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Emission Reduction Targets for International Aviation and Shipping

Study for the ENVI Committee

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Emission Reduction Targets for International Aviation and Shipping

DIRECTORATE GENERAL FOR INTERNAL POLICIES

POLICY DEPARTMENT A: ECONOMIC AND SCIENTIFIC POLICY

Emission Reduction Targets for International Aviation and Shipping

STUDY

Abstract

This study provides an overview of potential CO2 mitigation targets for international aviation and maritime transport and analyses which targets would be compatible with the global long-term goal of keeping the temperature increase below 2°C compared to pre-industrial levels. The analysis supports the view that it is important to establish targets for both sectors which clearly indicate that emissions cannot grow in an unlimited and unregulated way.

This study was provided by Policy Department A for the Committee on Environment, Public Health and Food Safety (ENVI).

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LIST OF ABBREVIATIONS

CAEP	Committee on Aviation Environmental Protection
CDM	Clean Development Mechanism
CNG	Carbon Neutral Growth
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalents
COP	Conference of the Parties
EAG	Environmental Advisory Group
EEA	European Economic Area
EEDI	Energy Efficiency Design Index
ETS	Emissions Trading System
EU	European Union
GHG	Greenhouse Gas
GMBM	Global Market-Based Mechanism
GMTF	Global Market-based Measure Task Force
GWP	Global Worming Potential
IATA	International Aviation Transport Association
ICAO	International Civil Aviation Organization
ICS	International Chamber of Shipping
IEA	International Energy Agency
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
LOSU	Level of Scientific Understanding
MBM	Market-Based Mechanism/Measure
MEPC	Marine Environment Protection Committee
MRV	Monitoring, Reporting, Verification
MW	Megawatt
NO_x	Nitrogen Oxide

RCP Representative Concentration Pathways

RFI Radiative Forcing Index

RMI Republic of the Marshall Islands

SEEMP Ship Energy Efficiency Management Plan

SLCF Short-Lived Climate Forcers

SO_2 Sulfur Dioxide

UNFCCC United Nations Framework Convention on Climate Change

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EXECUTIVE SUMMARY

The IPCC finds that the growth of global transport demand could pose a significant challenge to the achievement of potential emission reduction goals. Due to strong growth in transport demand, CO_2 emissions of international aviation and maritime transport were and are constantly growing despite considerable efficiency improvements. In 2012, both sectors together account for about 3 % to 4 % of global emissions depending on whether global GHG or only CO_2 emissions are considered. Initiatives and actions taken by ICAO and IMO to address GHG emissions started late and have been insufficient from an environmental perspective to date: they do not take appropriate account of global decarbonisation requirements. In the long run, measures proposed by IMO and ICAO will mitigate growth of the sectoral CO_2 emissions but not lead to absolute emission reductions.

If, as in the past, the ambition of these sectors continues to fall behind efforts in other sectors and if action to combat climate change is further postponed, their CO_2 emission shares in global CO_2 emissions may rise substantially to 22 % for international aviation and 17 % for maritime transport by 2050, or almost 40 % of global CO_2 emissions if both sectors are considered together. Establishing reduction targets for both sectors would provide clear signals for all actors in these sectors and thus contribute to improving investment perspectives in both sectors with their long investment cycles.

Based on several criteria, potential mitigation targets for the aviation and shipping sectors were developed. They range from a somewhat reduced increase of future emissions over stabilisation at 2020 levels to a full decarbonisation of those sectors by 2050. While full decarbonisation within only 30 years is rather unrealistic, stabilising emissions at 2020 levels (carbon neutral growth) is clearly not enough. To stay below 2°C, the target for aviation for 2030 should not exceed 39 % of its 2005 emission levels (50 % below the baseline) and should be -41 % compared to its 2005 emission levels in 2050. The respective targets for shipping are -13 % and -63 % compared to its 2005 emissions in 2030 and 2050, respectively. If non-CO_2 impacts are taken into account, these targets would need to be even more stringent.

Taking into account the estimated mitigation potential within the sectors, it is unlikely that targets which are compatible with the below 2°C objective can be achieved only with technological and operational improvements within the sectors. Thus, these potential targets indicate the extent to which both sectors could contribute adequately to global GHG mitigation efforts. Achieving these targets may require both encouraging behavioural change which leads to reduced demand for international transport services and enabling the offsetting of climate impacts by financing emission reductions in other sectors. Moreover, it needs to be taken into account that particularly the non-CO_2 climate impacts of aviation will not be reduced if fossil fuels are replaced by hydrocarbons extracted from renewable energies. Only electrical propulsion, demand reduction or offsetting remaining emission will enable full decarbonisation of the aviation sector.

These considerations support the view that it is important to establish targets for international aviation and maritime transport which clearly indicate that emissions cannot grow unlimited and unregulated. Enhancing the stringency of the targets can be aimed at in a second step. Yet, aiming for ambitious targets in line with the approaches outlined above should not prevent agreement on targets which will trigger emission reductions sooner rather than later.

1. INTRODUCTION

The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (Article 2, UN 1992). The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) reinforces evidence that limiting global warming to less than 2°C above pre-industrial temperatures considerably reduces the risk of triggering accelerated or irreversible changes in the climate system as well as large-scale adverse impacts. The report introduces a carbon budget which is based on cumulative carbon emissions over time. According to this approach, a budget of some 1 000 Gt of greenhouse gas (GHG) emissions remains, to avoid a global temperature increase of more than 2°C compared to preindustrial levels (IPCC 2014, p. 10). To remain within this carbon budget, all sectors need to contribute to global GHG reduction efforts.

Regarding the transport sector, the IPCC finds that the growth of global transport demand could pose a significant challenge to the achievement of potential emission reduction goals. In mitigation scenarios which aim to keep the global concentration of greenhouse gases around 450 ppm or 550 ppm, all transport modes would be required to improve their fuel efficiency considerably, use more low carbon fuels and adopt behavioural measures that reduce transport demand and emissions (Sims et al. 2014).

In 2012, the contribution to global CO_2 emissions of international aviation and maritime transport amounted to 1.3 % and 2.2 %, respectively. In both sectors emissions are predominantly international (62 % and 79 %, respectively), i.e. they are not counted towards domestic emissions by a specific country. Together, international and domestic civil aviation and marine transport accounted for 4.2 % of global CO_2 emissions (2.1 % per sector).

Projections indicate that under business-as-usual conditions, aviation and maritime transport will continue to increase considerably and, since demand growth in transport service is very likely to be stronger than efficiency improvements in these sectors (ICAO 2013b, IMO 2014), CO_2 emissions will continue to increase both in absolute terms and with respect to their share in global emissions.

In 2011, the International Civil Aviation Organization (ICAO) adopted an aspirational goal to stabilise the CO_2 emissions of international aviation after 2020. Further growth beyond that date should be offset to achieve Carbon Neutral Growth from 2020 (CNG 2020). The International Maritime Organization (IMO) discussed a proposal by the Republic of the Marshall Island (RMI) to agree on a reduction target for international shipping in May 2015 but postponed the discussion to a further meeting. To date, there are no plans to implement emission reduction targets for these sectors. This lack of adequate targets and appropriate action from international aviation and shipping risks undermining efforts in other sectors towards remaining within the 2°C objective compared to pre-industrial levels.

In its report on the implementation of the 2011 White Paper on transport, the European Parliament takes the view that the EU at the 2015 Climate Conference in Paris (COP 21) must promote “the decarbonisation of transport and the development of sustainable modes of transport, thus contributing to achieving the internationally agreed goal of keeping global warming below 2 °C” (European Parliament 2015, p. 13, para. 60). In addition, the coordinators of the ENVI committee underscore “the need for ambitious targets for aviation and shipping” (Liese et al. 2015).

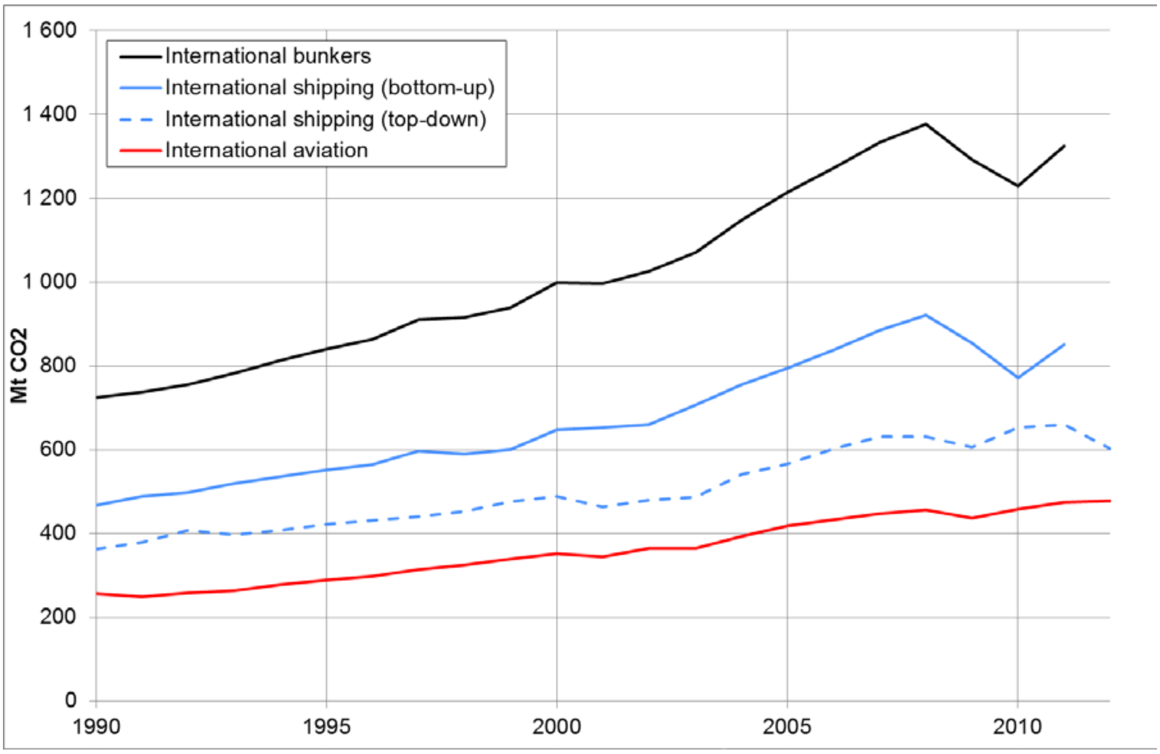
The aim of this study is to provide Members of the European Parliament with the necessary expertise to assess what adequate contributions of the two sectors would be in terms of emission reduction. We start with a summary of the historic CO_2 emission trends in both sectors (Chapter 2). Despite the fact that both international aviation and maritime transport contribute to climate change beyond their GHG emissions (Box 1), we focus our quantitative analysis on CO_2 only, due to limited availability of consistent data for non-CO_2 impacts. However, since these impacts cannot simply be ignored, we point out the implications for our conclusions if non-CO_2 impacts are taken into account as well. In Chapter 3 we provide a short overview of efforts undertaken at ICAO and IMO to address GHG emission of international aviation and maritime transport. In order to determine the future role of both sectors in terms of global GHG emissions, we examine emission projections for international aviation and maritime transport (Chapter 4) and provide estimates of their shares to global GHG emission pathways (Chapter 5). Based on these considerations we discuss concepts and approaches to determine adequacy in terms of emissions (Chapter 6) and derive potential emission stabilisation and reduction targets from these deliberations (Chapter 7). Conclusions of this study are provided in Chapter 8.

2. HISTORIC EMISSION TRENDS

Global greenhouse gas emissions have risen from approx. 40 000 Mt CO_2eq in 1990 to almost 50 000 Mt CO_2eq in 2010, an increase of 25 % (van Vuuren, D. P. et al. 2011). In the same period emissions from international aviation and maritime transport have increased by 70 % (Figure 1). In absolute terms emissions from bunker fuels rose from 724 Mt CO_2 in 1990 to 1 229 Mt CO_2 in 2010. Emissions from these two sectors are strongly linked to the global economic development. The effect of the financial crisis in 2009 but also of the attacks on the World Trade Center in New York in 2001 can be seen in the historic data. While these events led to a short decrease of emissions, the rising trend continued in the subsequent years. On average, emissions from both international aviation and shipping rose by 3.0 % per year between 1990 und 2010. In comparison, global GHG emissions including bunker fuels only rose by 1.1 % per year during that period. Consequently, international transport increased its share of global CO_2 emissions from 2.2 % in 1990 to 3.1 % in 2010. In addition to carbon dioxide, emissions from aviation also impact cloud formation, ozone generation and methane reduction amongst other effects. These non-CO_2 effects increase the impact of aviation on climate change by a factor of at least 2 (Box 1).

