EXPERT WORKGROUP IN PREPARATION OF FOURTH IMO GHG STUDY
Agenda item 2

GHG-EW 1/2/2
25 January 2019
ENGLISH ONLY

DRAFT TERMS OF REFERENCE OF THE FOURTH IMO GHG STUDY

Technical and methodological issues related to the Fourth IMO GHG Study

Submitted by BIMCO

SUMMARY

Executive summary:	This document presents the report of a study recalculating the *Third IMO GHG Study 2014* emissions projections to 2050 using updated historic transport work data and global GDP growth projections by OECD. This document furthermore proposes changes to the draft terms of reference of the Fourth IMO GHG Study.
Strategic direction, if applicable:	3
Output:	3.2
Action to be taken:	Paragraph 17
Related documents:	Resolution MEPC.304(72); MEPC 73/19, MEPC 73/WP.8, MEPC 73/7/9 and ISWG-GHG 1/2/3

Introduction

1 The *Initial IMO Strategy on reduction of greenhouse gas emissions from ships* (the Initial IMO Strategy) adopted by MEPC 72 and the *Programme of follow-up actions of the Initial Strategy up to 2023* approved by MEPC 73 identified the initiation of the Fourth IMO GHG Study at MEPC 74.

2 MEPC 73 further approved the holding of an Expert Workshop meeting ahead of MEPC 74 to consider in detail the draft terms of reference of the Fourth IMO GHG Study for consideration by MEPC 74.

3 This document discusses important aspects with regard to assumptions influencing global seaborne trade growth in future years under different scenarios and suggests consideration of scenarios for future global GDP growth in addition to those contained on the IPCC Shared Socio-economic Pathways (SSP1 to SSP5).

4 Annexed to this document is the report by CE Delft on a recalculation of the *Third IMO GHG Study 2014* using the OECD 2018 long-term GDP projection to 2050. The recalculation

is further examining the effect of meeting the 70% efficiency objective by 2050 compared to 2008 contained in the Initial IMO Strategy, as well as examining the effect on transport demand and emissions if the world is not meeting the objective of the Paris Agreement temperature goal, and other sensitivities of the modelling.

Discussion

5 Estimated future CO_2 emissions from shipping is a function of the assumed efficiency of the fleet in a given future year and the size of the fleet required to move the projected transport demand in that year. While it is relatively well understood how the efficiency in the fleet is derived from assumptions on size distribution of ships within each sector of the shipping industry, speed used for the ships in the scenarios, propulsion efficiency of the machinery and hull design, etc. it is much less understood how future transport demand may develop.

6 The *Third IMO GHG Study 2014* was built on the assumption that historic correlations between trade growth and global GDP growth would extend into the future. While extrapolation itself is uncertain, it is only valid if there is confidence in projections of future global GDP growth. The report annexed to this document brings the confidence in projections of future GDP growth contained in the SSP scenarios into question when compared to more recently published projections (annex, figure 1 – Historical and projected growth rates of global GDP). In fact, all the SSPs project considerably higher initial economic growth, with only SSP3 having an aggregate growth in the period in line with the OECD projection.

7 The recalculation of the *Third IMO GHG Study 2014* annexed to this document based on the 2018 OECD long-term GDP growth projection resulted in a transport work demand by 2050 of 135,000 10^9 tonne-mile.

8 Projections of future transport demand have recently been published by others with significantly lower expectations for future years. In its report entitled *Energy Transition Outlook 2018: Maritime Forecast to 2050,* DNV-GL projects transport demand to be as low as 76,000 10^9 tonne-mile by 2050 after having peaked at around 78,000 10^9 tonne-mile by 2040. These numbers assume a de-coupling of the GDP/transport demand growth correlation after 2030.

9 The World Maritime University (WMU) has recently published a report with the International Transport Workers Federation (ITF) on the effect of technology and autonomous ships on future demand for seafarers, entitled *Transport 2040: Automation, Technology, Employment – The Future of Work (2019)*. The report contains an important element of projecting future demand for transport by 2040, where the authors arrive at 84,500 10^9 tonne-mile. This result is also based on assumptions about a de-coupling of the GDP/transport demand growth correlation after 2030.

10 The effect of different transport work projections in three scenarios where the fleet meet the 70% efficiency objective by 2050 compared to 2008 has been calculated in the report set out in the annex to this document. The 2050 emissions from shipping were calculated to:

.1 more than 30% above the 2008 level (SSP1);

.2 5% above 2008 level (SSP4); and

.3 20% below 2008 level (OECD).

11 Keeping the relation between emissions and transport work in 2050 constant at the OECD scenario level and applying this relation to the transport work results of WMU/ITF and DNV-GL, the 2050 emissions from shipping can be roughly calculated to:

.1 40% below 2008 level (WMU/ITF); and

.2 more than 50% below 2008 level (DNV-GL).

12 Understanding the drivers for future transport demand and deciding on appropriate assumptions and modelling approaches for projecting this demand are crucial inputs to the modelling of the future fleet and its associated emissions.

13 While the draft terms of reference of the Fourth IMO GHG Study (MEPC 73/WP.8, annex 1) suggest in paragraph 2.1 that "the Fourth Study could include a revision of projected scenarios used in previous studies including all possible combinations of representative concentration pathways (RCPs) and shared socioeconomic pathways (SSPs)", it is evident that there are wider boundaries for the scenarios to be modelled.

Proposals

14 Both SSP1 and SSP5 reflect very high growth figures, especially in the near- and mid-term, which are inconsistent with recent projections by internationally recognized institutions. BIMCO therefore suggests that the high bound global GDP growth scenario should be in accordance with those of SSP2/SSP4.

15 Furthermore, BIMCO suggests complementing the global GDP growth scenarios in SSP2/SSP4 with those of the OECD.

16 Lastly, BIMCO suggests the modelling approach to the correlation between GDP growth and trade growth should take the de-coupling aspect of the DNV-GL and WMU/ITF work after 2030 into consideration.

Action requested of the Expert Workshop

17 The Expert Workshop is invited to consider the proposals above and update the draft terms of reference of the Fourth IMO GHG Study as appropriate.

***

Update of maritime greenhouse gas emission projections

CE Delft

Committed to the Environment

Update of maritime greenhouse gas emission projections

This report was prepared by:
CE Delft
David S. Lee

Delft, CE Delft, January 2019

Publication code: 19.7S18.009

Transport / Maritime shipping / Economic factors / Environmental factors / Emissions / Greenhouse gases / Reduction / European directives / Policy measures / Analysis

Client: BIMCO

Publications of CE Delft are available from www.cedelft.eu

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

CE Delft
Committed to the Environment

Through its independent research and consultancy work CE Delft is helping build a sustainable world. In the fields of energy, transport and resources our expertise is leading-edge. With our wealth of know-how on technologies, policies and economic issues we support government agencies, NGOs and industries in pursuit of structural change. For 40 years now, the skills and enthusiasm of CE Delft's staff have been devoted to achieving this mission.

Content

Summary

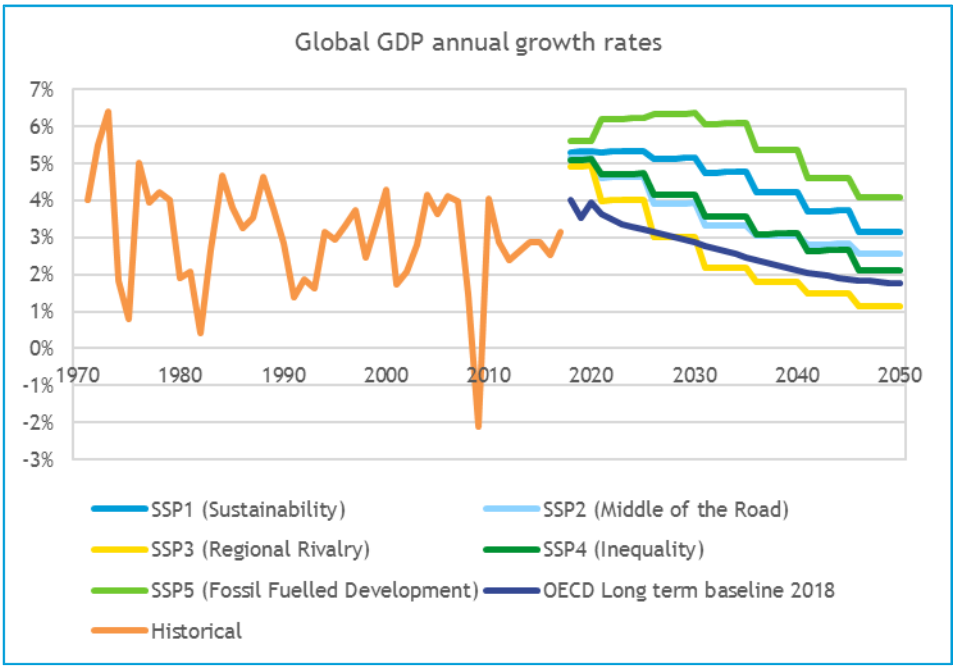
The Third IMO Greenhouse Gas Study 2014 presented emission projections from shipping that showed increases of 50-250% in 2050 relative to 2012, depending on the socio-economic developments and changes in the energy system. These projections were based, amongst many other factors, on an analysis of the relation between transport work and GDP or energy consumption that used transport work data provided by UNCTAD (United Nations Conference on Trade and Development) for the period 1970-2012.

This report presents an update of these emission projections that are based on updated transport work projections and contemporary GDP projections but otherwise employ the exact same methodology as the previously published projections.

New data on transport work have become available after 2014. Transport work has also grown at a markedly slower pace in recent years. In addition, the new data source provides more disaggregated transport work data that allows for a closer and more precise examination of the historical relation between transport work and GDP or energy consumption for different segments of the shipping sector.

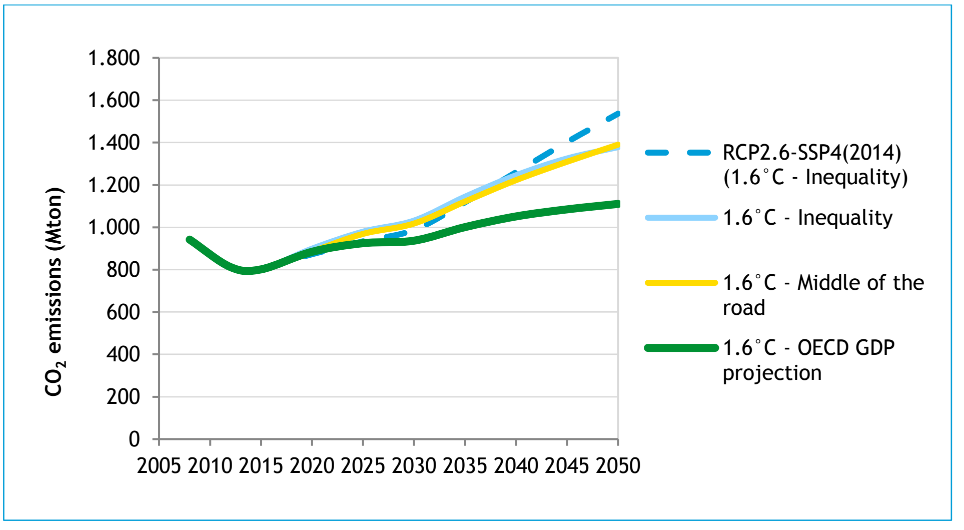
The Third IMO Greenhouse Gas Study 2014 used economic scenarios developed by the IPCC (Intergovernmental Panel on Climate Change) to develop long-term projections of transport demand. Most of these scenarios have much higher global GDP growth rates than scenarios that have recently been developed by other institutions (see Figure 1). For that reason, this report also includes projections that use GDP projections from the OECD (Organisation for Economic Cooperation and Development). Since these OECD projections incorporate the latest economic developments and outlooks, this report gives them greater emphasis.

Figure 1 - Historical and projected growth rates of global GDP



The update is also relevant because the policy context has changed since the Third IMO Greenhouse Gas Study 2014 was presented. In the Paris Agreement, countries have agreed on the goal to keep the global average temperature increase to well below 2°C. This means that most of the BAU (business as usual) scenarios presented in 2014 are less relevant, since only one of them (RCP2.6-SSP4(2014)) is compatible with the agreed temperature goal.

Figure 2 - CO_2 emission projections of shipping in 1.6°C BAU scenarios



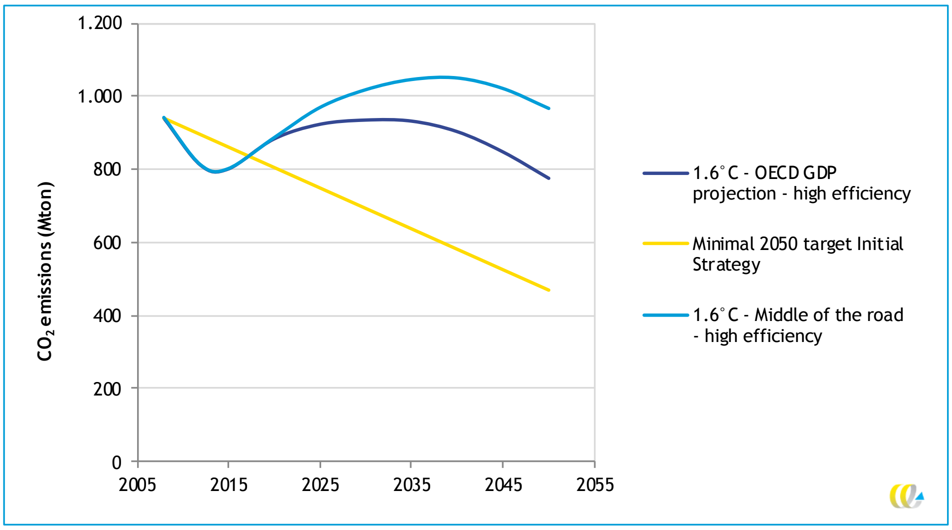
Source: CE Delft.

Figure 2 shows the CO_2 emission projections of shipping in three scenarios in which the demand for fossil fuels from other sectors is in line with the Paris Agreement temperature goal. For comparison, the one corresponding scenario from the Third IMO Greenhouse Gas Study 2014 has also been overlaid as a dashed line. Depending on the economic developments, CO_2 emissions increase by 20 to 50% between 2008 and 2050. The lowest emission projection is in line with recent GDP projection by the OECD whereas the higher projections reflect increasingly more optimistic global GDP projections.

For comparison, the Third IMO Greenhouse Gas Study 2014 presented only one scenario compatible with the Paris Agreement temperature goal (RCP2.6-SSP4(2014)) in which CO_2 emissions would increase by 60%. This original scenario 2014 has the same assumptions about economic growth as the new 1.6°C – Inequality scenario in this update. Hence, this update has resulted in lower projected emission increases than the Third IMO Greenhouse Gas Study 2014.

The MEPC has adopted the Initial IMO Strategy on Reduction of GHG Emissions from Ships. One of the ambitions of this strategy is to improve the carbon efficiency of shipping by 40% in 2030, pursuing efforts to a 70% improvement in 2050 compared to 2008. The 2050 efficiency ambition is in line with the so-called high efficiency scenarios from the Third IMO Greenhouse Gas Study 2014. Figure 3 shows how emissions will develop in these scenarios. In contrast to the BAU scenarios, the emissions peak and decline. Depending on economic developments, CO_2 emissions return to 2008 values or decrease by 20% by 2050. However, the high-efficiency scenario is not sufficient to meet another ambition of the Strategy, namely to reduce emissions by at least 50% in 2050 compared to 2008.

Figure 3 – CO_2 emission projections of shipping in 1.6˚C High Efficiency scenarios



Source: CE Delft.

1 Introduction

1.1 Policy Context

In the period 2007–2012, annual greenhouse gas emissions from shipping amounted to approximately 1,000 Mt CO_2 on average, which was about 3% of global manmade emissions (IMO, 2015). The Third IMO Greenhouse Gas Study 2014 projected that the emissions would increase by 50-250% in the period up to 2050, depending on climate policy and economic developments.

The Paris Agreement aims to hold 'the increase in the global average temperature to well below 2°C above pre-industrial levels'. To that end, emissions should peak 'as soon as possible', followed by a rapid reduction in order to 'achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century' (UNFCCC, 2015).

The MEPC has adopted the Initial IMO Strategy on Reduction of GHG Emissions from Ships, which sets a vision to phase out GHG emissions from international shipping as soon as possible in this century and states an ambition to reduce emissions by at least 50% in 2050, relative to 2008 (Resolution MEPC.304(72)).

In order to assess the effort that is required to meet the goals, it is essential to have a good understanding of how emissions will develop taking into account the 2030 and 2050 efficiency targets respectively. Furthermore, sensitivities in relation to the world's ability to stay within the temperature goal of the Paris Agreement as well as the emissions models approach to fuel cost and speed in the fleet are relevant. BIMCO has therefore asked CE Delft and David S. Lee, who developed the scenarios for the Third IMO Greenhouse Gas Study 2014, to update them.

1.2 Reasons for updating GHG emission projections

The emission projections of the Third IMO Greenhouse Gas Study 2014 were based, amongst others, on empirical historical relationships between transport work and shipping activity, and on preliminary scenarios for socio-economic developments and energy use obtained by CE Delft through personal communications.

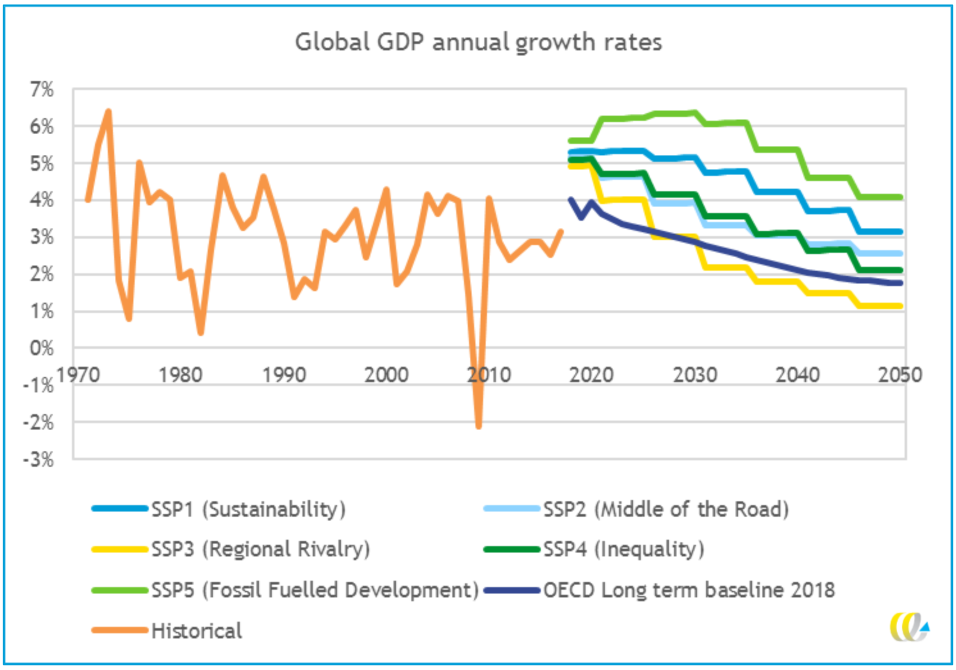
Since the publication of the Third IMO Greenhouse Gas Study 2014, maritime transport work has grown much less than projected in 2014, affected by a marked slowdown in global trade. Including the transport work data of recent years in the empirical analysis could result in lower projections of transport work in the future which, in turn, could lead to lower emission projections.

