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MARINE ENVIRONMENT PROTECTION COMMITTEE
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Agenda item 7

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REDUCTION OF GHG EMISSIONS FROM SHIPS

Update of maritime greenhouse gas emissions projections – Full report

Submitted by BIMCO

SUMMARY

Executive summary:	This document provides in the annex the report of the update of maritime greenhouse gas emissions projections, which is a recalculation of the projections for GHG emissions for international shipping in the period up to 2050
Strategic direction:	7.3
High-level action:	7.3.2
Output:	7.3.2.1
Action to be taken:	Paragraph 1
Related documents:	MEPC 71/7/5

Action requested of the Committee

1 The Committee is invited to note the report of the update of maritime greenhouse gas emissions projections as set out in the annex to this document.

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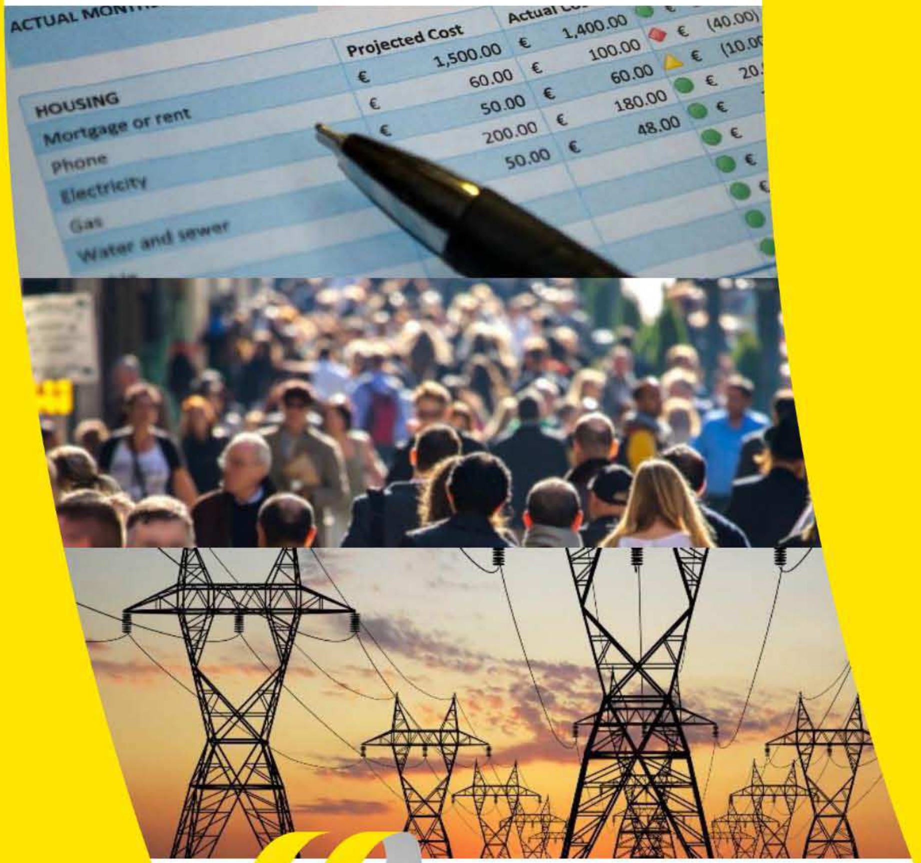
ANNEX

UPDATE OF MARITIME GREENHOUSE GAS EMISSION PROJECTIONS

Update of Maritime Greenhouse Gas Emission Projections



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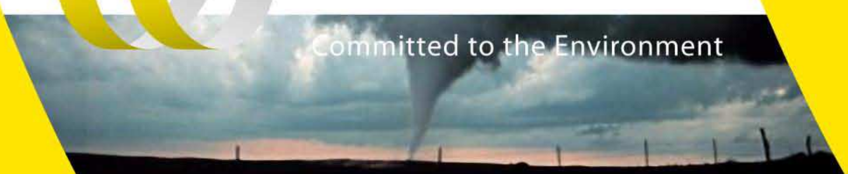

Update of Maritime Greenhouse Gas Emission Projections

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Client: BIMCO

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

CE Delft
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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 for the period 1970-2012.

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

This report presents an update of the emission projections from the Third IMO Greenhouse Gas Study 2014 that are based on updated transport work projections but otherwise employ the exact same methodology as the previously published projections.

The update is 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 not all BAU scenarios presented in 2014 are equally relevant, since only one of them is compatible with the agreed temperature goal. In addition, the IMO has agreed to develop a Comprehensive IMO Strategy on Reduction of GHG Emissions from Ships to which updated emission projections may provide useful input.

Figure 1 **CO_2 emission projections of shipping in three 1.6°C scenarios**

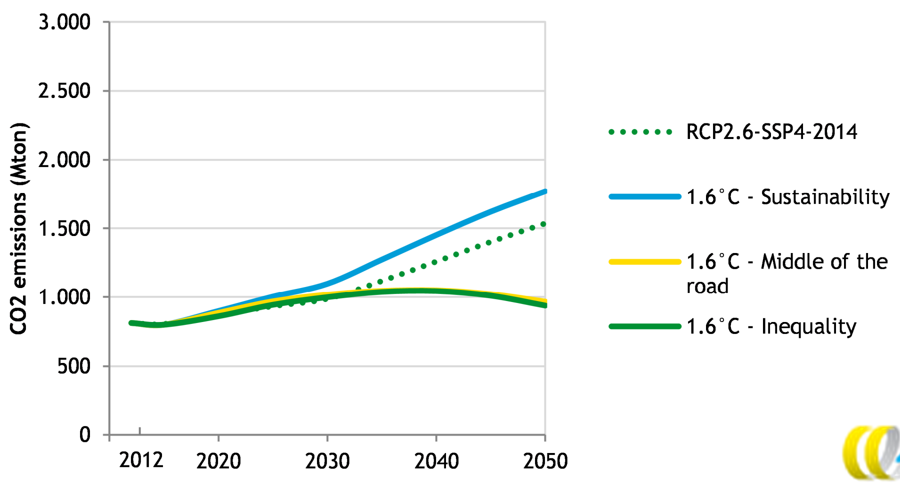
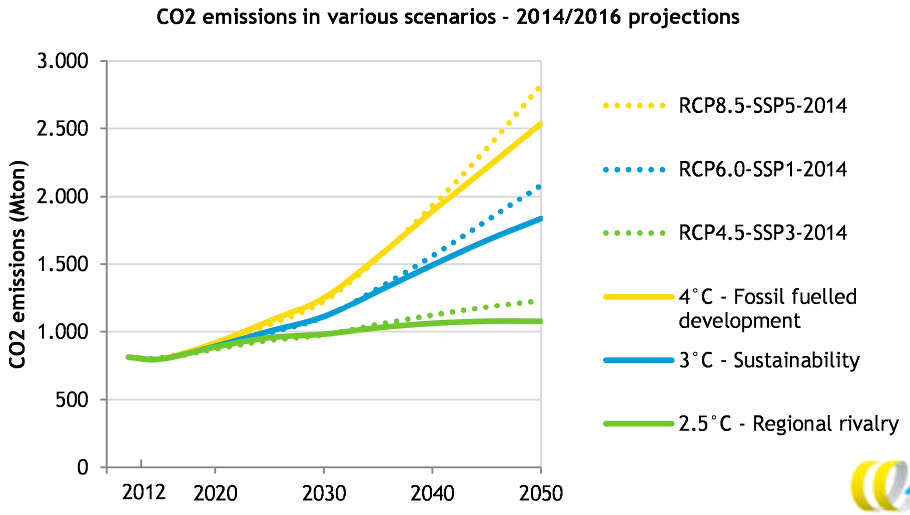


Figure 1 shows the CO_2 emission projections of shipping in three scenarios that are in line with the Paris Agreement temperature goal. For comparison, the one corresponding scenario from the Third IMO Greenhouse Gas Study 2014 has also been included as a dashed line. Depending on the economic developments, the emissions will increase by 20 to 120% between 2012 and 2050. For comparison, the Third IMO Greenhouse Gas Study 2014 presented only one scenario compatible with the Paris Agreement temperature goal in which CO_2 emissions would increase by 90%. This original scenario has the same assumptions about economic growth as the 1.6°C – Inequality scenario in this update. Hence, the update has resulted in considerably lower projected emission increases, in particular for unitized cargo.

Figure 2 **CO_2 emission projections of shipping in three scenarios with temperature increases exceeding 2°C**



New shipping emission projections have also been made for socio-economic and energy scenarios in which the global average temperature increase is higher than the Paris Agreement goal. These projections show increases between 2012 and 2050 that range from 35 to 210% (see Figure 2). All the updated projections are all lower than the corresponding projections from the Third IMO Greenhouse Gas Study 2014 as a result of working with the new transport work data. While emissions of dry bulk ships are projected to be higher than in the Third IMO Greenhouse Gas Study, the emissions of unitized cargo ships are not projected to grow as rapidly as in the Third IMO Greenhouse Gas Study 2014.

1 Introduction

1.1 Policy Context

In the period 2007–2012, annual greenhouse gas emissions from shipping amounted to approximately 1000 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).

MEPC has decided to develop a comprehensive IMO strategy on the reduction of greenhouse gas emissions from ships. This strategy will be initially adopted in 2018 and a revised version is foreseen in 2023.

One of the elements that will be taken into account in the development of the strategy is the emission scenarios. BIMCO has recognised that it is important to have up-to-date emission scenarios and has asked CE Delft and David S. Lee, who developed the scenarios for the Third IMO Greenhouse Gas Study, 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 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 used in the Third IMO Greenhouse Gas Study 2014, which had kindly been provided by the United Nations Conference on Trade and Development (UNCTAD). 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 the newly published scenarios differed in details from the preliminary scenarios used in the Third IMO Greenhouse Gas Study 2014.

Moreover, since the Paris Agreement has set the world on a course to limit the temperature rise to well below 2°C, not all the emission projections are equally relevant. In the current context, projections based on economic and energy scenarios which are in line with the Paris Agreement goals are arguably more relevant than scenarios which would result to higher increases in temperatures.

Because of 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 SSP scenarios 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.

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. 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 three 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.

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

1.6 Outline of the report

Chapter 2 presents 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. This chapter also presents the projections for transport demand. Other BAU projections are presented in Chapter 3. Chapter 4 concludes the report.

2 Climate Policy Relevant Emission Projections

2.1 Introduction

The Third IMO Greenhouse Gas Study 2014 presented four Business-as-Usual (BAU) scenarios which were 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, not all RCPs are equally 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’.

Therefore, this chapter will present the RCP2.6 scenarios. Not all SSPs can be combined with RCP2.6, as some would require a mitigation effort that is too high (Riahi, et al., 2017). In fact, only SSP1, SSP2 and SSP4 can be combined with RCP2.6, so this chapter presents those combinations. Note that the Third IMO Greenhouse Gas Study 2014 only projected emissions based on RCP2.6 in combination with SSP4.

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 has 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 apparently 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 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 exception to this modelling approach was the treatment of ‘other unitized cargo’. 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 behaviour justify their separate treatment, otherwise a combination would greatly overestimate the growth in ‘other unitized cargo’. 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.