The emission estimates presented above are based on fuel sales for international aviation and shipping as reported by countries to the IEA (top-down approach). Researchers have also estimated fuel consumption and therefore emissions based on activity data including routes, speeds as well as type and size of vessel/aircraft. For aviation these estimates show a close correlation to fuel sales. The situation is different for maritime transport: bottom-up models tend to estimate higher fuel consumption than official statistics. In a study conducted for the IMO both estimates are given for five years with discrepancies between 18 % and 46 % (IMO 2014, p. 24). The study lists incomplete activity data, inconsistencies between global fuel export and import data and misallocation of fuel sales as the main reasons for these differences. The study concludes that the estimates based on models likely overestimate emissions whereas the fuel sales data is likely to underestimate them, i.e. that the real fuel consumption is somewhere between the two estimates. The projections and targets for the shipping sector in this report are based on the modelled data. For that reason all further graphs are only based on the bottom-up approach for maritime transport.

Figure 1: CO_2 emissions from international bunkers (1990-2012)



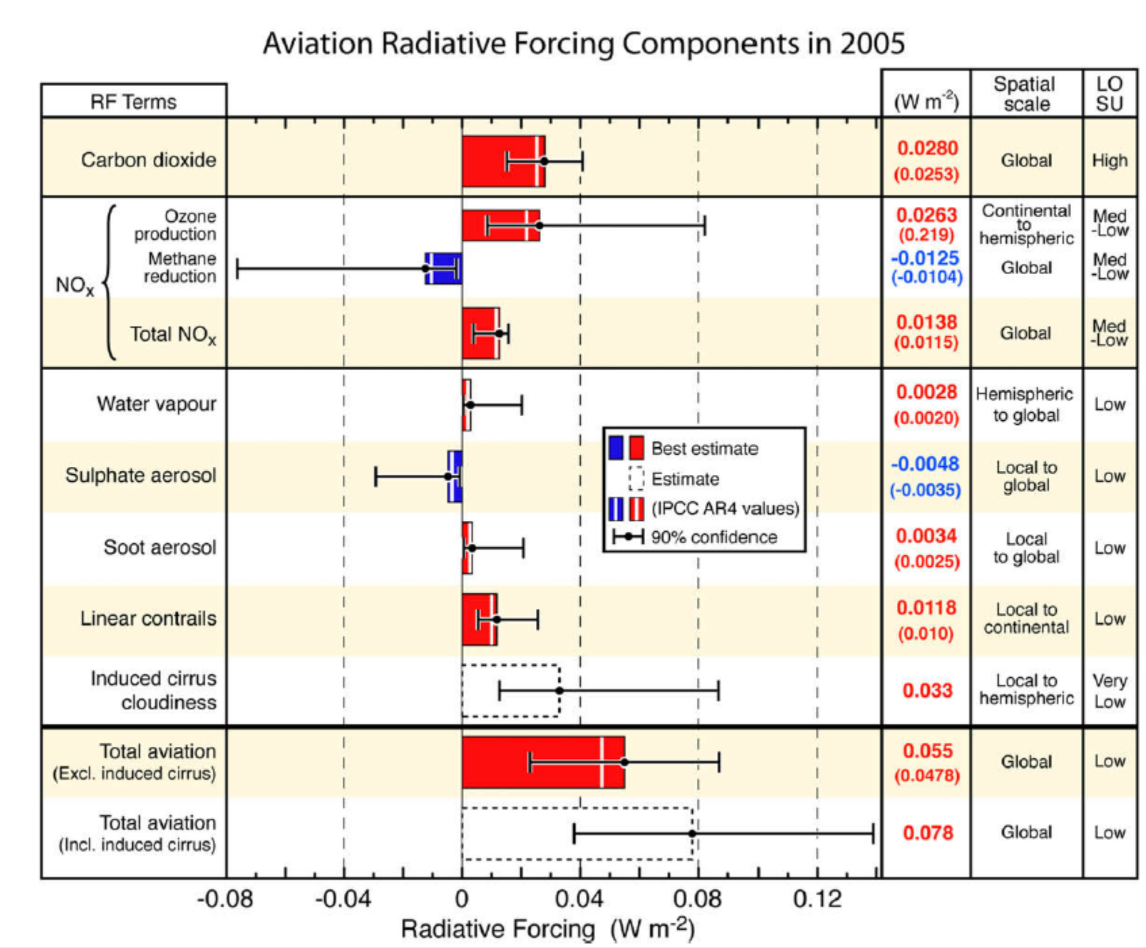
Source: IEA 2014, IMO 2009, IMO 2014, authors' own calculations

Notes: Top-down data is based on fuel sales whereas bottom-up data is calculated based on ship type and activity data. The real emission value is likely between those two estimates (see text above the graph).
The data for all graphs is included in the Annex.

Box 1: Non-CO_2 contribution of international aviation and shipping to climate change

Beyond CO_2 emissions, international aviation and shipping contribute to climate change in other aspects as well. International aviation produces short-lived emissions of NO_x and SO_2 and leads to cloud formation, the impacts of which are estimated to be two to five times higher than CO_2 emissions from aviation alone (Sausen et al. 2005). NO_x and SO_2 emissions have an indirect warming and (a much smaller) cooling effect on global warming as they produce or destroy GHGs (mainly ozone, methane and sulphate aerosols). Sulphate aerosols and water vapour additionally lead to contrails and cirrus cloud formation which contribute to global warming as well. While SO_2 emissions can be estimated rather accurately if the sulphur content of the fuel is known, there is generally high uncertainty with regard to the exact radiative forcing of the other indirect effects of aviation. Also, different methodologies for the estimation of CO_2, SO_2 and NO_x are used by countries in their national reporting on emissions under the UNFCCC (Graichen & Gugele 2006). Fuglestvedt et al. (2010) produced GWP values for contrails, water vapour and contrail-induced cirrus, which show large variations as well. Yet, generally, the non-CO_2 impact of aviation on climate change is measured by means of the Radiative Forcing Index (RFI) which is a ratio of the radiative forcing of the non-CO_2 effects of aviation at a given point of time and the radiative forcing of aviation-based CO_2 emissions, accumulated since 1950. The IPCC (1999) established the RFI of aviation in 1992 to be in the range of 2-4.

The graphic below illustrates the different climate impact of aviation in terms of radiative forcing. It shows the high uncertainty of the best estimates for each radiative forcing component. Furthermore, the level of scientific understanding (LOSU) is shown in the right column.



Source: Lee et al. 2009

According to Lee et al. (2010), the radiative forcing from global aviation from pre-industrial times to 2005 is estimated to be 55 MW m-2 excluding the effect of cirrus clouds (78 MW m^{-2}) and including cirrus. This forcing is equal to 3.5 % of current anthropogenic forcing, yet with a high uncertainty range of 1.3-10 %. Overall, non-CO_2 climate impacts of aviation are estimated to contribute 49 % (excluding contrail cirrus) and 64 % (including contrail cirrus) to the total forcing of the sector (Deuber 2013). According to Lee et al. (2010), the total effect of aviation is 1.3-1.4 times higher than the effect of CO_2 alone (excluding aircraft-induced cloudiness; GWP 100). If aircraft-induced cloudiness is included, this ratio increases to 1.9-2.0, i.e. the impact of aviation on the climate is about twice as high as the impact of the CO_2 emissions alone.

Due to the continuous growth of international aviation, the share of the sector of total global emissions can be expected to increase. If endeavours to achieve decarbonisation by 2050 are taken seriously and if effective measures to reduce the CO_2 impact of the aviation sector are implemented, the relative weight of non-CO_2 contributions of the sector will increase even further in the future. Yet, so far, the non-CO_2 effects of aviation remain unregulated (Deuber 2013).

Non-CO_2 effects from international shipping result from the emissions of short-lived climate forcers (SLCFs) as well, mainly in the form of black carbon and SO_2 that forms aerosols. Black carbon has a warming effect in the atmosphere and also on the ground when it is deposited on snow and ice surfaces. By contrast, SO_2 has a cooling effect on the climate. Yet, the climate impacts of SLCFs resulting from shipping vary, depending on different atmospheric conditions and sensitivity to high and low latitudes. Additionally, shipping generates indirect climate effects through the perturbation of greenhouse gases such as CH_4 and O_3 due to chemical interactions with NO_x emitted from ships (Eide et al. 2013). The combined climatic impact of CO_2 and non-CO_2 emissions of international shipping is an initial cooling on timescales of decades to centuries which do not, however, outweigh the long-term warming effects due to the persisting effect of long-lived GHGs (ACCESS 2015; Eyring et al. 2010; UNEP 2011). So far there is no multiplier for non-CO_2 effects from shipping due to there being a lower level of scientific understanding in this regard.

3. EFFORTS TO ADDRESS GHG EMISSIONS

GHG emissions from international aviation and maritime transport have been addressed since the first UNFCCC Conference of the Parties in 1995 in Berlin (COP 1, UNFCCC 1995). However, an agreement on how to allocate these emissions – a share of which occur above international waters and thus do not fit into the territorial approach under the UNFCCC in which individual countries are responsible for the emissions on their territory – was not met before the adoption of the Kyoto Protocol in 1997. Pursuant to Article 2.2 of to the Kyoto Protocol, Annex I Parties (industrialised countries) shall thus "pursue limitation or reduction of emissions of greenhouse gases [...] from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively" (UNFCCC 1998). The distinction between industrialised and developing countries further complicated efforts to address GHG emissions from both sectors, since their regulations are based on non-discrimination and non-preferential treatment of all ships and aircraft, independently of their nationality.

Only in recent years has some progress been made in both organisations on initiatives to limit GHG emissions of international aviation and shipping. Nevertheless, there have been no plans to date to establish global legally binding absolute caps on greenhouse gas emissions for these two sectors, let alone implement emission reduction targets.

3.1. Aviation

As early as 2001, ICAO had decided that an emissions trading system (ETS) is the most appropriate instrument to address GHG emissions from international aviation. With Resolution A-33-7, Appendix I, the ICAO Assembly "endorses the development of an open emissions trading system" and "requests the Council to develop as a matter of priority the guidelines for open emissions trading" (ICAO 2001, pp. 28-31). Since then, however, little progress had been made. Only at its 37th Assembly, ICAO (2010) agreed a global aspirational goal of Carbon Neutral Growth by 2020 (CNG 2020).[1] In 2013, ICAO established working groups for developing a Global Market-Based Mechanism (GMBM) to achieve this goal. According to its work program, the mechanism should be adopted in 2016 and come into force in 2020.

One of the main drivers for establishing ICAO working groups for the development of a GMBM was the European Union's (EU) decision in 2008 to include aviation in its ETS (EU 2009). From the beginning of 2012, carriers which called airports in the EU had to report their CO_2 emissions on routes within as well as to and from the EU. By the end of 2012, non-EU carriers increasingly complained about the EU's inclusion of aviation into its ETS. To address these complaints and to prevent a global aviation dispute, the ICAO's Secretary General established the working groups for the development of the GMBM. At the same time, the EU agreed to limit the geographical coverage of its aviation ETS to the territory of the European Economic Area (EEA) from 2013 to 2016 as an approach to provide ICAO with some leeway for developing a GMBM.

The main design elements of the GMBM are discussed by the ICAO's Environmental Advisory Group (EAG) and by the Global Market-based Measure Task Force (GMTF) established for developing the GMBM. Within EAG the core design features are being elaborated while GMTF, an expert group within the Committee on Aviation Environmental

[1] Earlier in 2010, the International Aviation Transport Association (IATA) had already set a goal of carbon neutral growth from 2020 and a 50 % absolute reduction in carbon emissions by 2050 compared to 2005 levels (IATA 2013).

Protection (CAEP), has been assigned the task of developing rules for monitoring, reporting and verification (MRV) of CO_2 emissions and quality and eligibility criteria for offset units. So far, the GMTF has agreed on a number of general principles to ensure environmental integrity but is unlikely to provide specific recommendations on how to meet these requirements due to considerable uncertainties as to which types of offset units will be available post-2020.