In addition, transport work data has become available to the authors of this study that is more disaggregated and more comprehensive than the data they used in the Third IMO Greenhouse Gas Study 2014. As a result, transport work could be projected for more categories of cargo.

In 2016, the long term Representative Concentration Pathways (RCP) and Shared Socio-Economic Pathways (SSP) were published (O'Neill, et al., 2107); (Riahi, et al., 2017). These scenarios project long-term changes in energy use and emissions (RCP) and socio-economic parameters (SSP) and are commonly used as a basis for the analysis of climate policies. Some of these scenarios differ in details from the preliminary scenarios used in the Third IMO Greenhouse Gas Study 2014.

The development of the RCPs and the SSPs started in the early 2000s and the economic outlook therein appears to reflect some of the optimism of that era. More recently published projections have lower growth rates. Figure 4 compares the growth rates of the global GDP in the different SSP scenarios with the latest OECD long-term baseline, showing that all of the SSPs project considerably higher initial economic growth, with only SSP3 having an aggregate growth in the period in line with that of the OECD.

Figure 4 – Annual growth rates of global GDP, historical and in scenarios



Moreover, since the Paris Agreement has set the world on a course to limit the temperature rise to well below 2°C, most of the emission projections of the Third IMO Greenhouse Gas Study 2014 are less relevant. In the current context, projections based on energy scenarios which are in line with the Paris Agreement goals are arguably more relevant than scenarios which would result in higher increases in temperatures. Furthermore, the combination of different economic development with different energy scenarios make it difficult to understand the results.

Finally, the analysis underlying the trade to emission calculations in the Third IMO Greenhouse Gas Study 2014 (i.e. the fleet model for future years) started five years ago. Input assumptions were based on an extensive literature review and stakeholder consultation, but the time that has evolved since the assumptions were made allows for a comparison of a number of them with empirical data.

Because of all these reasons, the update of the emission scenarios presented in this report has recalculated the relation between maritime transport work on the one hand and GDP and energy use on the other, taking the transport work data of recent years into account. Moreover, the projections are based on the published RCP and OECD GDP scenarios, with select SSP scenarios included for comparative purposes, and presented with more emphasis and detail about the scenarios that are compatible with the Paris Agreement goals.
All other inputs and assumptions used in the Third IMO Greenhouse Gas Study 2014 have been kept constant.

1.3 Aim of the study

The aim of the project is to update the emission projections of the Third IMO Greenhouse Gas Study 2014, using the same methodology as that study, but taking into account that trade growth has levelled off and taking advantage of the recently published long-term climate and socio-economic scenarios, as well as the OECD long term GDP projection 2018.

1.4 Scope of the study

The scope of the study is the same as the scope of the Third IMO Greenhouse Gas Study 2014 emissions projections. It includes CO_2 emissions of shipping, regardless of whether the ship is engaged in an international or a domestic voyage, and it includes all ship types included in the Third IMO Greenhouse Gas Study 2014.

1.5 Methodology

The method for projecting emissions from shipping in this report is the same as those employed by the authors in the Third IMO Greenhouse Gas Study 2014. The method comprises five steps:

1. Establishing the historical relation between maritime transport work and relevant economic parameters such as world GDP (for transport for unitized cargo and non-coal dry bulk); crude oil consumption (for liquid bulk transport) and coal consumption (for coal transport).
2. Projecting transport work on the basis of the relations described above and long term projections of GDP and energy consumption.
3. Making a detailed description of the fleet and its activity in the base year 2012. This involves assigning the transport work to ship categories and establishing the average emissions for each ship in each category.
4. Projecting the fleet composition and energy efficiency of the ships based on a literature review and a stakeholder consultation.
5. Combining the results of Steps 2 and 4 above to project shipping emissions.

The update uses four years of additional transport work data in comparison with the Third IMO Greenhouse Gas Study 2014 as a result of which the relation between transport work and GDP, coal and oil consumption could be re-estimated.

The new transport work data also allowed a disaggregation of the transport work of unitized cargo into containers, which are predominantly transported on container ships, and other unitized cargo which may be transported on general cargo carriers, car carriers, roro cargo ships, et cetera. Both categories have developed in a distinct way which could not be captured in the Third IMO Greenhouse Gas Study 2014.

A final input that has been updated is the long/term economic and energy scenarios. The Third IMO Greenhouse Gas Study 2014 used RCP and SSP scenarios developed for the IPCC which at the time had not been published but of which preliminary versions were kindly provided by the researchers. The scenarios have been published in 2016 together with guidance on how they can best be used. This has led to minor changes in the projections but also to the development of two new climate change scenarios for shipping. In addition, the OECD long-term baseline projection has been used as a primary GDP projection.

A more detailed description of the methodology used is provided in Annex A.

1.6 Outline of the report

Chapter 2 presents the projections for transport demand. The emission projections for shipping in scenarios that are compatible with the goal of the Paris Agreement to limit the global average temperature increase to well below 2°C are contained in Chapter 3. Chapter 4 looks at the carbon intensity of maritime transport taking into account the 2030 and 2050 efficiency targets contained in the Initial IMO GHG Strategy. Chapter 5 concludes the report.

2 Transport Work Projections

2.1 Introduction

The Third IMO Greenhouse Gas Study 2014 presented four Business-as-Usual (BAU) scenarios which were at that time considered to be equally likely to occur since the differences between them reflected either inherent uncertainties about the future (e.g. economic development, demographics and technological development), or uncertainties related to policy choices outside the remit of the IMO (e.g. climate, energy efficiency or trade policies).

The BAU scenarios were based on Representative Concentration Pathways (RCPs) and Shared Socio-economic Pathways (SSPs) that had been developed for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). The RCPs have different climate outcomes and the SSPs show different socio-economic developments (see Section 2.3) for more details on RCPs and SSPs.

With the Paris Agreement, some RCPs are less likely to occur since several of them will not result in a global temperature rise of well below 2°C. In fact, only RCP2.6 will result in a temperature increase in line with the Paris Agreement objective while there is a possibility that RCP4.5 limits the temperature increase to 2°C, although a larger temperature increase is considered to be 'more likely than not' for this pathway.

2.2 The historical relation between transport demand, GDP and energy consumption

As a first step in the development of emission projections, the historical relation between transport demand, GDP and energy consumption is established. This requires extensive data analysis.

In the Third IMO GHG Study (IMO, 2015), transport projections to 2050 were made using historical data on seaborne trade for different cargo types from 1970 to 2012 provided by the United Nations Conference on Trade and Development (UNCTAD) as part of their annual 'Review of Maritime Transport', which had been produced since 1968. The originator of the data was Fearnleys.

For this present work, data from Clarksons were used because these provided better discrimination and more detail and included more cargo types and more comprehensive coverage. On the negative side, some of the data did not go back as far as the Fearnleys data.

To project ship transport work, an external driver of transport growth is used, so that if external projections of the predictor data (e.g. economic growth) are available from other scenarios, then the historical relationship between the transport work data and the driver of the growth of transport can be used to determine potential future transport work growth. This assumes that the relationship in the past is causative and remains the same in the future. For shipping there is the widely-based assumption that there is a causative relationship between global economic growth (GDP) and shipping transport (e.g. (Eyring, et al., 2005; Buhaug, et al., 2009; IMO, 2015; Corbett, et al., 2010; Valentine, et al., 2013;

UNCTAD, 2015)). For the years of full data availability from Clarksons (1999–2015) vs World Bank global GDP (constant 2005 US$), the R^2 value is 0.98.

For the purposes of projections, whilst fossil fuel transport (oil, coal and gas) may have a causative relationship with GDP, this is less satisfactory for climate policy scenarios, where a clear decoupling between GDP and fossil fuel usage is envisaged. Similar to the method used in (IMO, 2015), an alternative correlating variable of coal, oil and gas consumption is used for coal, oil and gas transport. One of the limiting factors is that such an alternative variable needs to be available in the independent climate scenarios. The RCP/SSP data provide different energy scenarios (see Section 2.3), which is broken down into energy types by EJ yr^{-1} used.

As in (IMO, 2015), we largely use a non-linear projection method. The sigmoid curve in these models mimics the historical evolution of many markets with three typical phases: emergence, inflexion (maturation), and saturation, where the period of expansion and contraction are equal with symmetrical emergent and saturation phases. The first phase involves accelerated growth; the second, approximately linear growth; and the third decelerated growth.

The exception to this modelling approach was the treatment of 'other unitized cargo'. The ratio of other unitized cargo to GDP shows a small decrease over time. Here, there is no justification for using a non-linear model, since it would imply a reverse sigmoid curve that declined to zero, for which there is no basis to assume such behavior. In the absence of any other evidence, a simple linear model has been assumed for this category, which accounted for 17% of emissions in 2012 (IMO, 2015). However, the R^2 value for such a model is only 0.406.

It is important to note that the method used to project the ratio between transport work and GDP assumes that the future will resemble the past. If the ratio is increasing rapidly — i.e. if there is no sign of maturing demand — it will continue to do so for a long time in the future before the ratio levels off. If, on the other hand, the demand deems mature and the ratio between transport work and GDP is constant, it will remain so in the future.

Figure 5 shows the historical and modelled growth ratios according to the non-linear models derived from the analysis for all seaborne trade types, other than the 'other unitized cargo' category, which has a linear model fitted for the reasons described above.

Figure 5 – Historical and modelled growth to 2050 for ratios of total oil, coal, non-coal bulk dry goods, total gas, chemicals and other unitized cargo to either consumption or GDP

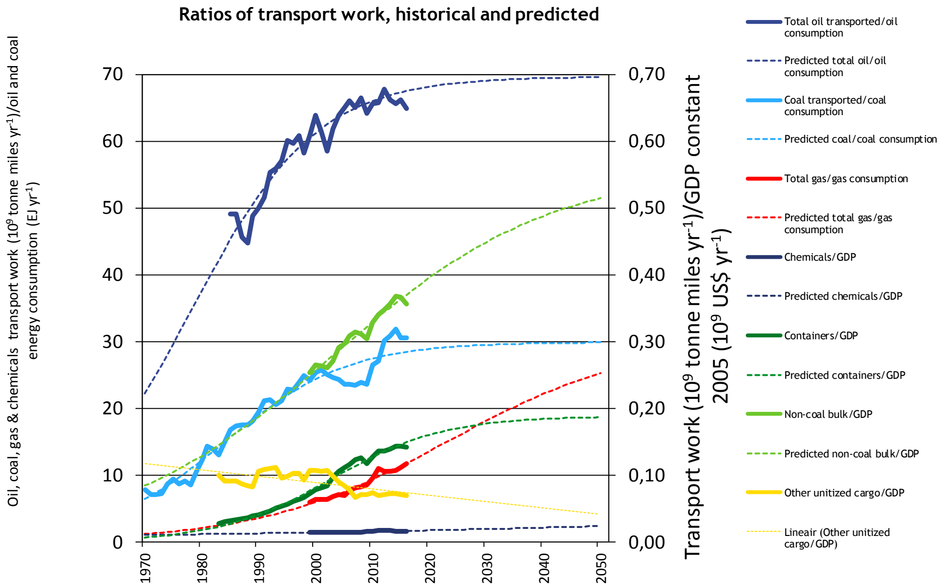


Figure 5 shows that future growth rates of total seaborne trade can be successfully modelled in a non-linear fashion, which according to economic literature is more realistic than the conventional linear model, for six different cargo types that clearly indicate different levels of market maturity, as modelled. This is a distinct advantage for the next step of assembling a simplified modelling system of future emissions. The next step is to multiply the modelled ratios for each transport type by the predictor variables (projected GDP; coal, oil and gas consumption) by scenario and combine with historical data.

2.3 Projections of GDP and energy consumption

Long term projections of transport work and emissions need to be based on scenarios for the future in order to account for the inherent uncertainty in the current knowledge about future developments. In climate research, long-term projections are especially needed because of the long-term nature of the phenomena studied. Consequently, the climate research community has long relied on scenarios.

Socio-economic and emission scenarios can be defined as 'descriptions of how the future may evolve with respect to a range of variables including socio-economic change, technological change, energy and land use, and emissions of greenhouse gases and air pollutants' (Vuuren, et al., 2011).

A large group of collaborating scientists from a large number of institutes in many countries has collaborated in the past decade to develop long term scenarios for assessing climate change and climate policies. They have developed two sets of scenarios:
1. A scenario set containing emission, concentration and land-use trajectories, called Representative Concentration Pathways (RCP).
2. A set of alternative futures of societal development known as the shared socioeconomic pathways (SSPs).

Four RCPs have been defined and five SSPs. They can be combined in different ways although not all combinations are plausible.

Projections of future transport work and emissions from shipping require both types of scenarios since an important share of maritime transport is transporting fossil fuels, which have different futures in different RCPs, while other shares are more closely linked to demographic and socio-economic developments which are reflected in the SSPs.

Table 1 presents the global mean surface temperature changes of the four RCPs. RCP2.6 projects a rapid energy transition away from fossil fuels towards renewables and nuclear energy. Insofar as fossil fuels continue to be used, they are increasingly combined with carbon capture and storage. In contrast, RCP8.5 relies heavily on fossil fuels and will lead to large increases in the global mean temperature by the end of the century. The other scenarios are in between these two extremes.

Table 1 - Global mean surface temperature changes relative to 1850-1900 in four RCPs

RCP	Mean temperature increase 2081-2100 (°C)	Likely range (°C)
RCP2.6	1.6	0.9-2.3
RCP4.5	2.4	1.7-3.2
RCP6.0	2.8	2.0-3.7
RCP8.5	4.2	3.2-5.4

Source: (IPCC, 2014). Adapted from table 2.1.

Note: The Likely range reflects 5-95% of model ranges.

Table 1 shows that only RCP2.6 is in line with the goal defined in the Paris Agreement to limit the increase in the 'global average temperature to well below 2°C above pre-industrial levels and (to) pursu(e) efforts to limit the temperature increase to 1.5°C above pre-industrial levels'. Consequently, we only consider the RCP2.6 scenarios to be relevant in this context for climate policy.

RCP2.6 can be combined with several SSPs, of which some characteristics are presented in Table 2. For reasons of completeness, the table contains all SSPs. Only SSP1, SSP2 and SSP4 can be combined with RCP2.6 (Riahi, et al., 2017). The other SSPs are too reliant on fossil fuel use to allow for a plausible combination with RCP2.6.

The development of the SSPs started before the recession of 2008 and their global GDP growth rates are higher than in many more recent projections. In all SSPs, growth rates in the next years are much higher than those currently projected by the OECD (and also by other institutions), as shown in Section 1.2, Figure 4. Only one — SSP3 called Regional Rivalry — has a compound growth equal to the latest OECD projections, although its storyline — a reversal of the trade liberalisation of the 1990s — starting out much higher but being less benign for growth over the future period than the OECD storyline, which assumes ongoing liberalisation (OECD, 2018).

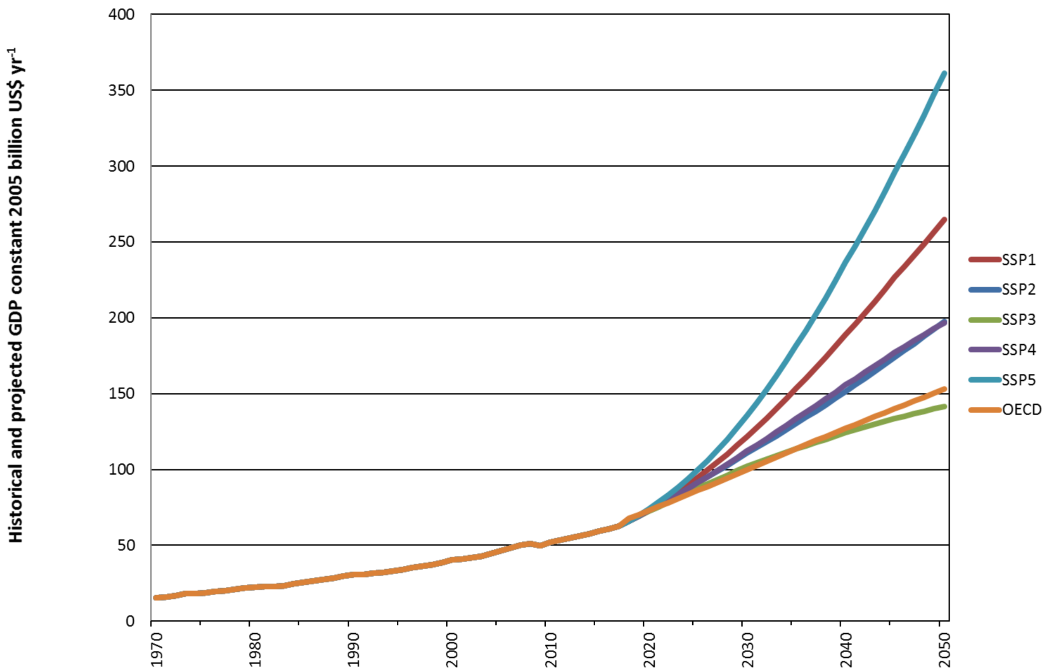
Still, the SSPs should not be discarded completely, mainly because they share some assumptions and storylines with RCPs. For that reason, this study has chosen to base its conclusion on a trade demand projection modelled on the most recent OECD long-term baseline projection (OECD, 2018) in addition to the lowest SSP/RCP2.6 combinations.

