratefully received input and comments from Bruce Anderson, Alastair Sim, Carlos Gonzalez Gutierrez, Yigit Demariel, Archana Agrawal, Dorte Kubel, and Peter H. Kirkeby.

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Highlights and Executive Summary of the Fourth IMO GHG Study 2020

Highlights

Emissions inventory

- The greenhouse gas (GHG) emissions — including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), expressed in CO_2e — of total shipping (international, domestic and fishing) have increased from 977 million tonnes in 2012 to 1,076 million tonnes in 2018 (9.6% increase). In 2012, 962 million tonnes were CO_2 emissions, while in 2018 this amount grew 9.3% to 1,056 million tonnes of CO_2 emissions
- The share of shipping emissions in global anthropogenic emissions has increased from 2.76% in 2012 to 2.89% in 2018.
- Under a new voyage-based allocation of international shipping, CO_2 emissions have also increased over this same period from 701 million tonnes in 2012 to 740 million tonnes in 2018 (5.6% increase), but to a lower growth rate than total shipping emissions, and represent an approximately constant share of global CO_2 emissions over this period (approximately 2%), as shown in Table 1. Using the vessel-based allocation of international shipping taken from the Third IMO GHG Study, CO_2 emissions have increased over the period from 848 million tonnes in 2012 to 919 million tonnes in 2018 (8.4% increase).
- Due to developments in data and inventory methods, this study is the first IMO GHG Study able to produce greenhouse gas inventories that distinguish domestic shipping from international emissions on a voyage basis in a way which, according to the consortium, is exactly consistent with the IPCC guidelines and definitions.[1]
- Projecting the same method to 2008 emissions, this study estimates that 2008 international shipping GHG emissions (in CO_2e) were 794 million tonnes (employing the method used in the Third IMO GHG Study, the emissions were 940 million tonnes CO_2e).

Carbon intensity 2008, 2012 – 2018

- Carbon intensity has improved between 2012 and 2018 for international shipping as a whole, as well as for most ship types. The overall carbon intensity, as an average across international shipping, was 21 and 29% better than in 2008, measured in AER and EEOI respectively in the voyage-based allocation; while it was 22 respectively 32% better in the vessel-based allocation (Table 2). Improvements in carbon intensity of international shipping have not followed a linear pathway and more than half have been achieved before 2012. The pace of carbon intensity reduction has slowed since 2015, with average annual percentage changes ranging from 1 to 2%.
- Annual carbon intensity performance of individual ships fluctuated over years. The upper and lower quartiles of fluctuation rates in EEOI of oil tankers, bulk carriers and container ships were around ±20%, ±15% and ±10% respectively. Quartiles of fluctuation rates in other metrics were relatively modest, yet still generally reaching beyond ±5%. Due to certain static assumptions on weather and hull fouling conditions, as well as the non-timely updated AIS entries on draught, actual fluctuations were possibly more scattered than estimated, especially for container ships.

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[1] The choice of the method to distinguish domestic shipping emissions from international shipping emissions does not interpret existing IMO instruments, nor prejudge any future policy developments at IMO and would not constitute IMO's views on the interpretation of the 2006 IPCC Guidelines on national greenhouse gas inventories.

Table 1 – *Total shipping and voyage-based and vessel-based international shipping CO_2 emissions 2012-2018 (million tonnes)*

Year	Global anthropogenic CO_2 emissions	Total shipping CO^2	Total shipping as a percentage of global	Voyage-based International shipping CO_2	Voyage-based International shipping as a percentage of global	Vessel-based International shipping CO_2	Vessel-based International shipping as a percentage 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%

Table 2 – *Estimates on carbon intensity of international shipping and percentage changes compared to 2008 values*

Year	EEOI ($gCO_2/t/nm$)				AER ($gCO_2/dwt/nm$)				DIST ($kgCO_2/nm$)				TIME (tCO_2/hr)			
	Vessel-based		Voyage-based		Vessel-based		Voyage-based		Vessel-based		Voyage-based		Vessel-based		Voyage-based	
	Value	Change	Value	Change	Value	Change	Value	Change	Value	Change	Value	Change	Value	Change	Value	Change
2008	17.10	—	15.16	—	8.08	—	7.40	—	306.46	—	350.36	—	3.64	—	4.38	—
2012	13.16	-23.1%	12.19	-19.6%	7.06	-12.7%	6.61	-10.7%	362.65	18.3%	387.01	10.5%	4.32	18.6%	4.74	8.1%
2013	12.87	-24.7%	11.83	-22.0%	6.89	-14.8%	6.40	-13.5%	357.73	16.7%	380.68	8.7%	4.18	14.6%	4.57	4.1%
2014	12.34	-27.9%	11.29	-25.6%	6.71	-16.9%	6.20	-16.1%	360.44	17.6%	382.09	9.1%	4.17	14.4%	4.54	3.5%
2015	12.33	-27.9%	11.30	-25.5%	6.64	-17.8%	6.15	-16.9%	366.56	19.6%	388.62	10.9%	4.25	16.6%	4.64	5.7%
2016	12.22	-28.6%	11.21	-26.1%	6.58	-18.6%	6.09	-17.7%	373.46	21.9%	397.05	13.3%	4.35	19.3%	4.77	8.7%
2017	11.87	-30.6%	10.88	-28.2%	6.43	-20.4%	5.96	-19.5%	370.97	21.0%	399.38	14.0%	4.31	18.2%	4.79	9.2%
2018	11.67	-31.8%	10.70	-29.4%	6.31	-22.0%	5.84	-21.0%	376.81	23.0%	401.91	14.7%	4.34	19.1%	4.79	9.2%

Emission projections 2018 – 2050

- Emissions are projected to increase from about 90% of 2008 emissions in 2018 to 90-130% of 2008 emissions by 2050 for a range of plausible long-term economic and energy scenarios (Figure 1).
- Emissions could be higher (lower) than projected when economic growth rates are higher (lower) than assumed here or when the reduction in GHG emissions from land-based sectors is less (more) than would be required to limit the global temperature increase to well below 2 degrees centigrade.
- Although it is too early to assess the impact of COVID-19 on emission projections quantitatively, it is clear that emissions in 2020 and 2021 will be significantly lower. Depending on the recovery trajectory, emissions over the next decades may be a few percent lower than projected, at most. In all, the impact of COVID-19 is likely to be smaller than the uncertainty range of the presented scenarios.

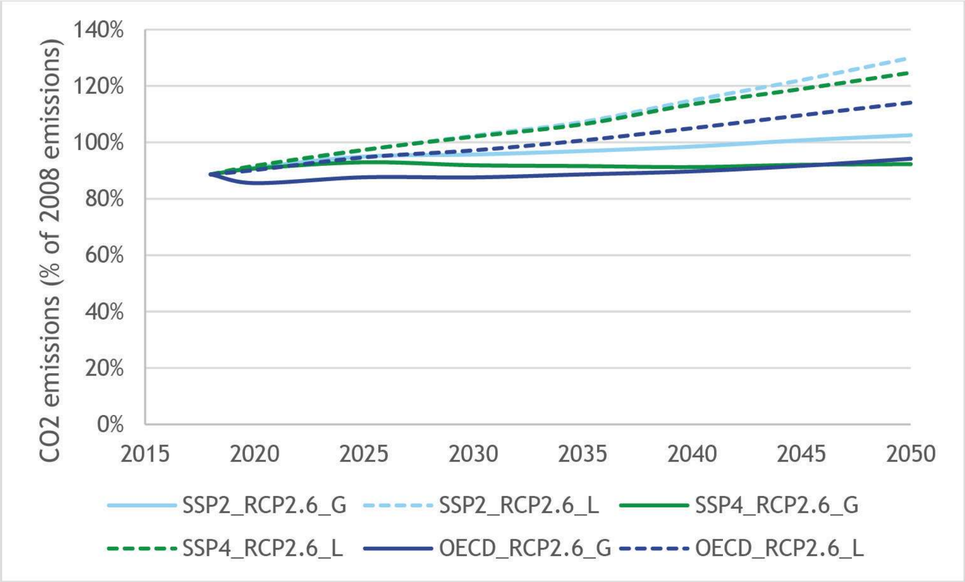

Figure 1 – *Projections of maritime ship emissions as a percentage of 2008 emissions*

Executive Summary

Inventory of GHG Emissions from International Shipping 2012-2018

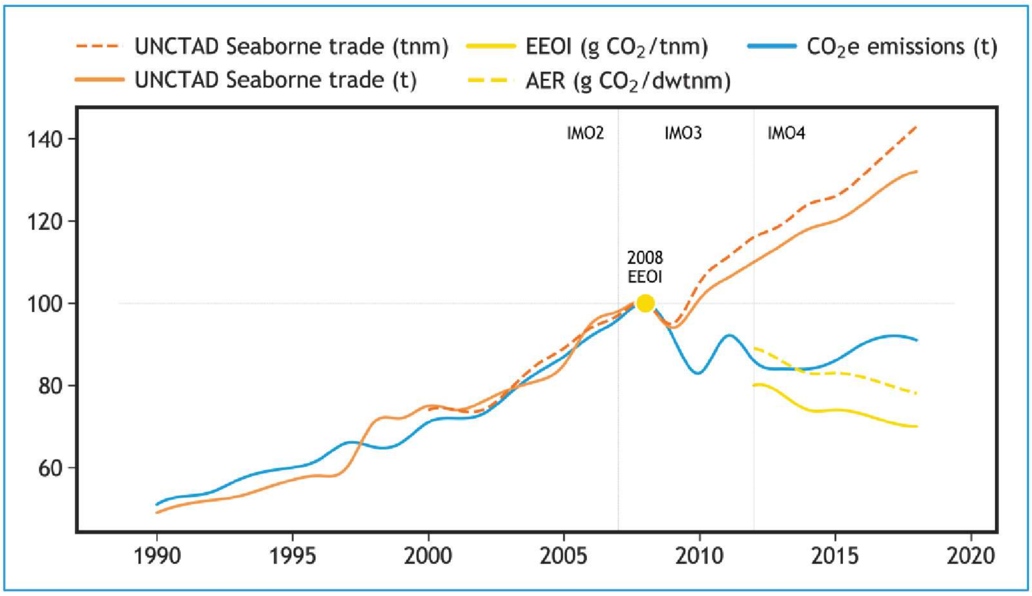

Figure 2 – *International shipping emissions and trade metrics, indexed in 2008, for the period 1990-2018, according to the voyage-based allocation[1] of international emissions[2]*

Figure 2 presents emissions, trade and carbon intensity trends as estimated across this Study and the two previous IMO GHG studies. Against a long-run backdrop of steadily increasing demand for shipping (growth in seaborne trade), the three studies approximately align with three discrete periods for international shipping's GHG emissions:

1 1990 to 2008 – emissions growth (CO_2e) and emissions tightly coupled to growth in seaborne trade (UNCTAD).

2 2008 to 2014 – emissions reduction (CO_2e) in spite of growth in demand (UNCTAD), and therefore a period of rapid carbon intensity reduction (EEOI and AER) that enabled decoupling of emissions from growth in transport demand.

3 2014 to 2018 – a period of continued but more moderate improvement in carbon intensity (EEOI and AER), but at a rate slower than the growth in demand (UNCTAD). And therefore, a return to a trend of growth in emissions (CO_2e).

This Study is the first IMO GHG Study able to produce GHG inventories that distinguish domestic shipping from international emissions, following a method that is exactly consistent with the IPCC guidelines and definitions in the view of the consortium. The method is enabled by advances in the use of AIS data to identify port calls which allows allocation of discrete voyages to a definition of either international or domestic shipping.

The improved split is reliable and provides a valuable advancement to the accurate assessment of international shipping's emissions, in line with the instruction of the Study's terms of reference:

> "…The Fourth IMO GHG Study should further develop clear and unambiguous definitions and refine methods for differentiation between domestic and international voyages with the aim to exclude domestic voyage from the inventory for 'international shipping'".

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[1] Voyage-based allocation defines international emissions as those which occurred on a voyage between two ports in different countries, whereas the alternative 'vessel-based' allocation defines emissions according to ship types, as per the Third GHG Study 2014.

[2] Vessel-based allocation of international emissions produces the same trends but different absolute values.