The EU has highlighted the need for a sectoral emission reduction target for international aviation consistent with the global below 2°C objective. It suggested setting the target at -10 % below 2005 levels by 2020 (Council of the European Union 2009) and supports a regular review of the environmental ambition (Council of the European Union 2015). In the EAG, the EU stresses the need to increase the ambition within ICAO and requests a review clause to allow the target to be strengthened in the medium term, e.g. to align it with IATA's -50 % by 2050 target. Moreover, the EU is constructively engaging in discussions to ensure that the design of the GMBM actually enables that the CNG2020 target is met and is not being undermined by exemptions.

3.2. Shipping

In view of the growth projections of world trade, technical and operational measures alone would not be sufficient to satisfactorily reduce the amount of GHG emissions from international shipping. From July 2007, IMO therefore considered several MBMs as an option to address GHG emissions. Governments and observer organisations proposed possible MBMs, ranging from a GHG fund, trading schemes and efficiency systems to the introduction of a levy. In this context Norway suggested potential targets for international shipping in January 2010 (MEPC 2010). These proposals were based on the philosophy that the economic effort for reducing GHG emissions in the shipping sector should be the same as in other sectors. Under the UNFCCC the EU has been advocating a -20 % emission reduction target below 2005 levels by 2020 for the sector as a whole (Council of the European Union 2009).

Although an expert group undertook a feasibility study and impact assessment evaluating the extent to which each proposed mechanism could incentivise reducing GHG emissions from international shipping, no decision has been taken yet with regards to which MBM proposal should be further developed. Also a one-week long working group meeting in March 2011 dedicated to MBMs was unable to identify a preferred MBM.

However, in 2011 IMO adopted two efficiency measures to address GHG emissions (IMO 2015b):

- the **Energy Efficiency Design Index** (EEDI) sets compulsory energy efficiency standards for new ships built after 2013, and
- the **Ship Energy Efficiency Management Plan** (SEEMP) requires ships to develop a plan to monitor and possibly improve their energy efficiency.

Despite efficiency improvements brought about by these measures and by market forces, emissions are projected to increase by 50 to 250 % in the period up to 2050 (IMO 2014). This trend risks undermining the efforts that are being made in order to stay on a trajectory that will keep the average global temperature increase below 2°C compared to pre-industrial levels. Unlike under ICAO, countries have so far not agreed on an emission limitation or reduction target in the IMO.

In 2013, the European Commission therefore tabled a legislative proposal to establish a CO_2 monitoring, reporting and verification (MRV) system for ships entering EU ports. The proposal was adopted by the European Council and Parliament in late 2014, came into force in April 2015 and will apply to port calls from 2018 onwards (European Parliament and Council 2015). According to this regulation "the Commission shall assess every two years the maritime transport sector's overall impact on the global climate including through non-CO_2-related emissions or effects." (Art. 21,5).

In March 2015, the Republic of the Marshall Islands (RMI) submitted a paper to the Marine Environment Protection Committee (MEPC), in which the RMI requests IMO *"to set clear net emission reduction targets in line with the UNFCCC's ultimate objective"* (MEPC 2015), as well as the development of measures to achieve these targets. The RMI is a small island state. However, it is the third largest ship register of the world, which puts some weight behind its initiative. However, the MEPC agreed "to focus on further reduction of emissions from ships through the finalisation of a data collection system" and postponed the discussion on a mitigation target to a future session (IMO 2015a).

Box 2: Alternative fuels and propulsions

Several options exist to reduce emissions from aviation and shipping through the use of alternative fuels and other renewable energies. For shipping, renewable energy is used in the form of wind energy (soft sails, fixed wings, rotors, kites and conventional wind turbines), photovoltaics in hybrid models with other energy sources, wave energy, hydrogen fuel cells, biofuels and super capacitors charged with renewables. Taking into account technical limitations as well as concerns with regard to the sustainability of the options, hybrid modes have the greatest potential in spurring the deployment of alternative energy sources in international shipping. However, the infrastructure lock-in of existing investments, limited R&D finance, the risk adversity of investors and the different classes and scales of ships are major barriers to driving actual deployment of existing renewable energy options, and so far, there has not yet been sufficient demonstration of commercially viable solutions in order to change this pattern (IRENA 2015).

For aviation, alternative fuels include liquid hydrogen, methane, kerosene manufactured by different processes (e.g. the Fischer-Tropsch process to produce a synthetic lubrication oil and synthetic fuel from coal, natural gas or biomass), liquid hydrogen and biofuels. In the context of biofuels, the use of so-called second generation biofuel feedstocks including Jatropha, Camelina and Halophytes which cannot be used as food for humans and animals and can (partly) be grown in non-arable areas, and third generation biofuels which are derived from algae are being discussed (ATAG 2009; Lee et al. 2010).

In terms of production possibilities, costs, environmental considerations in production and transport, advantages, disadvantages and usability, biodiesel, synthetic kerosene and liquid hydrogen (LH_2) are being discussed as the most promising options. All three options reduce fuel cycle carbon emissions, while liquid hydrogen would furthermore eliminate emissions of all carbon bearing species, including soot and sulphur oxides (thus producing only H_2O and NO_x as combustion products). A transition to LH2 would entail profound changes as the engines as well as the airframes would have to be redesigned (Lee et al. 2010).

However, replacing fossil fuels by alternative fuels with less GHG emissions does not eliminate the entire negative impact of aviation on global warming. If non-CO_2 combustion effects from aircraft in the upper atmosphere are taken into account, the relative merit of such Synthetic Paraffinic Kerosene (SPK) fuel compared to conventional jet fuel decreases considerably (an SPK fuel option with zero life cycle GHG emissions would entail a 100 % reduction in GHG emissions, but reduce the actual climate impact by only 48 % when estimated in a 100-year time window and on the basis of the nominal climate modelling assumption set outlined herein). This means "that methods of tracking climate change mitigation that rely exclusively on relative well-to-wake life cycle GHG emissions as a proxy for aviation climate impact may overestimate the impact of alternative fuel use on the global climate system" (Stratton et al. 2011). Further challenges implied by replacing conventional fuels with biofuels relate to the risk of direct and indirect land use change associated with some biofuels, the energy necessary to produce and transport them, and other social and environmental issues such as the production of other pollutants such as nitrous oxide. Also, further research in emerging feedstocks, building new infrastructure for biofuel production and supporting policies would be necessary in order to increase the economic viability of biofuels (Gençsü & Hino 2015).

4. EMISSION PROJECTIONS

While CO_2 emissions from international aviation and maritime transport were only responsible for 3.5 % of the global CO_2 emissions in 2012, this share is expected to increase considerably in the coming decades: projections from both sectors show a strong increase in emissions while global GHG emission trajectories need to decline to achieve the 2°C target. Both ICAO and IMO have commissioned studies to project demand for services and emissions from their respective sectors up to 2050 under different assumptions (ICAO 2013b, IMO 2014). These studies also evaluated the potential for emission reductions from technological and operational measures within their sectors.

In 2011 climate scientists developed *Representative Concentration Pathways*, a set of global GHG emission trajectories used in the climate models. The idea of these pathways is to provide a set of scenarios to be employed by the various climate models to be able to compare and combine results. Each pathway is linked to different levels of radiative forcing and therefore temperature increases of the earth. The global carbon budget approach is an alternative to emission pathways: it determines the total aggregated emissions since pre-industrial times without using a specific target path.

The combination of global emission pathways, budgets and sectoral projections allows an analysis of the role of and challenges facing international transport for achieving the 2°C target (Chapter 5).

4.1. Global emissions up to 2050

Representative Concentration Pathways

The four Representative Concentration Pathways (RCP) differ, inter alia, in their assumptions on economic development, population growth, share of fossil fuels in the energy system, total energy consumption and land use (van Vuuren et al. 2011). Of these, only the RCP 2.6[2] pathway is compatible with a global mean surface air temperature increase below 2°C (Table 1) by the end of the 21st century. To achieve this, the scenario assumes a rapid decline of GHG emissions after peaking in 2020 and a complete decarbonisation of the world by 2090. Emissions of methane and N_2O also decline but much more moderately. In comparison, emissions in the RCP 4.5 and RCP 6.0 pathways peak only in 2040 and 2060 respectively and decline at much lower rates afterwards. In the highest concentration pathway, emissions do not peak before 2100.

The RCP 4.5 pathway is expected to lead to a temperature increase of 2.4 C compared to 1850-1900 levels but the uncertainty range still includes a warming below 2°C. In line with the international goal and objective of the EU's climate policy only the RCP 2.6 and – to a limited extent – the RCP 4.5 scenarios are included in the next chapters of this analysis.

[2] The numbers of the RCPs indicate the level of anthropogenic radiative forcing in W/m^2 in the year 2100.

Table 1: Projected change in global mean surface air temperature

	2046-2065		2081-2100	
	Mean	Likely range	Mean	Likely range
	- °C relative to the reference period of 1850-1900 -			
RCP 2.6	1.6	1.0 to 2.2	1.6	0.9 to 2.3
RCP 4.5	2.0	1.5 to 2.6	2.4	1.7 to 3.2
RCP 6.0	1.9	1.4 to 2.4	2.8	2.0 to 3.7
RCP 8.5	2.6	2.0 to 3.2	4.3	3.2 to 5.4

Source: IPCC 2013, p. 23, authors' own calculations

Notes: Likely temperature ranges calculated from projections as 5–95 % model ranges. These ranges are then assessed to be likely ranges after accounting for additional uncertainties or different levels of confidence in models.

Carbon budget approach

The idea of determining cumulative global GHG budgets instead of emission targets for specific years was proposed by Meinshausen et al. (2009). It focuses on the long-term perspective instead of short- to medium-term goals as adopted under the Kyoto Protocol and the Copenhagen Accord. In this approach total CO_2 emissions since pre-industrial times need to stay below 2 900 Gt CO_2 to have a likely probability (>66 %) to limit anthropogenic warming to less than 2°C. Almost two thirds of this quantity was already exhausted by 2011, i.e. only 35 % of the budget remains for all subsequent years. The total available budget increases with reduced probabilities to stay below 2°C: 3 010 Gt CO_2 with a probability of >50 % or 3 300 Gt CO_2 with a probability of >33 % (IPCC 2013, p. 27).

4.2. Emissions from international aviation and maritime transport up to 2050

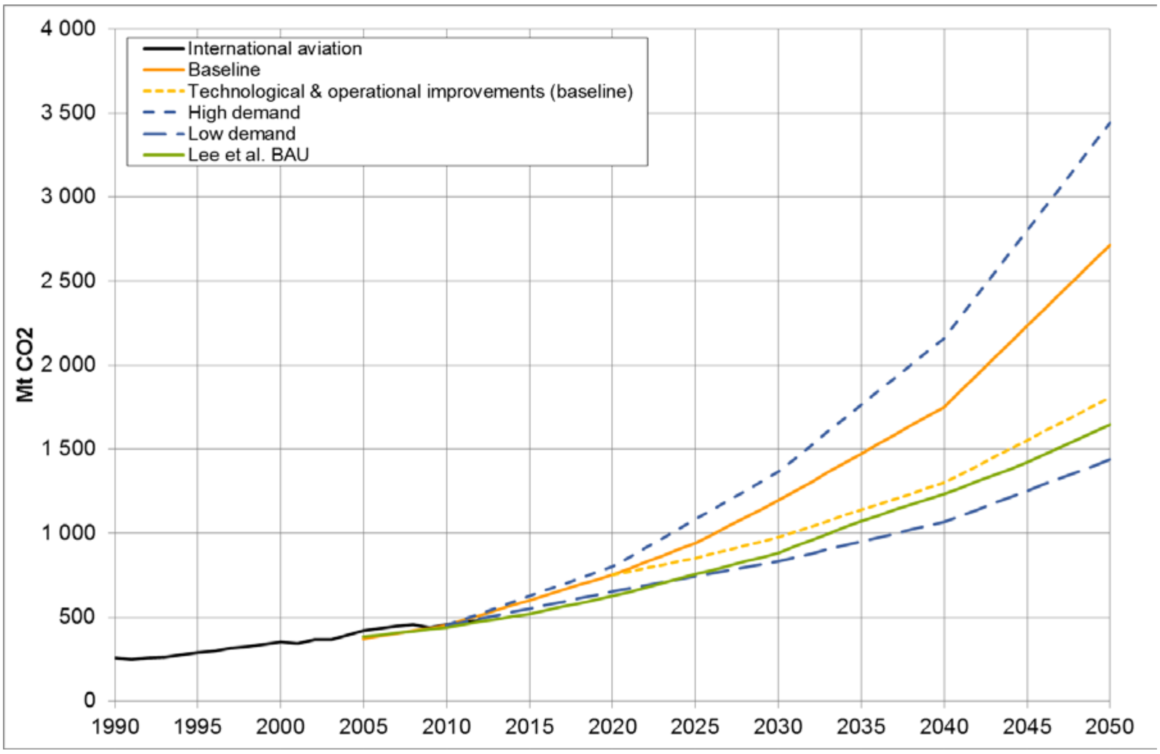
Aviation

In 2013 the Committee on Aviation Environmental Protection of the ICAO finished its assessment of "present and future impact and trends of aircraft noise and aircraft engine emissions" (ICAO 2013b). It includes projected fuel burn and therefore CO_2 emissions from international aviation for the period of 2005 to 2050 in a baseline scenario as well as a high and a low demand scenario. The impact of technological and operational improvements is given for the baseline scenario (Figure 2). According to this assessment, the improvements have a potential to reduce CO_2 emissions by 33 % in 2050 compared to the baseline. Despite this, emissions are still projected to be seven times higher in 2050 than in 1990; without the improvements, projections are ten times above 1990 levels in 2050. Other projections of CO_2 emissions from international aviation show a similar trend but are on the lower bound of the ICAO range.