Table 2 - Long term economic scenarios

Shared socio-economic pathway	Economic development	Consumption patterns	Energy and resources	GDP increase 2005-2050
SSP1: Sustainability	Connected markets, regional production	Low growth in material consumption	Efficiency and renewables	500%
SSP2: Middle of the Road	Semi-open globalized economy	Material-intensive consumption	Fossil fuels and renewables	300%
SSP3: Regional Rivalry	De-globalizing economy	Material-intensive consumption	Preference for domestic energy sources	200%
SSP4: Inequality	Globally connected elites	Unequal consumption patterns	Efficiency and low-carbon resources	300%
SSP5: Fossil fuelled development	Strongly globalised economy	Materialism and status consumption	Unconstrained fossil fuels	700%
OECD Long-term baseline projections July 2018	n.a.	n.a.	n.a.	200%

Source: Bauer et al., 2016. GDP increase as calculated by OECD; OECD 2018.

Figure 6 - Historical and projected GDP



Source: Bauer et al., 2016. GDP increase as calculated by OECD; OECD 2018.

Because SSP1 and 5 show much higher growth rates both in the near and the long term than more recent projections, this study attaches less value to them than to the other SSPs and the OECD scenario.

2.4 Transport work projections

This section presents the projections of transport work for the different cargoes included in this study. Figure 7 shows projections for transport of oil, coal and gas based on energy consumption projections in the RCP2.6 scenarios. Figure 8 shows projections for the other cargoes based on GDP projections in the three SSP scenarios that can be combined with RCP2.6.

Figure 7 - Historical and projected work to 2050 for coal, oil and gas in RCP2.6 scenarios

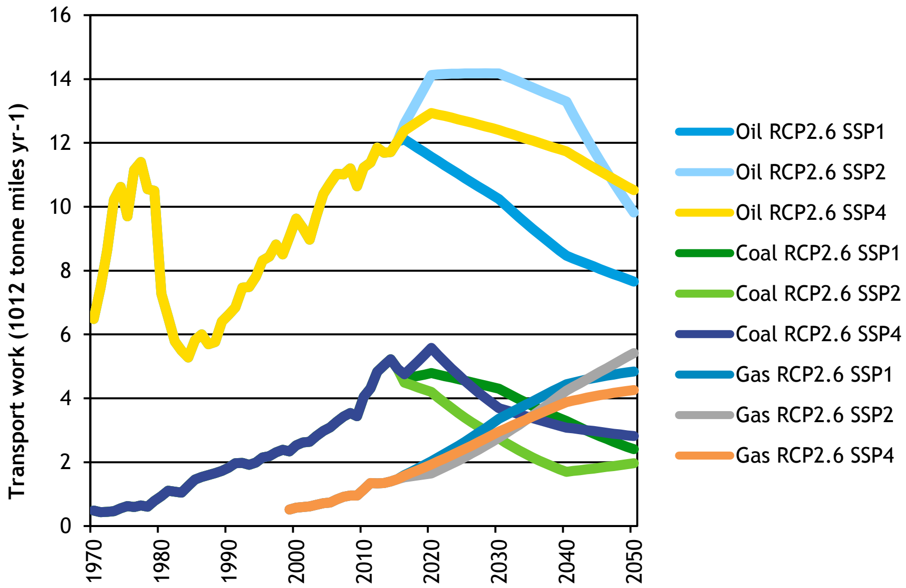
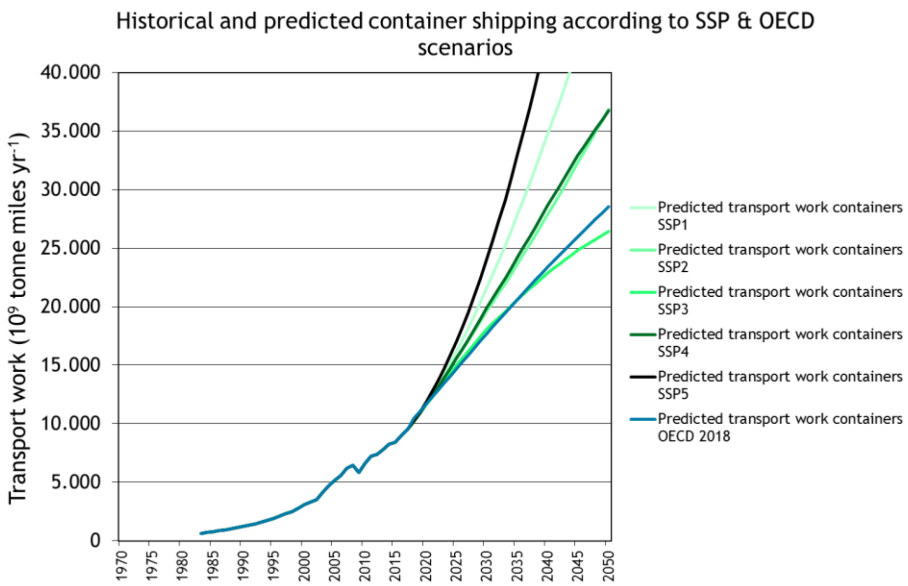


Figure 8 - Historical and projected transport work for containers



Note: As shown in Section 2.3, SSP1 and SSP5 have very high projections of economic growth and are therefore given less prominence in this report.

3 Emission projections

3.1 Introduction

The Third IMO Greenhouse Gas Study 2014 contained two sets of scenarios:

1. A set which assumed that the IMO would not adopt any additional efficiency measures, as a result of which the operational efficiency for each ship category would be 40% better in 2050 than it was in 2012.
2. A set which assumed that the IMO would adopt additional efficiency measures, as a result of which the operational efficiency would improve by 60%.

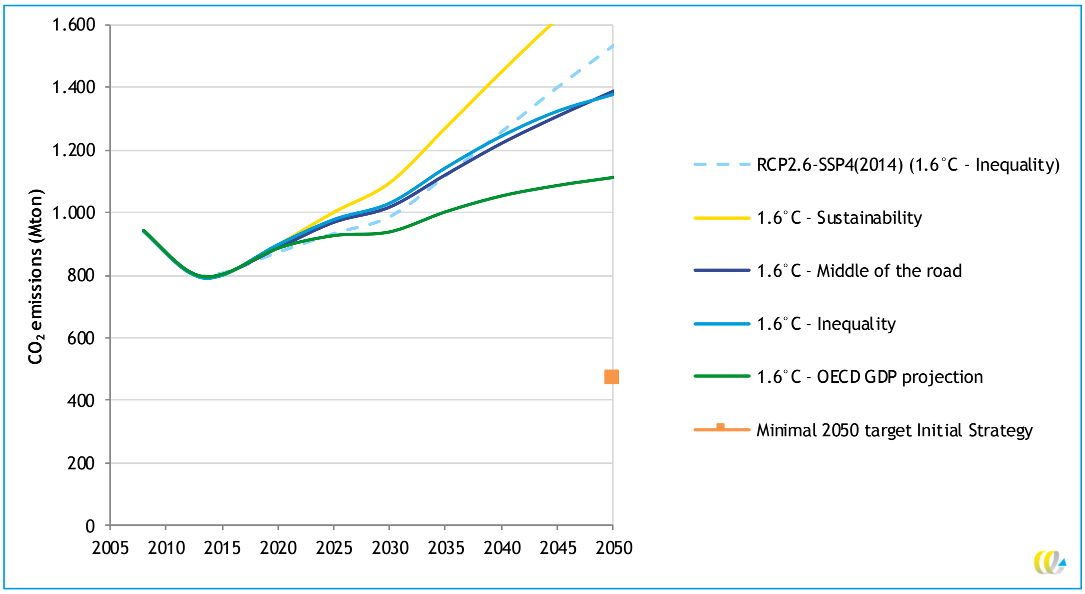
The Initial Strategy has as one of its ambitions to pursue efforts to 'reduce CO_2 emissions per transport work, as an average across international shipping, by towards 70% by 2050, compared to 2008'. Because of their relevance to the Initial Strategy, this report contains both BAU and High Efficiency projections.

In the remainder of this Chapter, Section 3.2 presents both BAU and High Efficiency emission projections. Section 3.3 analyses the impacts of projected developments of speed and fuel prices, while Section 3.4 analyses the sensitivity of the projections to different energy transition scenarios. Section 3.5 concludes.

3.2 BAU and High Efficiency emission projections

Figure 9 shows the CO_2 emission projections of shipping in the four scenarios that are in line with the Paris Agreement temperature goal. All of these scenarios assume that the IMO will not adopt further efficiency measures and can therefore be considered business-as-usual scenarios. For comparison, the sole corresponding scenario from the Third IMO Greenhouse Gas Study 2014 has also been included as a dashed line. This original 2014 projection was based on the same GDP and fuel projections as the new 1.6°C – Inequality scenario. Depending on the economic developments, the emissions will increase by 20 to 50% compared to 2008. For comparison, the one projection from the Third IMO Greenhouse Gas Study 2014, based on the same energy — and economic scenario as 1.6°C — inequality, showed that CO_2 emissions would increase by 90%. (Note that the bend in the curves around 2030 is the result of efficiency improvements slowing down).

Figure 9 – CO_2 emission projections of shipping in four 1.6°C BAU scenarios



Source: CE Delft.

Note: The names of the scenario are derived from the temperature increase above pre-industrial levels as well as the names given to the SSP scenarios by their authors ('sustainability', 'middle of the road' and 'inequality').

Note: As shown in Section 2.3, SSP1 has a very high projections of economic growth and is therefore given less prominence in this report.

In a scenarios with moderate economic growth (OECD, 2018), the overall emissions will increase by 20% over 2008 levels by 2050, as is shown in Figure 9. With lower economic growth, emissions of container ships and dry bulk carriers will increase by around 60%, but the emissions of other unitized ships will decrease.

Figure 10 – CO_2 emission projections of different ship types in the 1.6°C OECD GDP scenario

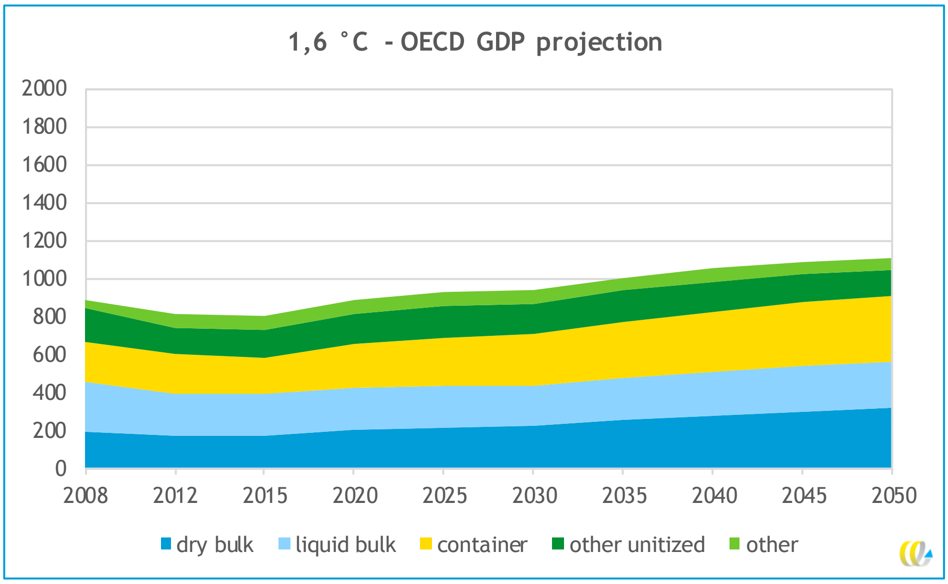
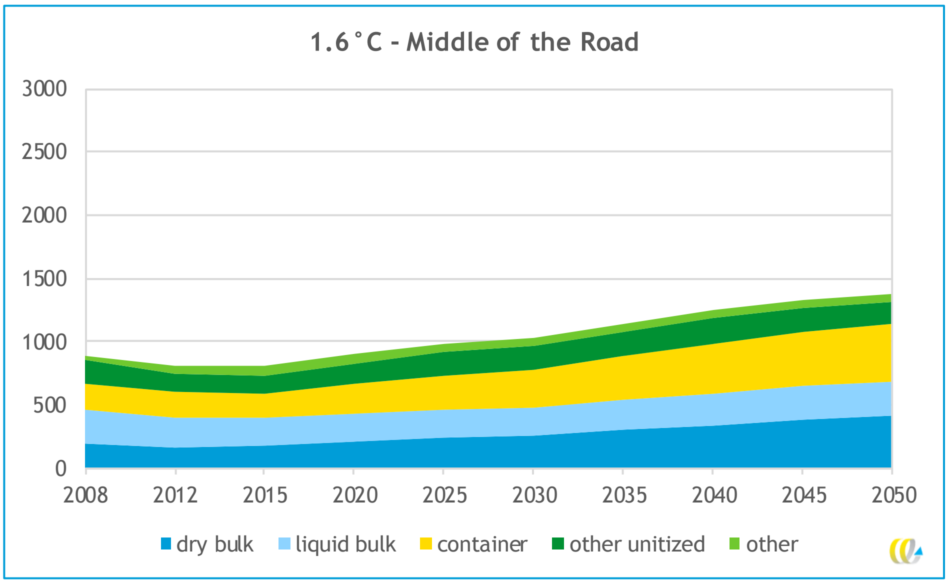


Figure 11 show the BAU emission projections broken down to different ship types in the 1.6˚C – Middle of the Road scenario. In this scenario with relatively high economic growth the overall emissions will increase by almost 50% in the period up to 2050, relative to 2008 levels. This increase is mainly the result of increases in emissions of containerships (more than 110% higher) and dry bulk carriers (100%). The historical data analysis has shown that transport demand for unitized cargo and non-coal dry bulk are well correlated with GDP. In case of bulk carriers, the lower demand for coal transport is more than compensated by an increase in demand for the transport of ores, grains and other dry bulk cargoes.
In contrast, the emissions from tankers stay at the same level because increased emissions of gas carriers and chemical tankers cannot make up for the loss of emissions from oil transport.

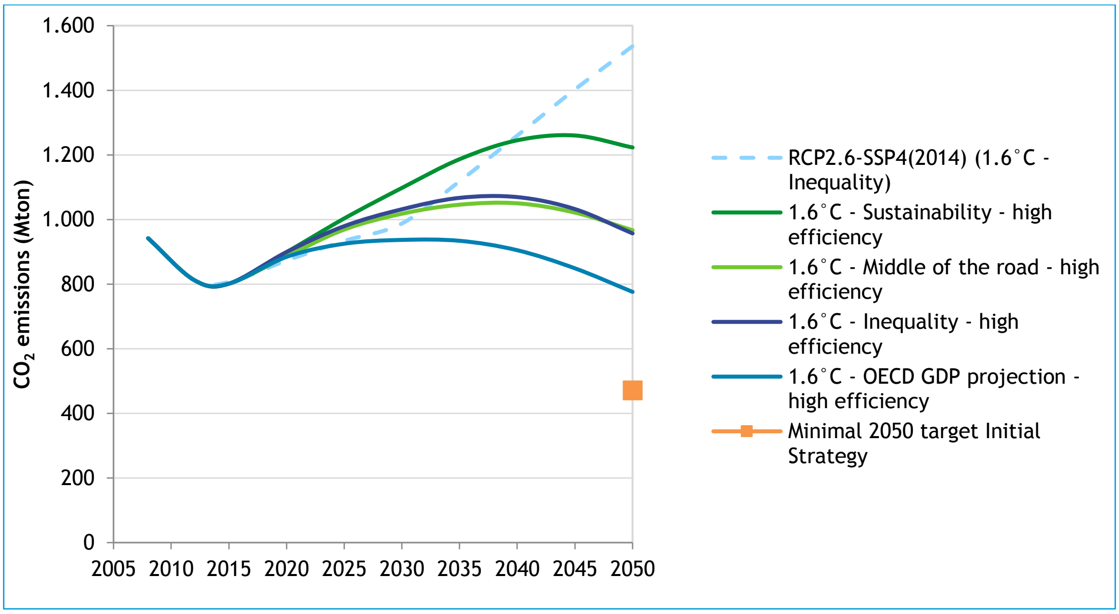
Figure 11 – CO_2 emission projections of different ship types in the 1.6˚C Middle of the Road scenario



Source: CE Delft.

If the efficiency of international shipping develops in line with the efficiency target of the Initial Strategy, i.e. towards a 70% improvement in 2050 relative to 2008 levels, the CO_2 emissions will, depending on trade demand, peak between 2030 and 2040 and decline thereafter to between 2008 levels or 20% below (see Figure 12).

Figure 12 – CO_2 emission projections of shipping in four 1.6°C High Efficiency scenarios

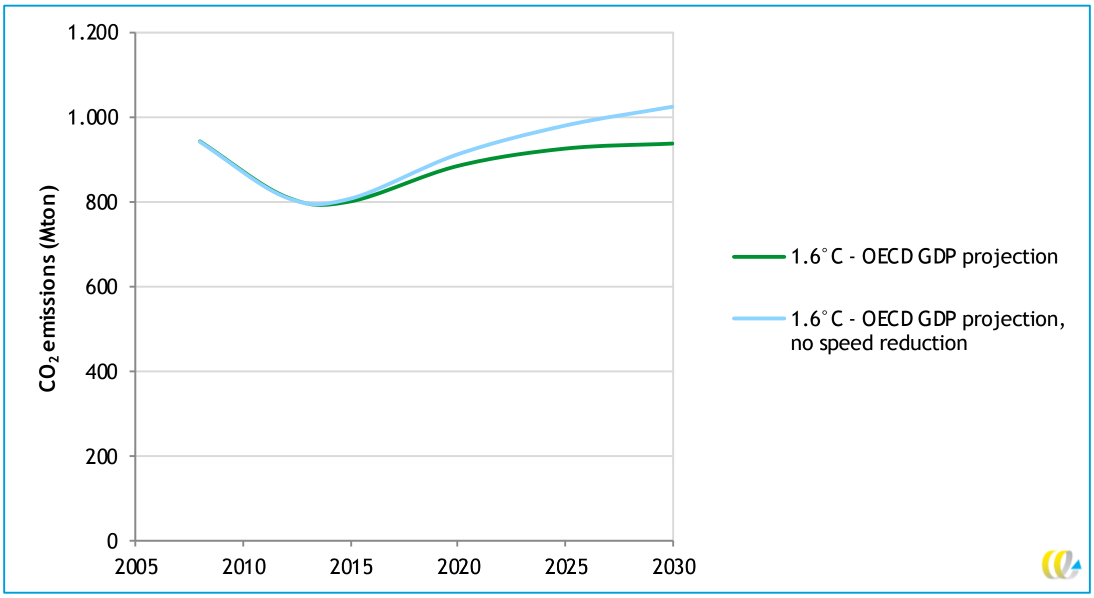


3.3 The impacts of assumptions on speed and fuel prices

Based on cost-effectiveness analyses, the model indicates that most ships will decrease their speed relative to 2012 levels by a further 10-20%, whereas the available evidence so far shows that speeds are more or less constant (see Annex A). Because many ships (even new ships) are designed to be able to sail at higher speeds than they currently do, the Third IMO Greenhouse Gas Study 2014 refers to ‘latent emission increases’.