Figure 3 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 3 **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**

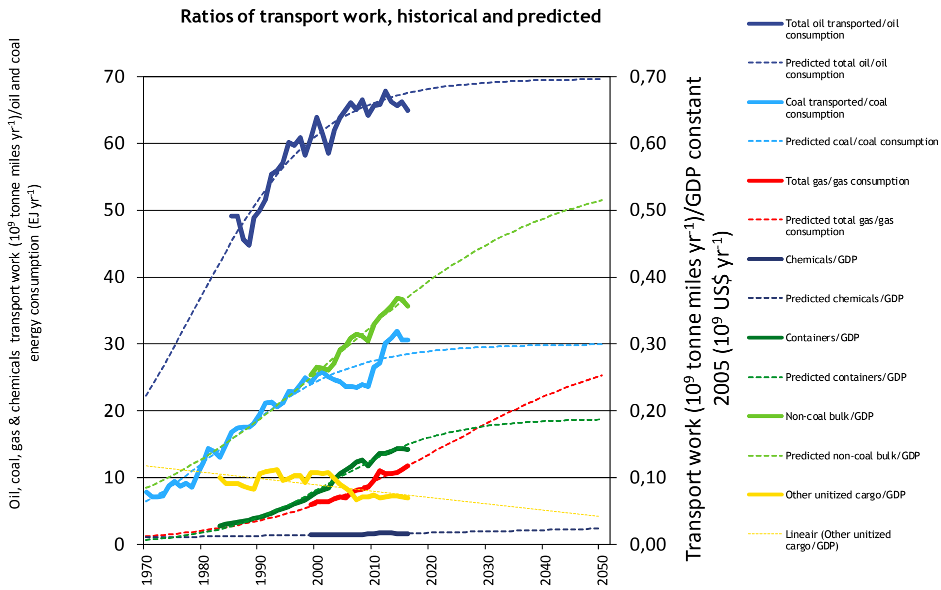


Figure 3 shows that future growth rates of total seaborne trade can be successfully modelled in a non-linear fashion, which according to economic literature is more realistic than the conventional linear model, for six different cargo types that clearly indicate different levels of market maturity, as 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.

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); and
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 consider the RCP2.6 scenarios to be relevant in this context for climate policy. These scenarios are developed in this chapter, while the scenarios leading to higher mean temperatures are developed in Chapter 3.

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.

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%

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

2.4 Transport work projections

This section presents the projections of transport work for the different cargoes included in this study. Figure 4 shows projections for transport of oil, coal and gas based on energy consumption projections in the RCP 2.6 scenarios. Figure 5 shows projections for the other cargoes based on GDP projections in the three SSP scenarios that can be combined with RCP 2.6.

Figure 4 Historical and projected transport work to 2050 for coal, oil and gas in RCP2.6 scenarios

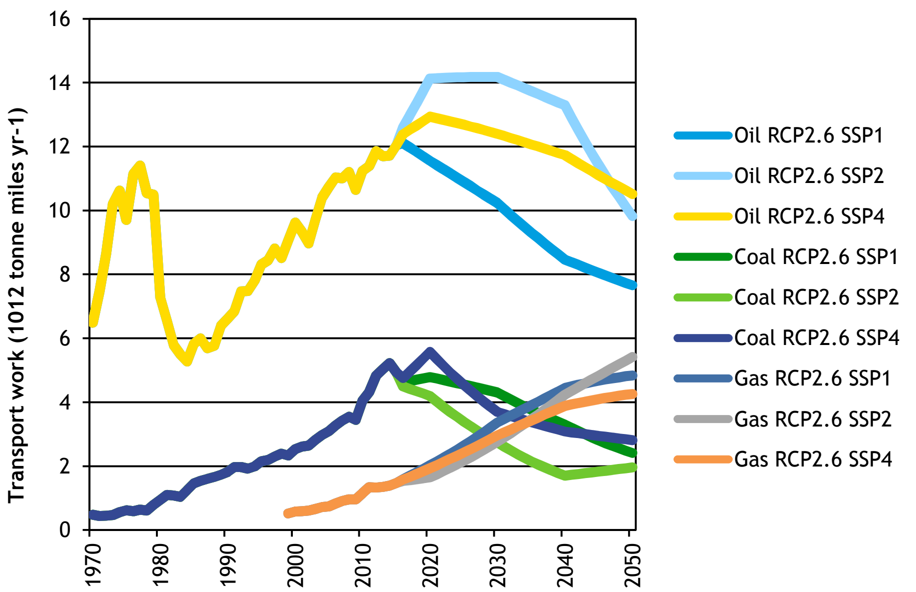


Figure 5 **Historical and projected transport work for container, non-coal dry bulk, chemicals and other unitized cargoes according to SSP scenarios**

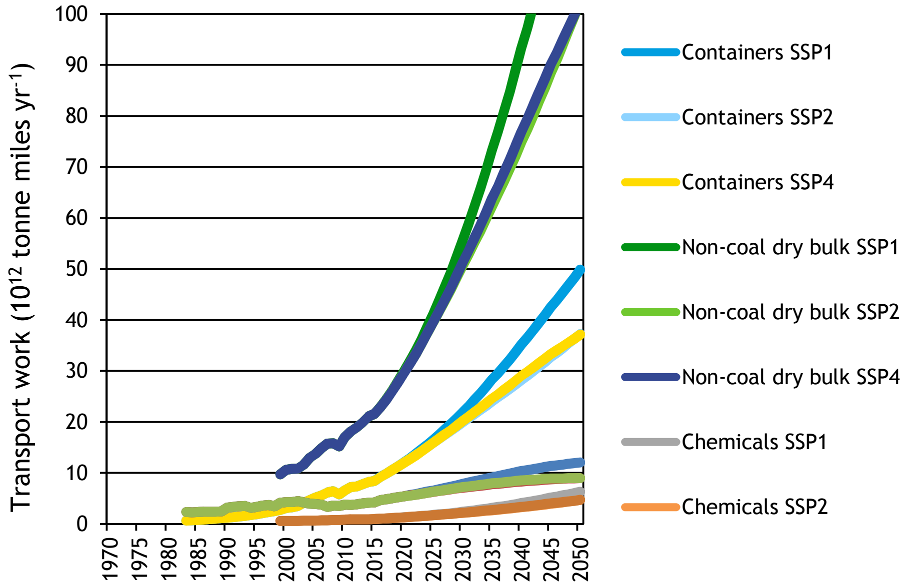
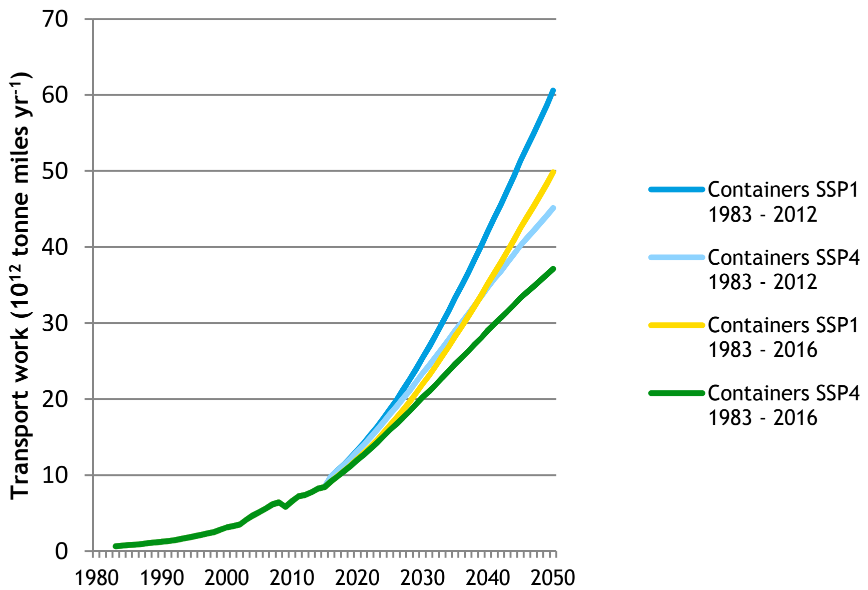


Figure 6 shows how the transport work projections for container transport demand have changed as a result of adding four recent years of data (2013-2016). Because the increase in transport work per unit of GDP has been lower in recent years than before, the analysis shows that the container shipping market is closer to maturity than it appeared to be in the Third IMO Greenhouse Gas Study 2014. As a result, projected transport work by 2050 is approximately 20% lower in the current study than in 2014.

Figure 6 **Transport work projections for two base year periods**



2.5 Emission projections

Figure 7 shows the CO_2 emission projections of shipping in the three scenarios that are 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 included as a dashed line. The original projection was based on the same GDP and fuel projections as the 1.6°C – Inequality scenario. Depending on the economic developments, the emissions will increase by 20% to 120%. 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, was that CO_2 emissions would increase by 90%.

Figure 7 CO_2 emission projections of shipping in three 1.6°C scenarios

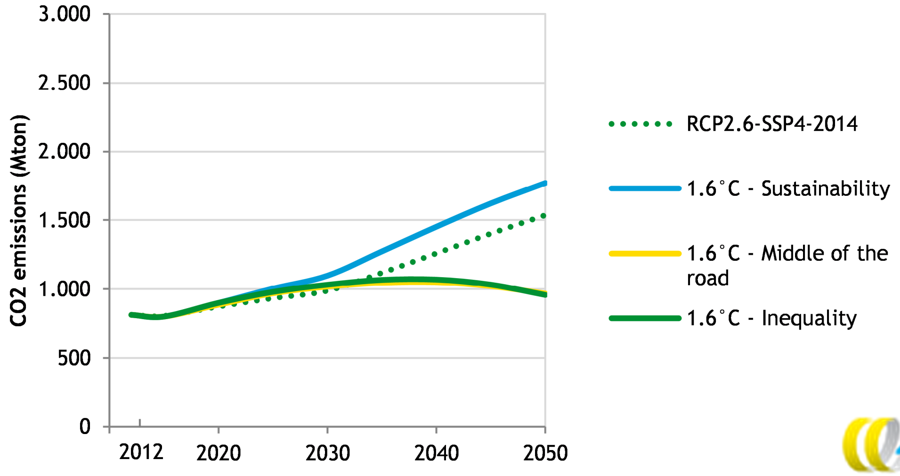
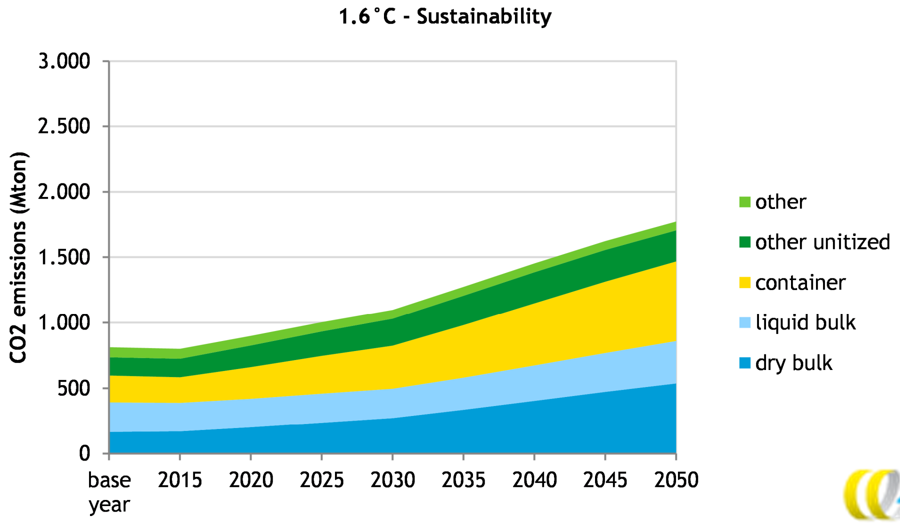


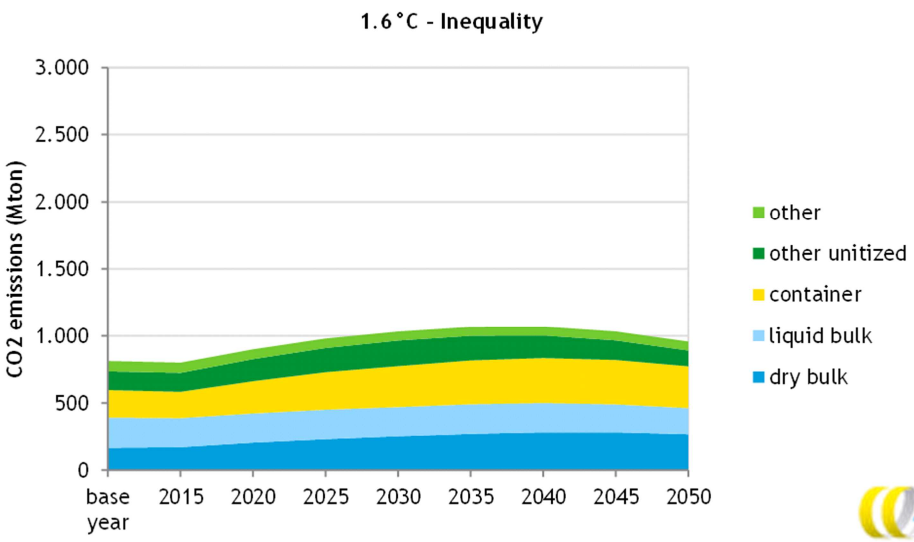
Figure 8 show the emission projections broken down to different ship types in the 1.6°C – Sustainability scenario. In this scenario with relatively high economic growth the overall emissions will increase by almost 120% in the period up to 2050, relative to 2012 levels. This increase is mainly the result of increases in emissions of containerships (almost 200% higher) and dry bulk carriers (225%). 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 decrease somewhat because increased emissions of gas carriers and chemical tankers cannot make up for the loss of emissions from oil transport.