The data used by ICAO for technological and operational improvements are based on the optimistic scenario (ICAO 2013a, p. 23) but this might not be realistic: Kharina & Rutherford (2015, p. 16) analysed historic trends in energy efficiency improvements for new aircraft and found that the industry is lagging behind ICAO's efficiency goals. Instead of achieving a reduction of 27-31 % compared to a set of reference aircraft by 2020, the target will only be met in 2032. The same time lag of 12 years also exists for the 2030 efficiency goal. The authors conclude that "it appears unlikely that ICAO can achieve its higher-level technology goals without additional policy support".

There is general consensus in the literature that technical and operational measures will not be able to offset emission growth in the coming decades. Bows-Larkin (2015) notes that only more radical long-term technical options such as blended wing bodies or hydrogen fuels will be able to reduce emissions beyond a 1-2 % annual energy efficiency improvement. Such options require setting up new infrastructure and are not easily implemented. In addition, new aircraft models only penetrate slowly into the market with emissions being driven by older models. Retrofitting of aircraft and infrastructure can help in reducing emissions of the existing fleet. Bows-Larkin is also sceptical about the possible impact of operational measures: reduced congestion and improved throughput of airspace and airports would lead to increased aviation growth increasing absolute energy consumption. She concludes that, albeit unpopular, demand-side reductions are necessary and no more challenging than other options which are in line with global emission constraints. In 2025 at the latest, annual demand growth would need to reach zero and decrease by 4-6 % p.a. thereafter (Bows-Larkin 2015). Chèze et al. (2012) analysed the anticipated technological progress in the aviation sector up to 2025 and concluded that none of the nine scenarios included in the study would even be compatible with "limiting global warming to 3.2°C compared to the preindustrial era" and much less so with 2°C pathways.

Figure 2: Projected CO_2 emissions from international aviation



Source: IEA 2014, ICAO 2013b, Lee et al. 2013

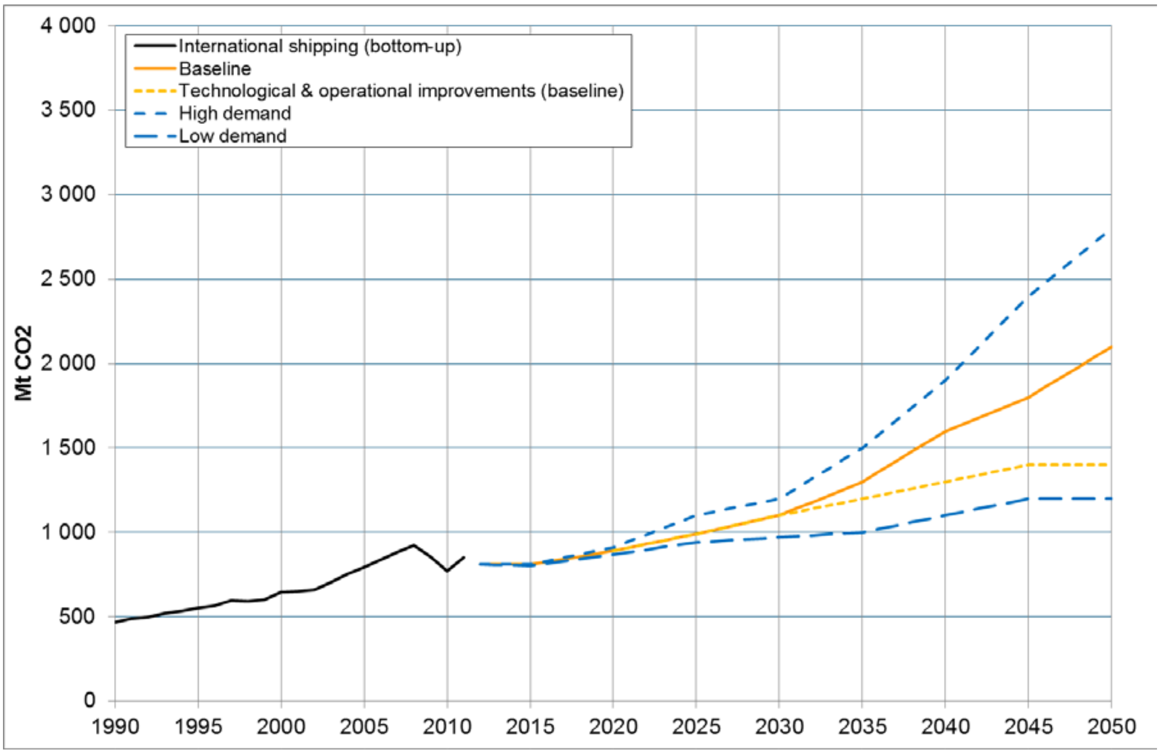
Notes: Data for all graphs disaggregated by transport mode is included in the Annex.

Shipping

The *Third IMO GHG Study 2014* (IMO 2014) includes projections of emissions from international maritime transport up to 2050. The four different scenarios use the Representative Concentration Pathways (Chapter 4.1) and the other long-term socio-economic scenarios to forecast demand for international shipping. For each scenario, three different mitigation options are also calculated. They differ in their fuel mix, impact of Emission Control Areas and assumptions on energy efficiency. Figure 3 shows projected emissions under three different scenarios as well as the effect of the most ambitious mitigation option on the reference scenario.[3] Identical to the case of aviation, the technological and operational improvements reduce CO_2 emissions in 2050 by 33 %. Despite this, they are still projected to increase by a factor of almost four compared to 1990. Without these improvements, the growth would be six-fold.

Other studies show a similar range of baseline emissions and upper/lower bounds (Figure 4). With a 39 % reduction in 2050 Bazari & Longva (2011) estimate a similar impact of the agreed Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). In a White Paper by the International Council on Clean Transportation, Wang & Lutsey argue that more reduction is possible within the sector only by applying existing technologies and practices. If all ships achieved the energy efficiency of the top 5 % of the current fleet disaggregated in nine ship types/sizes by 2035, global emissions from international maritime transport would decline despite the demand growth (Wang & Lutsey 2013). The most important measure to achieve such a level of efficiency is designing for and operating at lower speeds (Figure 5).

Figure 3: IMO projections of CO_2 emissions from international maritime transport

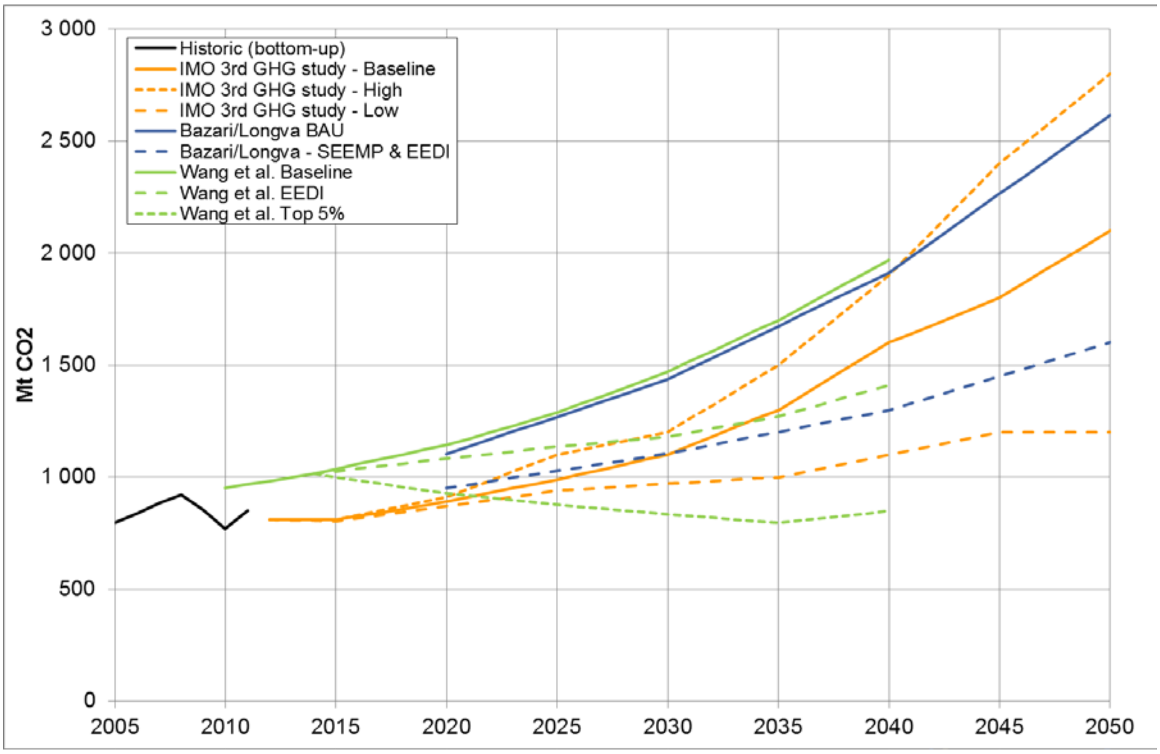


Source: IEA 2014, IMO 2009, IMO 2014

Notes: Data for all graphs disaggregated by transport mode is included in the Annex.

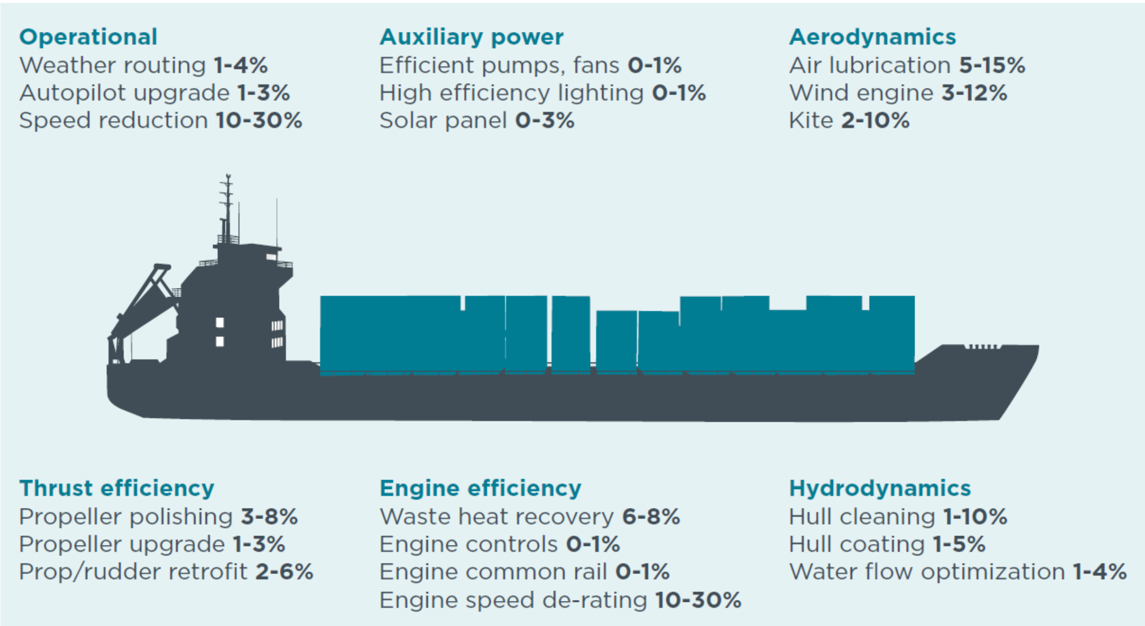
[3] For consistency reasons and to enhance the reader-friendliness of this analysis, the IMO scenarios have been named in an identical way to the nomenclature used by ICAO. The IMO study does not provide a baseline but rather four scenarios without identifying one as the central estimate. The three scenarios included in this report show the range of the scenarios in the 3rd IMO GHG study.