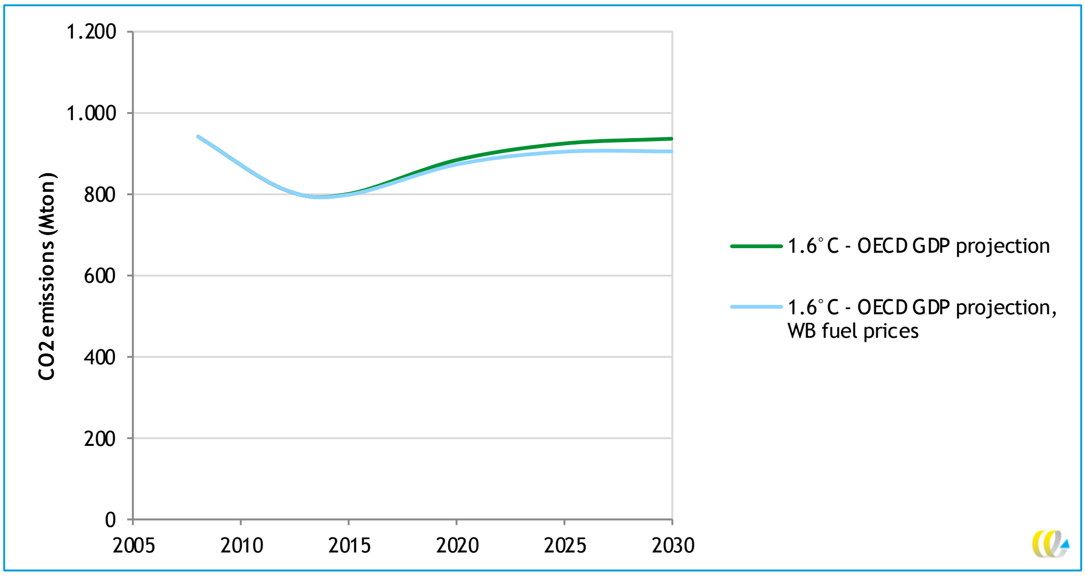
Figure 13 compares a scenario with and without market-driven speed reduction. When speeds are constant at their 2012 level, emissions are projected to be about 10% higher in 2030 than when they are reduced further. Note that this analysis can only be done for the period up to 2030 because of model constraints.

Figure 13 - The impact of speed on emission projections



The SSP and RCP scenarios have assumptions about crude oil prices that are low compared to the current oil prices. For example, in RCP2.6 (the scenario underlying the 1.6°C projections), oil prices are projected to stay more or less constant at around USD 35 per barrel. We have also calculated a scenario where these values have been replaced by the latest projections of the World Bank, in which prices increase to USD 70 per barrel in 2030. Higher fuel prices result in more measures becoming cost-effective and therefore gradually implemented in the fleet. Figure 14 shows that the impact of fuel price assumptions is modest in comparison to the impact of assumptions on speed (a 3% reduction in 2030 in this example).

Figure 14 - The impact of fuel prices on emission projections



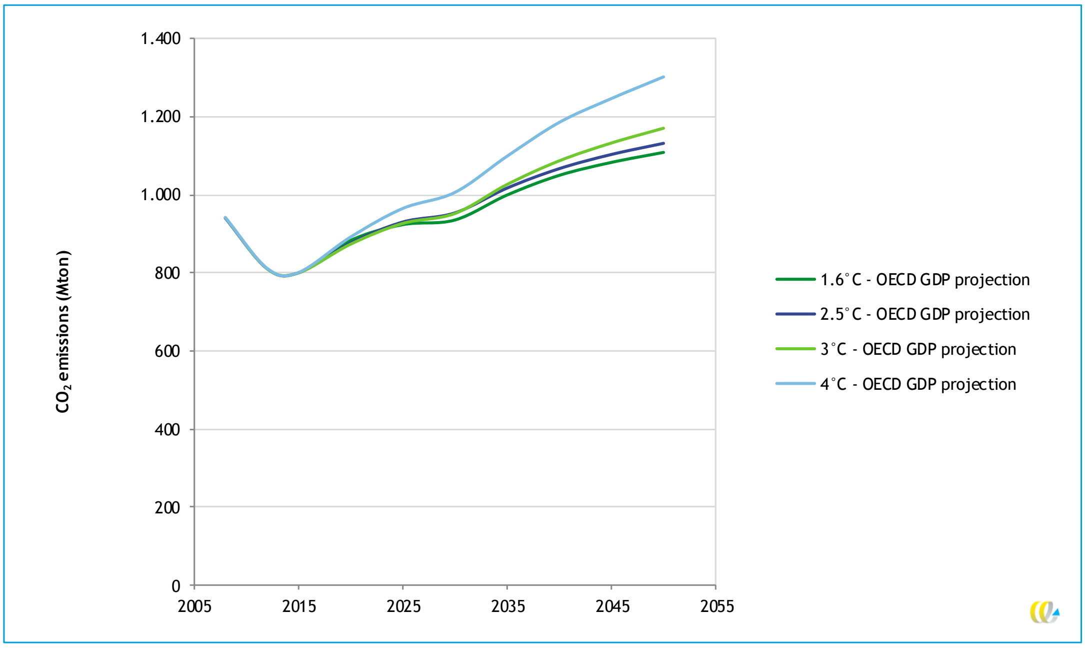
3.4 The impacts of energy transition scenarios on emissions

A significant share of maritime transport work is assigned to transport of fossil fuels. As the energy mix changes, demand for this kind of transport will change as well. The various RCPs offer projections of future energy use, and as can be inferred from Section 2.4, Figure 7, they vary as a result of different assumptions about the use of technologies (for example, some scenarios assume a continues use of coal in combination with carbon capture and storage, while others assume a more radical transition to renewable energies).

In most projections, the share of fossil-fuel transport decreases and the share of other commodities increases. Because the latter are linked to GDP growth, the choice of a GDP scenario has a larger impact on emissions than the choice of an energy scenario.

Figure 15 shows that emissions may be some 70 Mt higher in 2030 and 190 Mt in 2050 in scenarios that project an increase in fossil fuel use, compared to scenarios that are in line with the Paris Agreement goals.

Figure 15 - Emission projections in various RCP scenarios



3.5 Conclusions

When the world is on a course towards a temperature increase of well below 2°C, the energy mix is changed accordingly and the economic developments are commensurate with this goal, shipping emissions are projected to increase by 20-50% between 2008 and 2050 in the BAU scenarios. The difference between the projections reflects the uncertainty about the economic development. Higher global GDP growth is likely to coincide with higher transport demand growth, especially for containers and dry bulk, and consequently higher shipping emissions. Recent projections of GDP growth are more in line with the lower emission projections than with the high growth scenarios.

If the efficiency of the fleet increases by 70% in 2050, relative to 2008, the emissions may decrease by up to 20% in the period 2008 to 2050 depending on economic growth — but this is not sufficient to meet the 2050 level of ambition of the Initial IMO Strategy on Reduction of GHG Emissions from Ships.

If ships maintain their 2012 average speeds, emissions may increase more than projected. Fuel prices have a limited impact on emission projections.

4 Efficiency projection

4.1 Introduction

The Initial IMO Strategy on Reduction of GHG Emissions from Ships has expressed as one of the ambitions to improve the efficiency of shipping by 40% in 2030 compared to 2008. This chapter analyses how the efficiency of the fleet will develop under BAU conditions until 2030.

The Initial IMO Strategy on Reduction of GHG Emissions from Ships does not define the indicator of efficiency. One possibility is that it will be expressed as fleet-average EEOI, i.e. CO_2 emissions per tonne-mile of transport work. This would require the IMO to combine data from different sources. The IMO has set up a data collection system which will collect information on fuel use and CO_2 emissions but not tonne-miles. These tonne-mile estimates can be sourced externally.

A second option is that the IMO will use one of the metrics it will consider in the so-called three step approach. Of these metrics, the so-called Annual Efficiency Ratio (AER) may be best suited to express the efficiency of transport work on a fleet-wide basis. It shows the efficiency of the supply of transport work: the average emissions per deadweight-tonne mile. All relevant data for calculating this efficiency metric will be available in the data collection system, so the IMO will have an internally consistent and verified dataset that contains all relevant data to calculate the metric.

4.2 BAU projections of carbon intensity

Figure 16 shows the projected carbon intensity of shipping, expressed as fleet-average EEOI. It improved by approximately 30% between 2008 and 2012 and is projected to improve by 50-55% by 2030, depending on whether ships will slow down further or not (see Section 2.2). Hence, choosing this metric would render the Initial Strategy's 2030 level of ambition unambitious.

Figure 16 – BAU development of fleet average EEOI

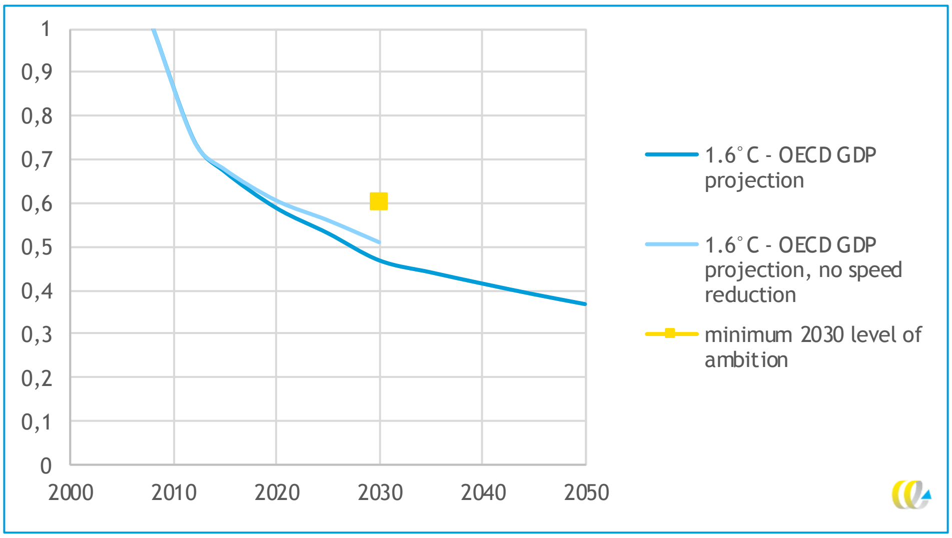
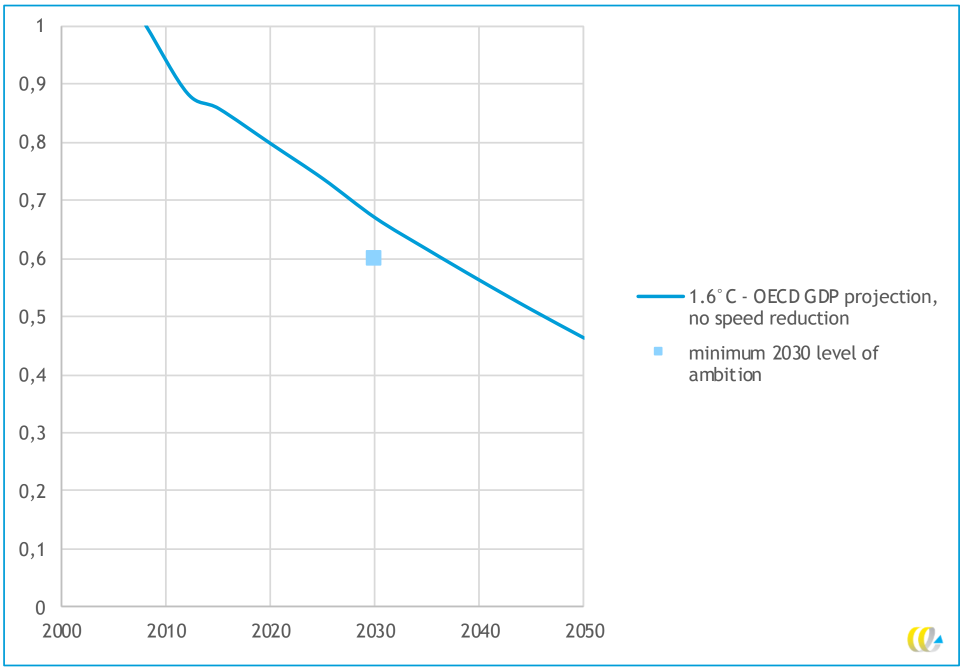


Figure 17 shows the development of the fleet-average AER. It could only be calculated for the scenario without speed reduction. Measured in this way, the carbon intensity improved by approximately 12% between 2008 and 2012 and is projected to improve by 33% by 2030. This would imply that the efficiency of international shipping has to improve by a further 7% to meet the 2030 level of ambition, which, in that case, would be beyond BAU.

Figure 17 – BAU development of fleet average AER



4.3 Conclusions

The carbon intensity of both supply and demand of maritime shipping improved considerably between 2008 and 2012, mainly as a result of ships lowering their speed. In the coming decades, the carbon intensity is projected to improve further as a result of an increase in the average size of ships, fleet renewal and retrofits of cost-effective technologies.

The carbon intensity of the *demand* for maritime transport (i.e. expressed as emissions per unit of transport work performed) will overshoot the 2030 level of ambition in each business as usual projection analysed in this report. This would render the Initial Strategy's 2030 level of ambition unambitious.

The carbon intensity of the *supply* of maritime transport (i.e. expressed as emissions per deadweight tonne-mile offered) will fall 7% short of the 2030 level of ambition, thus necessitating the need to implement additional measures to improve the carbon intensity of shipping, in line with the Initial Strategy.

5 Conclusions

This report presents an update of the emissions projections for shipping that were published in the Third IMO Greenhouse Gas Study 2014. The update has been made with the same methodology as the previous projections, but the data inputs have changed in two important aspects. First, four additional years of transport work data have been added which showed a continuation of the deceleration of the transport demand growth rates and led to a different assessment of the maturity of the demand. Second, the new data source has more comprehensive coverage and a greater level of disaggregation. This has enabled splitting unitized cargo in container shipping and other unitized transport.

The Third IMO Greenhouse Gas Study 2014 used economic scenarios developed by the IPCC (Intergovernmental Panel on Climate Change) to develop long-term projections of transport demand. Most of these scenarios have much higher global economic growth rates than scenarios that have recently been developed by other institutions. For that reason, this report also includes projections that use GDP projections from the OECD. Since these OECD projections incorporate the latest economic developments and outlooks, this report gives them greater emphasis.

The new BAU projections show increases in CO_2 emissions of 20-50% over 2008 levels, when the transport of fossil fuels is reduced in line with the temperature goals of the Paris Agreement. The difference between these scenarios is caused by differences in economic growth projections. Higher economic growth results in higher growth rates for most cargoes, except for fossil fuels.

The BAU projections assume that ships will on average sail at lower speeds than in 2012. If they don't, emissions will be higher.

Even when the efficiency of the fleet improves in line with the levels of ambition in the Initial IMO Strategy on Reduction of GHG Emissions from Ships, i.e. by 70% in 2050 compared to 2008, the level of ambition on absolute emissions will be missed: shipping emissions will not decrease by at least 50% relative to 2008 values. Hence, in addition to traditional efficiency measures, other means are required to reduce emissions. Such means could be new technologies and low- or zero-carbon fuels. Additional regulatory measures to assist application of these means may be needed.

6 References

BRS, 2013. *2013 Annual Review : Shipping and Shipbuilding Markets,* Paris: Barry Rogliano Salles (BRS).

Buhaug, Ø., Corbett, J., Endresen, Ø. & et al., 2009. *Second IMO Study 2009,* London: IMO.

Clarksons Research, ongoing. *World Fleet Register (shipping on-line systems) : data 1999-2015,* s.l.: Clarkson Research Services Limited.

ContPort Consult, 2013. Are the terminals ready for ULCVs – indeed they are!. *News from DNV to the container ship industry no.1.*

Corbett, J. et al., 2010. Arctic shipping emissions inventories and future scenarios. *Atmospheric Chemistry and Physics.,* Volume 10, pp. 9689-9704.

Eide, M. et al., 2007. *Report for EC Quantify project, Deliverable D1.2.3.2: Ship emissions of the future,* s.l.: Det Norske Veritas.

Eyring, V., Köhler, H., Lauer, A. & Lepmer, B., 2005. Emissions from international shipping: 2. Impact of future technologies on scenarios until 2050. *Journal of Geophysical Research,* Issue D17306.

ICCT, 2017. *Greenhouse gas emissions from global shipping, 2013-2015,* Washington: International Council on Clean Transportation (ICCT).

IMO, 2015. *Third IMO Greenhouse Gas Study 2014 : Safe, secure and efficient shipping on clean oceans,* London: International Maritime Organization (IMO).

IPCC, 1999. *IPCC special report : aviation and the global atmoshere,* sl: IPCC.

IPCC, 2014. *Climate change 2014: Synthesis report. Contribution of working groups I, II and III to the Fifth Assessment Report* , Geneva: Intergovernmental Panel on Climate Change (IPCC).

Jarne, G., Sánchez-Chóliz, J. & Fatás-Villafranca, F., 2005. The Logistc and Gompertz curves generalized. *The Electronic Journal of Evolutionary Modeling and Economic Dynamics,* 2005(1048).

OECD, 2018. *The long view : scenarios for the world economy to 2060.* [Online]
Available at: https://www.oecd-ilibrary.org/docserver/b4f4e03e-en.pdf?expires=1547730680&id=id&accname=guest&checksum=7CD535A3563C9848A946F6400C04358C
[Accessed 2018].

O'Neill, B. C. et al., 2107. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change,* Volume 42, pp. 169-180.