The Third IMO GHG Study used a different method for distinguishing the international and domestic GHG inventories, instead using the ship type and size characteristics to group ships which were assumed to be operating either as domestic or international shipping. This method relies on assumptions and uniform behaviour within fleets of similar ship types and size, which this Study's more detailed analysis shows to have shortcomings. However, in order to enable comparison with the Third IMO GHG Study and continued use to understand trends, wherever possible the results from both of these methods are included. The method as used in the Third IMO GHG Study is referred to as vessel-based (Option 1), the new method is referred to as voyage-based (Option 2).

For the avoidance of doubt, where results for international shipping using only one method are presented, this choice is not interpreting existing IMO instruments, does not prejudge any future policy developments at IMO and does not constitute IMO's views on the interpretation of the 2006 IPCC Guidelines on national greenhouse gas inventories.

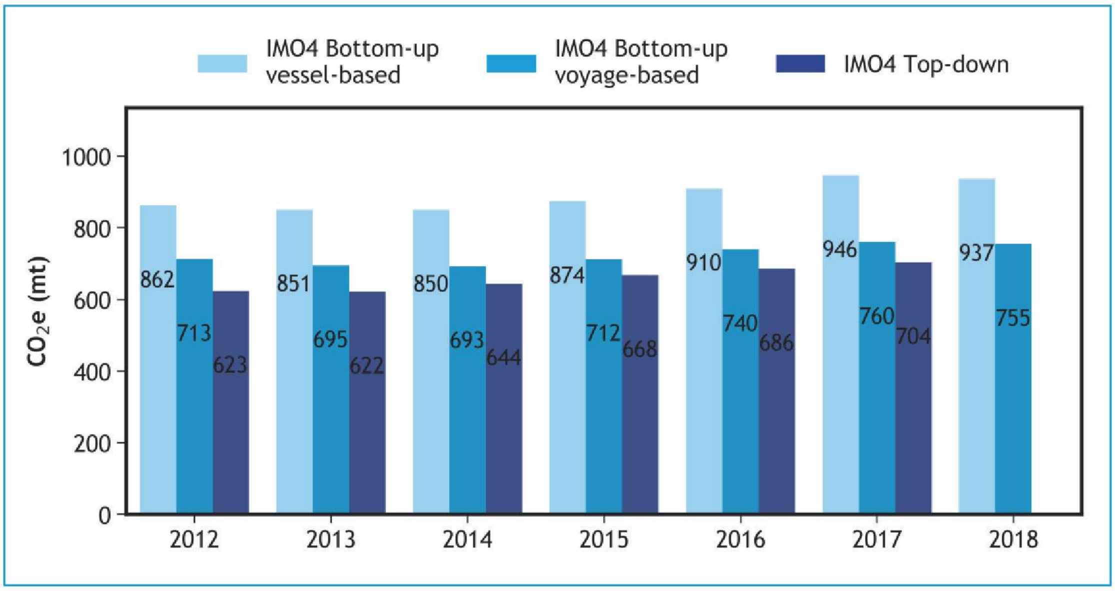

Figure 3 – *Annual greenhouse gas emissions (in CO_2e) for international shipping, according to the vessel-based and voyage-based allocation of international emissions (excluding black carbon (BC) emissions). Both the bottom-up emissions estimates, using ship activity data, as well as the top-down emissions estimates, using fuel sales statistics, are shown.*

Source: UMAS.

Figure 3 (all GHG emissions in CO_2e, excluding black carbon (BC)) presents the detailed results for the inventory of international shipping emissions for the period of this Study (2012-2018), considering the CO_2e impact of N_2O and CH_4. Over the period, bottom-up international shipping CO_2-equivalent emissions increased by 5.7 and 8.3% by voyage-based and vessel-based allocation, respectively.[1] Including BC, represented with a global warming potential (GWP) of 900, the voyage-based international GHG emissions for shipping in 2018 would be 7% higher, totalling 810 million tonnes CO_2e.

Consistent with the Third IMO GHG Study, CO_2 remains the dominant source of shipping's climate impact when calculated on a GWP-100 year basis, accounting for 98%, or 91% if BC is included, of total international GHG emissions (in CO_2e).

Insights into the composition and drivers for these high-level results and aggregate trends can be formed from the disaggregated data. To simplify presentation, only the voyage-based allocation of international shipping is used here. The vessel-based allocation produces the same insights, albeit with small differences in absolute values. Figure 4 presents the estimated fuel consumption break down across ship types, for each

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[1] Voyage-based allocation defines international emissions as those which occurred on a voyage between two ports in different countries, whereas the alternative "vessel-based" allocation defines emissions according to ship types, as per the Third GHG Study 2014.

year 2012-2018. Over the period of study, three ship types remain the dominant source of international shipping's GHG emissions: container shipping, bulk carriers and oil tankers. In combination with chemical tankers, general cargo ships and liquefied gas tankers, these ship types constitute 86.5% of international shipping's total emissions when calculated on a voyage-based allocation.

Heavy fuel oil (HFO) remains the dominant fuel in international shipping (79% of total fuel consumption by energy content in 2018, by voyage-based allocation). However, during the period of the study, a significant change in the fuel mix has occurred. The proportion of HFO consumption has reduced by approximately 7% (an absolute reduction of 3%), while the share of marine diesel oil (MDO) and liquid nitrogen gas (LNG) consumption grew by 6 and 0.9% (absolute increases of 51 and 26%, respectively). Methanol's use as a fuel developed during this period and is estimated as the fourth most significant fuel used growing to approximately 130,000 tonnes of consumption in 2018 on voyage-based international routes (160,000 tonnes of total consumption).

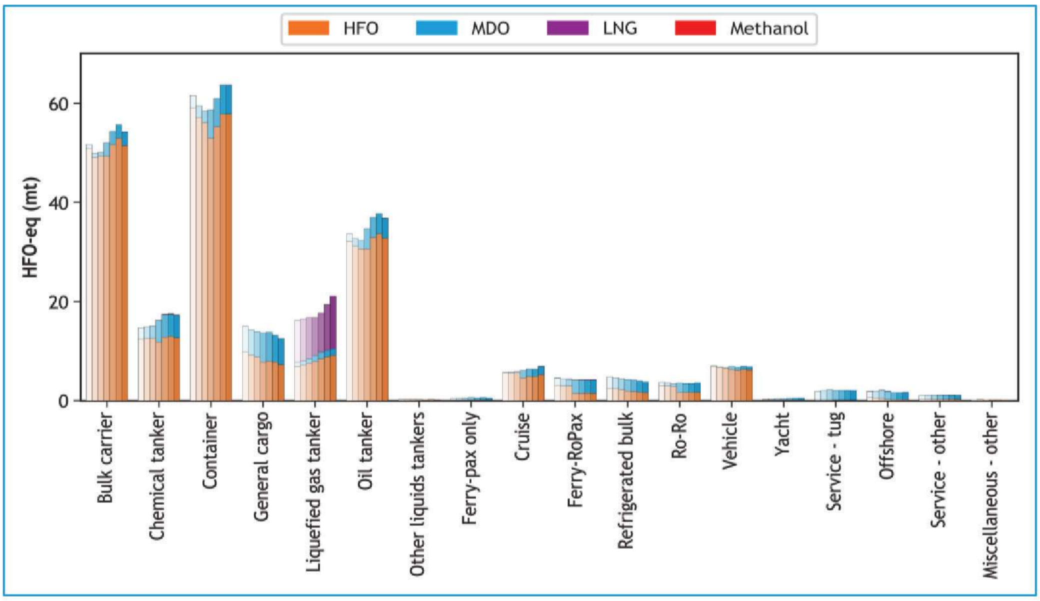


Figure 4 – *International HFO-equivalent fuel consumption per ship type, according to the voyage-based allocation of international emissions*

Voyage-based allocation defines international emissions as those which occurred on a voyage between two ports in different countries, whereas the alternative "vessel-based" allocation defines emissions according to ship types, as per the Third GHG Study 2014.

Figure 5 presents the estimated fuel consumption across onboard machinery with broadly different end uses (main engines – propulsion, auxiliary engines – electrical power and boilers – heat). The results are similar to equivalent estimations in earlier GHG studies.

Consistent with the Third IMO GHG Study, energy use for propulsion remains the primary demand for energy across all ship types, albeit that for some ship types (cruise ships, refrigerated bulk and miscellaneous fishing) total propulsion energy demand is approximately equivalent to total auxiliary and heat energy demand.

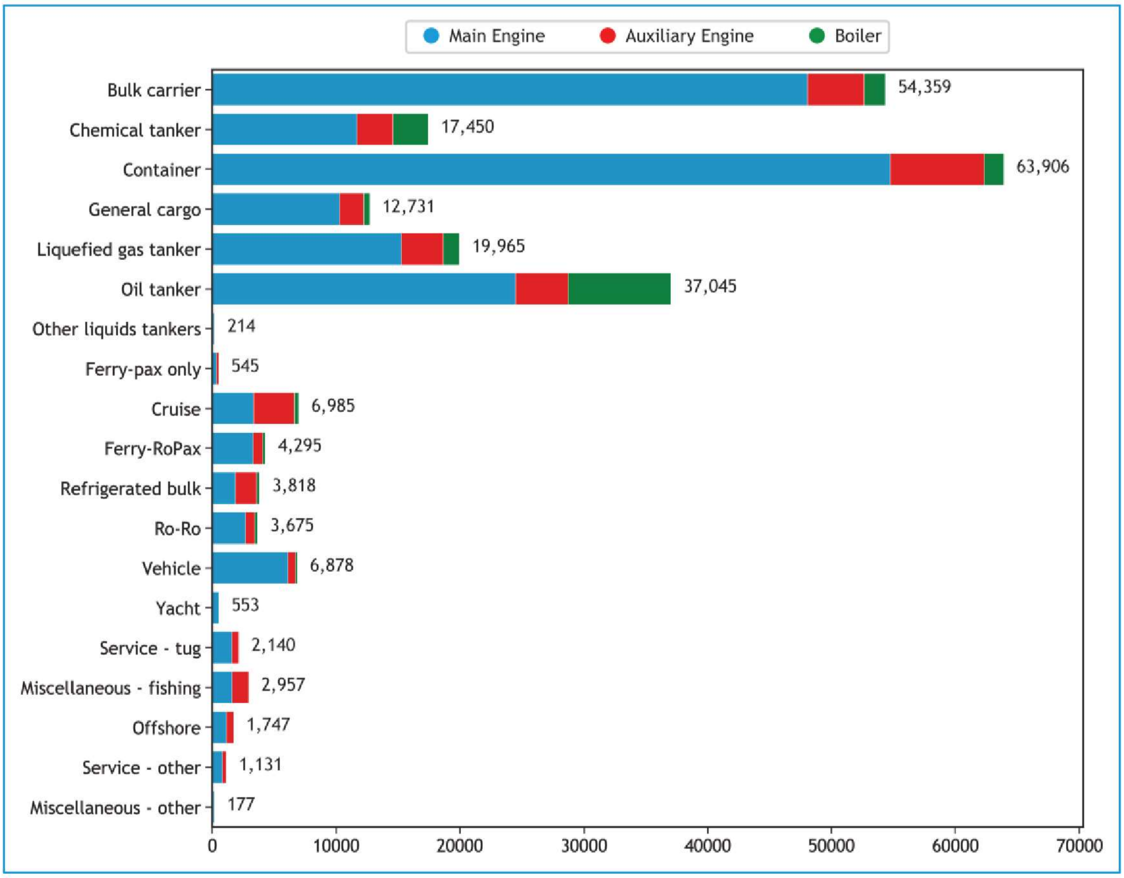


Figure 5 – *International, voyage-based allocation, HFO-equivalent fuel consumption (thousand tonnes), 2018, split by main engine, auxiliary engine and boiler. Highlighted values are in thousand tonnes*

Source: UMAS.

Figure 6 presents the breakdown of GHG emissions across different phases of operation for each ship type. Depending on the ship type, there are differences in the share of emissions that occur at sea on passage, as opposed to during a manoeuvring, anchorage or berthed phase of operation. Of the six ship types most important to the emissions inventories, chemical tankers and oil tankers have on average the largest portion of their total emissions (greater than 20%) associated with phases at or near the port or terminal.

Container ships, cruise ships and oil tankers have the smallest share of their total emissions associated with cruising (definition) due to dominance of time spent slow cruising and/or phases at or near port, with liquefied gas tankers and other liquid tankers showing the largest share of their emissions associated with cruising.