Figure 4: Other emission projections for international maritime transport



Source: IMO 2009, IMO 2014, Bazari & Longva 2011, Wang & Lutsey 2013

Figure 5: Potential fuel use and CO_2 reductions from various efficiency approaches for shipping vessels

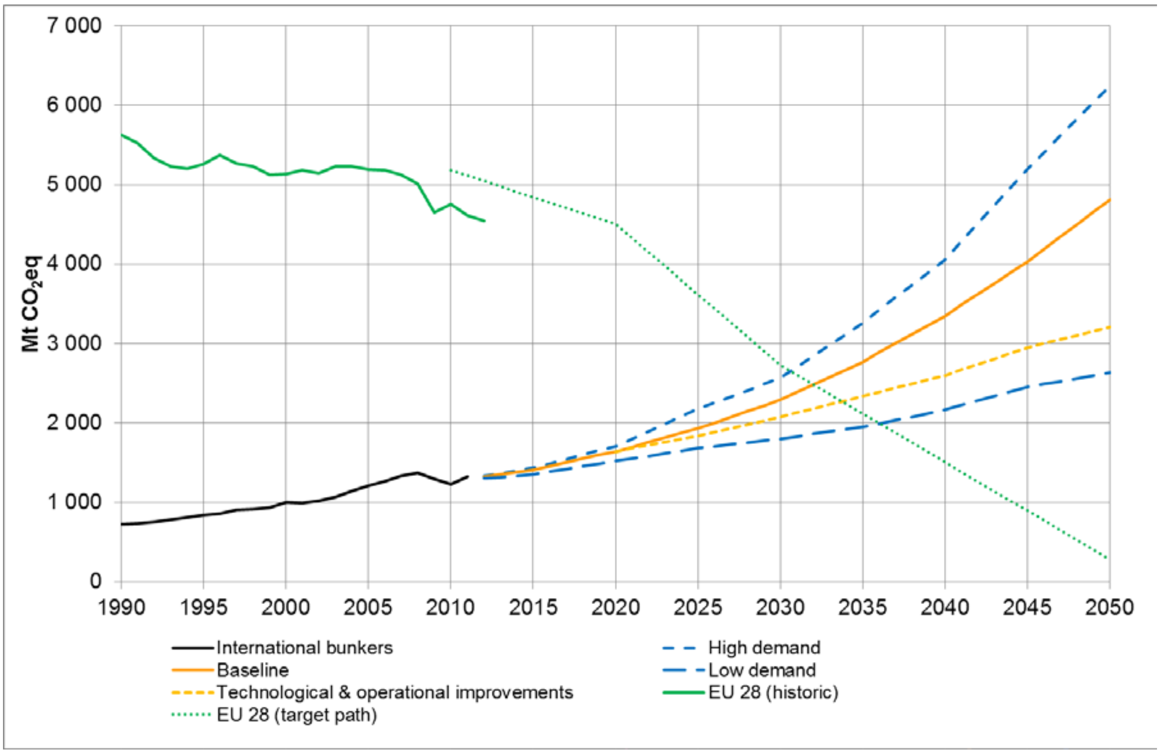


Source: Wang & Lutsey 2013

Aviation and shipping

Combining both projections shows the range of total CO_2 emissions from the two sectors combined (Figure 6). The graph and all subsequent analysis are based on the projections by ICAO/IMO. As a reference, the graph also includes the historic emissions of all greenhouse gases and the EU's target path up to 2050. It shows that, if unchecked, international aviation and shipping will, in 2050, emit about as much as the European Union today but without any indications of reducing or at least stabilising emissions.

Figure 6: Projected emissions from international bunker fuels and the EU target path



Source: IEA 2014, ICAO 2013b, IMO 2009, IMO 2014, EEA 2015, Council of the European Union 2011, authors' own calculation

Notes: EU emissions are based on all GHG excluding land-use, land-use change and forestry. For 2050, the upper limit of the EU's ambition of 80-95 % below 1990 is used.
Data for all graphs disaggregated by transport mode is included in the Annex.

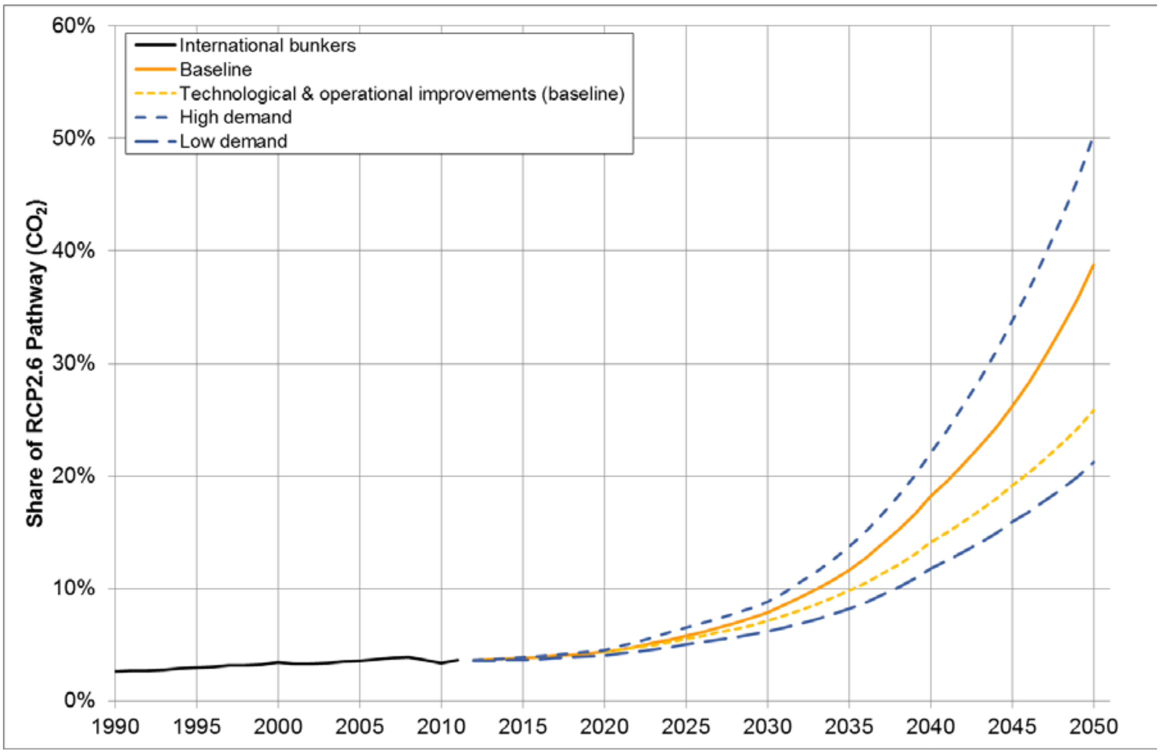
5. CONTRIBUTION TO GLOBAL GHG EMISSIONS

Based on the data included in chapter 4, it is possible to estimate the potential impact of international aviation and maritime transport on global GHG emissions under the different scenarios and budgets. Figure 7 shows the share of global CO_2 emissions under the RCP 2.6 pathway that relates to international aviation and maritime transport in the various emission scenarios. In the baseline scenario international transport would be responsible for almost 40 % of the available global CO_2 emissions in 2050. If all technological and operational improvements deliver the expected impact, the sectors would still be responsible for 25 % of global permissible CO_2 emissions of a 2°C path. The comparison is based on CO_2 emissions only because the RCP 2.6 scenario has very different emission pathways for the different greenhouse gases. The underlying reason is that CO_2 emissions from some sources such as combustion of fossil fuels can be mitigated much easier than CH_4 and N_2O emissions from other sources such as agriculture.

The impacts of the emissions from the two sectors on the total permissible carbon budget after 2020 are shown in Figure 8. The budget is based on a likelihood of at least 66 % of limiting anthropogenic global warming to under 2°C (for more details, see Table 2). Under this approach emissions from international bunker fuels will consume over 11 % of the remaining global carbon budget after 2020 within 30 years. Both sectors will use almost the same share of the total available global budget in that period: aviation 5.9 % and maritime transport 5.3 %. It has to be noted that the global budget is a long-term budget, i.e. not just for the period up to 2050. With the high emission levels in 2050 and the still strongly growing trends, the two sectors would use up an ever increasing share of the remaining global budget in the subsequent decades. This would severely restrict the available budget for all other sectors and countries requiring them to go beyond their share of emission reductions. Bows-Larkin et al. (2015) noted that so far “no sector has openly discussed cuts over and above the scale necessary for a reasonable chance of avoiding the 2°C rise”.

An approach to determining a fair budget for international aviation and maritime transport is discussed in chapter 7.

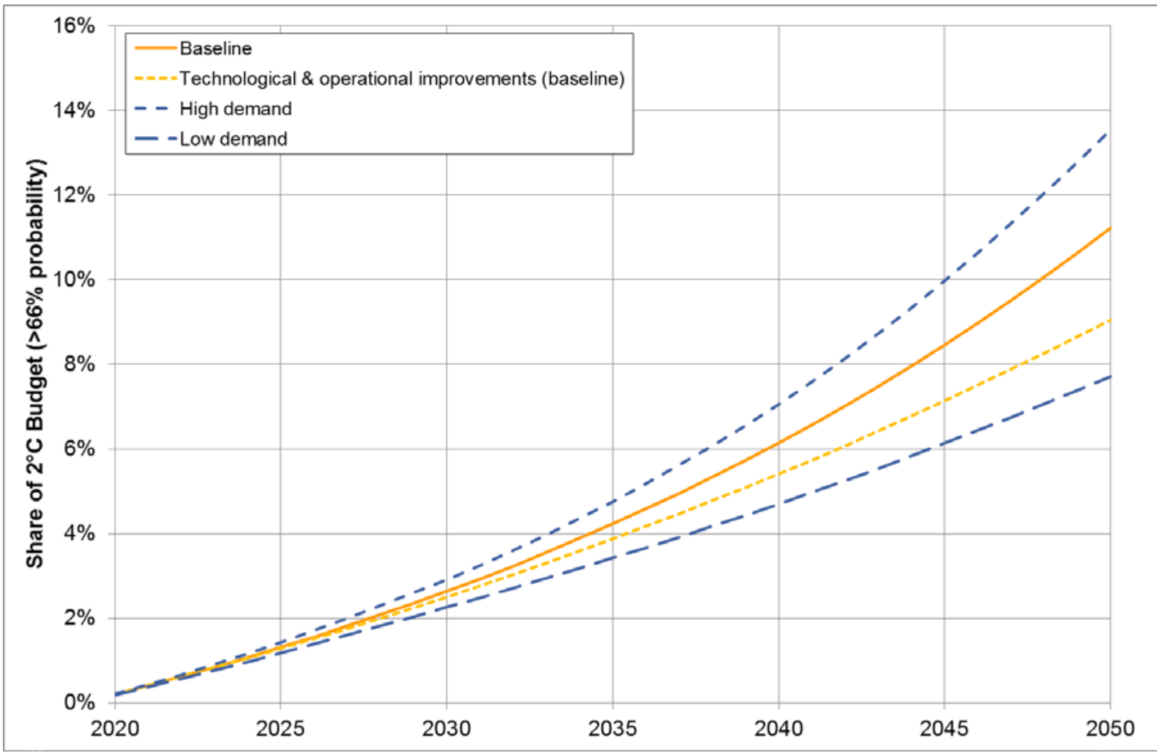
Figure 7: International aviation and maritime transport's share of global GHG emissions under the RCP 2.6 pathway



Source: ICAO 2013b, IMO 2014, van Vuuren, D. P. et al. 2011

Notes: Data for all graphs disaggregated by transport mode is included in the Annex.