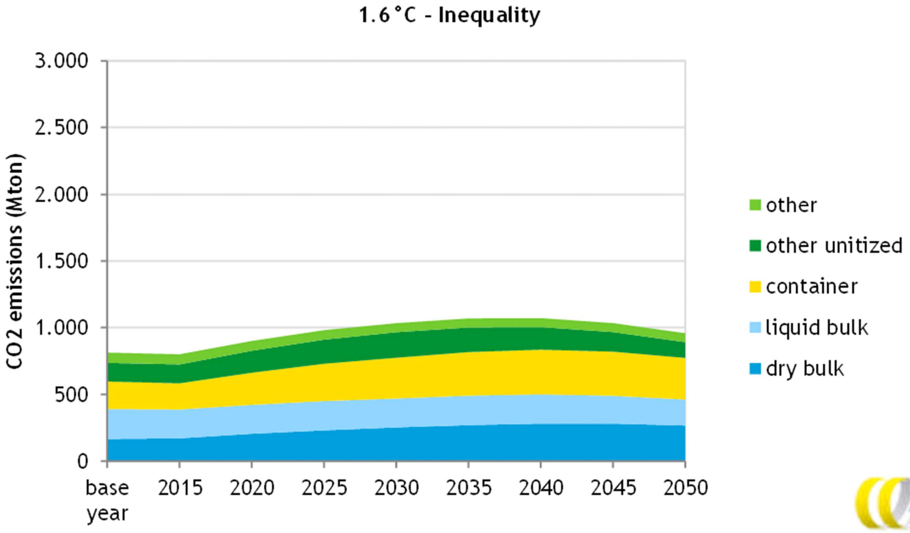
Figure 8 CO2 emission projections of different ship types in the 1.6°C - sustainability scenario



In the two scenarios with moderate economic growth (‘middle of the road’ and ‘inequality’), the overall emissions will almost return to 2012 levels by 2050 after an initial increase, 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 increase will be largely compensated by decreases in emissions of liquid bulk ships and other unitized ships.

Figure 9 CO2 emission projections of different ship types in the 1.6°C - middle of the road and 1.6°C - inequality scenarios





2.6 Comparison with the Third IMO Greenhouse Gas Study 2014

Figure 10 compares the one 1.6°C scenario from the Third IMO Greenhouse Gas Study 2014 with the three updated scenarios. In order to facilitate the comparison, each of the updated scenarios is presented next to the same scenario from the Third IMO GHG Study 2014.

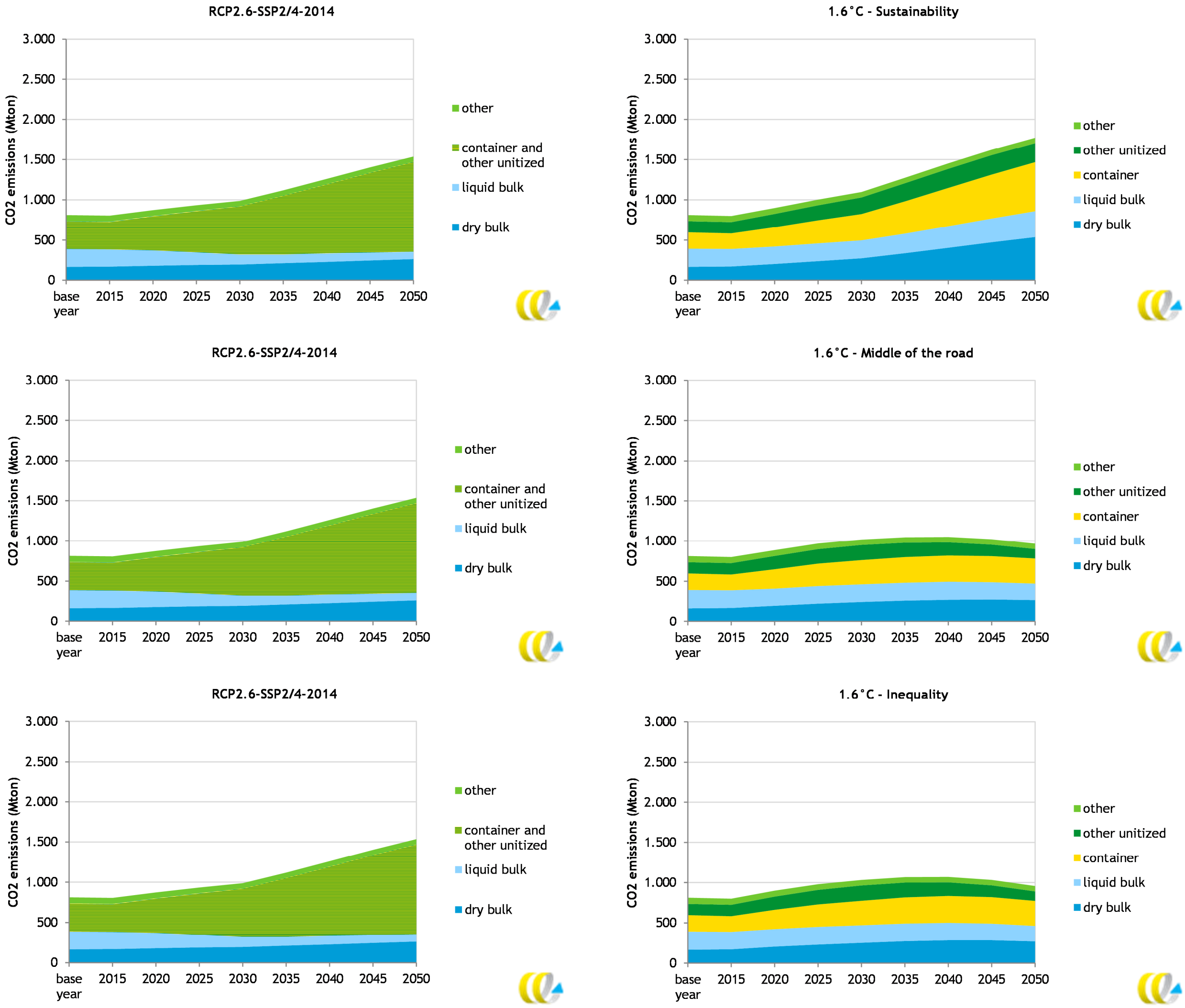
Remember that the update involved three major data-driven changes in the analysis:
1. Disaggregating unitized cargo into containers and other unitized made possible by a new data source on transport work data.
2. Adding more categories of non-coal dry bulk and thus increasing the weight of non-coal cargoes in the dry bulk transport work projections.
3. Adding three years of historical transport work data to the historical analysis of the relation between transport work and its drivers.

The first change impacts the emissions of other unitized cargo ships (general cargo ships, roro ships and car carriers). Whereas the Third IMO Greenhouse Gas Study projected them to increase together with emissions from container ships, both driven by GDP growth, the update projects them to grow moderately or even decline as the demand for transport of these ships appears to be mature. Note, however, that projections of transport work for non-container unitized cargoes have a larger uncertainty than other transport work projections because of the relatively low R^2 (see Section 2.4). This uncertainty affects a only the emissions from car carriers, ro-ro and ro-pax ships.

The second change has an impact on the emissions of dry bulk carriers, which increase more in the updated scenarios than in the previous ones. The reason is that the new data show that a larger share of the dry bulk fleet is engaged in transporting non-coal dry bulk cargoes, the demand for which is assumed to be driven by GDP growth, and that consequently the projected decline in demand for coal affects a smaller share of the fleet.

The impact of the three years of new data is clear when comparing the projections of other unitized and container ships in the bottom four panels, which have similar GDP growth rates. In particular, the emissions of containerships are projected to grow at a lower rate because the new data show that the container transport demand is closer to maturity than the 2014 analysis showed.

Figure 10 Comparison of the 2°C scenario from the Thirds IMO Greenhouse Gas Study 2014 with the updated scenarios



2.7 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 grow by 20-120% between 2012 and 2050. 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.

3 Emission projections when global climate policy goals are not met

3.1 Introduction

This chapter presents emission projections that are based on scenarios in which the mean projected temperature increase is more than 2°C.
These scenarios cannot be considered to be in line with the Paris Agreement temperature goal.

The scenarios have been chosen to reflect the BAU scenarios in the Third IMO Greenhouse Gas Study 2014, and they are renamed to show clearly which climate and socio-economic pathway has been used:
- RCP8.5 in combination with SSP5 is now called 4°C – Fossil fuelled development;
- RCP6.0 in combination with SSP1 is now called 3°C – Sustainability;
- RCP4.5 in combination with SSP3 is now called 2.5°C – Regional rivalry.

All the projections in this chapter have been calculated in the same way as the emission projections presented in Chapter 2. For a description of the methodology, please refer to Sections 2.2 through 2.4.

3.2 Transport work projections

This section presents the projections of transport work for the different cargoes included in this study. Figure 11 shows projections for transport of oil, coal and gas based on energy consumption projections in the RCP4.5, RCP6.0 and RCP 8.5 scenarios. Figure 12 shows projections for the other cargoes based on GDP projections in the three SSP scenarios that have been combined with these RCPs.