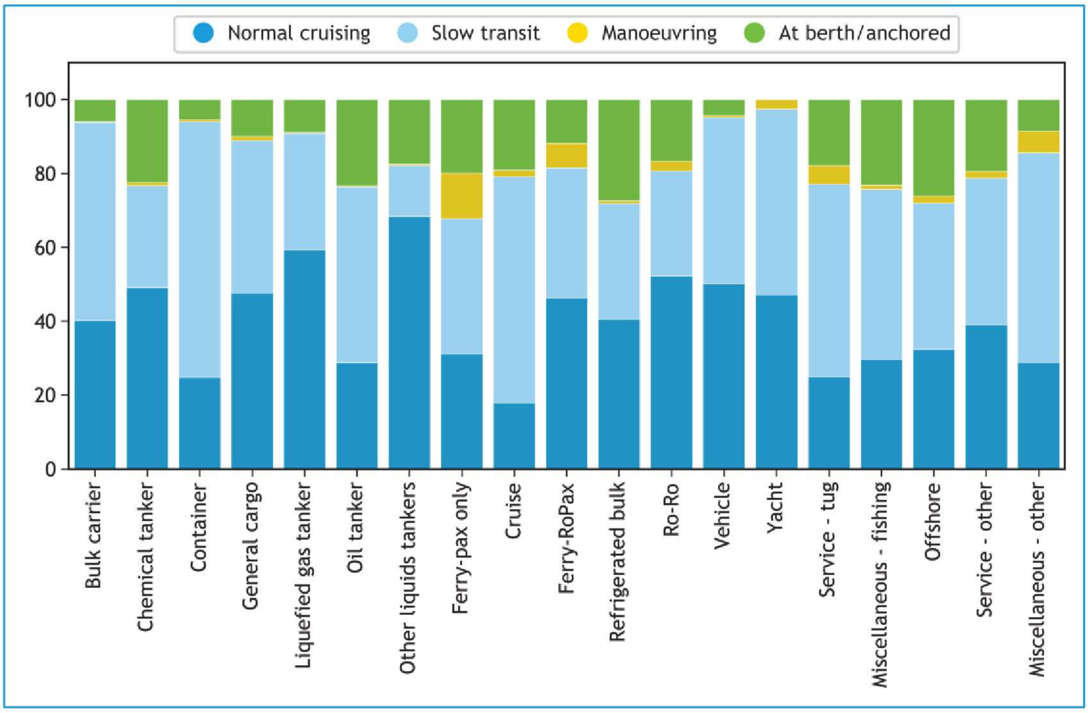


Figure 6 – *Proportion of international GHG emissions (in CO_2e) by operational phase in 2018, according to the voyage-based allocation of emissions. Operational phases are assigned based on the vessel's speed over ground, distance from coast/port and main engine load (see Table 16)*

Source: UMAS.

Explanations for some of the trends observed over the period can be obtained from the underlying information used to produce the emissions inventories. Figure 7 presents the breakdown of a number of parameters that can further explain the results, and Figure 8 shows trends in average operating speed across the three ship types that dominate the inventory of international shipping emissions (size bins as defined in section 2.2.1).

Trends also observed in the Third IMO GHG Study have continued. Average ship sizes across these three ship types have increased, as has the average installed power. For each of these three ship types, the average ship's fuel consumption has increased over the period, but at a lower rate than the increase in average installed power. This decoupling in the rate of increase in installed power and fuel consumption is the consequence of a general trend of continued reduction in operating speeds (also observed in the Third IMO GHG Study), and continued reductions in the average number of days at sea.

The reduction in operating speeds was not a constant decline for all ship types over the period, with oil tankers and containers seeing increases in average speeds during 2015 and 2016 relative to other years during the period of study. For some of the ship size categories, the increase in speed was temporary and by 2018 average speeds were similar to minimum values over the period. Across the period of the Study, 2015 and 2016 account for the highest rate of total CO_2 emissions growth. This shows that operating speeds remain a key driver of trends in emissions and rate of emissions growth, and are currently susceptible to fluctuating market forces and behaviour trends (e.g. they are not fixed or constrained by the technical or design specifications of the fleet).

This Study's results of continuations of these trends suggest that there has been a further reduction of productivity of the fleet in this period. This in turn means that in 2018, relative to 2012, there is an increased risk of a rapid increase in emissions should the latent emissions in the fleet be realized. This builds further upon a similar finding from the Third IMO GHG Study which noted that the fleet in 2012:

> "…is currently at or near the historic low in terms of productivity (transport work per unit of capacity)…" and that "…these (and many other) sectors of the shipping industry represent latent emissions increases, because the fundamentals (number of ships in service) have seen upwards trends that have been offset as economic pressures act to reduce productivity (which in turn reduces emissions intensity)".

As concluded in the Third IMO GHG Study whether and when the latent emissions increase appears is uncertain and depends on the future market dynamics of the industry. Under certain market conditions, operating speeds could increase again and the associated increases in average fuel consumption and emissions in 2015 and 2016 could return. If their return is sustained, some or all of the reductions in carbon intensity achieved to date can be reversed.

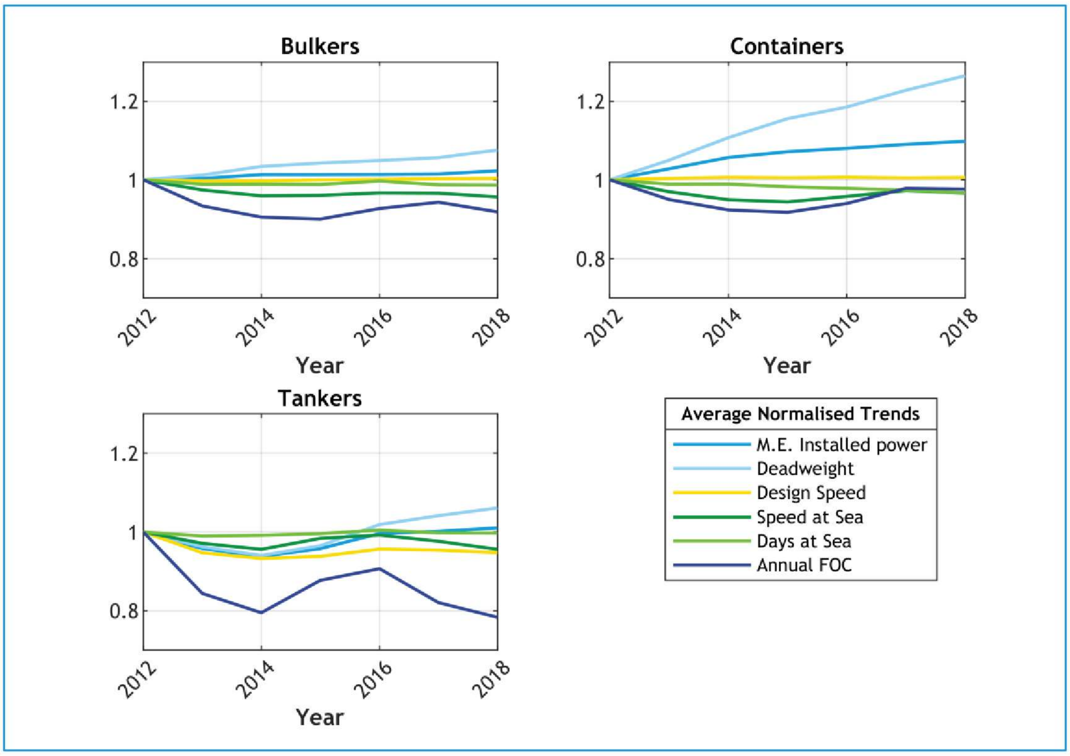


Figure 7 – *Trends for average ships for the three most high emitting fleets over the period 2012 to 2018, where fuel consumption represents international activity according to voyage-based allocation*

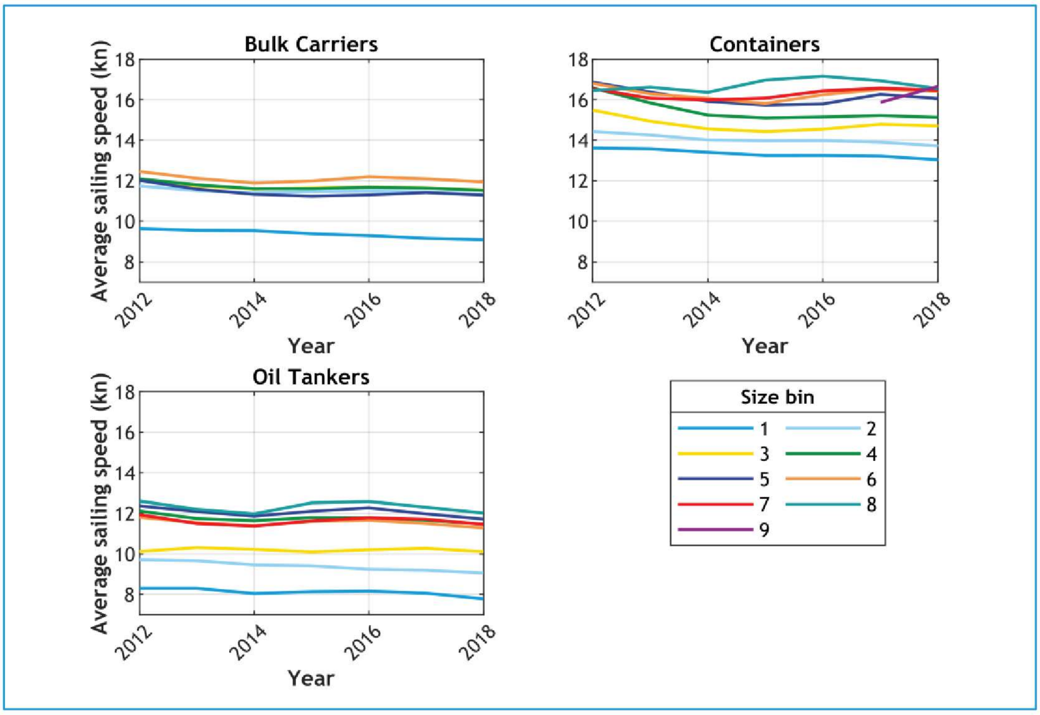


Figure 8 – *Speed trends for the three highest emitting fleets aggregated (top left) and broken down for each ship type's size categories, which can be found in Section 2.2.1*

Figure 9 presents the trends in a number of emissions species, both GHG and air pollutants.

The majority of these trends follow the trend in total fuel consumption over the period. Important details include:

- CH_4 trend saw an 87% increase over the period, which was driven by both an increase in consumption of LNG but the absolute increase is dominated by a change in the machinery mix associated with the use of LNG as a fuel, with a significant increase in the use of dual-fuel machinery that has higher specific exhaust emissions of CH_4.
- SO_X and PM emissions increased over the period in spite of an overall reduction in HFO use and increase in MDO and LNG use (partly driven by the entry into force in 2015 of a number of Emission Control Areas associated with limits on sulfur content of fuels). The explanation is that the average sulfur content increase in HFO over the period exceeds the sulfur content reduction associated with the change in fuel use.
- NO_X emissions saw lower rates of increase over the period than the trend in fuel consumption. This is consistent with the increased number of ships fitted with, and where appropriate operating with, NO_X Tier II and Tier III compliant machinery. In spite of these regulations, the overall trend in NO_X emissions was an increase over the period.