Figure 8: International aviation and maritime transport's use of remaining global CO_2 budget from 2020 onwards



Source: ICAO 2013b, IMO 2009, IMO 2014, IPCC 2013, p. 27

Notes: The total budget is calculated to give a probability of at least 66 % to stay below 2°C. Data for all graphs disaggregated by transport mode is included in the Annex.

If, as in the past, the ambition of these sectors continues to fall behind efforts in other sectors and if action to combat climate change is further postponed, their CO_2 emission shares in global CO_2 emissions may rise substantially to 22 % for international aviation and 17 % for maritime transport by 2050, or almost 40 % of global CO_2 emissions if both sectors are considered together.

6. APPROACHES TO DETERMINE CONTRIBUTIONS

In addition to ICAO's above-mentioned CNG 2020, several other suggestions for potential contributions of international aviation and maritime transport to global GHG mitigation efforts can be identified. Cames et al. (2015) provide an overview of these proposals which is supplemented by a more recent proposal by ICS:

- In 2009, before the climate conference in Copenhagen, the **EU** suggested an emission reduction target of -10 % for international aviation and -20 % for maritime transport by 2020 compared to 2005 (Council of the European Union 2009).
- In 2010, **Norway** suggested two targets for international shipping based on growth scenarios A1B and B2 of IPCC's Third Assessment Report (IPCC 2001). The targets are based on the philosophy that the economic effort to reduce emissions in the shipping sector should be the same as in other sectors (MEPC 2010).
- Also in 2010, **IATA** agreed to a target of keeping CO_2 emissions of international aviation from 2020 to 2030 at the level of 2020 and to reduce emissions by 50 % compared to 2005 from 2030 to 2050 (IATA 2013).
- Later in 2010, **ICAO** agreed to freeze the sector's CO_2 emissions at its 2020 level (CNG 2020) and to accommodate further emission growth by means of technical and operational measures as well as by extending the use of biofuels. The emission reduction which cannot be achieved by measures within the sector should be addressed by the purchase of offsets from other sectors in order to achieve carbon neutral growth (ICAO 2010).
- In 2014, the **Tyndall Centre** suggested a target for maritime transport. Based on the assumption that the shipping sector's current share in global GHG emissions should at least remain constant and using carbon budgets for an emission pathway compatible with staying below 2°C, they derive targets which are 70-80 % below the emission levels of 1990 (Tyndall Centre 2014).
- In 2015, the International Chamber of Shipping (**ICS**) promised that international shipping will deliver a -50 % reduction of CO_2 emissions per tonne mile by 2050 including by means of further technical and operational measures and preferably an emission levy (Einemo 2015, 2015, ICS 2015).[4]

This overview illustrates that there are a number of somewhat heterogeneous and not fully distinguishable criteria which may be considered for the development of mitigation targets:

- **Time horizon**: Does the target have a short- or medium-term orientation of 5-15 years or is it derived from a long-term perspective, potentially striving for decarbonisation?
- **Reference**: How is the target quantified? Is it an absolute emission target or is a performance target indexed to an activity data such as the tonne mile?
- **Shape**: Is the target determined for a single year, provided as a trajectory for the entire target period or based on a budget of remaining emissions?
- **Comparability**: Is the target compared to efforts elsewhere, either in terms of emission reductions or in terms of estimated mitigation costs?

[4] There are various interpretations of the ICS's target proposal. We used the most stringent one for this paper. In other interpretations the target would actually exceed the baseline emissions.

- **Origin**: Does the target refer to the currently known mitigation potential or is it derived from scientifically justified mitigation requirements for staying below 2°C?

Time horizon: While at the beginning of global climate policy in the 1990s it was acceptable to focus on emission reductions within the next couple of years, evidence provided by the IPCC suggests that the time remaining to address climate change is shrinking and that global emissions need to peak sooner rather than later. It would thus be short-sighted to focus only on the next steps without a clear vision towards the ultimate goals. Targets agreed today need to be derived from the ultimate goal of staying below 2°C. They may include intermediate steps to verify whether the target path is met but a purely stepwise approach may provide the wrong signals.

This is even more relevant for sectors with long investment cycles of 30 years or more. Investment decisions taken today are still likely to contribute to GHG emissions in 2050. A long-term goal also provides clear signals to the covered entities to consider potential GHG mitigation options in their short- and long-term decisions.

Reference: Performance indicators such as CO_2 emissions per tonne mile can inform the discussion on the challenges and ambition of a target. They also provide clear information to the stakeholders of the covered activities. However, they may also obscure a lag of ambition. If the growth of the activity data is stronger than the efficiency improvement of performance indicator, absolute emissions continue to grow despite an ambitious looking efficiency target. Moreover, to determine whether the global effort to reduce GHG emissions is sufficient to stay below 2°C, indexed targets need to be transformed into absolute targets so that the global effort can be aggregated.

Shape: Individual target years can be more easily negotiated and communicated. However, GHG emissions accumulate in the atmosphere. Climate change is caused by the accumulation of GHG in the atmosphere over long periods of time rather than by the emissions of one single year. Individual target years, therefore, need to be converted into trajectories which cover all years of the envisaged period. Such a trajectory will also allow determination of the extent to which the remaining budget of global GHG emissions will be utilized.

Comparability: There are mainly two dimensions to how a target could be compared with efforts elsewhere. Comparability could either be given in terms of emission reductions or in terms of economic efforts, i.e. similarity of the cost burden. However, before looking at these dimensions, it needs to be determined what the suitable reference for comparison is, i.e. should a target be compared to the global average, certain other sectors, a group of countries, etc.

Opinions on the appropriate reference for comparison with international aviation and maritime transport may differ among the stakeholders involved. In the first place they are industrial sectors similar to sectors such as electricity generation, steel or cement production. They are equally important to the global economy and to economic development as other economic sectors but not more or less important than, for example, electricity, chemicals or retail. Since all other sectors are likely to be extensively covered by the post-Paris global mitigation targets, international aviation and shipping need to be covered by similar requirements. Otherwise production abroad would be implicitly subsidised via local production through inappropriate low transport prices and thus again induce higher GHG emissions.

If international aviation and maritime transport were two additional countries, several evidences suggest that they would be industrialised countries rather than developing countries. ATAG (2014), for example, claims that aviation would rank 21st in terms of gross domestic product (GDP), be larger than several members of the G 20 and have about the same size as Switzerland. The European Community Shipowners' Association (ECSA 2015) suggests that the European shipping industry contributes € 147 billion to the European GDP. Extrapolating this figure based on UNCTD's shipowner statistics (UNCTAD 2014, pp. 33–37) to the world at large, the shipping industry would rank 23rd. But not only in terms of size both sectors rank among the top ones. Also with regard to productivity the European aviation and shipping industry are 38 % and 60 %, respectively, above the EU average (Oxford Economics 2015, p. 14). Even if these figures are not necessarily fully representative for the world at large, they still give a strong indication that these sectors are well advanced and highly industrialised.

Which of the dimensions is the more appropriate basis for comparison depends to some extent on the purpose of the target. If the target should be exactly met through mitigation activities solely within a sector, a comparison of the marginal abatement cost would be essential. A significant difference in the marginal abatement cost would indicate that global GHG mitigation efforts would, on average, induce higher costs than necessary or that the costs of global GHG mitigation could be reduced if the sectoral targets were aligned based on marginal abatement costs.

While in theory a comparison of marginal abatement costs seems to be a straight forward option, it is quite difficult to implement. Marginal abatement cost curves are compiled from bottom-up estimates of the mitigation potential of individual technical and operational measures and estimates of the average cost to implement this potential. Both estimates depend on a number of assumptions, such as global fuel prices, technological development and innovation, interest and exchange rates, etc. In addition, the potentials and costs of the estimates may overlap so that the aggregated potential may be smaller than just the sum of the individual potentials, though it will be difficult to determine the extent to which measures overlap. An example of this are energy efficiency measures and the introduction of renewable energies: the larger the share of renewables the lesser the impact on GHG emissions that can be achieved through efficiency improvements.

Due to these and other limitations of marginal abatement cost curves, Kesicki & Ekins (2011) and Vogt-Schilb & Hallegatte (2014) call for caution when applying these curves in policy design. Since the information required for deriving adequate marginal abatement cost curves are mainly private and/or confidential data, often only implicitly but not explicitly known, it is conceptually virtually impossible to derive adequate marginal abatement cost curves. One way to overcome this hurdle is to determine targets independently of marginal abatements cost curves but allowing entities, covered by these targets, to offset emissions through some kind of trading mechanism if mitigation can be achieved more cheaply elsewhere.

In other words, a comparison in terms of emission reductions would be both sufficient and actually implementable if the target is not considered as a so-called "closed target" for the covered entities. A closed target may only be achieved through technological and operational mitigation activities in the respective sector whereas an open target may also be achieved through offsets from sources beyond the scope of the target.

Origin: This criterion refers to the perspective from which a target is derived. On the one hand, there is the perspective from within the two sectors. Stakeholders often claim that there are intrinsic incentives to reduce GHG emissions because fuel costs represent a relatively large share of the operational costs. Future mitigation potentials depend on the pace of technological progress. These arguments originate from the question of what is achievable within the sector. On the other hand, there is the global long-term perspective, which looks at which global efforts are required to prevent severe damage due to climate change. Both perspectives are relevant and neither can be entirely ignored. Nevertheless, if the precautionary principle of environmental policy is adequately respected, the global perspective needs to be given preference over the particular perspective from within the sector.

Objective criteria like those elaborated above and their scientific analysis are often the starting point for processes which aim at determining a target. However, these objective criteria also usually involve a number of subjective judgments or assumptions. Often several not directly compatible criteria are combined in a heuristic way to a compound criterion. Nevertheless, the decision on a target finally is and remains a normative decision which can be informed by objective and transparent analysis but not directly derived from such analysis. Targets need to accommodate diverging interests and are thus the result of a negotiation process in which political powers and negotiation tactics may play a greater role than objective analysis.

Based on these criteria we have developed a number of potential mitigation targets for international aviation and maritime transport which will be explained and illustrated in the following chapter.

7. POTENTIAL GHG MITIGATION TARGETS

By taking into account the projections illustrated in Chapter 4 and the considerations elaborated in Chapter 6 we have identified a number of potential targets for international aviation and maritime transport:

- **Constant share** (blue lines): For these target proposals we assume that the share of global GHG emissions from international aviation and maritime transport projected for 2020 is kept constant in the future. Applying this assumption to the RCP 2.6 (dashed blue line) and 4.5 (continuous blue line) pathways, two target trajectories can be plotted.
- **EU target path** (green lines): This is based on the assumption that international aviation and maritime transport could be considered as additional countries and that they resemble an industrialised rather than a developing country. From a European perspective it is then appropriate to apply the same reduction path as for the EU, albeit in a reduced time-frame. The Council of the European Union (2009) has declared a reduction of its GHG emissions by 80 to 95 % by 2050 compared to 1990 levels. Together with the respective targets for 2008-2012 (-8 %), 2020 (-20 %) and 2030 (-40 %) target paths consistent with the EU's own ambition can be sketched.
- **Budget approach** (yellow line): Taking up the concept of a remaining global carbon budget together with international aviation and maritime transport's 2020 share in global GHG emissions, the respective sectoral target path consistent with the carbon budget can be derived (see also Table 2, p. 34).
- **Carbon neutral growth** (dashed grey line): ICAO has agreed to keep its CO_2 emissions constant from 2020 onwards (CNG 2020). By applying this target to maritime transport both an individual as well as a combined target trajectory can be illustrated.
- **Industry proposals** (continuous grey line): IATA suggested starting with carbon neutral growth from 2020 onwards and reducing international aviation's emissions by 50 % by 2050 compared to 2005. ICS "is confident" that emissions per tonne mile will be reduced by 50 % by 2050 compared to 2005.