Figure 11 Historical and projected transport work to 2050 for coal, oil and gas in RCP4.5, RCP6.0 and RCP8.5 scenarios

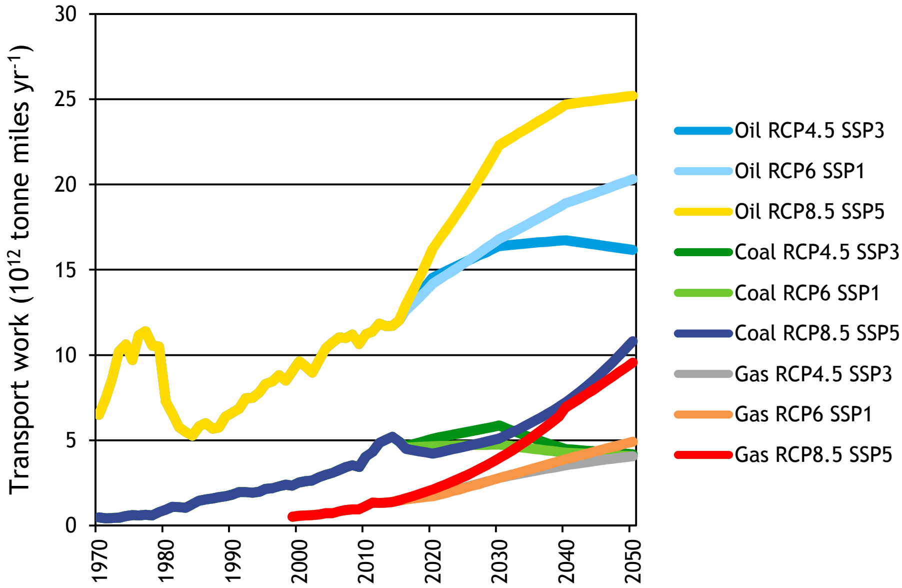
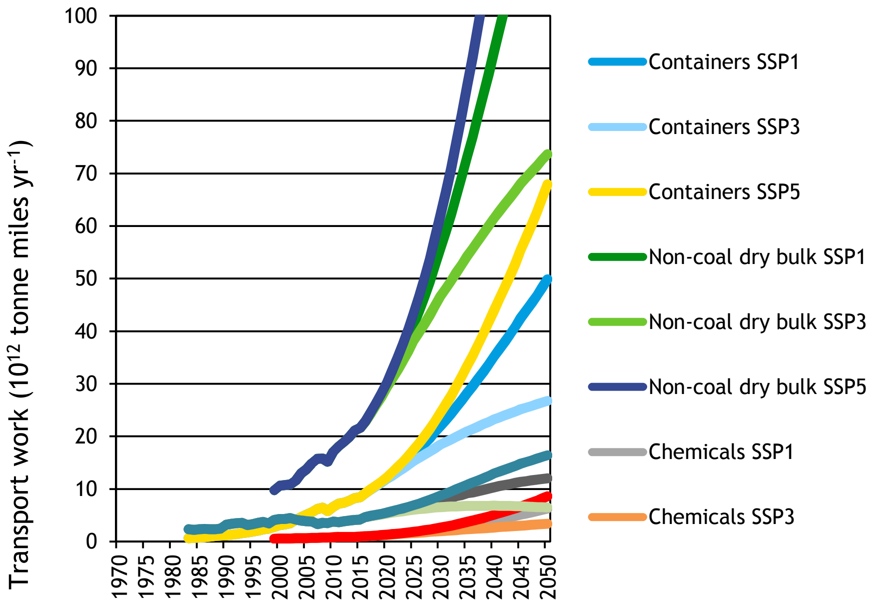


Figure 12 Historical and projected transport work for container, non-coal dry bulk, chemicals and other unitized cargoes according to SSP scenarios



3.3 Emission projections

Figure 13 presents the emission projections from three BAU scenarios. The projections are all well below the projections in the Third IMO Greenhouse Gas Study 2014. By 2050, emissions are projected to range from 35% above 2012 levels in a scenario with a moderate economic development to 210% in a scenario with the highest economic growth rates.

Figure 13 CO_2 emission projections of shipping in three scenarios with temperature increases exceeding 2°C

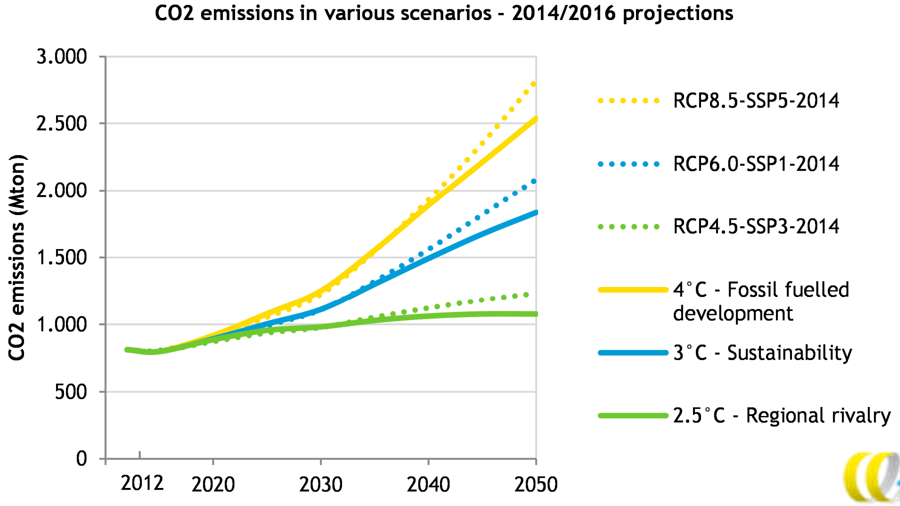


Figure 14 through Figure 16 show how the emissions of various groups of ship types are projected to evolve over time. In the scenario 2.5°C - Regional Rivalry total CO_2 emissions are projected to increase to 35% above 2012 levels, mainly because of low economic growth assumptions. While both emissions from containerships and bulkers increase, the emissions from ships carrying other unitized goods and tankers remain the same. The increase in emissions is higher in the 3°C - Sustainability scenario, around 125%. Compared to 2.5°C - Regional Rivalry, the emissions of bulkers and especially containerships are much higher. In the 4°C - Fossil Fuelled Development scenario emissions more than triple compared to 2012 levels. Besides even higher emissions from containerships and bulkers, also emissions from tankers more than double in this scenario, which remains heavily dependent on consumption of fossil fuels to drive development.

Figure 14 CO_2 emission projections of different ship types in the 2.5°C - regional rivalry scenario

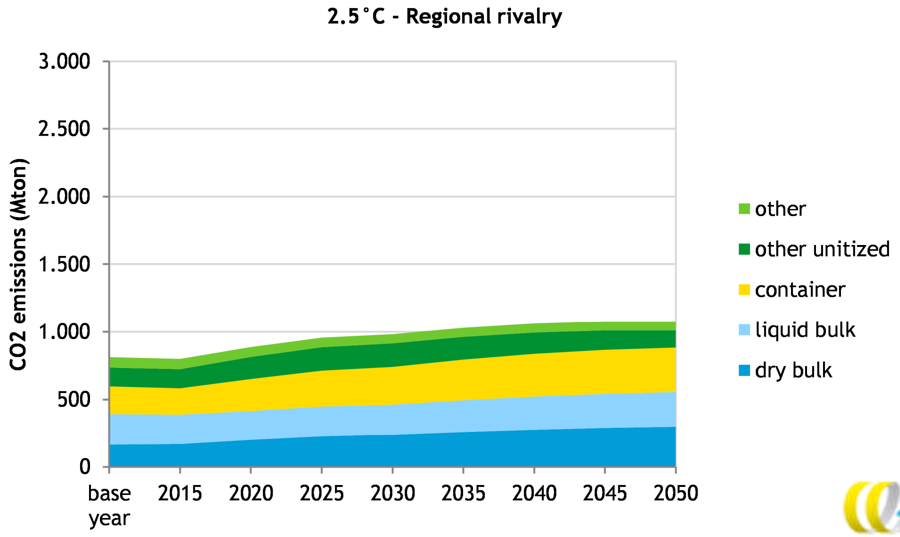


Figure 15 CO_2 emission projections of different ship types in the 3°C - sustainability scenario

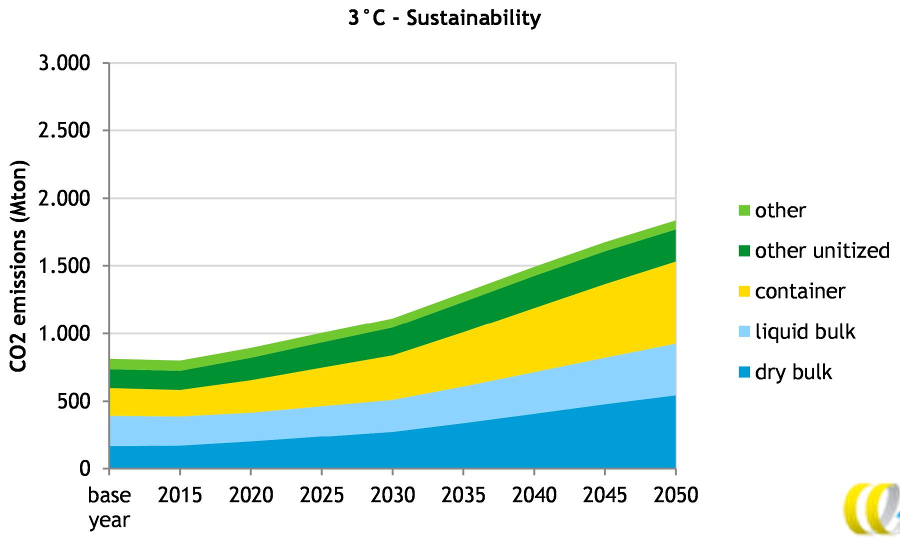
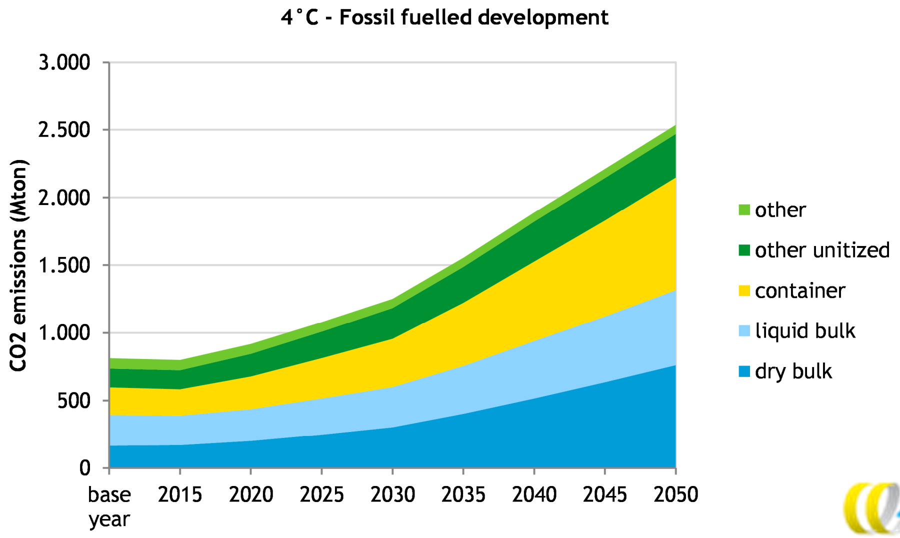


Figure 16 CO_2 emission projections of different ship types in the 4°C - fossil fuelled development scenario