Owen, B., Lee, D. & Lim, L., 2010. Flying into the future: aviation emission scenarios to 2050. *Environmental Science and Technology,* Issue 44, pp. 2255-2260.

Riahi, K. et al., 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change,* 42(Januari), pp. 153-168.

Stopford, M., 2009. *Maritime Econmics*. 3rd ed. London: Taylor & Francis.

U.S. Dot, 2013. *Panama Canal Expansion Study : Phase I report: Developments in Trade and National and Global Economics,* s.l.: U.S. Department of Transportation (U.S. Dot), Maritime Administration.

UNCTAD, 2015. *Review of martime transport 2015,* Geneva: United Nations Conference on Trade And Development (UNCTAD).

UNFCCC, 2015. *Paris Agreement*. [Online]
Available at:
http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf
[Geopend 2017].

Valentine, V., Benamara, H. & Hoffman, J., 2013. Maritime transport and international seaborne trade. *Martime Policy & Management,* 40(3), pp. 226-242.

Vuuren, D. P. v. et al., 2011. RCP2.6: exploring the possibility to keep global mean temperature increase below 2°C. *Climatic Change,* Volume 109, pp. 95-116.

A Description of the emissions model and input assumptions

A.1 Introduction

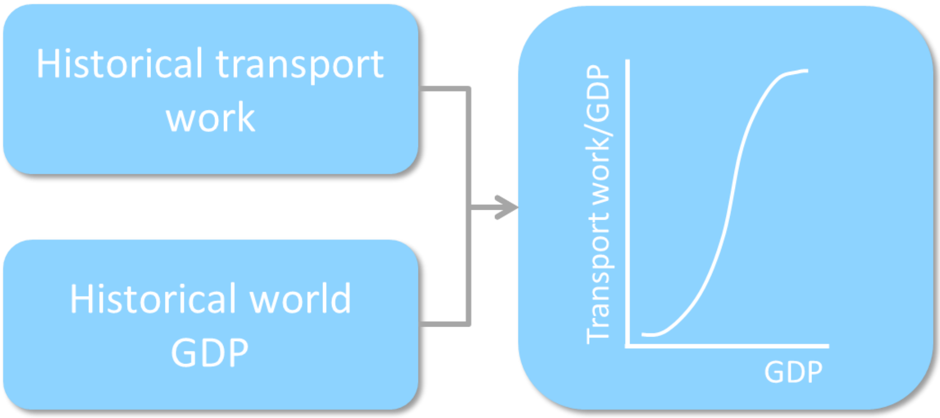
The method for projecting emissions from shipping in this report is the same as those employed by the authors in the Third IMO Greenhouse Gas Study 2014. The method comprises five steps:
1. Establishing the historical relation between maritime transport work and relevant economic parameters such as world GDP (for transport for unitized cargo and non-coal dry bulk); crude oil consumption (for liquid bulk transport) and coal consumption (for coal transport).
2. Projecting transport work on the basis of the relations described above and long term projections of GDP and energy consumption.
3. Making a detailed description of the fleet and its activity in the base year 2012. This involves assigning the transport work to ship categories and establishing the average emissions for each ship in each category.
4. Projecting the fleet composition and energy efficiency of the ships based on a literature review and a stakeholder consultation.
5. Combining the results of Steps 2 and 4 above to project shipping emissions.

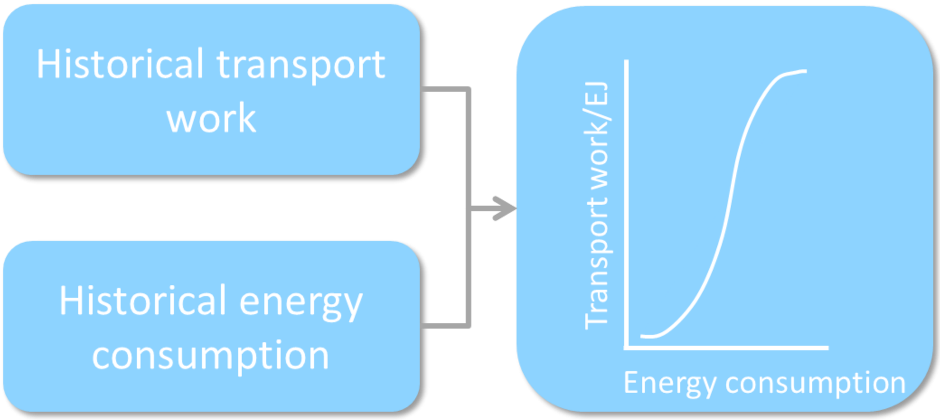
Each of these steps is described in detail in subsequent sections.

A.2 The historical relation between maritime transport work and relevant economic parameters

The first step of the emissions model is the establishment of the historical relation between maritime transport work and relevant economic parameters such as world GDP (for transport for unitized cargo and non-coal dry bulk); crude oil consumption (for liquid bulk transport) and coal consumption (for coal transport) (see Figure 18).

Figure 18 - Establishing the historical relation between transport work and GDP or energy consumption





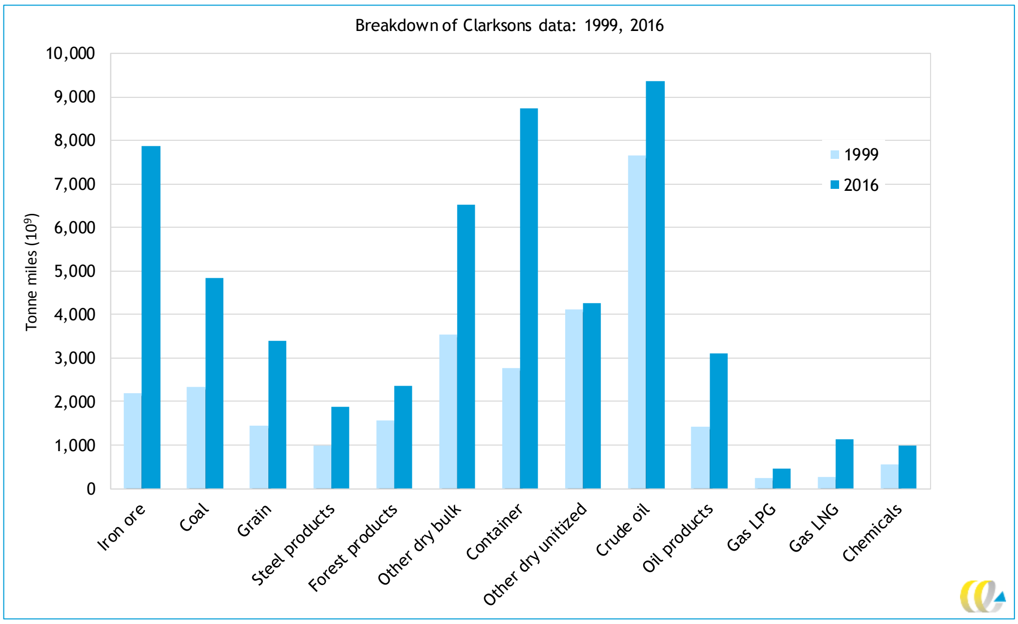
In the Third IMO GHG Study (IMO, 2015), transport projections to 2050 were made using historical data on seaborne trade for different cargo types from 1970 to 2012 provided by the United Nations Conference on Trade and Development (UNCTAD) as part of their annual 'Review of Maritime Transport', which has been produced since 1968. The originator of the data was Fearnleys. The data used in the Third IMO GHG Study included the following cargo types: crude oil, other oil products, iron ore, coal, grain, bauxite and aluminia, phosphate, other dry cargos. These categories were combined to represent different ship types in the following ways: total oil, coal, total (non-coal) bulk dry goods, total dry goods.
These groupings of seaborne trade approximate to three different ship types of, tankers, bulk raw material ships, container (and other) ships but discriminating between fossil-fuel transport and non-fossil fuel transport.

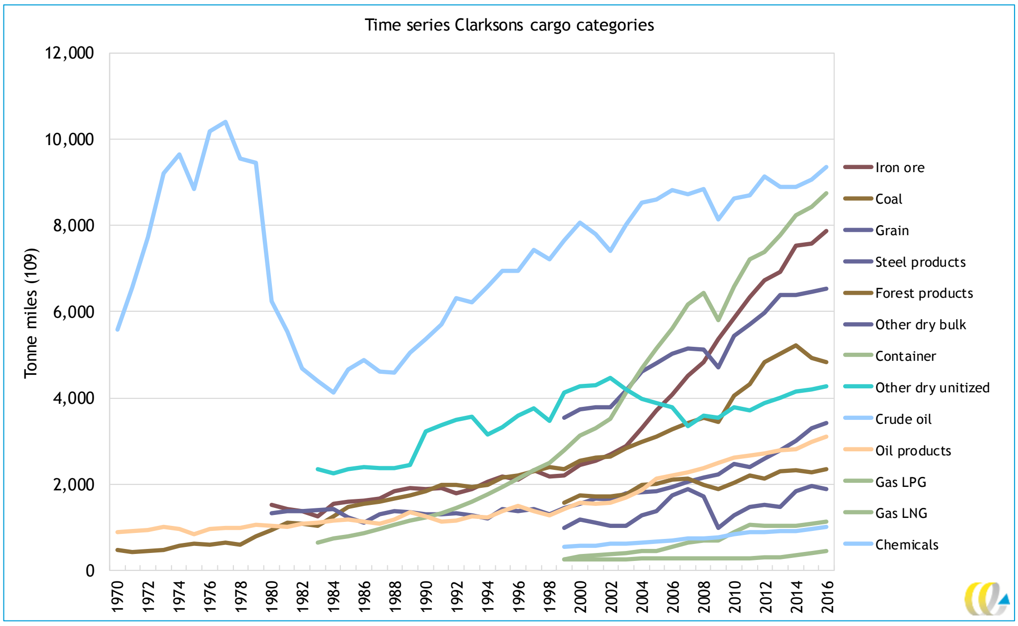
For this present work, data from Clarksons were used and the categories provided did not map exactly to the Fearnleys data, but provided better discrimination and more detail. On the negative side, some of the data did not go back as far as the Fearnleys data.

Extensive efforts were made to examine the two data sources for comparability and compatibility. After analysis and discussion with BIMCO and the data providers themselves, it was decided to use the Clarksons data, which whilst not dating back as far as Fearnleys for some cargo types, were more recent and the advantages of being up to date and providing better discrimination between cargo types outweighed the disadvantages.

The categories provided were: iron ore, coal, grain, steel products, forest products, other dry bulk cargos, containers, other dry unitized cargos, crude oil, oil products, gas LPG, gas LNG, and chemicals. These categories were not available over a uniform period but had varying lengths of data availability. A breakdown in terms of transport work (billion tonne miles) for 2016 is shown in Figure 19(a) and compared with 1999, which was the first year that data on all cargo types was available. Figure 19(b) also shows the development over time, which also indicates the length of time that the various categories were available.

Figure 19 - Breakdown of Clarksons cargo types, 1999 and 2016 (upper panel, a) and time series of data (lower panel, b)





Total seaborne trade between 1999 and 2016, as shown in Figure 19(a) nearly doubled (increase of factor 1.9). The cargo types that showed the largest factor increases were iron ore (3.6), containers (3.2) and LNG gas (4.3).

Basic methodology and assumptions

To project ship transport work, an external driver of transport growth is used, so that if external projections of the predictor data (e.g. economic growth) are available from other scenarios, then the historical relationship between the transport work data and the driver of the growth of transport can be used to determine potential future transport work growth. This assumes that the relationship in the past is causative and remains the same in the future. For shipping there is the widely-based assumption that there is a causative relationship between global economic growth (GDP) and shipping transport (e.g. (Eyring, et al., 2005; Buhaug, et al., 2009; IMO, 2015; Corbett, et al., 2010; Valentine, et al., 2013; UNCTAD, 2015)). For the years of full data availability from Clarksons (1999–2015) (Clarksons Research, ongoing) vs World Bank global GDP (constant 2005 US$), the R^2 value is 0.98.

For the purposes of projections, whilst fossil fuel transport (oil, coal and gas) may have a causative relationship with GDP, this is less satisfactory for climate policy scenarios, where a clear decoupling between GDP and fossil fuel usage is envisaged. Similar to the method used in (IMO, 2015), an alternative correlating variable of coal, oil and gas consumption is used for coal, oil and gas transport. One of the limiting factors is that such an alternative variable needs to be available in the independent climate scenarios. The RCP/SSP data provide different energy scenarios, which is broken down into energy types by EJ yr^{-1} used. For oil, this is relatively straightforward, given that large amounts of the world's crude oil and derivatives (67% in 2015) are transported by ships. For coal and gas, evidently the proportions carried by ships is less, calculated here to be 21 and 13%, respectively in 2015, using the Clarksons data and BP Statistical data. Nonetheless, the R^2 value in all cases between consumption and transport work data are > 0.9, allowing energy projections to be used.

Grouping of cargo data and ship types

The 13 cargo types from the Clarksons data were grouped to retain clarity on ship types but also allowing consideration of the different historical growth rates apparent from the data into seven types as following: coal; total oil products (crude oil plus oil products); chemicals; total gas (LPG plus LNG); non-coal bulk (sum of iron ore, grain, steel products, forestry products, other dry bulk); containers; other unitized dry cargos.

Figure 20 - Transport work for all grouped categories of cargo provided in billion tonne-mil, also illustrated with global GDP (right hand axis) in billion US$ (constant 2005 prices)

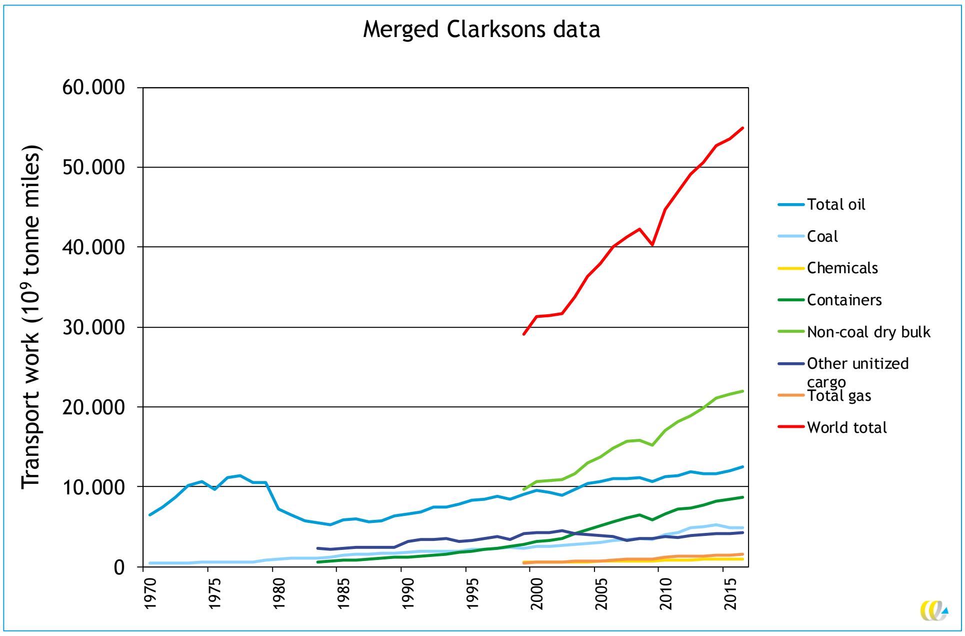
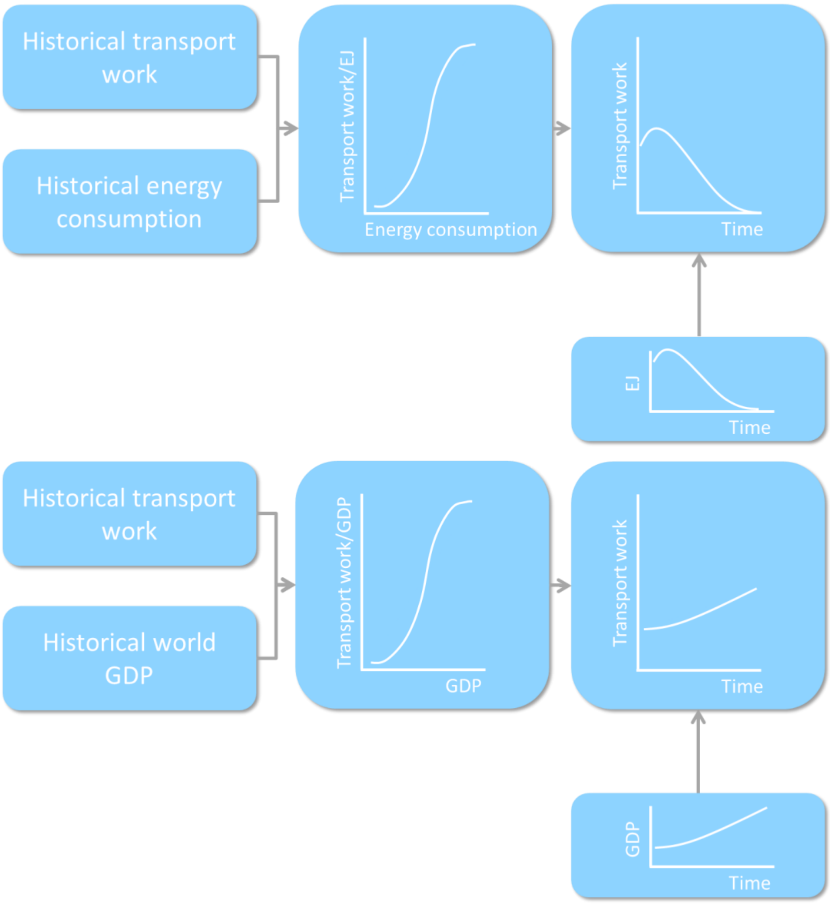


Figure 20 shows the groupings of data over time periods possible, because of different start dates of data collection. These groupings of time-series data were then used in the analysis to derive projections. The only exception in terms of data screening was the total oil data, where data prior to 1985 were excluded (as has been similar in other studies, (e.g. ((Eyring, et al., 2005; Eide, et al., 2007; Buhaug, et al., 2009)). There is a large excursion of the total oil data over the period 1970 to 1985, which was driven by political and economic factors, some of which are connected with the political situation over oil prices during this period. Moreover, the tanker sector was extremely volatile over this period (Stopford, 2009), with an over-supply of ships that in some cases led to ships being scrapped straight after being produced, and some being laid up uncompleted. The volatile situation in the Middle East also led to avoidance of the Suez Canal, and ships also increased dramatically in size such that the Panama Canal became un-navigable for some ships. Therefore, the period 1970 to 1985 is known to have a particular explicable data excursion for tonne-miles of total oil data, and these data were excluded from the analysis.