Under the carbon budget approach, a global total of 2 900 Gt CO_2eq can be emitted across all sectors between 1861 and 2100 to stay below an anthropogenic warming of 2°C with a likelihood of above 66 %. Of this budget 1 890 Gt have already been emitted by 2011 and another approx. 200 Gt are projected in all RCPs by 2019. The remaining budget of 810 Gt CO_2eq is then distributed to international aviation and maritime transport based on their share of global GHG emissions in 2020, leaving a total budget of 12 Gt and 15 Gt respectively for the two sectors after 2020.

The target trajectories in the subsequent graphs are plotted from 2020 onwards, mainly because the implementation of policies and instruments aiming at achieving these targets will take time before they come into force even if decisions on the targets for international aviation and maritime transport were taken immediately.

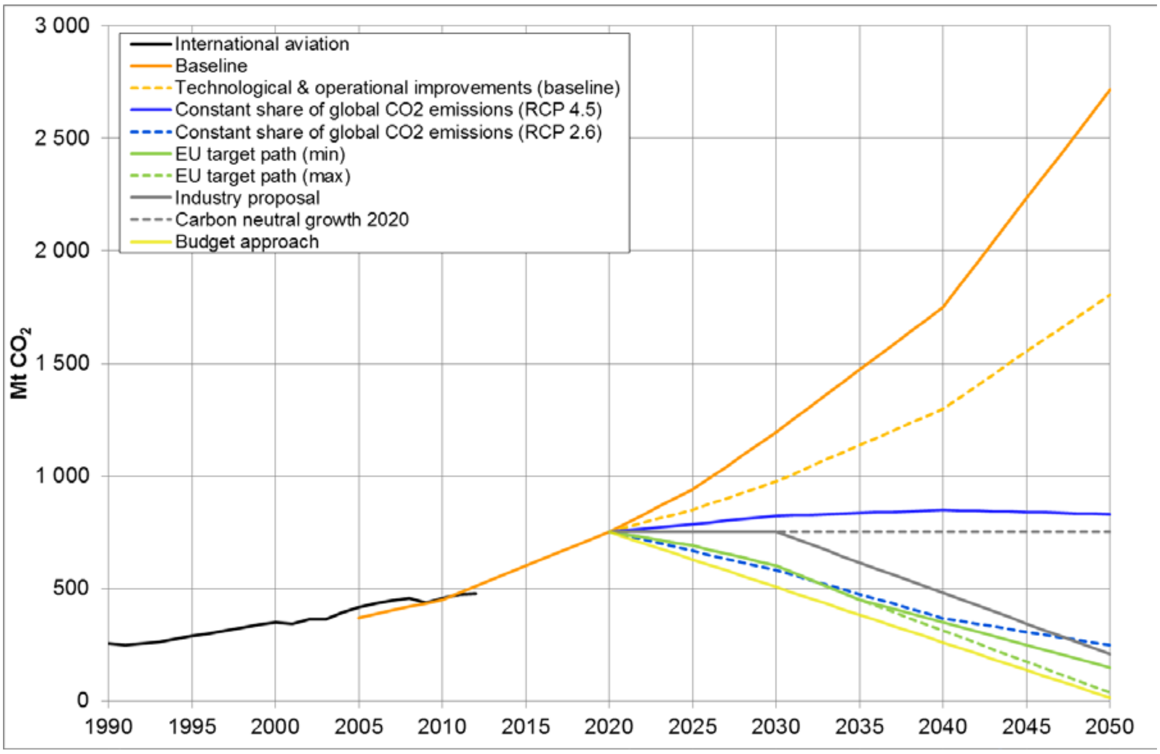
The following figures illustrate these potential targets in the context of the baseline projection and the estimated CO_2 reduction potential within the sectors, for both international aviation (Figure 9) and maritime shipping (Figure 10) individually and aggregated for both sectors together (Figure 11).

Table 2: Emission budgets 2020-2100 for international aviation and maritime transport

		Likelihood to stay below 2°C		
		about as likely as not (>33%)	more likely than not (>50%)	likely (>66%)
Global budget 1861-2100	[Gt CO_2]	3 300	3 010	2 900
Used budget (emissions 1861-2019)	[Gt CO_2]	-2 090	-2 090	-2 090
Remaining budget 2020-2100				
Global	[Gt CO_2]	1 210	920	810
Aviation	[Gt CO_2]	18.7	14.2	12.5
Shipping	[Gt CO_2]	22.1	16.8	14.8

Source: IPCC 2013, p. 27, van Vuuren, D. P. et al. 2011

Figure 9: Potential CO_2 emission targets for international aviation

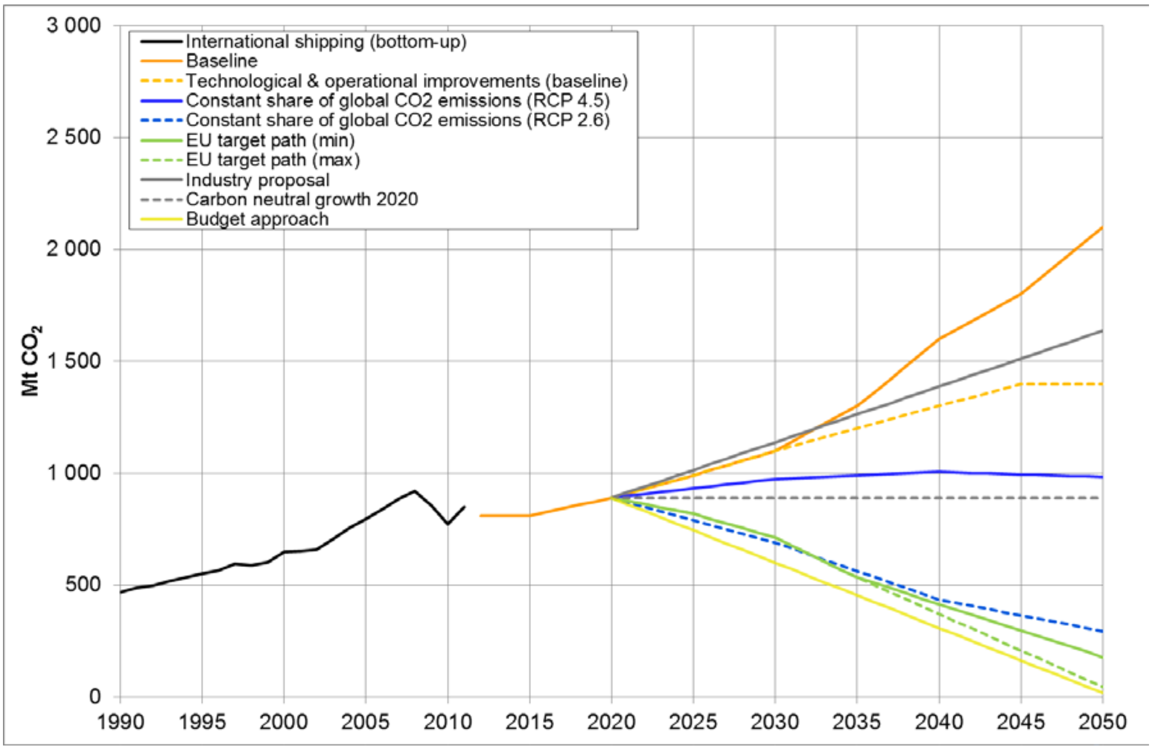


Source: Authors' own calculations based on IEA 2014, ICAO 2013b, van Vuuren, D. P. et al. 2011, Thomson et al. 2010, IATA 2013, IPCC 2014, ICAO 2010

Notes: Data for all graphs disaggregated by transport mode is included in the Annex.

The potential targets for both the individual sectors and their aggregate can be clearly distinguished in terms of their slope towards 2050. The budget approach, targets based on a constant share of the CO_2 emissions in the RCP 2.6 scenario and the EU's target path would result in clearly descending GHG emission trends in both sectors and be compatible with limiting the increase in global temperature to below 2°C.

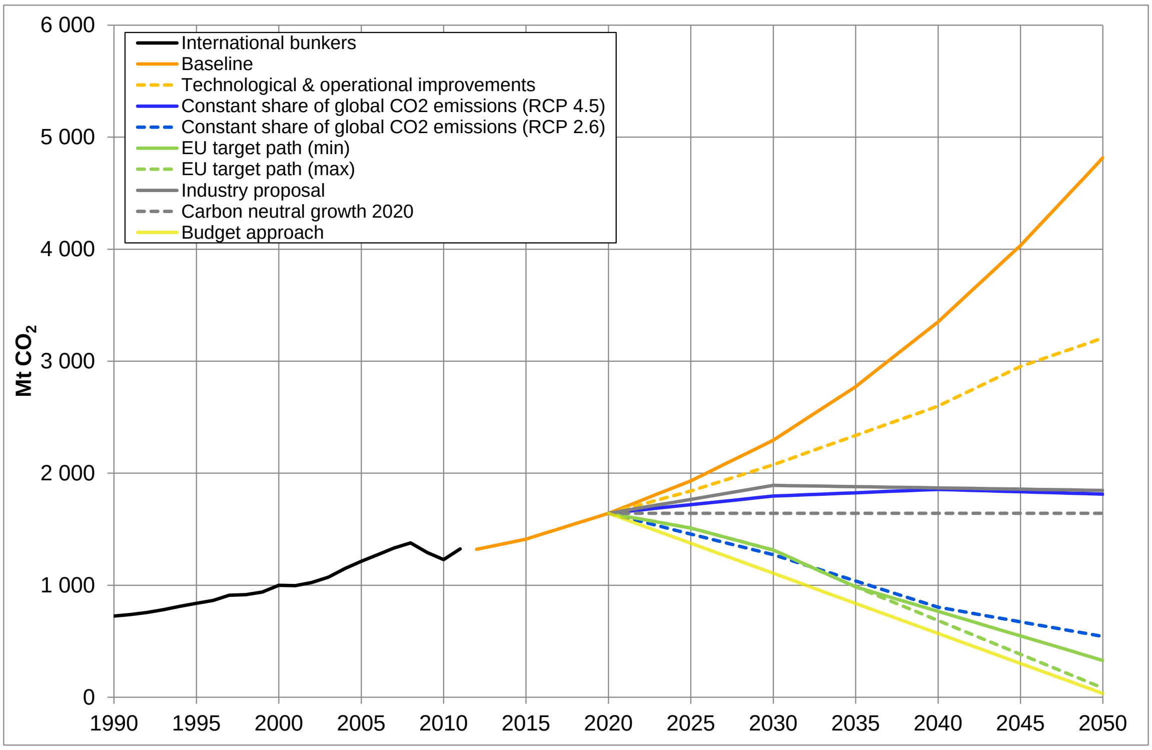
Figure 10: Potential CO_2 emission targets for international maritime transport



Source: Authors' own calculations based on IEA 2014, IMO 2009, IMO 2014, van Vuuren, D. P. et al. 2011, Thomson et al. 2010, IATA 2013, IPCC 2014, ICS 2015

Notes: Data for all graphs disaggregated by transport mode is included in the Annex.

Figure 11: Potential CO_2 emission targets for international aviation and maritime transport



Source: Authors' own calculations based on IEA 2014, ICAO 2013b, IMO 2009, IMO 2014, van Vuuren, D. P. et al. 2011, Thomson et al. 2010, IATA 2013, IPCC 2014, ICAO 2010, ICS 2015

Notes: Data for all graphs disaggregated by transport mode is included in the Annex.

If the world would strive towards a 4.5 RCP, emissions of both sectors would develop similarly to the carbon neutral growth approach and remain more or less 10 % above 2020 levels. The approaches based on the carbon budget decrease to almost zero emissions in 2050. Even under such an ambitious target the cumulative emissions in the 30 year period would reach 95 % of the total budget. To leave some more budget for the period after 2050 it would therefore be necessary to start with higher emission reductions in 2020.

The trajectories of the respective industries look quite different, though. The IATA's target proposal would result in slightly more emission reduction in 2050 than the RCP 2.6 constant share trajectory but with much higher aggregated emissions. The ICS' trajectory is even above the sectors mitigation potential. Both proposals together compensate each other to some extent.

The figures also illustrate that all potential targets, except one, are more stringent than the operational and technical potential identified by IMO and ICAO. If these targets would be considered as absolute caps for each sector, this would certainly induce severe changes within the sectors and at the global economy. However, these trajectories should not be considered as absolute caps but rather indicate to which extent both sectors could contribute to an adequate share to global GHG mitigation efforts, either through mitigation of GHG emissions within their sectors or through taking responsibility for emission reductions to be achieved in other sectors.