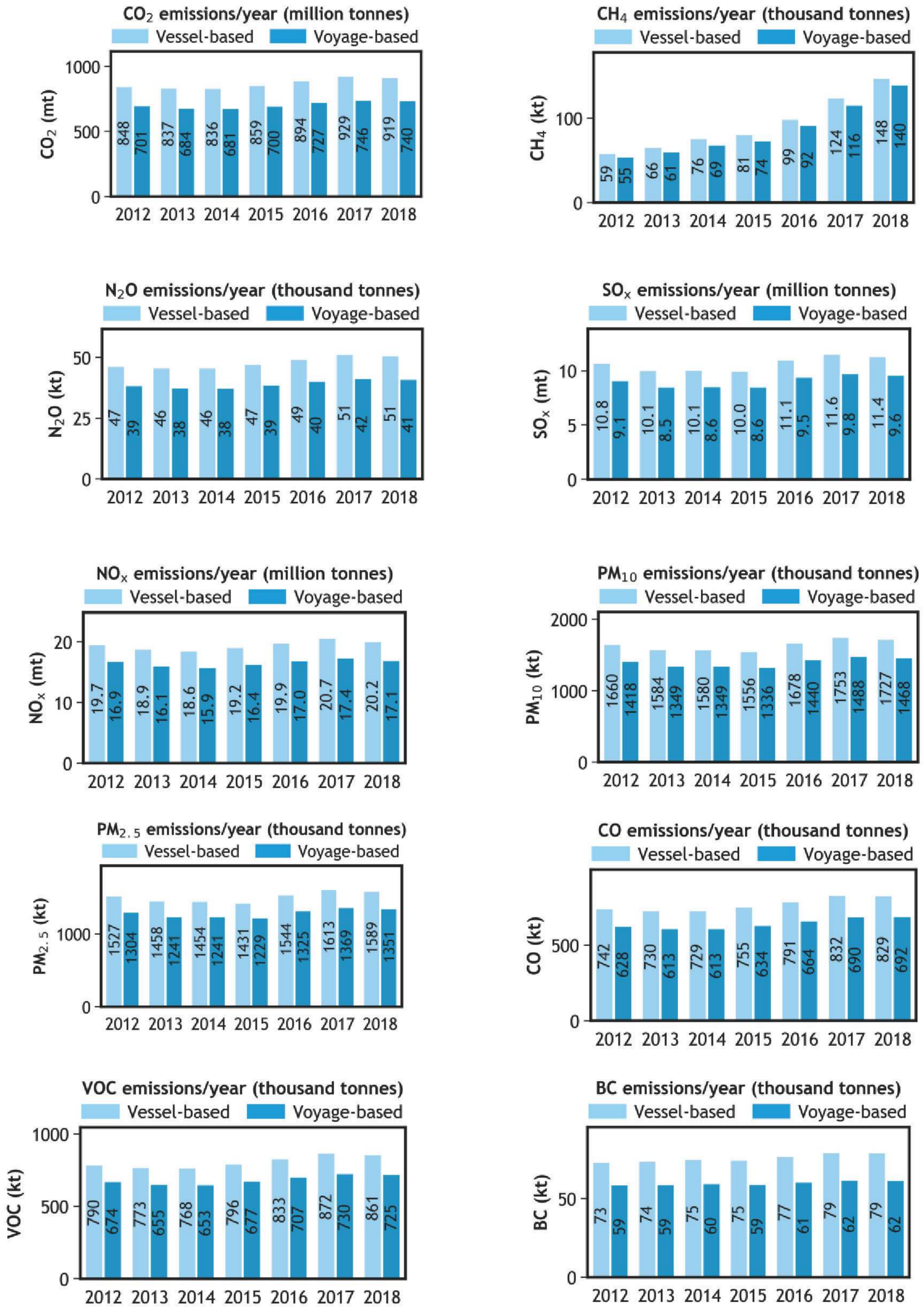


Figure 9 – *Emissions species trends, all species 2012-2018, showing both the estimates for voyage-based and vessel-based international shipping emissions*

Split between domestic and international shipping

This Study deploys a new method to produce GHG Inventories that distinguish domestic shipping from international emissions on a voyage basis which is in the view of the consortium exactly consistent with the IPCC guidelines and definitions. The method is enabled by advances in the use of AIS data to identify port calls which allows allocation of discrete voyages to a definition of either international or domestic shipping. The improved split is reliable and provides a valuable advancement to the accurate assessment of international shipping's emissions. Figure 10 presents this method graphically.

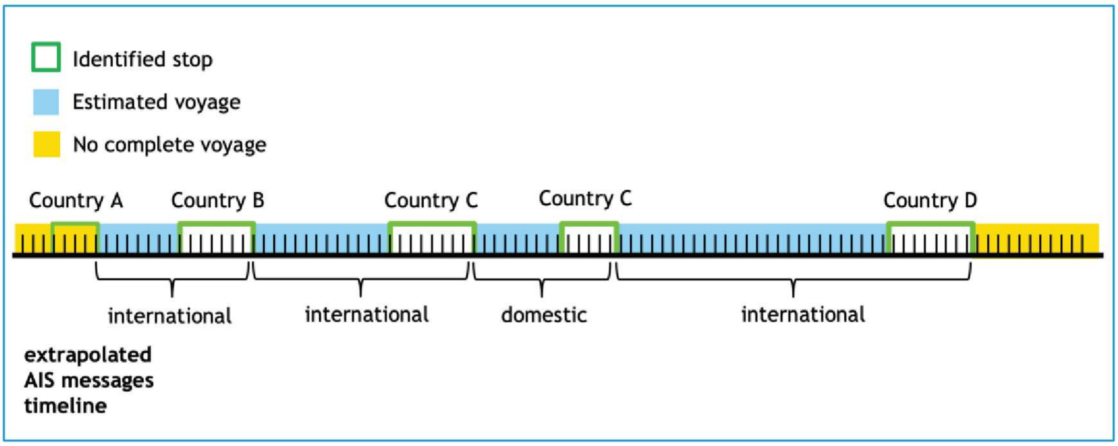


Figure 10 – *Allocation of international and domestic nature of shipping according to voyage-based method*

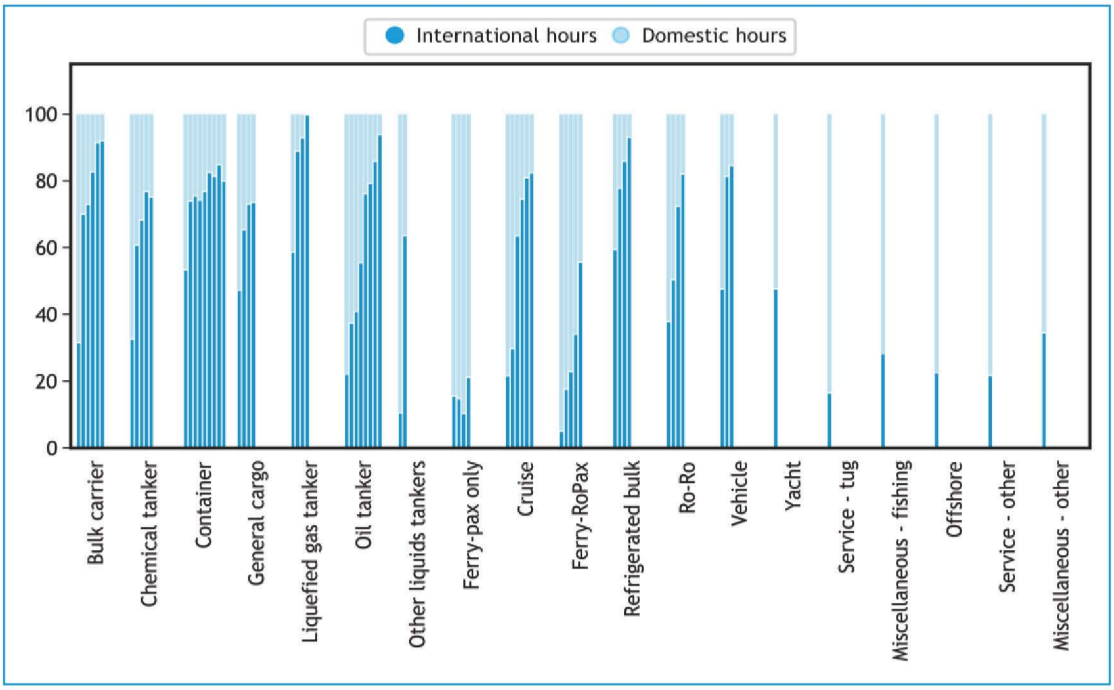


Figure 11 – *Proportion of time spent on international and domestic voyages on average by ship type and size in 2018 (%), where ship sizes are order small to large*

As presented in Figure 11, this Study finds that every one of the ship type and size categories of ships has some portion of international shipping emissions. For ship types dominant in the inventory of international shipping emissions (oil tankers, bulk carriers and containers), the smallest size categories have 20-40% of their emissions allocated to international shipping. For the largest ship sizes, the allocation to international shipping varies depending on ship type e.g. general cargo ~70%, containers ~80%, oil tankers and bulk carriers ~90% and liquefied gas tankers ~100%.

Quality and uncertainty of the estimates

Extensive quality assurance and control efforts were taken to ensure the highest quality of the inputs, method and results in the bottom-up and top-down inventories. This included validation against:

- Shipowners reported high frequency measurements of fuel consumption and operational parameters.
- Other published studies and inventories.
- Reported results from shipowners in the EU's MRV scheme (EU, 2019).

- The results of the Third IMO GHG Study. The difference in total fuel consumption figures is 3% in the overlapping year 2012, demonstrating both quality and coherency with the preceding study.

Of these validation efforts, the greatest sample size and most comprehensive validation was undertaken by comparing the bottom-up inventory results against reported fuel consumption and other key parameters describing 11,000 ships. This represented a significant step forwards in validation for this GHG Study, and demonstrated high quality in the consensus estimate because:

- The CO_2 and distance travelled at sea estimates across the entire fleet covered by MRV are showing only a very small overall deviation – overestimation error of 5.5 and 4.7%, respectively.
- When breaking down the MRV based comparison by vessel type as shown on Figure 12, the CO_2 emissions for three major vessel types are showing only -0.2% error for bulk carriers, 6% for container vessels, and 3% for oil tankers.
- These three vessel types contribute to over 65% of the international CO_2 emissions in 2018 and so represent a dominant share of global international shipping.
- For vessel types, where a poorer agreement is observed, they are shown to be of negligible influence on the inventory's overall accuracy as their overall contribution to the international CO_2 emissions is no more than 3%.

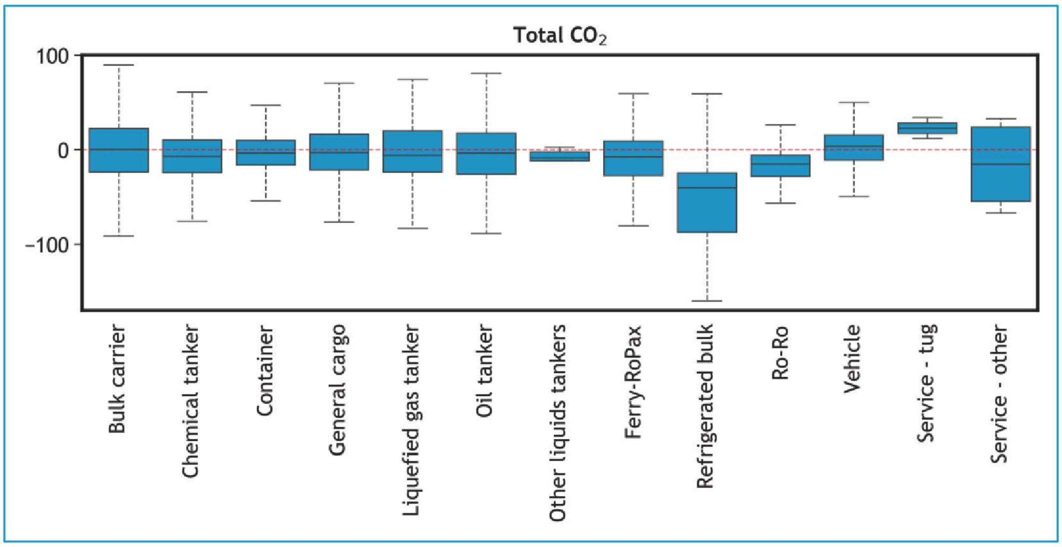


Figure 12 – *Agreement between this Study's inventory, with respect to its vessel-specific CO_2 emissions estimates, and entries for 9,739 ships reported in the EU MRV database for 2018, for the duration of shipping activity covered by the EU MRV scheme's reporting requirement*

Source: UMAS.

Estimates of carbon intensity of international shipping

This report presents four metrics of carbon intensity, namely Energy Efficiency Operational Indicator (EEOI, g CO_2/t/nm), Annual Efficiency Ratio (AER, g CO_2/dwt/nm), DIST (kg CO_2/nm) and TIME (t CO_2/hr). These metrics can either be calculated with data from the Data Collection System or are included in the SEEMP Guidelines.

These metrics are used in this Study to estimate the carbon intensity performance of international shipping from 2012 to 2018, as well as in 2008. Other variants of AER, including cDIST which uses different capacity units (such as teu, gt and cbm) and Energy Efficiency Performance Indicator (EEPI) which uses laden distance instead of total distance at sea, are also estimated where applicable, for reference purposes. Different carbon intensity metrics have different implications, drivers and reduction potentials, thus yielding different results in indicating the same performance level and percentage changes. Metrics such as EEOI, AER, cDIST and EEPI are potentially applicable to typical cargo and passenger ships, while DIST and TIME as well as their possible variants are more suitable for service, working or fishing vessels.