A.3 Projecting transport work

The second step in the mission projections is to use the historical relation between transport work and its drivers, in combination with projections of GDP and energy use, to project transport work into the future.

Figure 21 – Projecting transport work into the future



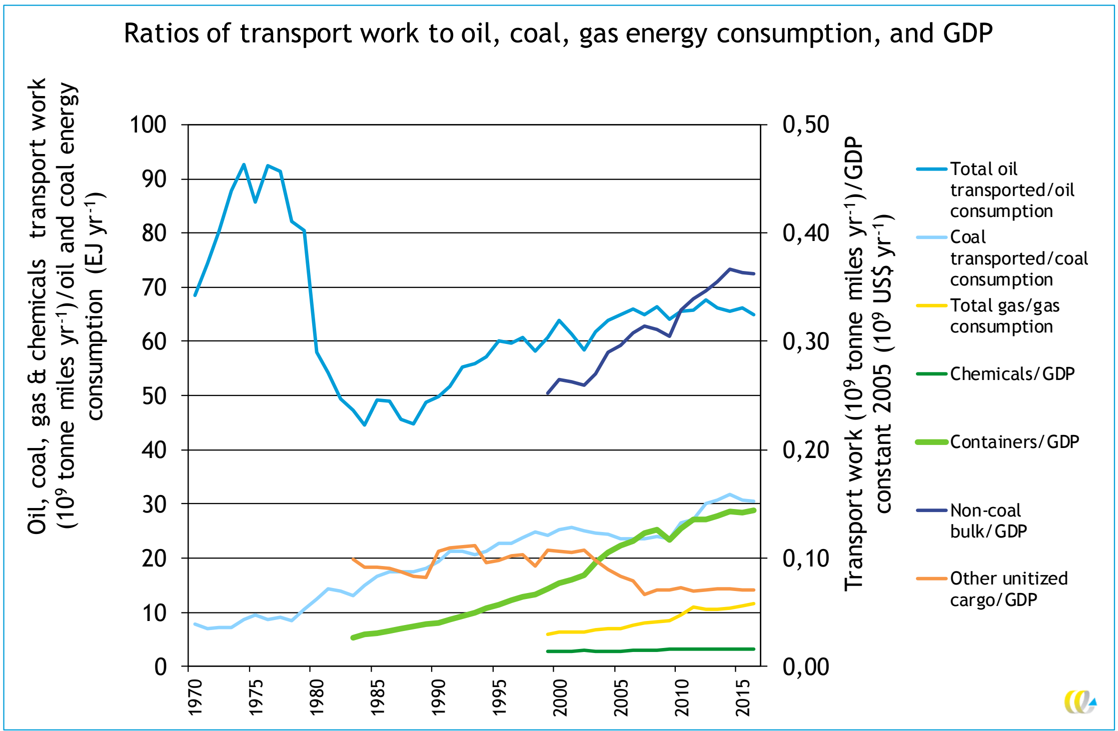
Projection data

Projection data of global GDP and oil and coal consumption data were used, as outlined above, so that low fossil fuel scenarios could be dealt with by decoupling fossil fuel from GDP. GDP projection data for the five SSP scenarios obtained from the IIASA website. OECD 2018 data on their long term GDP projections were obtained from the OECD website.
All data were normalized to constant 2005 USD prices, so historical data on GDP used the same normalization year of 2005.

Extensive historical data on coal, oil, and gas consumption data are available from the BP Statistical Review of World Energy 2016[1] and were used to relate shipped total oil, coal, total gas in units of EJ yr^{-1} as projection data of total EJ yr^{-1} by oil, coal, gas were available from IIASA for SSP1-SSP5. Ratios of total coal, total oil, total gas seaborne trade (10^9 tonne miles) to respective EJ yr^{-1} consumption; and non-coal bulk, chemicals, containers, other unitized cargo to GDP (constant 2005 USD) are shown in Figure 22. Note that in Figure 22, the early period of total oil data (1970–1985) are shown, but as outlined above, these data were excluded from the analysis.

[1] Statistical Review of World Energy

Figure 22 - Ratios of 7 categories of seaborne trade (total oil, coal, total gas, chemicals, non-coal dry bulk, containers, other unitized cargo in 109 tonne miles) to global oil, coal, gas consumption data (EJ yr-1, left hand y axis), or GDP (constant 2005 USD, right hand y axis)



Projection model

As in (IMO, 2015), we largely use a non-linear projection method as this represents an improvement over previous studies (e.g. (Eyring, et al., 2005; Eide, et al., 2007)) that have based projections on linear regression models or the Second IMO GHG Study projections (Buhaug, et al., 2009), which were non-analytical Delphi consensus based.
Non-linear statistical models have been for long-term projections of aviation transport (e.g. (IPCC, 1999; Owen, et al., 2010)). Such non-linear models used are sometimes referred to as ‘logistic models’, or more simply ‘non-linear regression models’. A range of these models exists, such as the Verhulst or Gompertz models, and they are commonly used in the econometric literature where the requirement is to simulate some form of market saturation (Jarne, et al., 2005).

The sigmoid curve in these models mimics the historical evolution of many markets with three typical phases: emergence, inflexion (maturation), and saturation, where the period of expansion and contraction are equal with symmetrical emergent and saturation phases. The phase first involves accelerated growth; the second, approximately linear growth; and the third decelerated growth. Logistic functions are characterized by constantly declining growth rates. The Verhulst function is particularly attractive as it calculates its own asymptote from the data and is described as follows, where *x* is the future demand and *t* is time in years and *a*, *b* and *c* are model constants:

$$x = a / (1 + b * \exp(- c * t)) \qquad [3]$$

The constants a, b, and c are estimated from initial guesses of asymptote, intercept and slope, and solved by converged iterative solution. SPSS v23 provided a suitable program for this model.

The exception to this modelling approach was the treatment of other unitized cargo. Figure 20 and Figure 22 show that there has only been a small increase in this category over time, as opposed to containerized cargo which shows large increases. These fundamental differences in behavior justify their separate treatment, otherwise a combination would greatly overestimate the growth in other unitized cargo. Figure 22 shows that the ratio of other unitized cargo to GDP shows a small decrease over time. Here, there is no justification for using a non-linear model, since it would imply a reverse sigmoid curve that declined to zero, for which there is no basis to assume such behavior. In the absence of any other evidence, a simple linear model has been assumed for this category. However, the R^2 value for such a model is only 0.406.

Results

Figure 23 shows the historical and modelled growth ratios according to the non-linear models derived from the analysis for all seaborne trade types, other than the other unitized cargo category, which has a linear model fitted for the reasons described above.

Figure 23 - Historical and modelled growth to 2050 for ratios of total oil, coal, non-coal bulk dry goods, total gas, chemicals, containers and other unitized cargo to either consumption or GDP

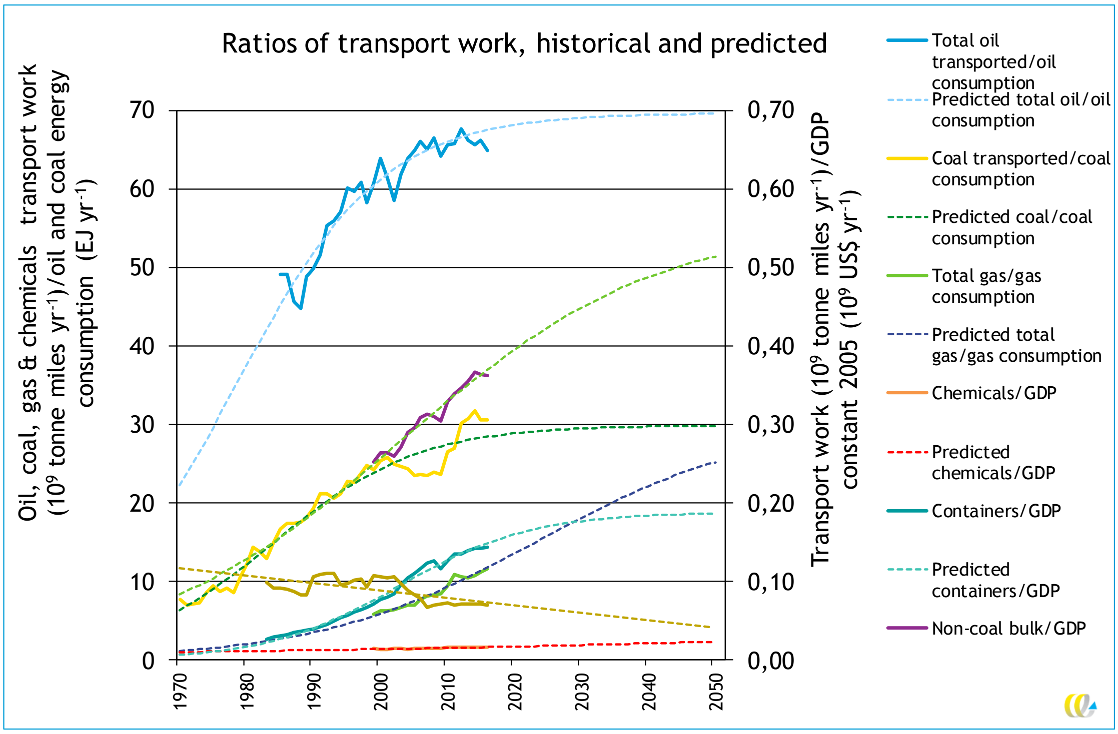


Figure 23 shows that future growth rates of total seaborne trade can be successfully modelled in a non-linear fashion, which according to economic literature is more realistic than the conventional linear model, for six different cargo types that clearly indicate different levels of market maturity, as modelled. This is a distinct advantage for the next step of assembling a simplified modelling system of future emissions. The next step is to multiply the modelled ratios for each transport type by the predictor variables (projected GDP; coal, oil and gas consumption) by SSP scenario and combine with historical data. Figure 25 shows the projected annual GDP growth rates for each SSP and Figure 27 the resulting world GDP up to 2050. The resultant transport work projections are shown in Figure 28 to Figure 31.

Figure 24 - Historical and projected annual world GDP growth rates

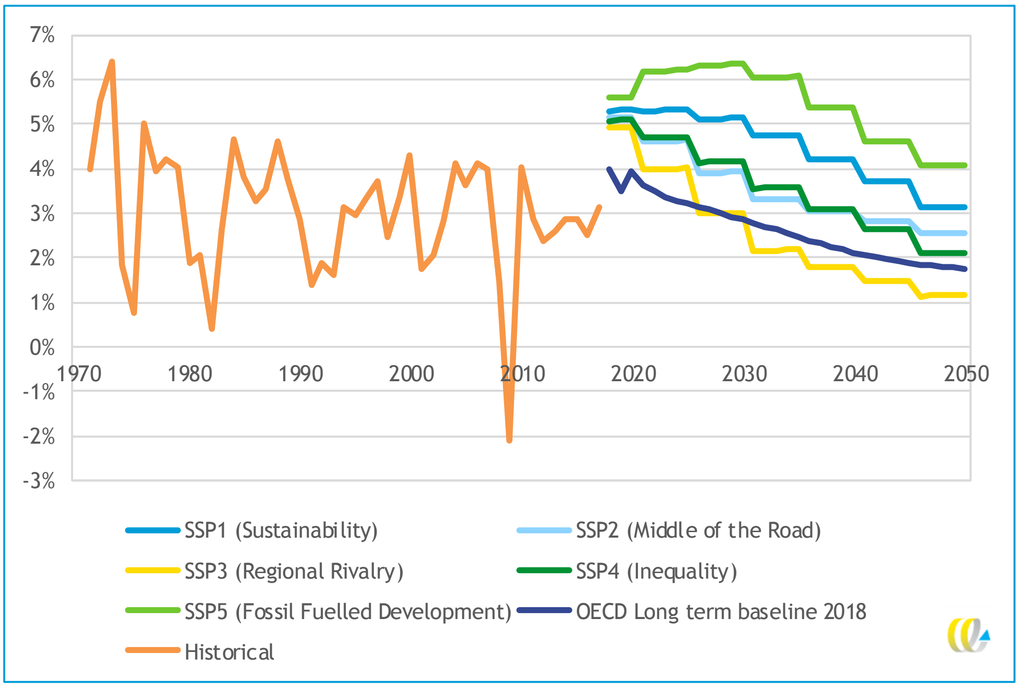


Figure 25 - Historical and projected world GDP (constant USD, index: 2012 = 100)

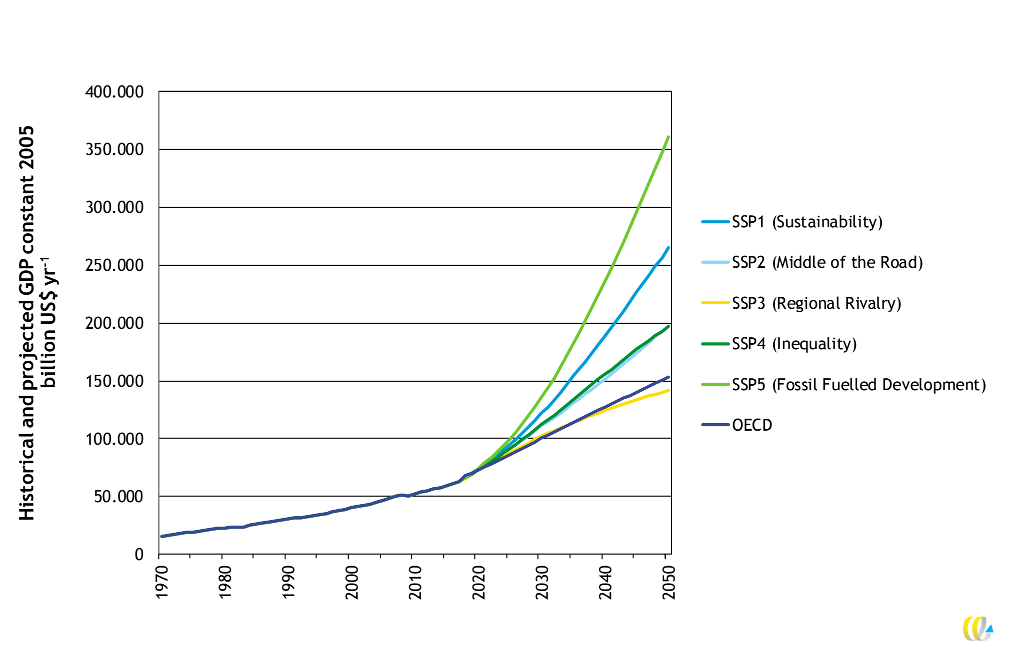


Figure 26 - Historical and projected transport work (109 tonne miles yr-1) to 2050 for coal and oil according to RCP/SSP scenarios

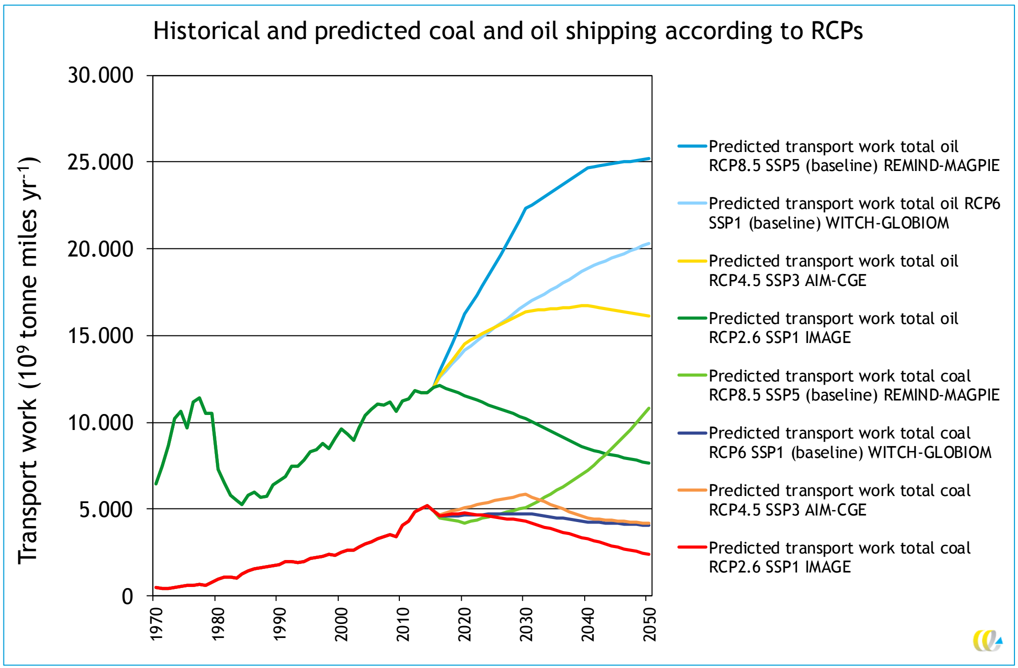


Figure 27 - Historical and projected transport work (10^9 tonne miles yr^{-1}) to 2050 for gas according to RCP/SSP scenarios

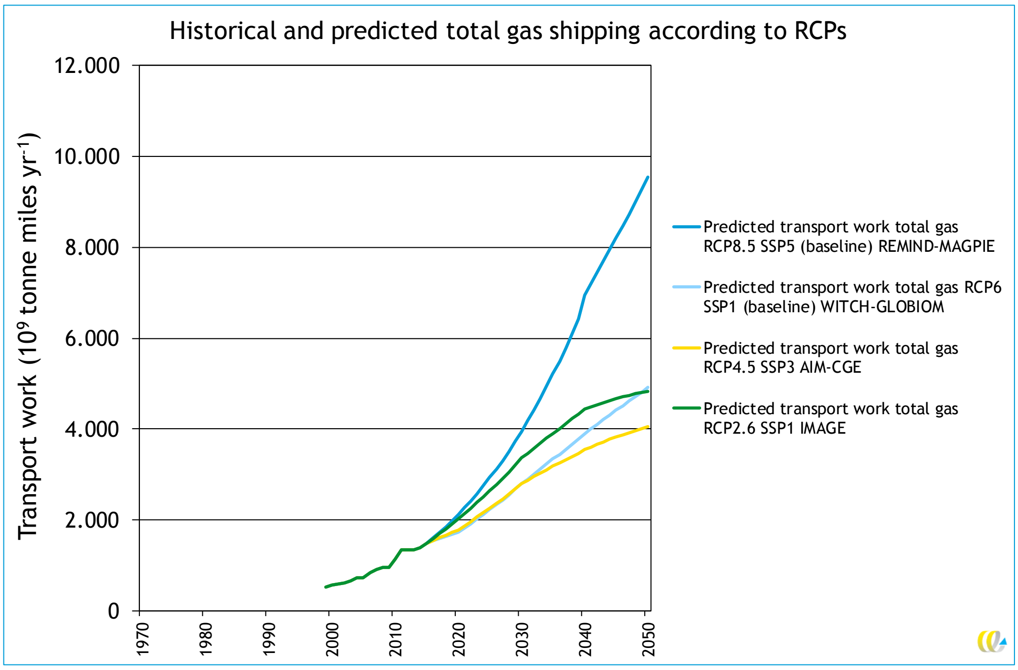


Figure 28 - Historical and projected transport work (10^9 tonne miles yr^{-1}) to 2050 for container shipping according to SSP scenarios