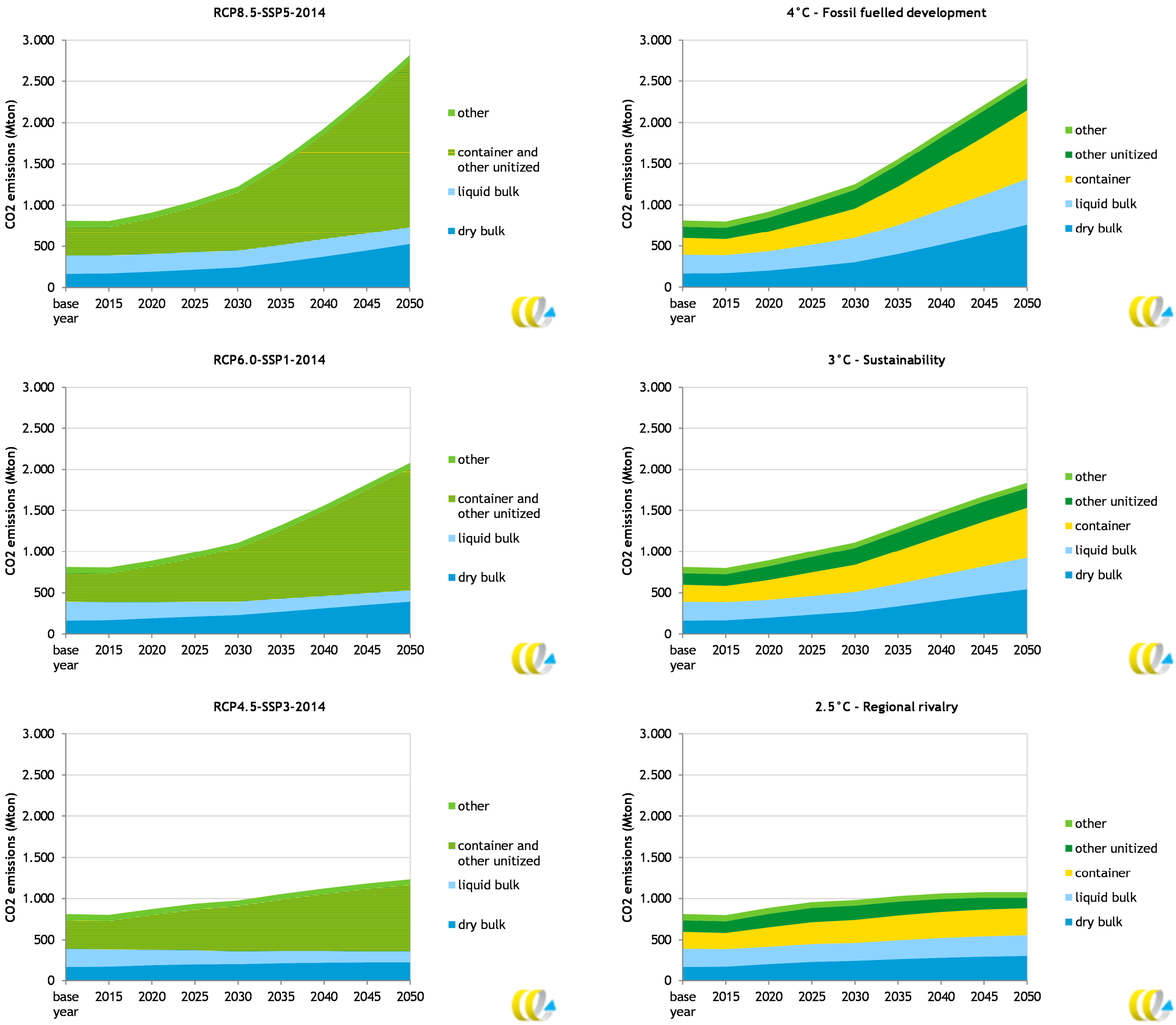


3.4 Differences with the Third IMO Greenhouse Gas Study 2014

Figure 17 presents a comparison of the emission projections for various ship types from the Third IMO Greenhouse Gas Study 2014 (on the left) and from this update study (on the right). In all cases, the emissions of dry bulk carriers are likely to increase more. This is due to the fact that the new transport work data employed in this study show that the share of non-coal dry bulk in total dry bulk was larger in 2012 and also in more recent years. Since non-coal dry bulk is driven by GDP, whereas coal consumption and transport are reduced for climate policy reasons in most scenarios, emissions of dry bulk carriers grow faster.

Due to the fact that more disaggregated data were available, the emissions of unitized cargo ships have been split into emissions of containerships and of non-container unitized cargo ships (general cargo carriers, car carriers, roro ships, et cetera). The sum of the emissions from these ship types is lower in the projections in this report because transport work data of recent years show that the market is closer to maturity than the previous analysis showed.

Figure 17 Comparison of three scenarios from the Thirds IMO Greenhouse Gas Study 2014 with the updated scenarios



3.5 Conclusions

In the three different BAU scenarios in which the Paris Agreement temperature goal will be exceeded, greenhouse gas emissions of shipping will increase by 35% to 210% in the period between 2012 and 2050. Although projected changes in energy use account for some of the difference, the differences between the scenarios can mostly be attributed to varying projections on GDP growth. In all cases, the updated emission projections are lower than the corresponding projections in the Third IMO Greenhouse Gas Study 2014. This is mainly due to lower increases of unitized cargo transport as a result of the levelling off of demand growth in recent years.

4 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, three 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 new BAU projections that are compatible with the Paris Agreement goal of keeping the global average temperature increase well below 2°C show increases in CO_2 emissions of 20-120% over 2012 levels. 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 new BAU scenarios for a world in which the temperature goal of the Paris Agreement will not be met, show increases in CO_2 emissions ranging from 35 to 210%.

All the new BAU projections are lower than the corresponding projections presented in the Third IMO Greenhouse Gas Study 2014.

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Annex 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:

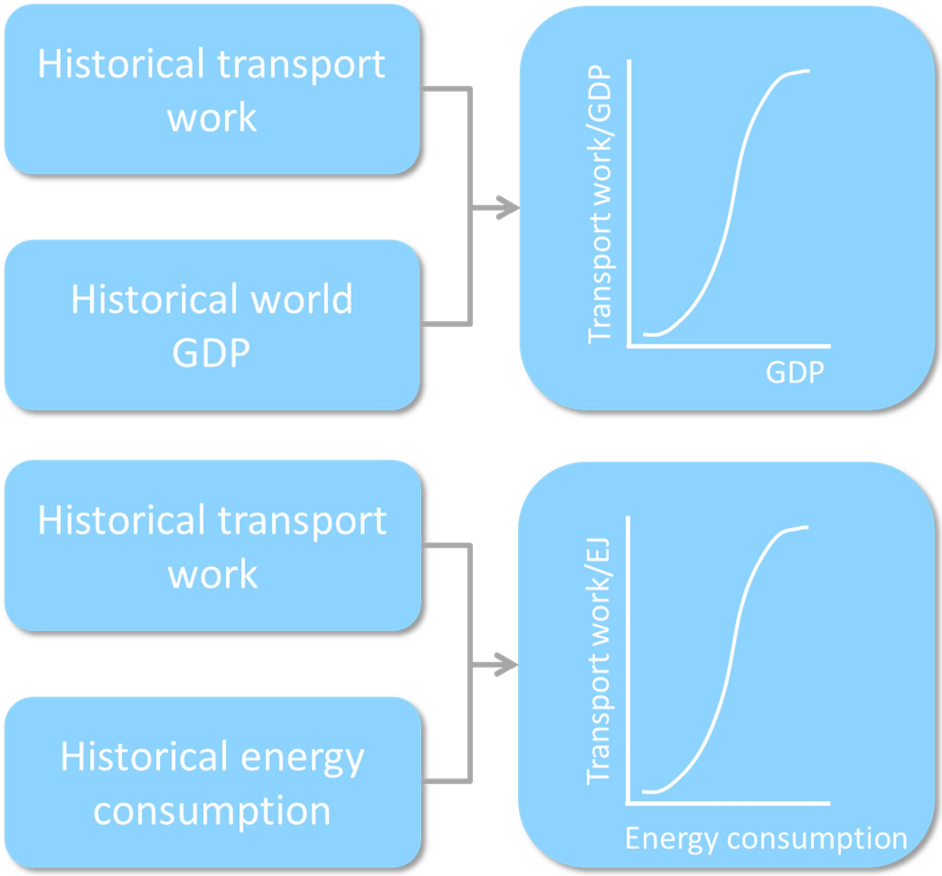
1. Establishing the historical relation between maritime transport work and relevant economic parameters such as world GDP (for transport for unitized cargo and non-coal dry bulk); crude oil consumption (for liquid bulk transport) and coal consumption (for coal transport).
2. Projecting transport work 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 1.52 and 1.54 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



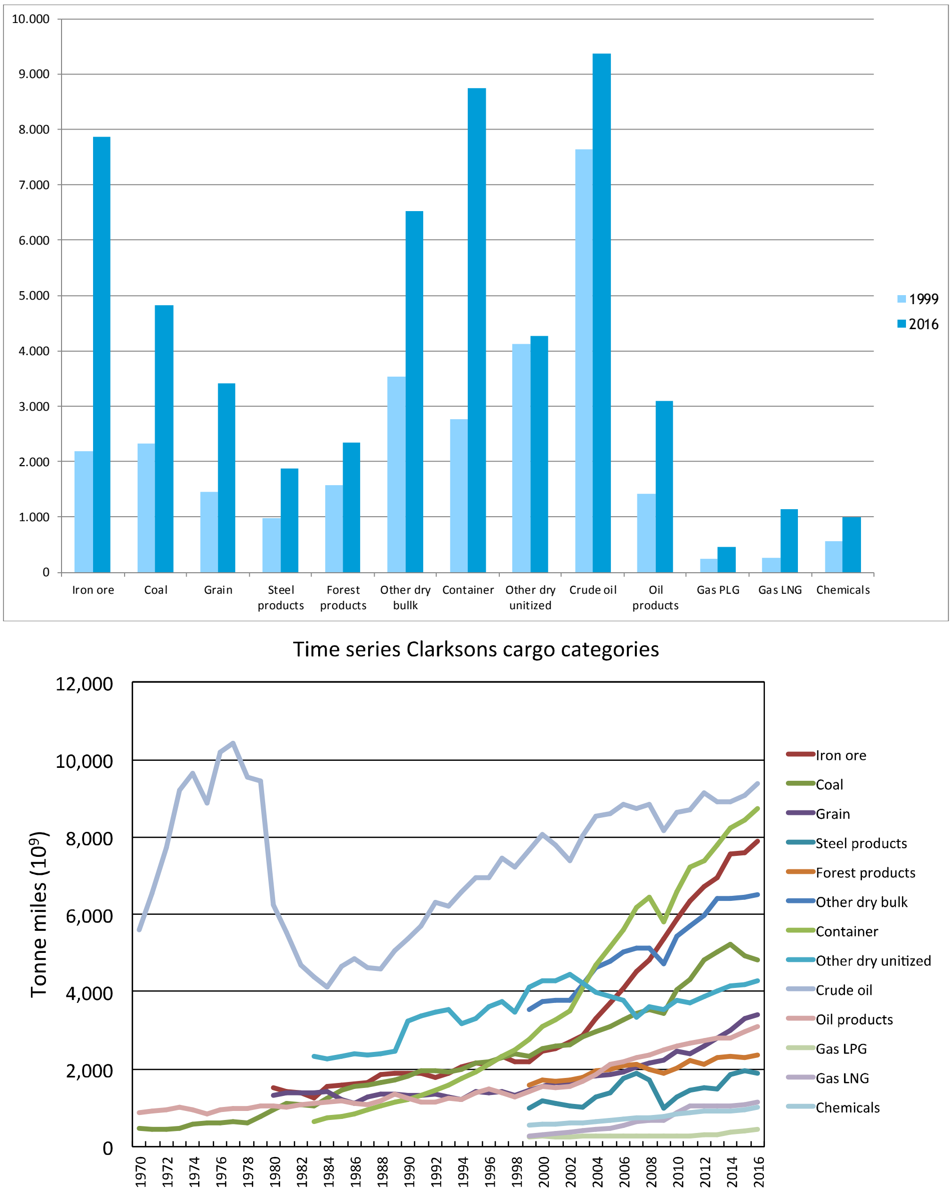
In the Third IMO GHG Study (IMO, 2015), transport projections to 2050 were made using historical data on seaborne trade for different cargo types from 1970 to 2012 provided by the United Nations Conference on Trade and Development (UNCTAD) as part of their annual 'Review of Maritime Transport', which 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 1(a) and compared with 1999, which was the first year that data on all cargo types was available. Figure 1(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 1a 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 date 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)**