Table 3 and Table 4 report the carbon intensity levels of world fleet derived from both vessel-based and voyage-based. Seven typical ship types have been chosen as a representative of the world fleet, namely bulk carriers, oil tankers, container ships, chemical tankers, liquefied gas tankers, general cargo ships and refrigerated bulk carriers, which all together accounted for around 88% of CO_2 emissions and 98% of transport work of the world total. The percentage changes in overall and individual based carbon intensity of international shipping are jointly provided in these tables, indexed at 2008 and 2012, respectively. The overall percentage changes are calculated on aggregated data, while the individual based percentage changes are estimated through regression fit.

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

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	18,6%	-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 (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%

As illustrated in Figure 13 and Figure 14, values of EEOI and AER have generally kept decreasing between 2012 and 2018, and reached a reduction rate of around 29% and 21% in 2018, respectively, in comparison with 2008. Discrepancies between the two metrics were mainly caused by their opposite reflections on payload utilization. Values of DIST and TIME both showed an increasing trend due to the increasing average ship size, whereas the increasing magnitudes have been diminished to a certain extent by sea speed reduction, especially for values of TIME.

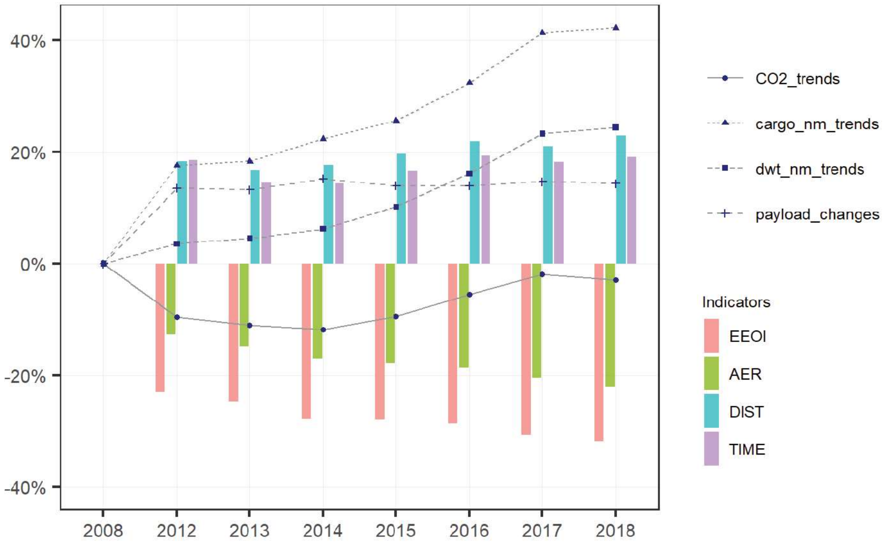


Figure 13 – *Percentage changes in overall carbon intensity of international shipping (vessel-based)*

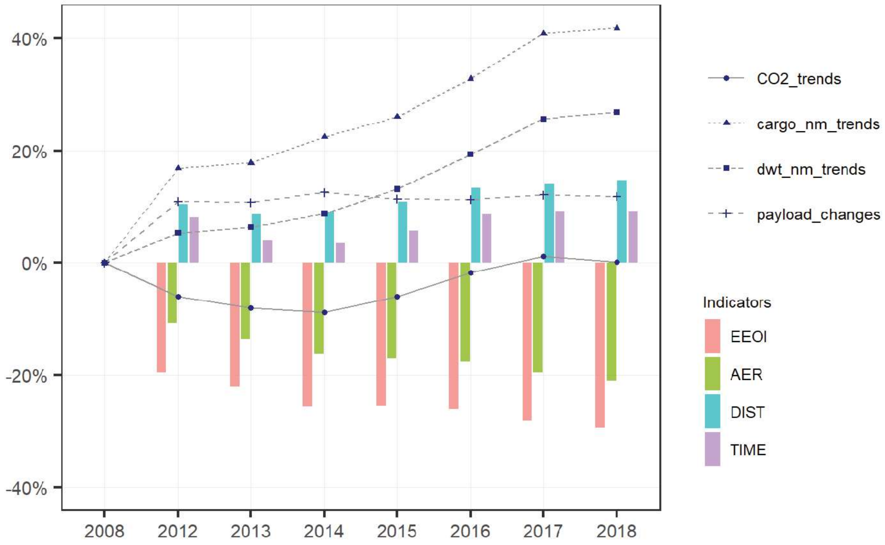


Figure 14 – *Percentage changes in overall carbon intensity of international shipping (voyage-based)*

As shown in Figure 15 and Figure 16, having not taken the influence of fleet composition shift into account, reduction magnitudes in EEOI and AER both narrowed down significantly. In comparison with 2008, the reductions in EEOI, AER/DIST and TIME in 2018 were around 17%, 9% and 22%, respectively. The relatively smaller improvements in AER/DIST, when compared with in EEOI, were due to their negative response (metric values going up) to the increasing payload utilization, while the relatively larger improvements in TIME were due to their high sensitivity to speed reduction.

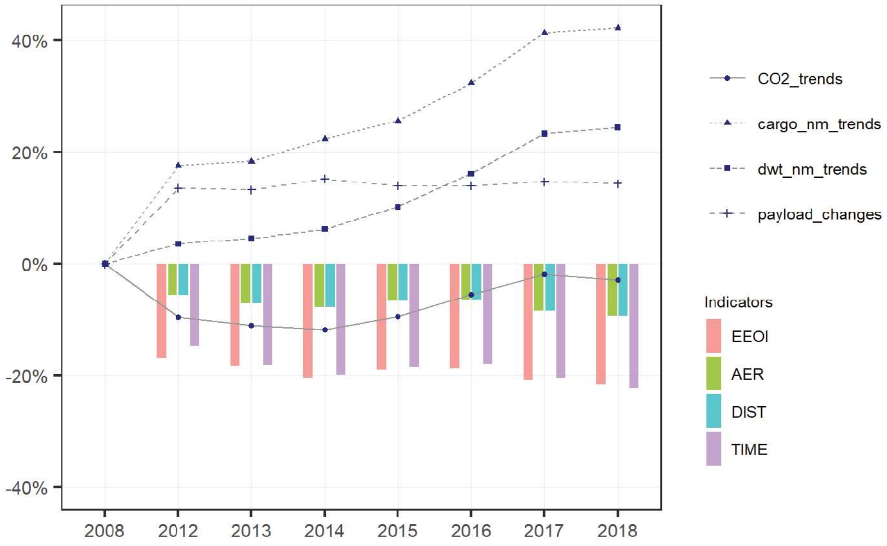


Figure 15 – *Percentage changes in individual based carbon intensity of international shipping (vessel-based)*

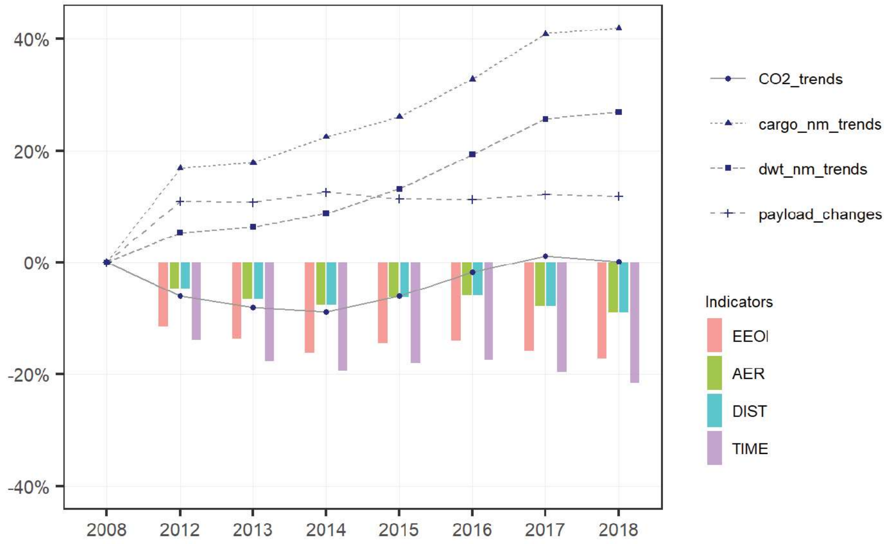


Figure 16 – *Percentage changes in individual based carbon intensity of international shipping (voyage-based)*

Note that the reduction rates in carbon intensity of international shipping discussed above are all indexed at year 2008, at which time the shipping market was just reaching its peak right before the long-lasting depression. Taking 2012 as the reference instead, the reductions in overall carbon intensity of international shipping narrowed down from 29% (in EEOI) and 21% (in AER) to around 12% (in both EEOI and AER). The individual based percentage changes further shrank to 7% (in EEOI), 5% (in AER/DSIT) and 9% (in TIME). This implies that the improvements in carbon intensity of international shipping has not followed a linear pathway, and more than half have been achieved before 2012. The pace of carbon intensity reduction has been further slowing down since 2015, with average annual percentage changes ranging from 1 to 2%, due to the limit in speed reduction, payload utilization, as well as the technical improvements of existing ships.

Figure 17 and Figure 18 present the carbon intensity levels of typical cargo ships over years in EEOI and AER, estimated through both vessel-based (Option 1) and voyage-based (Option 2). As shown in these figures, lowest carbon intensity levels were achieved by bulk carriers and oil tankers, followed by container ships. In the vessel-based option, ships covered by certain types have been undifferentiated categorized as international regardless of their sizes and operational features, including a number of small ships which have been merely or mainly serving domestic transportation. Therefore, carbon intensity levels estimated for the vessel-based option were a little bit higher than (i.e. inferior to) those derived for the voyage-based option. For the sake of brevity, results derived from both vessel- and voyage-based are reported, but discussions on trends and drivers of carbon intensity have mainly focused on voyage-based unless otherwise specified.

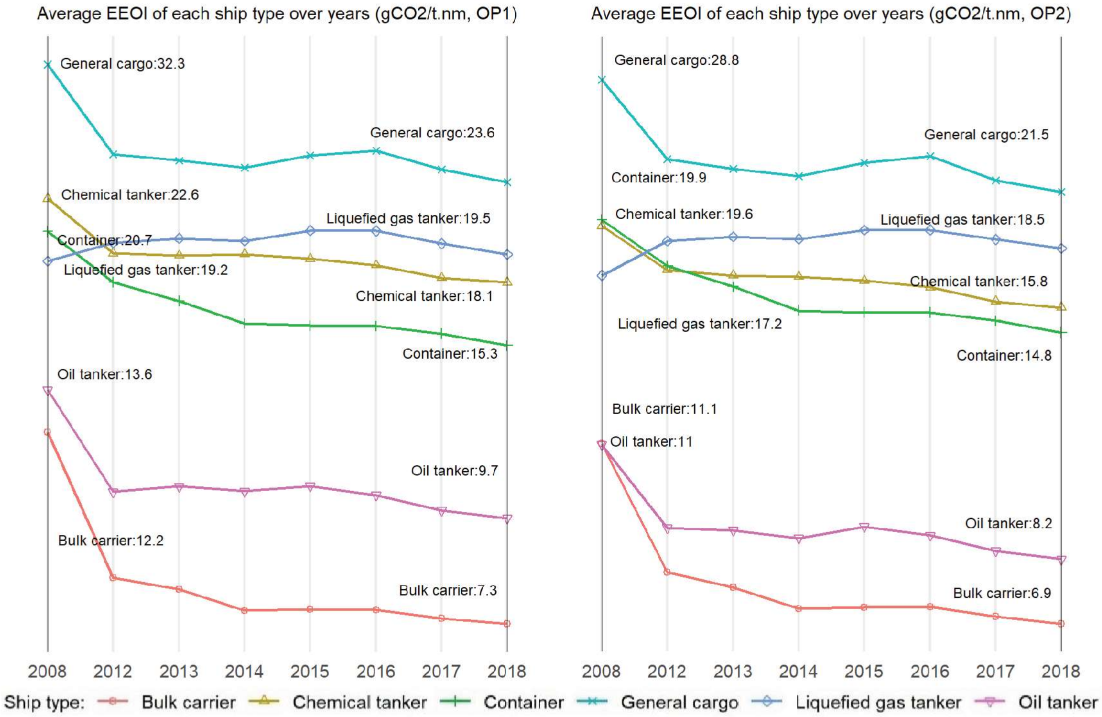


Figure 17 – *Carbon intensity levels of typical cargo ships over years (in EEOI; left panel: vessel-based; right panel: voyage-based)*