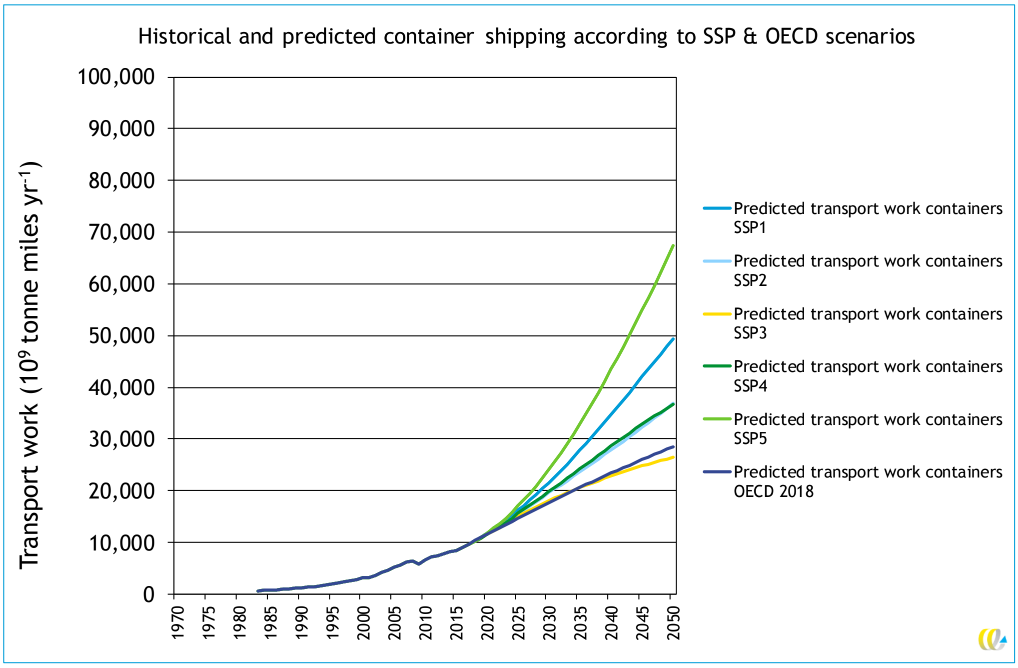


Figure 29 - Historical and projected transport work (10^9 tonne miles yr^{-1}) to 2050 for non-coal dry bulk shipping according to SSP scenarios

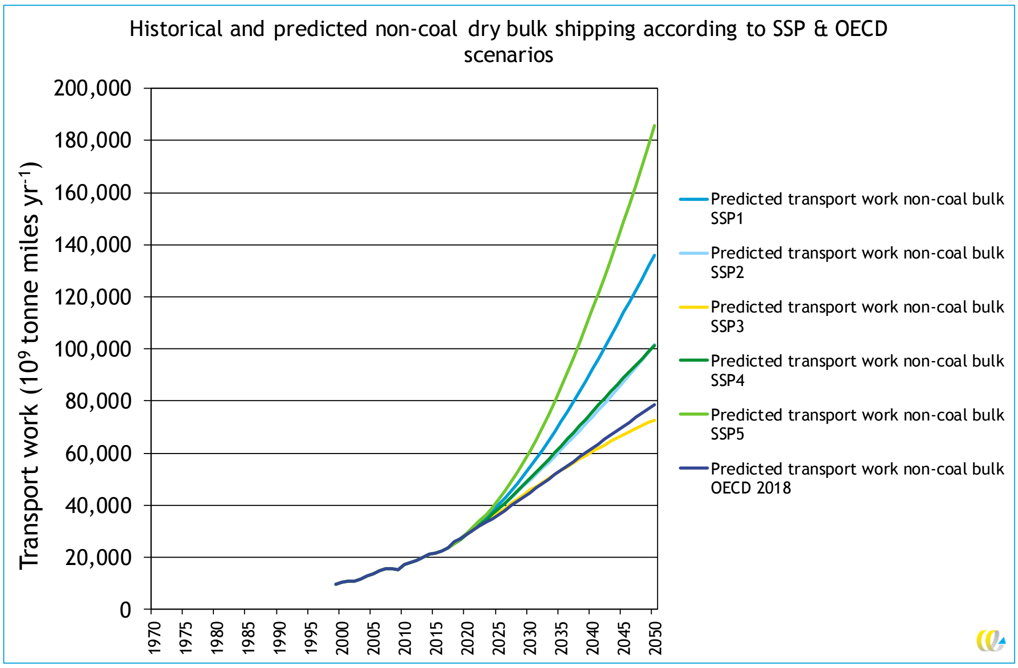


Figure 30 - Historical and projected transport work (10^9 tonne miles yr^{-1}) to 2050 for other unitized cargo shipping according to SSP scenarios

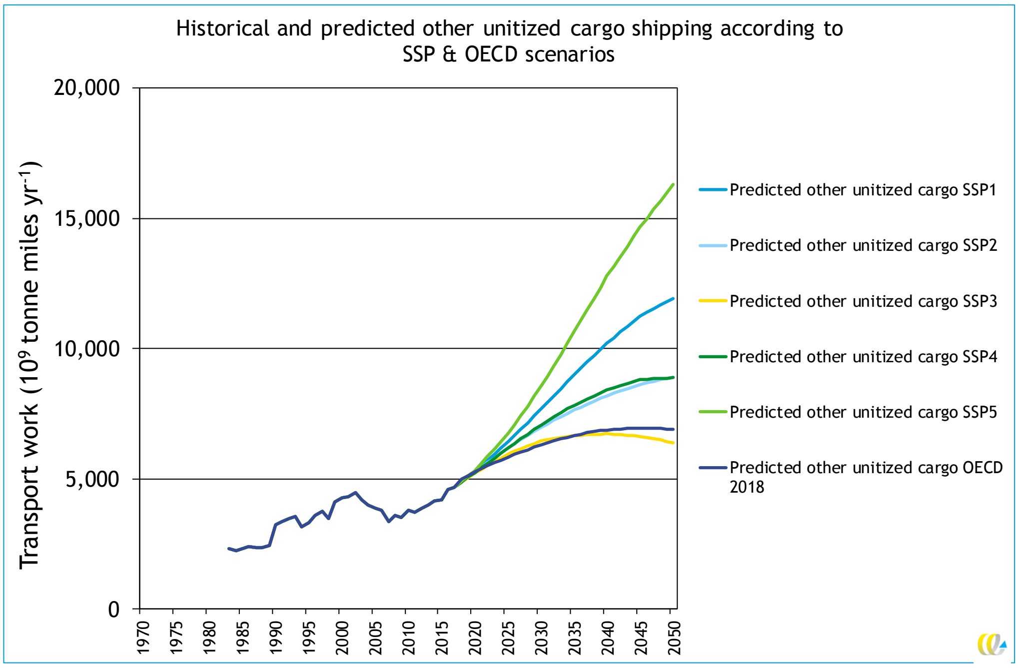


Figure 31 - Historical and projected transport work (10^9 tonne miles yr^{-1}) to 2050 for chemicals shipping according to SSP scenarios

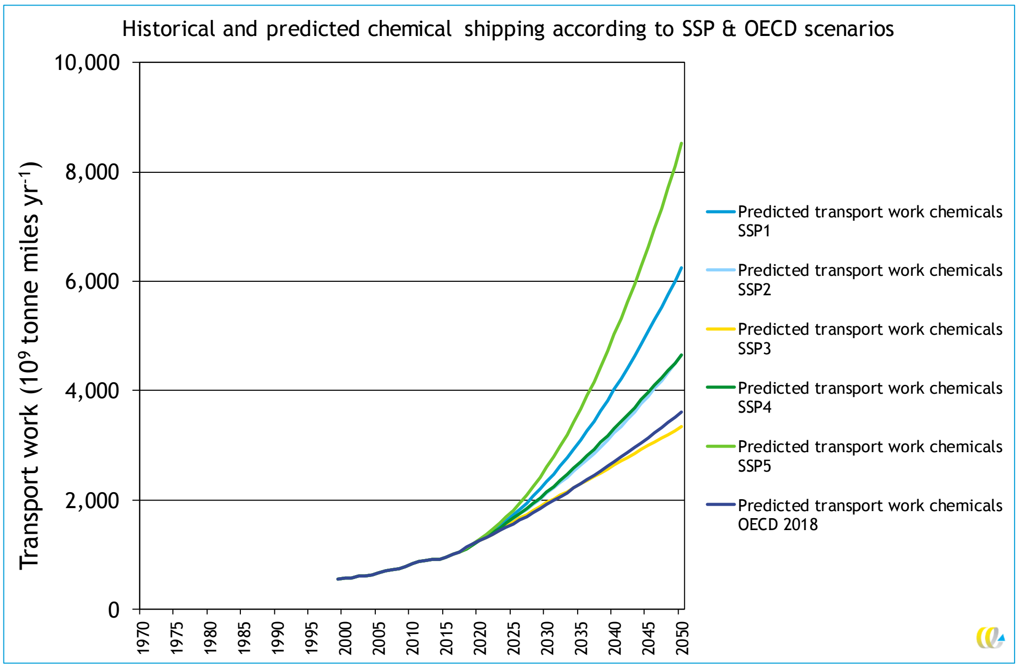
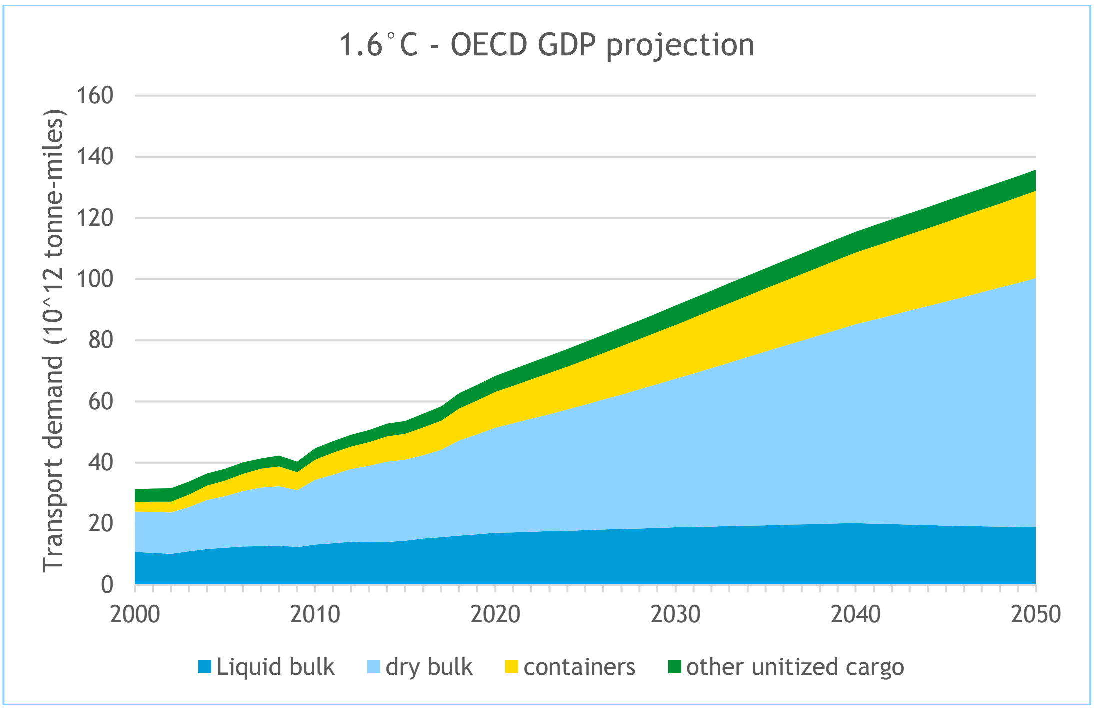


Figure 32 - Transport work projections in the 1.6°C - OECD GDP scenario



Uncertainties in transport work projections

The uncertainties in any study of projections of emissions (or underlying driver such as transport work performed) are inherently large and not quantifiable. The best approach to minimize uncertainties is to adopt reasonable models of behaviour, use data as appropriately as possible, use assumptions that appear reasonable, and diagnose the statistics of the model outputs. The adoption of a non-linear conventional economic growth model is more appropriate than a linear model, and the visual and statistical fit of the models produced (Figure 23) bears this out. The exception is the other unitized ship traffic, which shows a marginal growth over the data period of 1999–2016 with a growth of 1.03, and, importantly and different from all other sectors, the ratio to GDP shows a small decline. Hence, a (declining) linear growth of the ratio of transport to GDP was used as the model in the absence of a better-informed model. Nonetheless, splitting the containerized from the other unitized cargos is an appropriate treatment of the data that minimizes uncertainties, as if they had been combined, the other unitized cargo would have been greatly overestimated. The most uncertain non-linear model is the shipment of chemicals. This ratio (to GDP) only shows a very small increase, which implies that the market is in emergent phase, which implies an asymptote greatly beyond the observed data. Nonetheless, the non-linear approach has not 'failed' since the projected ratio shows (Figure 4) an increase over the projection that is only marginally greater than a linear projection with a small slope.

The magnitudes of the contributions of the split in types also needs to be considered: so, the models which show the clearest fit are those of e.g. total oil, containers, non-coal dry bulk which all have large contributions to the total. By contrast, the uncertainties with the chemicals shipping are small since the overall contribution to total sea-borne trade is small.

Lastly, the appropriateness of the projection should be considered with other assumptions, or 'storylines'. So, for the low-fossil fuel scenarios of RCP2.6, for example, it is important to decouple shipping traffic of fossil fuels from GDP.

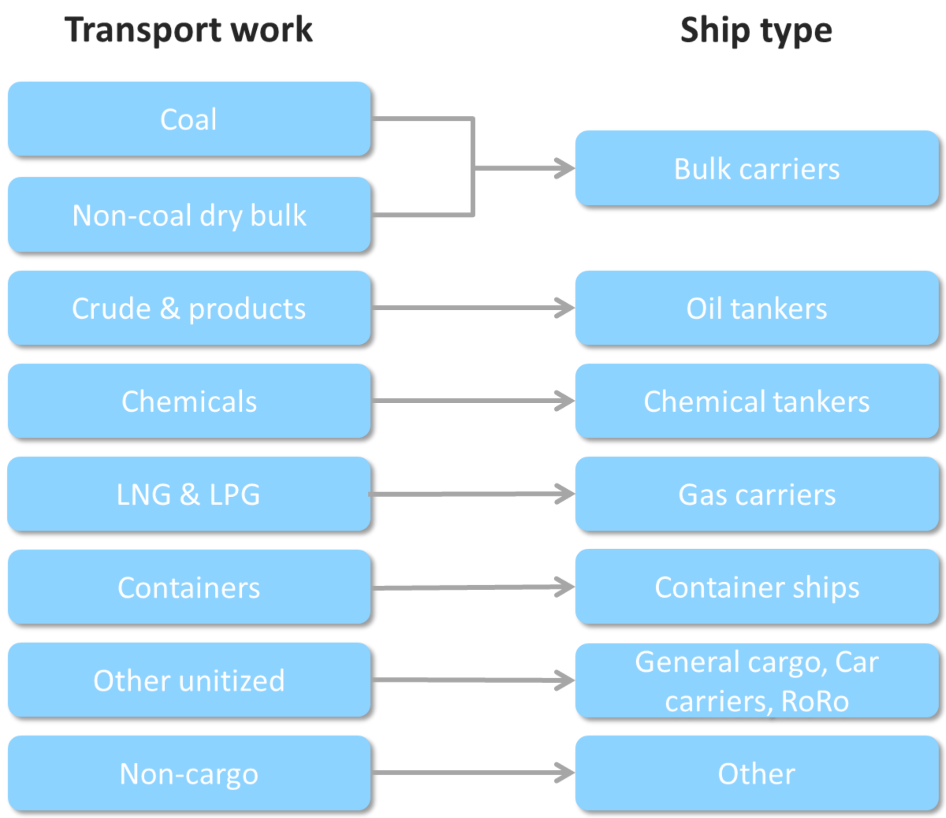
Overall, the representation in this work of different ship cargo types with different stage economic non-linear models and inherently different growth rates along with decoupling of fossil fuel transport from GDP represents a large step up in 'appropriateness' from the original projections of shipping transport that were simple linear projections of total sea-borne trade against GDP.

A.4 Making a detailed description of the fleet in the base year 2012

The third step in the emissions projection model is to make a detailed description of the fleet in the base year. 2012 was chosen as a base year because this is the last year for which detailed emissions data are available in combination with detailed fleet statistics from the Third IMO Greenhouse Gas Study 2014.

Each cargo type for which transport work has been projected into the future is mapped to the ship type that is most likely to transport this type of cargo. Figure 33 shows the mapping. In this way, the change of activity for each ship type can be projected into the future.