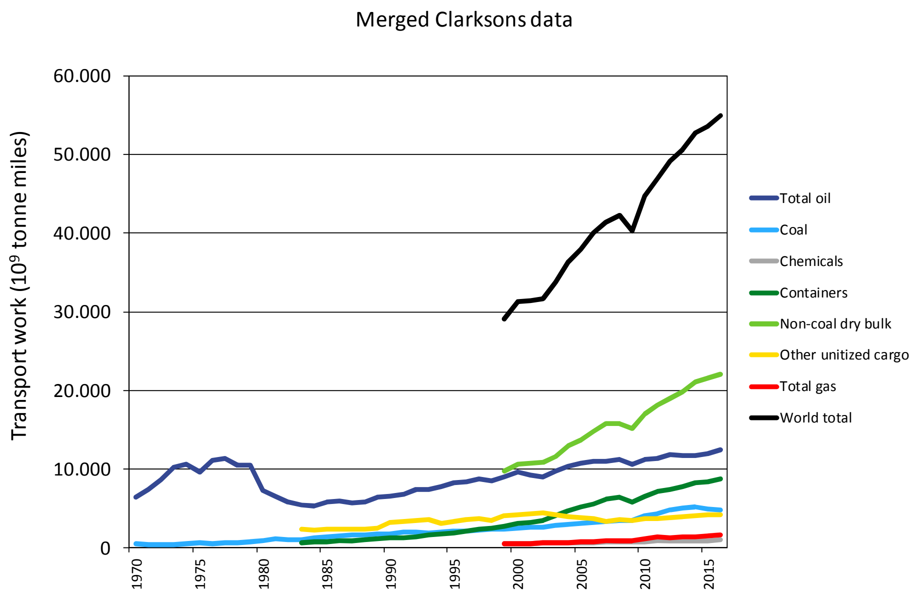
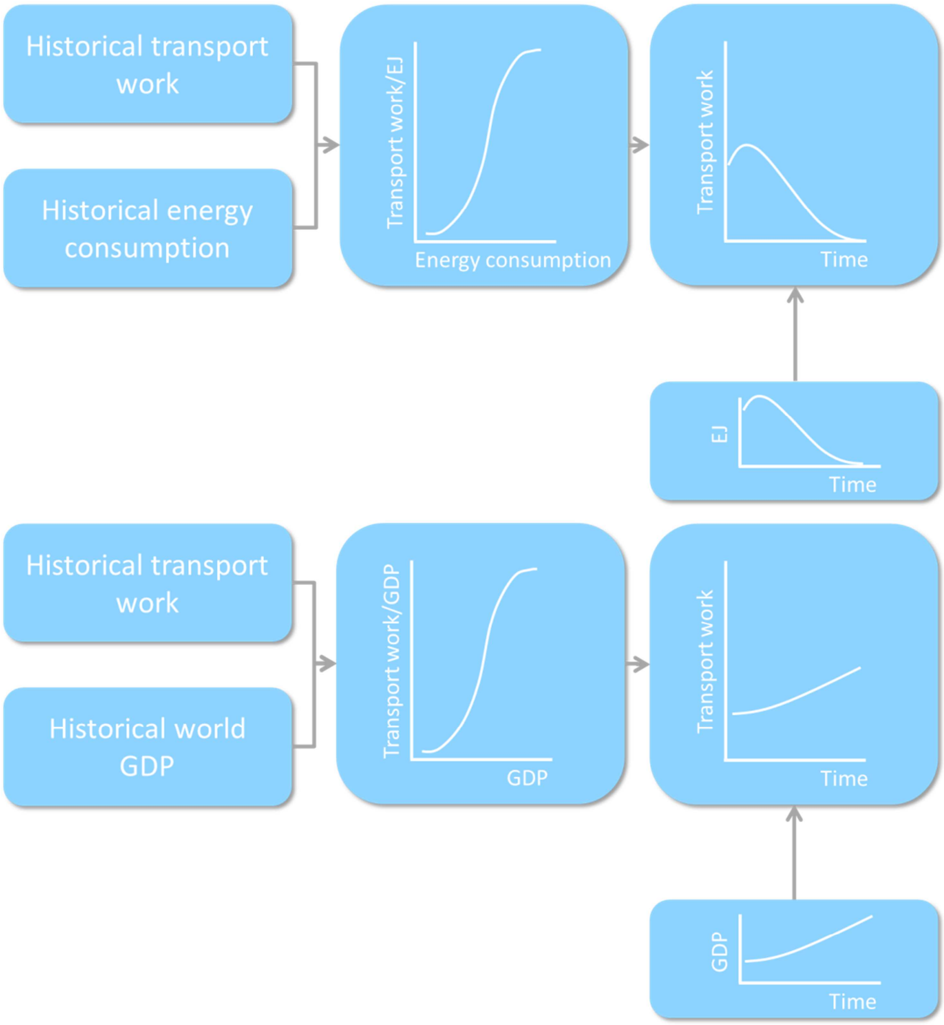


Figure 2 shows the groupings of data over time periods possible, because of different start dates of data collection. These groupings of time-series data were then used in the analysis to derive projections. The only exception in terms of data screening was the total oil data, where data prior to 1985 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 thee 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



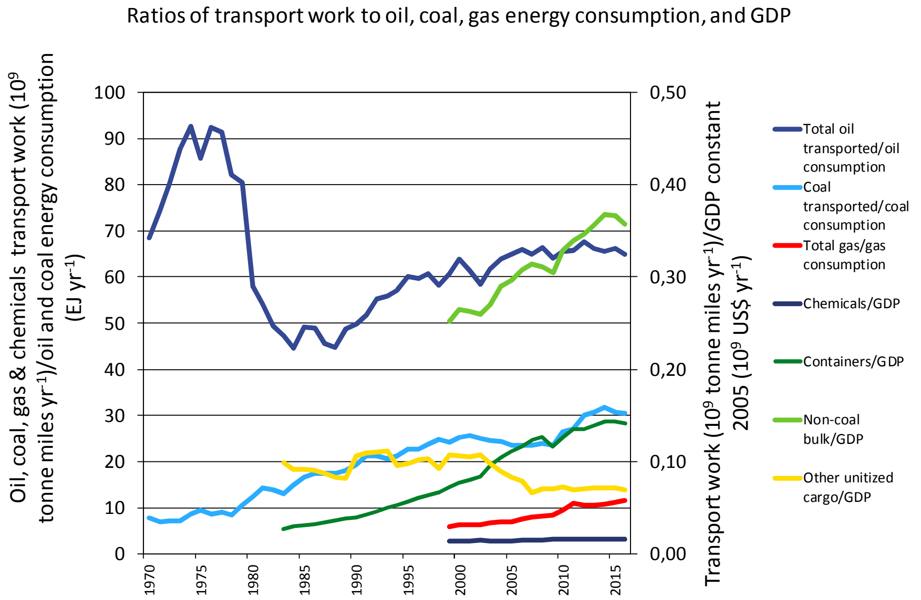
Projection data

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. The IIASA GDP projection 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 3. Note that in Figure 3, the early period of total oil data (1970–1985) are shown, but as outlined above, these data were excluded from the analysis.

1 http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

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. Figures 1 and 2 shows 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 3 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 4 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**

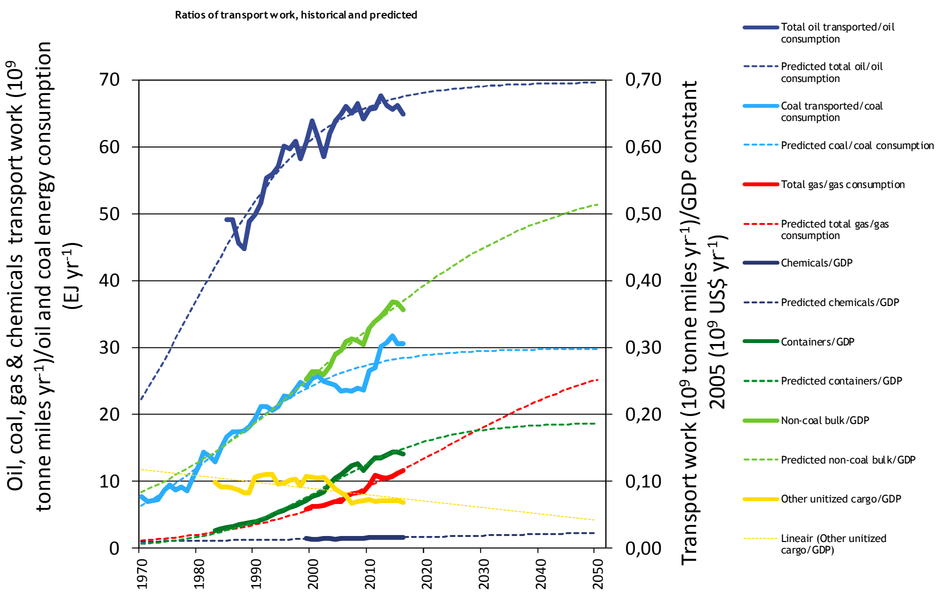


Figure 4 shows that future growth rates of total seaborne trade can be successfully modelled in a non-linear fashion, which according to economic literature is more realistic than the conventional linear model, for six different cargo types that clearly indicate different levels of market maturity, as 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 24 shows the projected annual GDP growth rates for each SSP and Figure 25 the resulting world GDP up to 2050. The resultant transport work projections are shown in Figures 26-30.

Figure 24 Historical and Projected annual world GDP growth rates

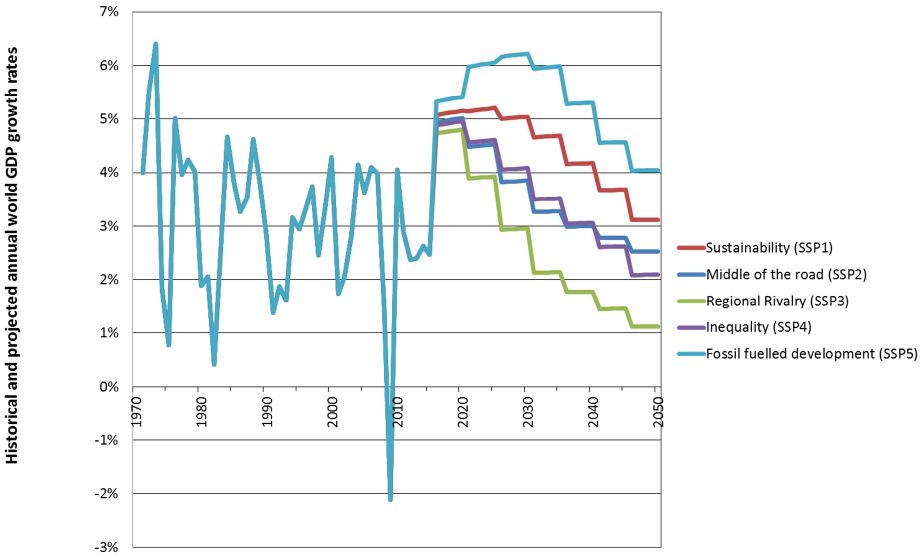
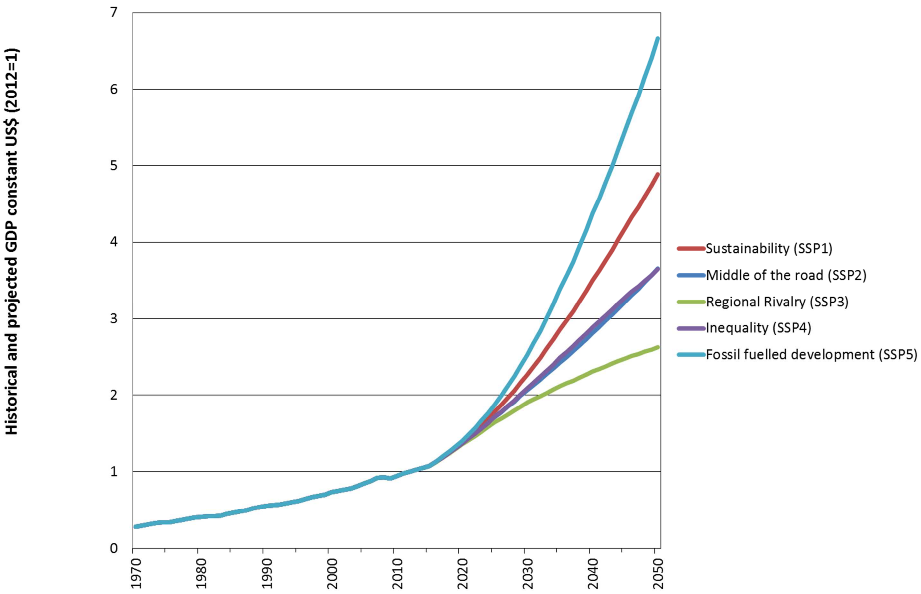