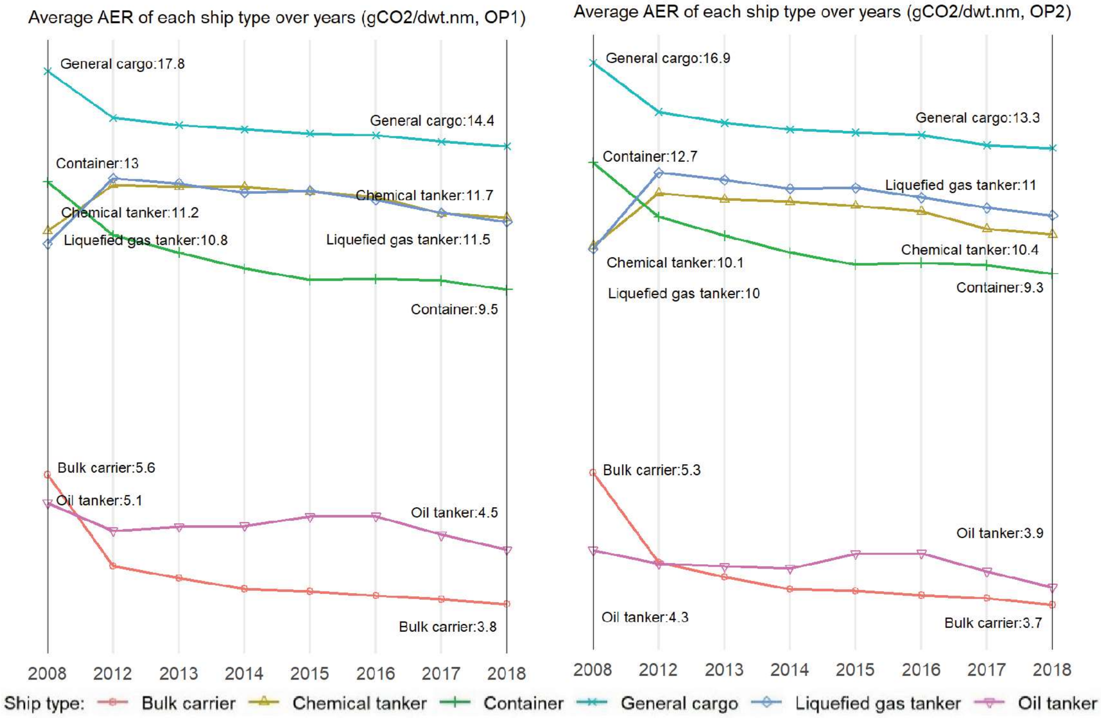


Figure 18 – *Carbon intensity levels of typical cargo ships over years (in AER; left panel: vessel-based; right panel: voyage-based)*

Carbon intensity performance per ship type varied from each other, but most of which have shared a decreasing trend between 2012 and 2018. Figure 19 and Figure 20 present of the trends in overall carbon intensity per ship type derived from both vessel-based (Option 1) and voyage-based (Option 2), as well as changes in drivers for carbon intensity reduction. Taking the year 2008 as a reference, the most significant carbon intensity reduction was achieved by bulk carriers, where the overall EEOI and AER in 2018 was around 38% and 31% lower. The trends in overall EEOI of oil tankers, container ships and general cargo ships were roughly identical, all of which decreased by 25-26% in 2018 compared with year 2008.

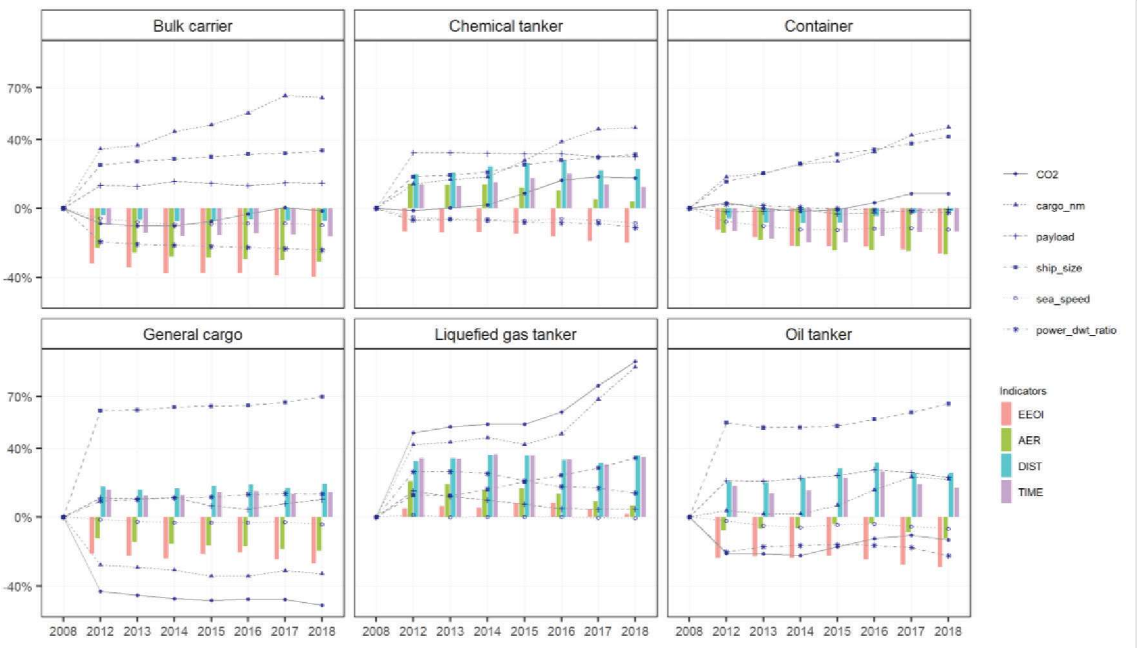


Figure 19 – *Percentage changes in overall carbon intensity per ship type indexed at 2008 (vessel-based)*

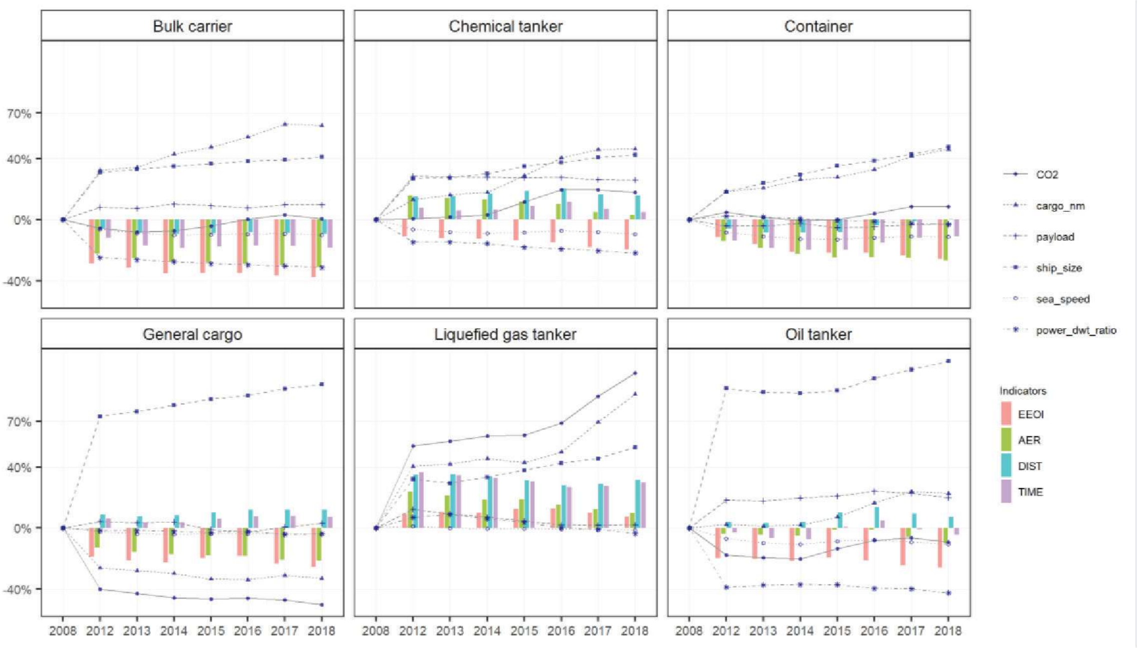


Figure 20 – *Percentage changes in overall carbon intensity per ship type indexed at 2008 (voyage-based)*

The increasing average ship size had taken a dominant role in carbon intensity reduction in all typical ship types when compared with 2008, yet got less significant when compared with 2012, except for container ships and liquefied gas tankers. In the meanwhile, large improvement in overall design efficiency has been observed in most segments, especially in oil tankers, bulk carriers and chemical tankers. Speed reduction has been another key driver especially for bulk carriers, chemical tankers, container ships and oil tankers since 2008. However, most ship type ceased slowing down further from 2015, due to the improving market situation, decreasing fuel oil price as well as certain technical limitations or concerns. Similarly, payload utilization has been improved more or less for most ship types compared with 2008, but went downwards or fluctuated during 2012-2018. Such volatile trends in speed

and payload utilization were largely the lagging consequences of the sluggish recovery from the global financial crisis which started from mid-2008. Another noteworthy finding is that changes in payload utilization showed opposite impacts on the trends in EEOI and AER. This implies that an increase in payload utilization generally leads to a reduction in EEOI, but leads to an increase in AER or compromises its expected reduction magnitude.

Figure 21 and Figure 22 present the trends in individual based carbon intensity per ship type derived from both vessel-based and voyage-based, as well as the changes in drivers for carbon intensity reduction. Such trends are estimated through fitting a series of power law regression curves.

Having not taken the influence of ship size composition shift into account, the individual based carbon intensity reductions in most ship types narrowed down when measured in EEOI or AER. The differences are quite significant in bulk carriers (from 38% to 28%), chemical tankers (from 19% reduction to 4% increase) and oil tankers (from 26% to 8%), yet modest in container ships (from 26% to 20%) and general cargo ships (from 26% to 21%). This implies that the sharp carbon intensity reductions in the former group of ships were largely led by increasing ship size, while in the latter group were mainly achieved by individual design and operational improvement. In this like-to-like comparison, identical trends of AER and DIST can be clearly identified. Having been jointly influenced by increasing ship size and decreasing sea speed, changes in the overall TIME were determined by the one which was dominant, thus showed divergent trends between ship types. Having decoupled from the size factor, however, TIME has showed a decreasing trend in most ship types, with reduction rates even larger than in EEOI. This implies that TIME is much more sensitive to speed reduction than other metrics.