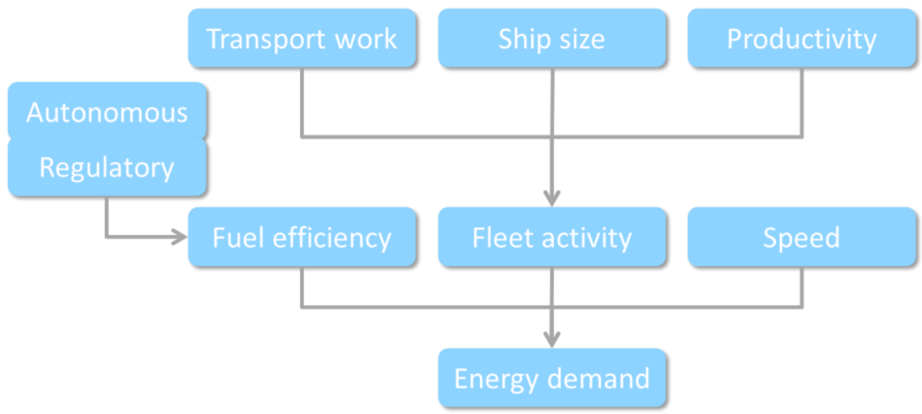
Figure 33 - Mapping of cargo types to ship types



A.5 Projecting the fleet composition and energy efficiency

The fourth step calculates the number of ships for each of the 39 ship type and size categories in the model and their energy efficiency, taking into account projected changes in transport work, size and productivity, as well as autonomous and regulatory changes to the operational and design fuel efficiency of ships and changes in the average speed. Figure 34 provides a graphical presentation.

Figure 34 - Projecting the fleet composition and energy efficiency



All the projected changes have been based on an extensive literature review and a stakeholder consultation conducted for the Third IMO Greenhouse Gas Study 2014.
The results have been presented in detail in that report and will not be reproduced here, with the exception of the projections of the development of the size of container ships, which may have been underestimated in 2014.

Projections of the size of container ships

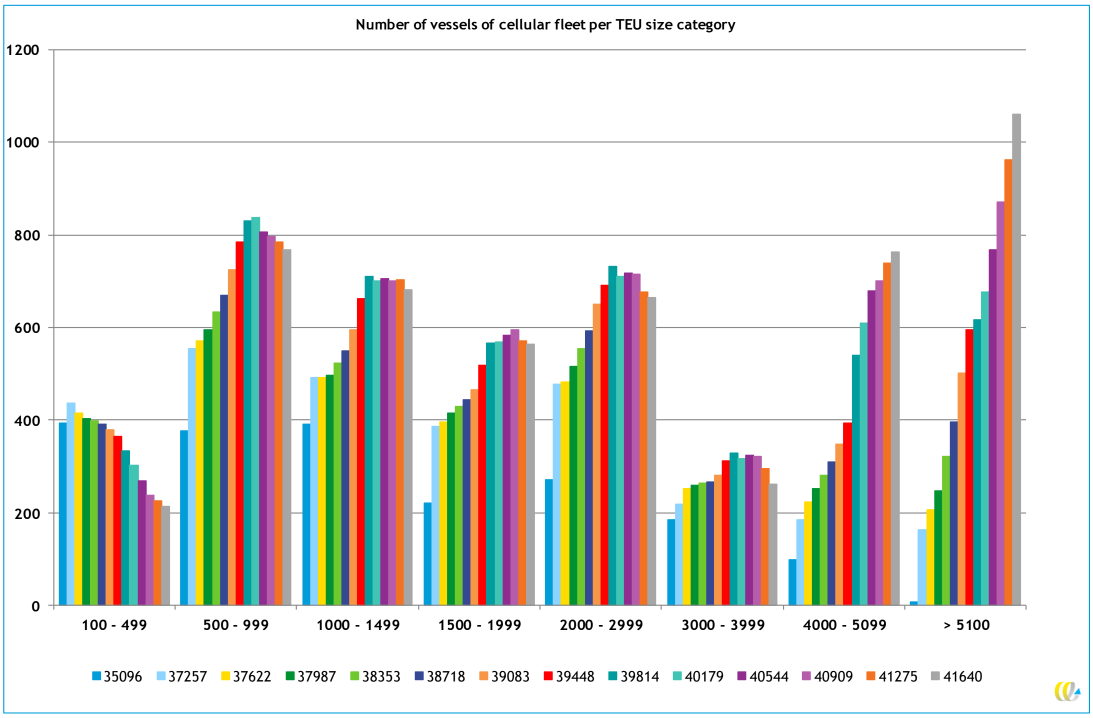
Starting point of the analysis is the 2012 distribution of the container ships over the size categories as determined in the emissions inventory (see Table 3).

Table 3 - 2012 distribution of container ships over the size categories in terms of numbers

Size category	Distribution of ships in terms of numbers
0-999	22%
1,000-1,999 TEU	25%
2,000-2,999 TEU	14%
3,000-4,999 TEU	19%
5,000-7,999 TEU	11%
8,000-11,999 TEU	7%
12,000-14,500 TEU	2%
14,500 TEU +	0.2%

In Figure 35 the development of the distribution of the ships of the cellular fleet over the size categories is given for the period 2002–2014.

Figure 35 - Composition of global container fleet in the period 2002-2014 (beginning of year figures)



Source: Based on Alphaliner data that has been collected from various sources.

Over this period the number of ships in the 500–1,000 TEU and in the 4,000–5,100 range has been relatively high, whereas the number of ships in the 3,000–4,000 TEU range relatively low.

Figure 35 also illustrates that over the last decade, the number of the smallest ships in the 100–500 TEU range has steadily decreased, whereas the number of the ships above 4,000 TEU has steadily increased. For all the other, i.e. the medium-sized ships, it holds that their number increased until the crises whereas it decreased thereafter.

Due to economies of scale, a trend towards using larger ships has taken place. Ships of 10,000 TEU and above have substituted smaller ships, mainly in the range 2,800–5,000 TEU and ships of 1,000-2,000 TEU have been mostly been displaced by 2,000–2,700 TEU ships (BRS, 2013). In many markets, ever larger ships are being deployed. There is a broad agreement amongst observers of the container fleet that old Panamax ships (those in the 4,000-5,000 TEU range) are becoming almost obsolete as they are being replaced by more efficient larger ships.

In contrast, ships that are being used as regional network carriers or as feeders, i.e. ships of 2,800 TEU or less have naturally not been replaced by 10,000 + ships.

About 93% of the 10,000 + TEU ships currently in operation are deployed in the East Asia-Europe trade lanes because they have the requisite volume scale, voyage length, channel depths, and configuration of ports to support the use of such ships (U.S. DOT, 2013).

Nearly 55% of the existing 7,500-9,999 TEU ships in operation are also assigned to the East Asia-Europe trade, while another 22% are serving the East Asia-U.S. West Coast markets; the remaining 23% are deployed mainly in the Far East-West Coast of South America trade and the Far East-Suez Canal-U.S. East Coast corridor (U.S. Dot, 2013).
Regarding the development of the size of the container ships until 2050 we expect two main factors to have an impact: a further trend towards larger ships due to economies of scale as well as infrastructural changes.

As mentioned above, a trend towards building and utilizing larger ships has taken place in the container ship market. Due to current infrastructural barriers which can be expected to be removed until 2050 some trades can be expected to experience a catch-up effect in this regard:

- The Suez Canal can be used by container ships of up to 22,000 TEU which is the size of the currently largest ships. This is not the case for the Panama Canal: before expansion, a container ship of up to 5,000 TEU, and after expansion of probably up to 13,000 TEU will be able to pass the Panama Canal. This can be expected to lead to more large ships being used in the East Asia – U.S. East Coast trade.
- The East Asia – U.S. West Coast trade, is, next to the East Asia – Europe trade, the only trade that is currently ready for the 18,000 TEU size in terms of cargo volumes (ContPort Consult, 2013). So far, ship owners have been hesitant to utilise very large container ships due to the demand for a high sailing frequency and the low terminal productivity at US ports (ContPort Consult, 2013). Terminal productivity however can be expected to increase until 2050 and more very large container ships can expected to be utilised for this trade as well.

Whether for the other trades even larger ships will be utilized until 2050 is of course debatable. Utilization rates may not be sufficient enough in the future or intensive growth, i.e. higher capacity utilization, could for example lead to a slowing down of the ship size growth. For our projection we therefore assume that the number of larger ships does increase but that this increase is not very pronounced.

In Table 4, an overview of the development of the distribution of the ships over the size categories that we expect and the respective estimation of the 2050 distribution is given.

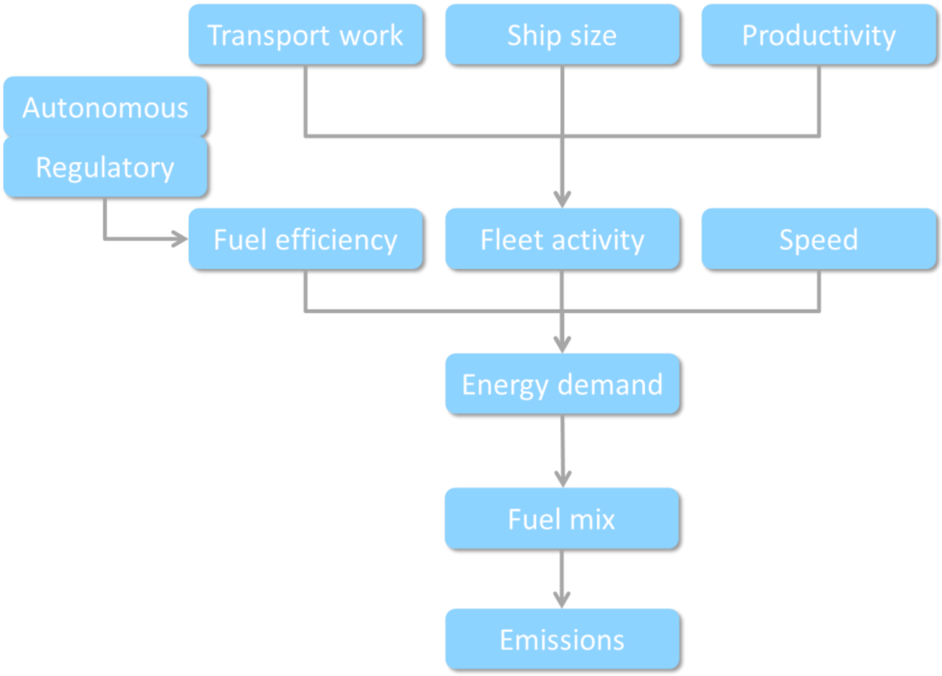
Table 4 - Development of the distribution of container ships over size categories (in terms of numbers)

Size category (TEU)	2012 distribution	Development until 2050	2050 distribution
0-999	22%	Very low share of 0-499 does not change; high share of 500-999 unchanged.	22%
1,000-1,999	25%	Trend that 1,000-1,999 TEU are replaced by 2,000-2,999 TEU ships continues.	20%
2,000-2,999	14%		18%
3,000-4,999	19%	Replaced by very large (14,500 +) and by larger ships that can transit Panama Canal after expansion (probably 8,000-11,999 TEU and parts of 12,000-14,500 TEU)	5%
5,000-7,999	11%	Share as in 2012.	11%
8,000-11,999	7%	Share increases due to expansion of Panama Canal.	10%
12,000-14,500	2%	Share increases due to the ongoing trend of using larger ships, replacing 3,000-4,999 TEU ships and due to the expansion of Panama Canal, replacing 3,000-4,999 TEU ships.	9%
14,500 +	0.2%	Share increases due to the ongoing trend of using larger ships, replacing 3,000-4,999 TEU ships.	5%

A.6 Project shipping emission

In the final step, shipping emissions are projected by multiplying the energy demand by the emission factors of the projected fuel mix (see Figure 34). As in the Third IMO Greenhouse Gas Study 2014, we have assumed a relatively modest uptake of LNG and a full implementation of the Marpol Annex VI sulphur requirements. More details on the emission factors and the fuel mix are in the Third IMO Greenhouse Gas Study 2014.

Figure 36 - Emission projections



B Review of the assumptions made in the Third IMO GHG Study

B.1 Introduction

The emission projections presented in the Third IMO Greenhouse gas Study 2014 have been calculated with a model that uses a number of input assumptions. The most important are:
1. Projections of transport demand.
2. Assumptions on the development of ship speed.
3. Assumptions about ship size.
4. Assumptions on the development of fleet operational and design efficiency.
5. Assumptions on fleet productivity.
6. Assumptions about the future development of the fuel mix.

The projections of transport demand are the subject of the next chapter. This chapter focusses on the other assumptions. It compares the assumptions made in the Third IMO GHG Study with empirical data on the same parameters.

B.2 Assumptions about ship speed

Speed is an operational measures that a ship can take to yield the benefits of reduced fuel consumption. For the emission projections, the speed is considered as an operational measure and the model allows for two speed reduction options of 10 or 20%, respectively, relative to the 2012 baseline. The model assumes that when the speed is reduced by 10% will lead to a savings in fuel consumption of 15% and when the speed is reduced by 20% will lead to savings in fuel of 36%.

In the emission projection model, most ship types reduce their average speed by 10% relative to their 2012 speed, which is the historical baseline.

ICCT (2017) has analysed the speed of three major ship types namely oil tankers, container and bulkers. The study shows that the average ship cruising speeds remained largely unchanged between 2013 to 2015, reporting an average cruising speed between 11.4 to 11.6 knots.

For a few categories of ships, ICCT (2017) found an increase in average speed between 2012 and 2015. Table 5 shows the differences.

Table 5 - Actual and projected speed of selected ship types

2014 study	ICCT 2013 - 2015
Oil tanker 200,000 + has reduced their speed by 10%	Oil tanker 200,000 + has increased their speed over ground (SOG) by 4%
Oil tanker 120,000–199,999 dwt has reduced their speed by 10%	Oil tanker 120,000–199,999 has increased their speed over ground (SOG) by 2.3%.
Oil tanker 80,000–119,999 dwt has reduced their speed by 10%	Oil tanker 80,000–119,999 dwt has increased their SOG by 1.4%
Container > 14,500 TEU has reduced their speed by 10%	Container ships > 14,500 TEU has increased their SOG by 11.4%

Source: Third IMO Greenhouse Gas Study 2014; ICCT (2016).

The analysis shows that the largest oil tankers (> 200,000) and the largest container ships (+ 14,500 TEU) have increased their speed. The study also points that there is a significant increase in ship speeds in for next largest oil tankers. The carbon intensity of oil tanker and container as a ship class has decreased but the same is not applicable to the largest oil tankers and container ships within the above mentioned capacity bin. This might lead to a drop in the shipping efficiency and a rise in the ship emissions.

We conclude that there may be a case to change the assumptions of the emission projection model on ship speed and assume that speeds will stay at their 2012 level instead of decrease.

B.3 Assumptions on ship size

Assumptions about the average ship size are relevant because they determine the number of active ships required to supply the transport demand, and because large ships have lower fuel use and emissions, per unit of transport work, than small ships.

The emission projection model categorises ships in ship types and, for most ship types, into two to six size categories. Whilst the average size in each category is assumed to be constant, the distribution of the number of ships over size categories can vary over time. For example, the number of the largest containerships increases while the number of old Panamaxes decreases.

We have compared the projected fleet composition in the model with the actual fleet composition from Clarksons World Fleet Register. Table 6 shows that while the number of active bulk carriers is smaller than the projected number, the share in each size category is roughly in line with the projected values. The different in the total number of ships could due to the fact that the model projects them to slow down further after 2012, whereas ICCT (2016) shows they have maintained their 2012 speeds.

Table 6 - Actual and projected composition of the fleet of bulk carriers

Size category (dwt)	Average ship size 2012 - Derived from the model	Average ship size 2018 - Data from clarksons	No of ships 2018 - Derived from the model	No of ships 2018 - Data from clarksons
10,000 - 34,999	26,217	25,668	2,690	2,532
35,000 - 59,999	49,211	49,455	3,690	3,639
60,000 - 99,999	76,827	76,122	2,720	3,349
100,000 - 199,999	167,135	170,297	1,600	1,213
200,000 +	252,006	246,951	360	497

Source: Third IMO Greenhouse Gas Study 2014; Clarksons World Fleet Register.

Table 7 shows the actual and projected composition of the fleet of oil tankers. The number of active tankers is much larger than the projected numbers. One reason may be that many oil tankers are inactive. Another reason could be that the activity is underestimated.

Table 7 - Actual and projected composition of the fleet of oil tankers

Size category (dwt)	Average ship size 2012 - Derived from the model	Average ship size 2018 - Data from clarksons	No of ships 2018 - Derived from the model	No of ships 2018 - Data from clarksons
10,000 - 19,999	14,672	14,095	190	249
20,000 - 59,999	43,238	45,077	660	1,978
60,000 - 79,999	72,016	72,975	390	438
80,000 - 119,999	106,909	108,895	910	989
120,000 - 199,999	155,139	156,134	470	575
200,000 +	305,183	307,929	600	726

Source: Third IMO Greenhouse Gas Study 2014; Clarksons World Fleet Register.

Table 8 shows that there are significantly more containerships in the largest size categories than the model projected, partly at the expense of the ships with a capacity between 3,000 and 8,000 TEU.

Table 8 - Actual and projected composition of the fleet of container ships

Size category (TEU)	Average ship size 2012 - Derived from the model (dwt)	Average ship size 2018 - Data from clarksons (dwt)	No of ships 2018 - Derived from the model	No of ships 2018 - Data from clarksons
1,000 - 1,999	19,893	16,861	1,430	1,251
2,000 - 2,999	35,489	30,353	830	2,540
3,000 - 4,999	52,802	49,389	990	799
5,000 - 7,999	74,610	72,118	640	560
8,000 - 11,999	106,680	11,041	400	618
12,000 - 14,500	149,751	163,942	160	226
14,500 + (173,275)	158,038	216,832	40	128

Source: Third IMO Greenhouse Gas Study 2014; Clarksons World Fleet Register.

B.4 Assumptions on the development of fleet operational and design efficiency

The projected average efficiency improvements, relative to 2012, in the Third IMO Greenhouse Gas Study 2014 3% in 2015 and 9% in 2020 for cargo ships.

ICCT (2017) finds that the CO_2 intensity has improved by 2-9% between 2013 and 2015, with an average of 3.5% in this period. This corresponds well with the projected value.

B.5 Assumptions on fleet productivity

The assumptions on fleet productivity could not be checked because UNCTAD discontinued publishing the data.

B.6 Assumptions about the future development of the fuel mix

ICCT (2017) estimates that 72% of the fuel is HFO, 26% distillate and 2% LNG. This is very close to the input assumptions of the model: 73% HFO, 25% distillate and 2% LNG in 2020.

B.7 Conclusions

There are discrepancies in the model assumptions about the development of ship size and operational speed that may have an impact on emission projections. The other input assumptions can either not be checked or will probably have a minor impact on the emission projections.