Figure 25 Historical and projected world GDP (constant USD, index: 2012 = 100)



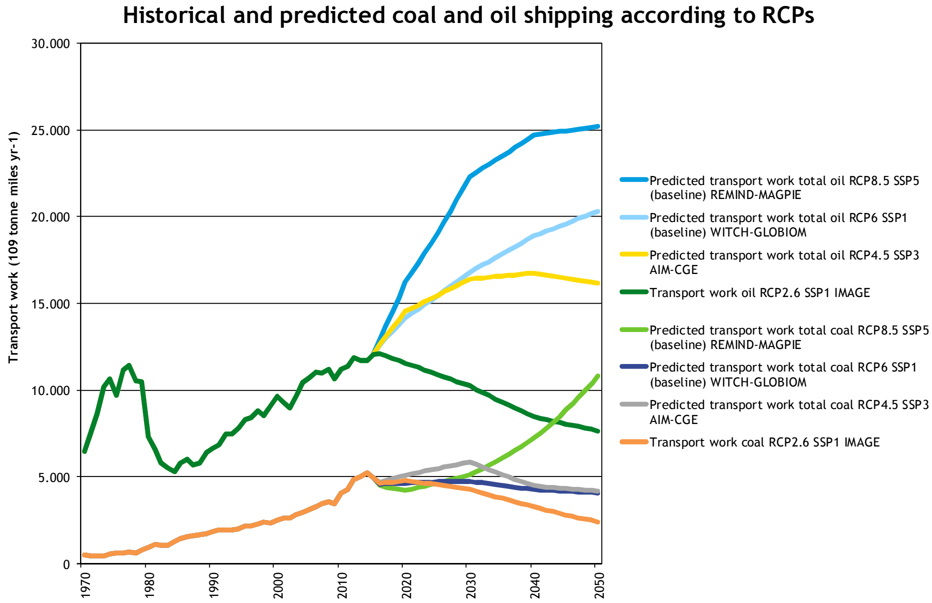


Figure 26 Historical and projected transport work (10^9 tonne miles yr^{-1}) to 2050 for coal, oil (upper chart) and total gas (lower chart) according to RCP/SSP scenarios

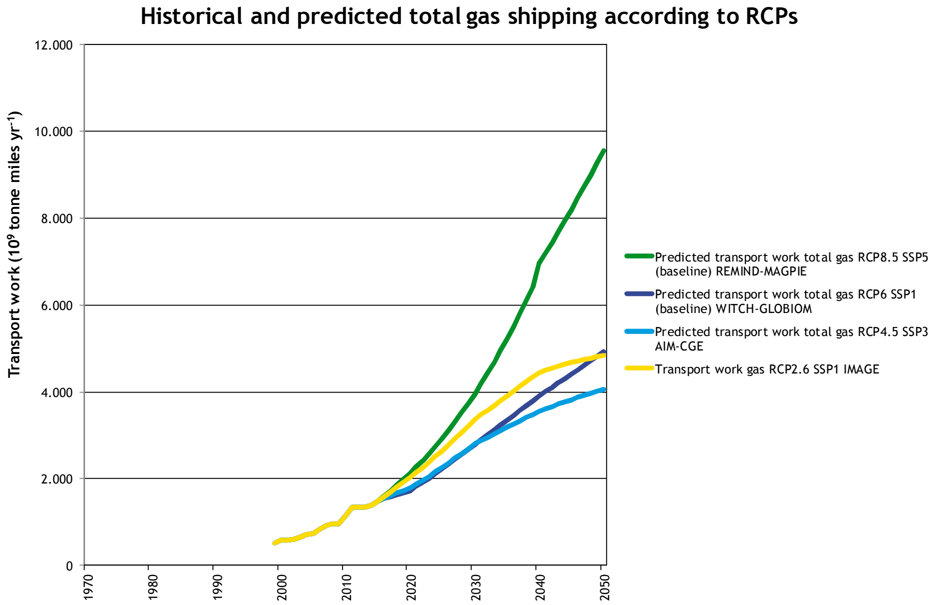


Figure 27 Historical and projected transport work (10^9 tonne miles yr^{-1}) to 2050 for container shipping according to SSP scenarios

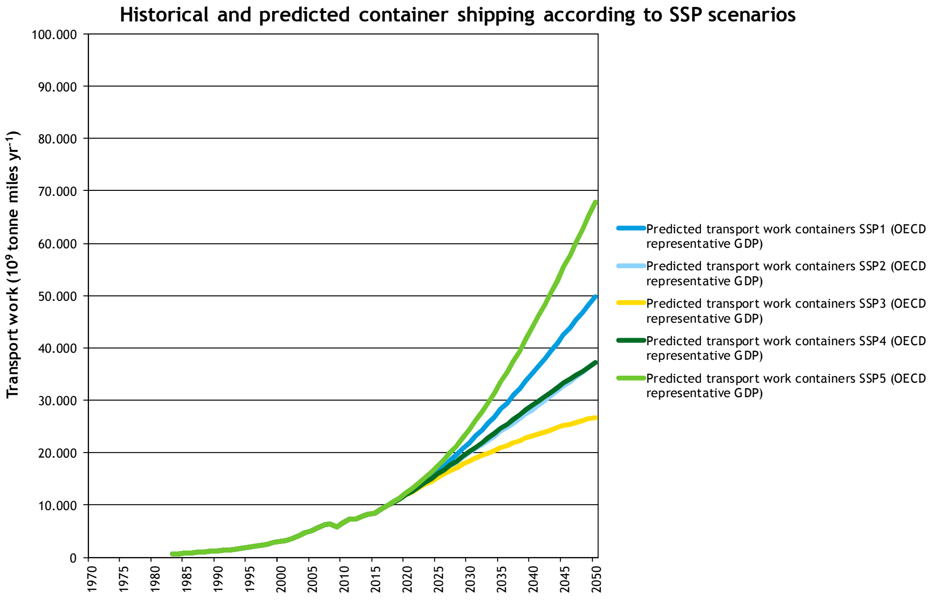


Figure 28 Historical and projected transport work (10^9 tonne miles yr^{-1}) to 2050 for non-coal dry bulk shipping according to SSP scenarios

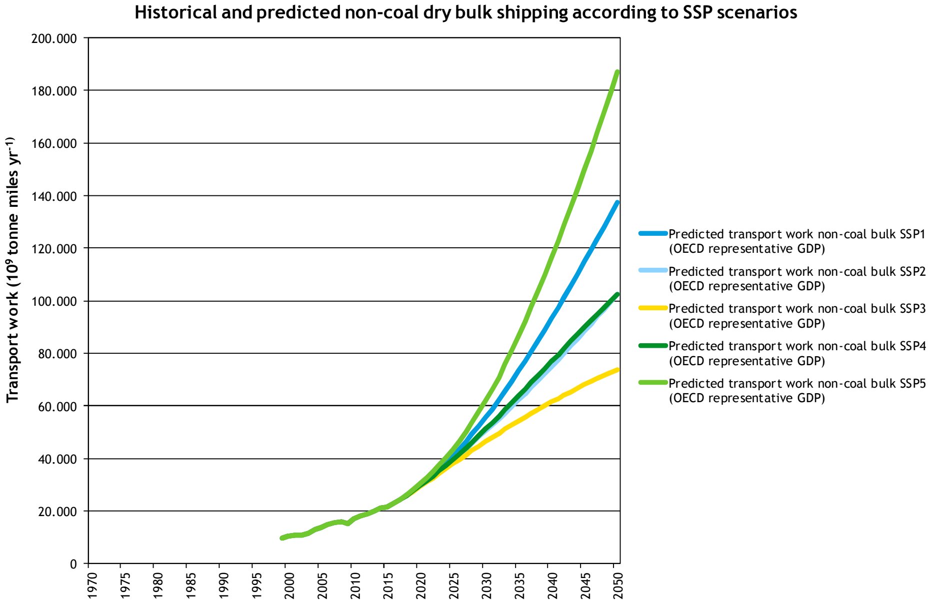


Figure 29 Historical and projected transport work (10^9 tonne miles yr^{-1}) to 2050 for other unitized cargo shipping according to SSP scenarios

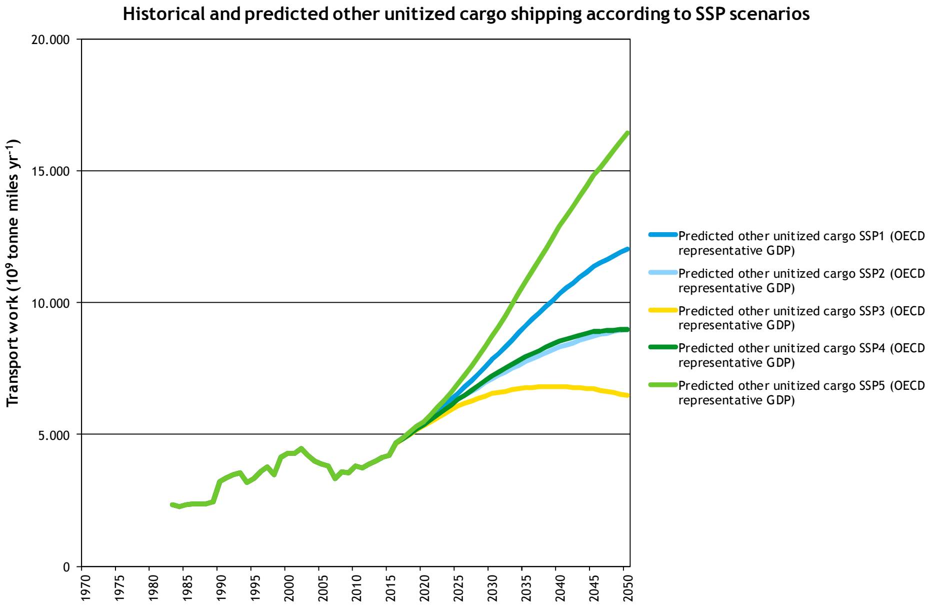
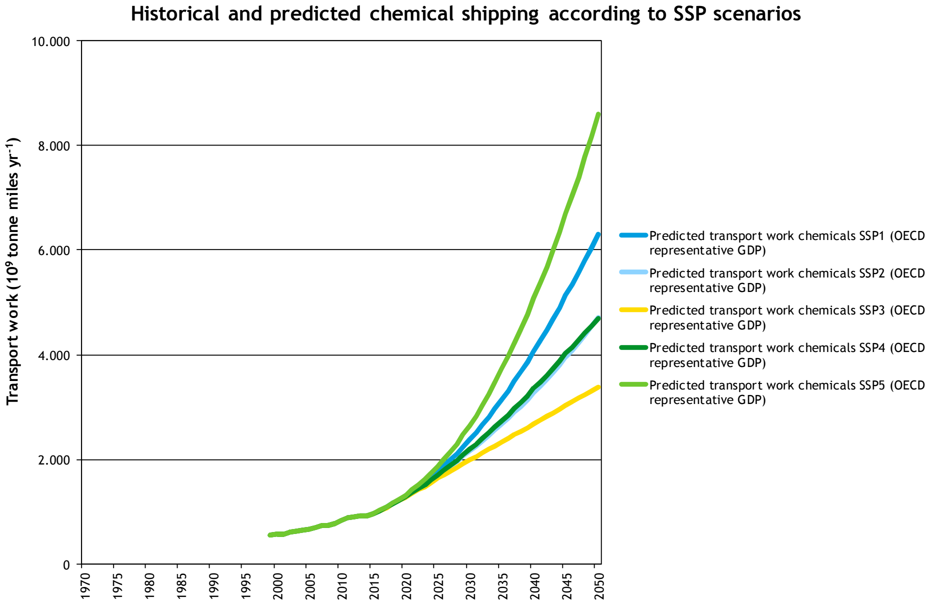


Figure 30 Historical and projected transport work (10^9 tonne miles yr^{-1}) to 2050 for chemicals shipping according to SSP scenarios



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, 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 4 and Appendix 1) 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 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.