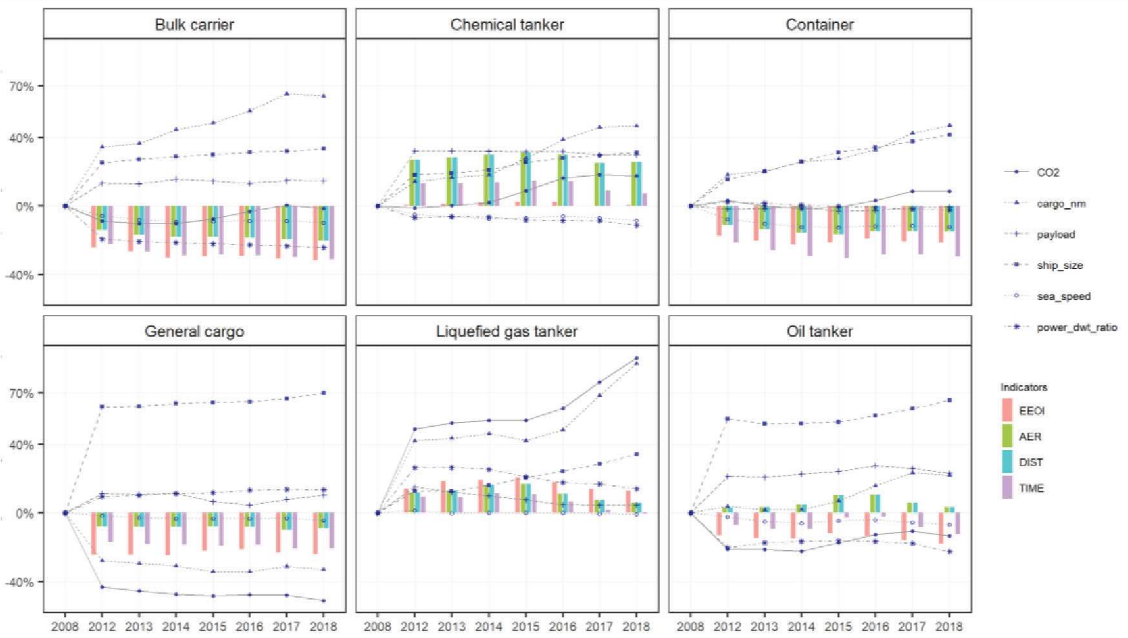


Figure 21 – *Percentage changes in individual based carbon intensity per ship type indexed at 2008 (vessel-based)*

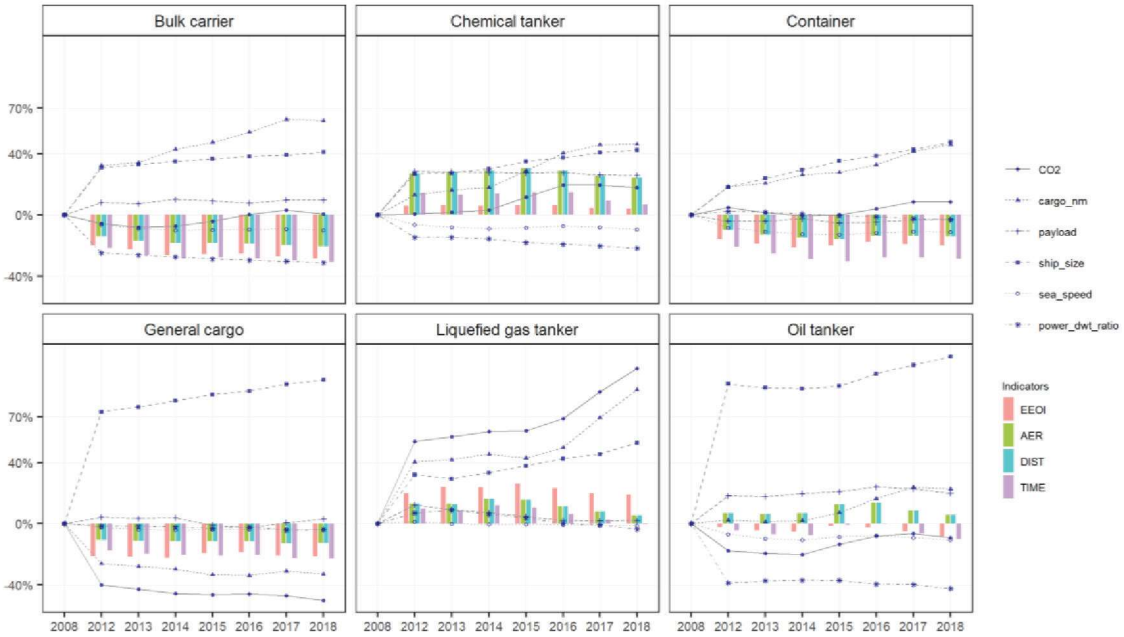


Figure 22 – *Percentage changes in individual based carbon intensity per ship type indexed at 2008 (voyage-based)*

Large spread scales of metric values have been observed across all ship types and size bins, which are mainly caused by differences in design and operational profiles of individual ships, as well as various external influencing factors. The spread scales in all metrics are generally larger for smaller ships while smaller for larger ships. As per ship types, the largest spread scales of EEOI have been observed in oil tankers, followed by general cargo ships, bulk carriers, liquefied gas tankers and chemical tankers. Spread scales in AER are a little bit smaller than in EEOI due to its immunity to variations in payload utilization. Further to the differences between ship type and size categories, carbon intensity of a specific individual ship also varied over time, due to the various operational and navigational conditions beyond control. The upper and lower quartiles of fluctuation rates in EEOI of oil tankers, bulk carriers and container ships were around ±20%, ±15% and ±10%, respectively. Quartiles of fluctuation rates in other metrics were relatively modest, yet still generally reaching beyond ±5%. Due to certain static assumptions on weather and hull fouling condition, as well as non- timely updated AIS entries on draught, factual fluctuations were possibly more scattered than estimated, especially for container ships.

Uncertainties in carbon intensity estimation partly stem from the inventory estimation and partly from the estimates on transport work. Cross validation with EU MRV data showed that the metric values in EEOI might be underestimated by 10-25% for bulk carriers, container ships, chemical tankers and general cargo ships, while by 50% for liquefied gas tankers.

The discrepancies in oil tankers were less than 5%. Since CO_2 emissions could have been overestimated, the underestimation on EEOI values was likely caused by a larger overestimation on payload utilization. Comparison against the published transport demand in UNCTAD's Review of Maritime Transport (2018) showed that the deviations in estimated cargo ton-miles undertaken by oil tankers, container ships and dry cargo ships (covering bulk, general cargo and refrigerated bulk carriers) were consistently around –2%, 30% and –28% between 2012 and 2018, while the deviations in total cargo ton-miles ranged within ±2%. This was likely caused by the different categorization strategy applied to seaborne trade and to marine transportation. This observation highlights two points: first, the estimates on carbon intensity of international shipping as a whole was more reliable than the results for ship types; second, the estimated trends in carbon intensity performance (in percentage change), which could not be substantially affected by systematically biased estimation in transport work, are more reliable than the absolute metric values. Given the limited data available for validation, subjective rectification such as introducing a series of correction factors to carbon intensity estimates of ship types may incur another uncertainty. Therefore, no corrections have been made to the estimated results. To avoid misleading, however, whenever the estimated carbon intensity levels of ship types are referred to, the possible biasness should be specified jointly.

Scenarios for future shipping emissions

CO_2 emissions of shipping have been projected out to 2050. The method for projecting emissions from shipping in this Study comprises of six steps:

1 Projecting transport work – non-energy products:

- **a.** Establishing the historical relation between maritime transport work and relevant economic parameters such as world (or country) per capita GDP and population (for transport of non-energy products, such as unitized cargo, chemicals and non-coal dry bulk);
- **b.** Projecting transport work on the basis of the relations described in (a) and long-term projections of GDP and population (global or by country).

2 Projecting transport work – energy products

- **a.** Collecting IPCC formal projections of evolution of energy consumption and energy consumption (for transport of energy products like coal, oil and gas).
- **b.** Projecting transport work using the variation of energy consumption projection when considering seaborne transportation of energy products (coal dry bulk, oil tankers and gas tankers).

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

4 Projecting the future fleet composition.

5 Projecting future energy efficiency of the ships, taking into account regulatory developments and market-driven efficiency changes using a marginal abatement cost curve (MACC).

6 Combining the results of steps 4, 5 and 6 above to project shipping emissions.

Figure 23 is a graphical representation of the methodology.

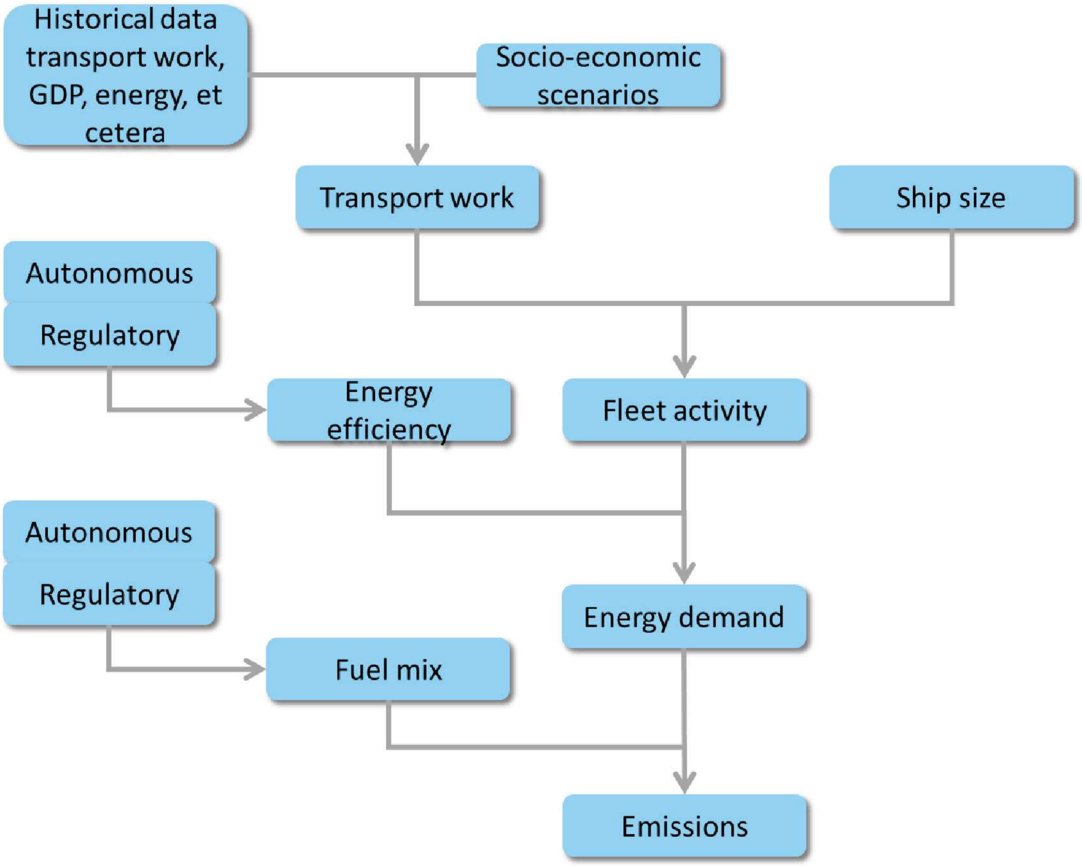


Figure 23 – *Graphical representation of methodology to develop emission projections*

The transport demand projections depend on three factors:

The long-term socio-economic scenario underlying the projection. The higher the projected per capita GDP growth and the population growth, the higher the projected transport work for products that are strongly correlated with economic developments, such as non-coal dry bulk, containerized and other unitized cargoes, and chemicals.

The long-term energy scenario. The more fossil fuel is projected to be consumed, the higher transport work of coal dry bulk, oil tankers and gas tankers.

The method to establish the relation between transport work and the relevant drivers. This Study has employed two methods for projecting transport work for non-energy products: a logistics analysis which analyses the relation between global transport work and its drivers over the longest period available and projects that relation further using a logistics curve; and a gravitation model analysis, in which bilateral trade flows between countries are analysed to establish the elasticities of trade between those countries and the relevant drivers. We find that typically the logistics approach results in higher transport work projections than the gravitation model approach.

The factors are summarised in Table 5.

Table 5 – *Characteristics of transport work demand projections*

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

In scenarios with an aggregate economic growth in line with SSP 2 and OECD baseline projections and energy demand from land-based sectors that just about limits the global temperature increase to well below 2 degrees centigrade (RCP 2.6), aggregate transport work increases by 40-100%. In general, projections using a logistics analysis exhibit higher growth rates (75-100%) than projections using a gravitation model approach (40-60%). Scenarios that have higher aggregate income and size growth see a larger increase in transport work (see Figure 24).

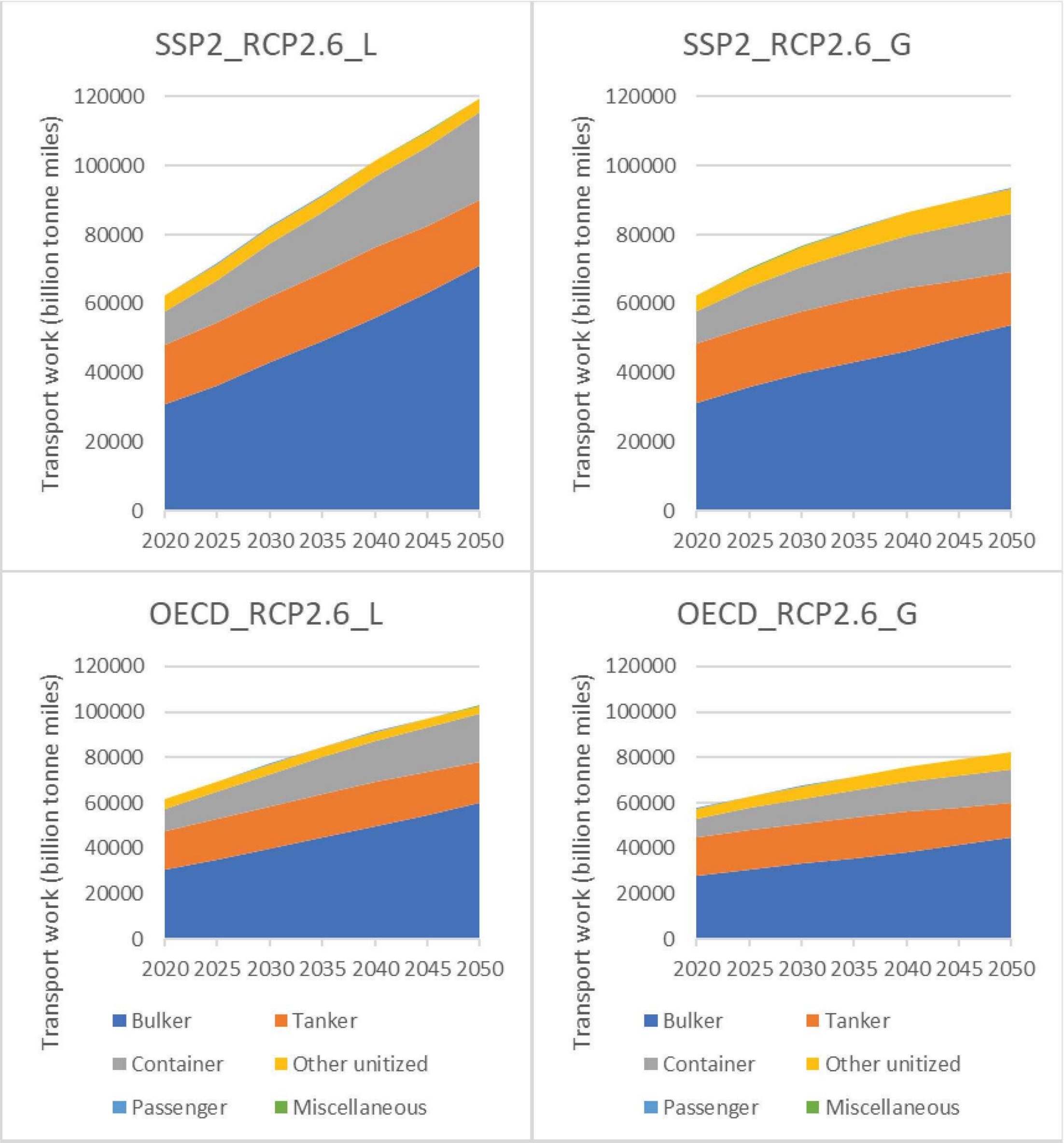


Figure 24 – *Transport work projections (billion tonne miles)*

Updated marginal abatement cost curves

There are many ways to improve the energy efficiency or carbon intensity of shipping. This report has assessed the abatement potential and costs of 44 technologies in four groups: energy-saving technologies; use of renewable energy; use of alternative fuels; and speed reduction.

Applying all the potential mitigation measures selected to all newly built ships from 2025, CO_2 emissions reduction in 2050 can achieve both the mid-term and long-term levels of ambition specified in the *Initial IMO Strategy on Reduction of GHG Emissions from Ships*.

In 2050, about 64% of the total amount of CO_2 reduction is contributed to by use of alternative fuels. The marginal abatement cost curve (MACC) depends to a large extent on the projected prices of zero-carbon fuels.

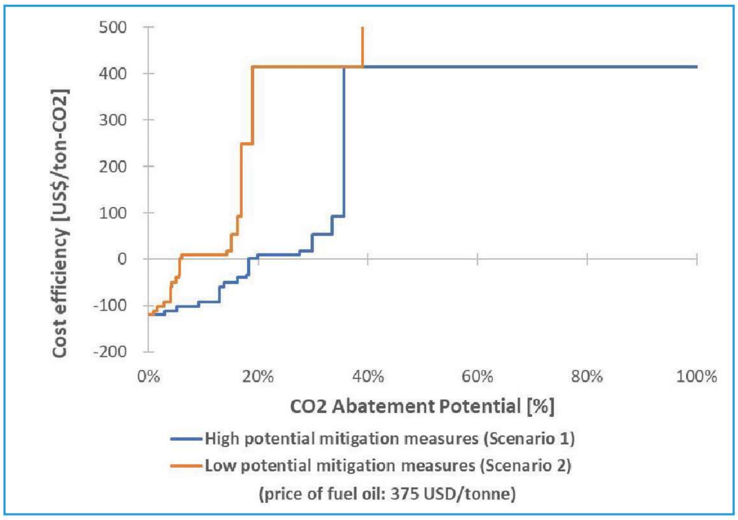


Figure 25 – *Marginal abatement cost curve for 2050*

Emission projections

All the projections are so-called business as usual (BAU) projections. In the context of this Study, BAU refers to the shipping sector and is defined as "no adoption of new regulations that have an impact on energy efficiency or carbon intensity". As noted above, the projections are based on long-term socio-economic pathways and representative concentration pathways of the IPCC. Some of these pathways assume that non-shipping sectors undergo transitions that require policies like carbon prices or energy-efficiency regulations. These are still considered to be BAU scenarios in the context of this Study.

Figure 26 shows the BAU scenarios for three long-term scenarios in which the energy mix of land-based sectors would limit the global temperature increase to well below 2 degrees centigrade (Van Vuuren, et al., 2011a) and which have GDP growth projections from the OECD or from the IPCC that are in line with recent projections from the OECD. In these BAU scenarios, the emissions of shipping are projected to increase from 1,000 Mt CO_2 in 2018 to 1,000 to 1,500 Mt CO_2 in 2050. This represents an increase of 0 to 50% over 2018 levels and is equal to 90-130% of 2008 levels.

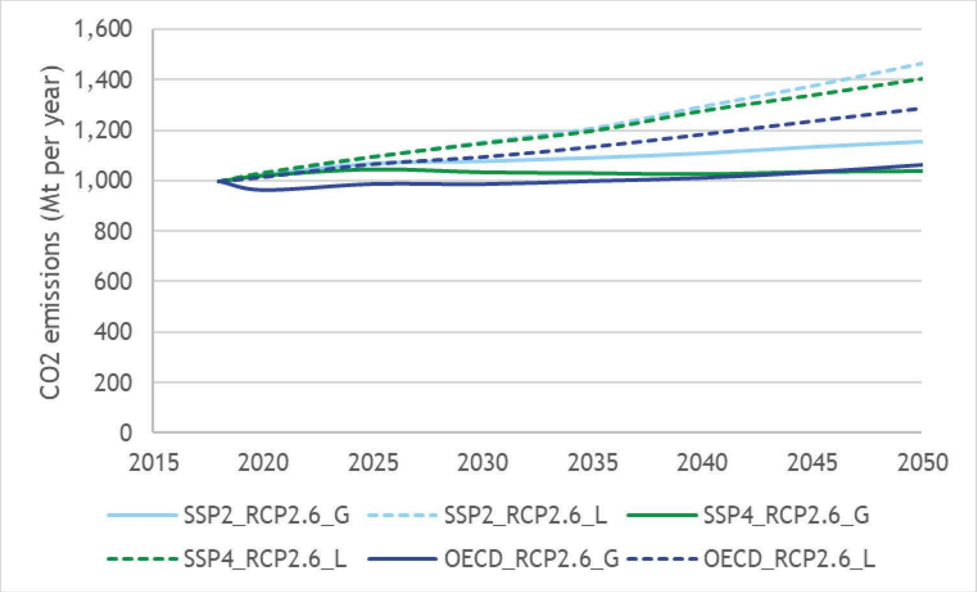
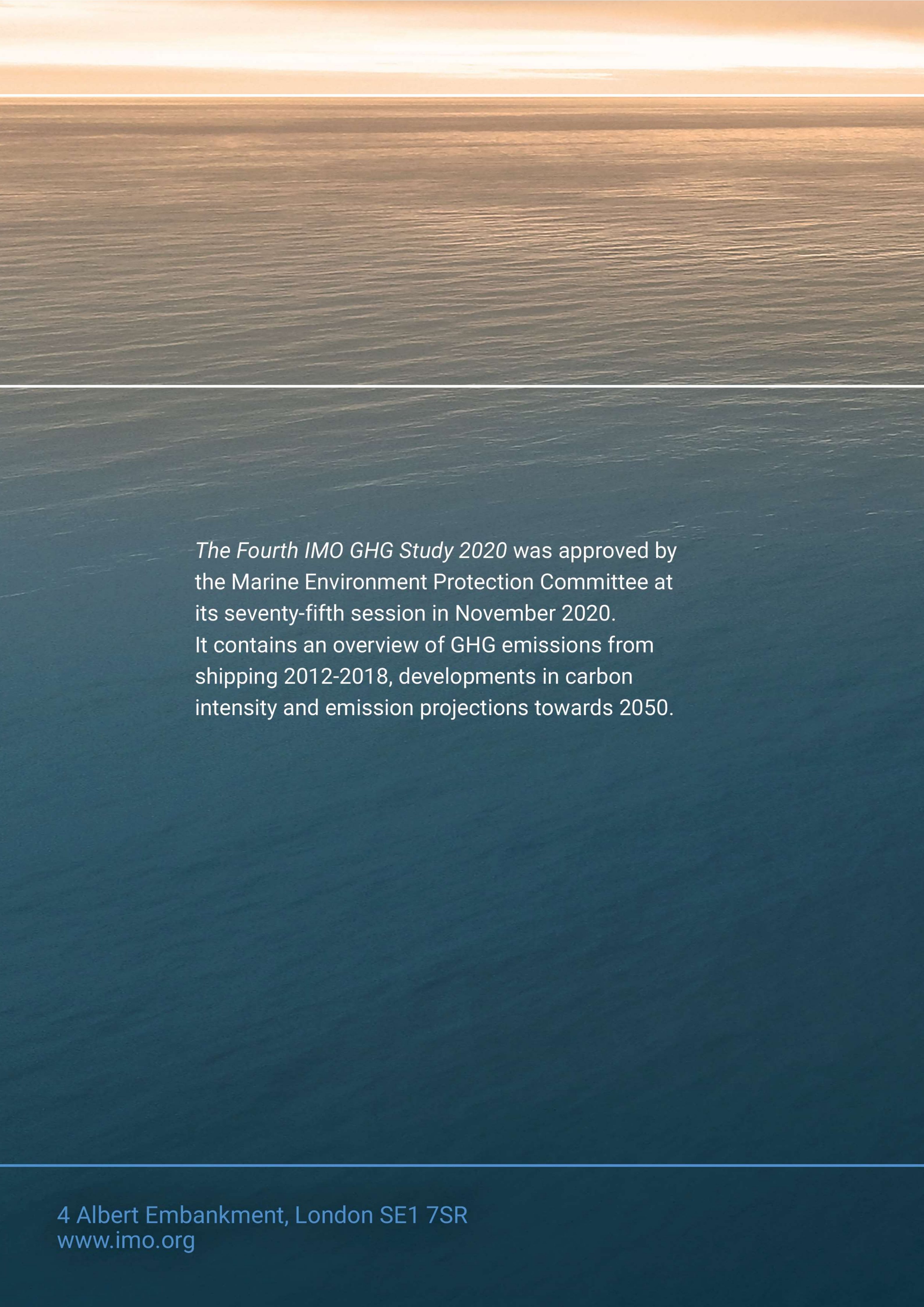


Figure 26 – *BAU scenarios GDP growth in line with recent projections, energy transition in line with 2 degrees target*

The differences in the BAU emission projections are caused by differences in transport-work projections which, in turn, are caused by differences in socio-economic projections and different methods to establish the relation between transport work and independent variables like per capita GDP, population and primary energy demand.

The emissions in Figure 26 are for total shipping. It is expected that the share of domestic and international emissions will not change.

Although it is too early to assess the impact of COVID-19 on emission projections quantitatively, it is clear that the emissions in 2020 and 2021 will be significantly lower. Depending on the recovery, the emissions in the next decades may be a few percent lower than projected, at most. In all, the impact of COVID-19 is likely to be smaller than the uncertainty range of the presented scenarios.



The Fourth IMO GHG Study 2020 was approved by the Marine Environment Protection Committee at its seventy-fifth session in November 2020. It contains an overview of GHG emissions from shipping 2012-2018, developments in carbon intensity and emission projections towards 2050.

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