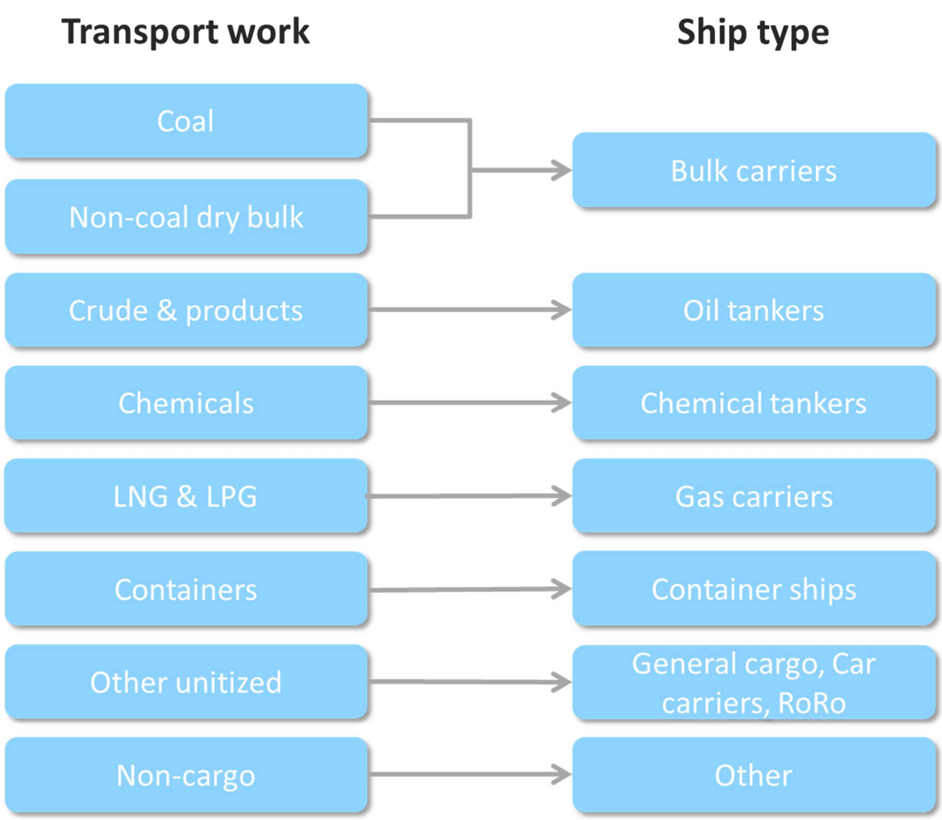
Overall, the representation in this work of different ship cargo types with different stage economic non-linear models and inherently different growth rates along with decoupling of fossil fuel transport from GDP represents a large step up in 'appropriateness' from the original projections of shipping 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 31 shows the mapping. In this way, the change of activity for each ship type can be projected into the future.

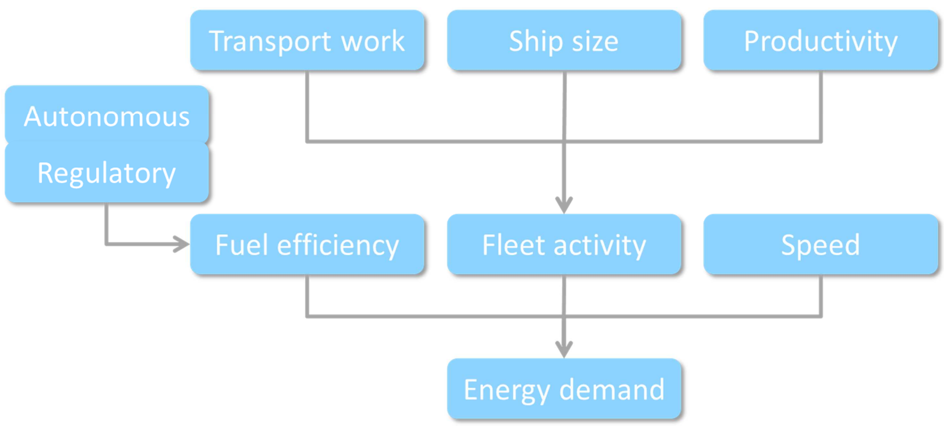
Figure 31 Mapping of cargo types to ship types



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 32 provides a graphical presentation.

Figure 32 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

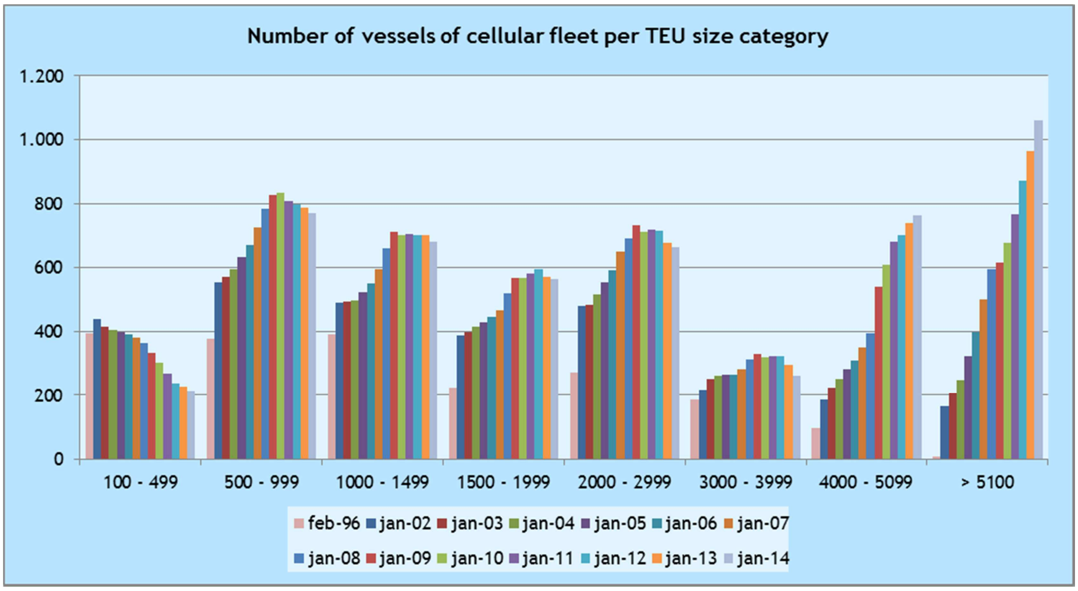
Starting point of the analysis is the 2012 distribution of the container ships over the size categories as determined in the emissions inventory (see Table 3).

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 33 the development of the distribution of the ships of the cellular fleet over the size categories is given for the period 2002-2014.

Figure 33 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 3,000-4000 TEU range relatively low.

Figure 33 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 2,800–5000 TEU and ships of 1,000-2,000 TEU have been mostly been displaced by 2,000–2,700 TEU ships (BRS, 2013). There is a broad agreement amongst observers of the container fleet that 'mid-size' 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 18,000 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.

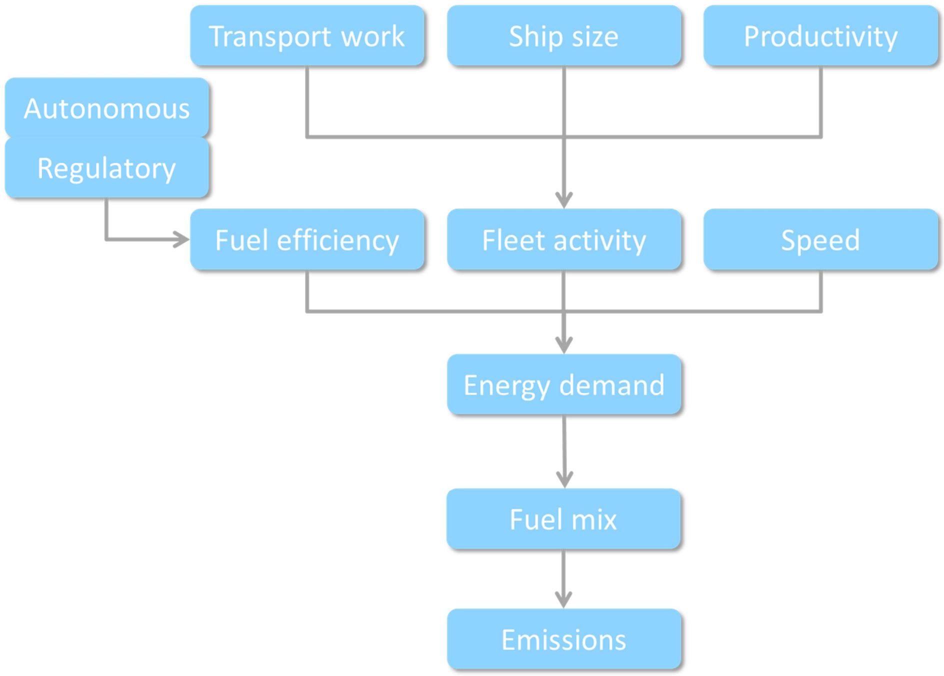
Table 4 Development of the distribution of container ships over size categories (in terms of numbers)

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 emissions

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 34 Emission projections



A.7 Detailed results emission projections

Table 5 and Table 6 present the detailed results of the CO_2 emission projections of shipping in the three 1.6°C scenarios and the three scenarios with temperature increases exceeding 2°C. All emissions figures are presented in Mtonnes.

Table 5 Detailed results CO_2 emission projections of shipping in three 1.6°C scenarios (Mtonnes)

Ship type	2012	1.6°C - Sustainability 2050	1.6°C - Middle of the road 2050	1.6°C - Inequality 2050
Dry bulk	170	540	270	270
Liquid bulk	230	320	200	190
Container	200	610	310	310
Other unitized	140	240	120	120
Other	80	70	70	70
Total[2]	810	1.770	970	960

2 The sum of emissions per ship type do not always add up tot the total emissions, because emissions were rounded to tens.

Table 6 CO_2 emission projections of shipping in three scenarios with temperature increases exceeding 2°C (Mtonnes)

Ship type	2012	2.5°C - Regional rivalry 2050	3°C - Sustainability 2050	4°C - Fossil fuelled development 2050
Dry bulk	170	300	540	760
Liquid bulk	230	260	380	550
Container	200	330	610	830
Other unitized	140	130	240	320
Other	80	70	70	70
Total	810	1.080	1.830	2.540