Table 3 provides an overview of the aggregated CO_2 emissions over the period 2020 to 2050 under the different target scenarios. The scenarios are compared to the RCP 2.6 target path because it represents an emission pathway where the world at large would stay below 2°C (Linthorst et al. 2015).

Table 3: Aggregated CO_2 emissions 2020 to 2050 and deviation from 2°C pathway

	Gt CO_2	Deviation from RCP 2.6
International transport		
Baseline	91.3	179%
Technological & operational improvements	73.6	125%
Industry proposal	56.8	73%
Constant share of global CO2 emissions (RCP 4.5)	55.5	69%
Carbon neutral growth 2020	50.9	55%
Constant share of global CO2 emissions (RCP 2.6)	**32.8**	**0%**
EU target path (min)	31.5	-4%
EU target path (max)	29.6	-10%
Budget approach	26.0	-21%
Aviation		
Baseline	48.4	222%
Technological & operational improvements	36.8	145%
Constant share of global CO2 emissions (RCP 4.5)	25.4	69%
Carbon neutral growth 2020	23.3	55%
Industry proposal	17.6	17%
Constant share of global CO2 emissions (RCP 2.6)	**15.0**	**0%**
EU target path (min)	14.4	-4%
EU target path (max)	13.5	-10%
Budget approach	11.9	-21%
Shipping		
Baseline	42.9	142%
Technological & operational improvements	36.8	107%
Industry proposal	39.2	121%
Constant share of global CO2 emissions (RCP 4.5)	30.1	69%
Carbon neutral growth 2020	27.6	55%
Constant share of global CO2 emissions (RCP 2.6)	**17.8**	**0%**
EU target path (min)	17.1	-4%
EU target path (max)	16.0	-10%
Budget approach	14.1	-21%

Source: Authors' own calculations

The overview illustrates that the mitigation targets derived from the EU's mitigation path and from the budget approach would, in both sectors, be compatible with the global below 2°C objective. Carbon neutral growth, on the other hand, would clearly not be sufficient in the long term. In terms of the proposals put forward by industry, the findings are mixed. While the shipping sector's proposal is certainly not compatible, the aviation sector's proposal may still be compatible with the global long-term goal. This mainly depends on the year by which carbon neutral growth is turned into a declining trajectory. In our analysis we assumed that the decline would start in 2030. Under this assumption international aviation's aggregated emissions are 17 % above the RCP 2.6 aggregate and in 2050 slightly below the RCP 2.6 target path. However, the more the decline from carbon neutral growth is postponed, the stronger the deviation of aviation from a trajectory which is compatible with the global long-term goal. None of these targets include non-CO_2 effects from aviation (Box 1) and are therefore only part of the necessary contribution of the sector towards achieving 2°C.

These target scenarios can be translated into targets for certain years. Table 4 provides an overview of the scenarios which are compatible with staying below 2°C objective.

Table 4: CO_2 emissions targets compatible with staying below 2°C compared to 2005 emissions

	2020	2030	2040	2050
International transport				
Constant share of global CO2 emissions (RCP 2.6)	35%	5%	-34%	-55%
EU target path (min)	35%	8%	-37%	-73%
EU target path (max)	35%	8%	-44%	-93%
Budget approach	35%	-9%	-53%	-97%
Aviation				
Constant share of global CO2 emissions (RCP 2.6)	79%	39%	-12%	-41%
Industry proposal	79%	79%	15%	-50%
EU target path (min)	79%	44%	-16%	-64%
EU target path (max)	79%	44%	-25%	-91%
Budget approach	79%	21%	-38%	-96%
Shipping				
Constant share of global CO2 emissions (RCP 2.6)	12%	-13%	-45%	-63%
EU target path (min)	12%	-10%	-48%	-78%
EU target path (max)	12%	-10%	-53%	-94%
Budget approach	12%	-25%	-61%	-98%

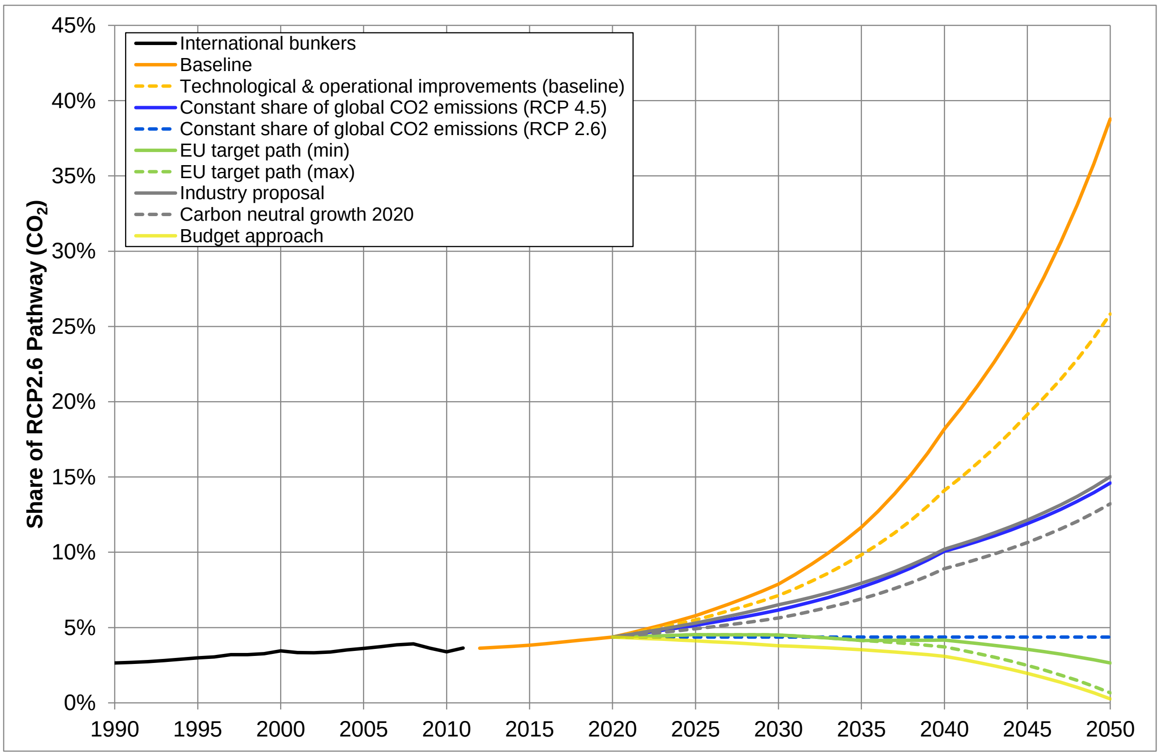
Source: Authors' own calculations

Notes: The target proposed by the shipping industry is not compatible with the below 2°C objective and is therefore not included in this table.

In 2020, CO_2 emissions from international aviation and maritime transport are projected to be 79 % and 12 %, respectively, above their 2005 emission levels. By 2050, emissions from international aviation need to be between -41 % and -96 % lower than in 2005. For maritime transport, the range is -63 % to -98 %. The lower ambition is based on a constant share of global CO_2 emission under the RCP 2.6 scenario. However, a constant share of historic emissions favours polluters and penalizes especially least developed countries with very low emissions in the reference year. Based on their structure and size both sectors are closer to industrialized countries than developing countries and should therefore reduce their share of global emissions (Chapter 6). Taking the EU target path as a reference for these sectors, the 2050 target for aviation needs to be between -64 % and -91 % below 2005 emission levels. The target for shipping needs to be in the range of -78 % to -94 % below the 2005 emission level for 2050. Shipping targets are more ambitious than those for aviation compared to 2005. This is due to the much stronger growth of emissions between 2005 and 2020 in the aviation sector.

If international aviation or maritime transport were to continue to evade their responsibility, their share in global emissions may rise considerably. Figure 12 illustrates how the share of international bunkers would develop under the potential target trajectories.

Figure 12: Potential CO_2 emission targets as share of global emissions



Source: Authors' own calculations based on IEA 2014, ICAO 2013b, IMO 2009, IMO 2014, van Vuuren, D. P. et al. 2011, Thomson et al. 2010, IATA 2013, IPCC 2014, ICAO 2010, ICS 2015

Notes: Data for all graphs disaggregated by transport mode is included in the Annex.

All mitigation scenarios start in 2020. Between 2012 and 2020 emissions are expected to grow by 24 %, which corresponds to 4.4 % of the global CO_2 emissions in 2020. Even if both sectors pursued the carbon neutral growth trajectory after this date, their share would triple between 2020 and 2050, provided that the world at large pursued an emission trajectory compatible with the RCP 2.6. This is in conflict with the shipping industry's own ambition[5] and supports the view that striving for carbon neutrality is hardly ambitious enough from the perspective of mitigation requirements. In the longer term, emissions of both sectors need to be reduced in absolute terms if they intend to comply with their global responsibility (Bows-Larkin 2015; Merk 2015; Smith et al. 2015).

[5] "The shipping industry therefore accepts that the CO_2 emission reduction which ships must aim to achieve should be at least as ambitious as the CO_2 emissions reduction agreed under any new United Nations Climate Change Convention." (ICS 2013).

8. CONCLUSIONS

Due to strong growth in transport demand, CO_2 emissions of international aviation and maritime transport were constantly growing in the past despite considerable efficiency improvements. On average they grew by 2.9 %/yr in aviation and by 3.0 %/yr in maritime transport and they are expected to grow even more strongly in the future (4.4 %/yr and 2.9 %/yr, respectively). In 2012, both sectors together account for about 3 % to 4 % of global emissions, depending on whether global GHG or only CO_2 emissions are considered.

Initiatives and actions taken by ICAO and IMO to address GHG emissions started late and have been insufficient from an environmental perspective to date: they do not take appropriate account of global decarbonisation requirements. ICAO has agreed to carbon neutral growth from 2020 onwards but policies to ensure that this target is achieved will not be adopted before autumn 2016. Even this target is only aspirational, i.e. non-binding and without concrete responsibilities for countries or operators. IMO has agreed to technical and operational measures in 2011. In the long term, these measures will mitigate growth of the sectoral CO_2 emissions but not lead to absolute emission reductions. A sectoral CO_2 mitigation target was suggested by the Republic of the Marshall Islands in spring 2015 but serious discussions on establishing a target were postponed to a future IMO meeting.

If, as in the past, the ambition of these sectors continues to fall behind efforts in other sectors and if action to combat climate change is further postponed, their CO_2 emission shares in global CO_2 emissions may rise substantially to 22 % for international aviation and 17 % for maritime transport by 2050, or almost 40 % of global CO_2 emissions if both sectors are taken together (Chapter 5). Establishing reduction targets for both sectors would provide clear signals for all actors in these sectors and thus contribute to improving investment perspectives in both sectors with their long investment cycles.

Mitigation targets are normative decisions which ultimately can only be informed scientifically. Adequacy cannot be determined by analysis and research alone but has to be determined and negotiated by policy makers. However, a number of somewhat heterogeneous and not fully distinguishable criteria to assess the adequacy of targets can be identified, including the time horizon of the target (short-, medium- or long-term), the reference (absolute or relative/indexed), the shape (single year target, trajectory or budget), the comparability in terms of emission reductions or mitigation costs and, last but not least, whether the targets originate from bottom-up estimated mitigation potentials or from global mitigation requirements.

Based on these criteria a number of potential mitigation targets for both sectors have been identified (Chapter 7). These potential targets range from a somewhat reduced increase of future emissions over a stabilisation at 2020 levels to a full decarbonisation of those sectors by 2050 derived from a global carbon budget approach. Fully decarbonising these sectors within only 30 years is certainly too ambitious and ultimately unrealistic. However, stabilising emissions at 2020 levels (carbon neutral growth) is certainly not enough. If global decarbonisation requirements are taken seriously, a clear downward trend of emissions needs to be established sooner rather than later. To stay below 2°C, the target for aviation for 2030 should not exceed 39 % of its 2005 emission levels (50 % below the baseline) and should be -41 % compared to 2005 emission levels in 2050. The respective targets for shipping are -13 % and -63 % compared to its 2005 emissions in 2030 and 2050, respectively (Table 4). If the EU target path were taken as a reference for these sectors, aviation's target for 2050 needs to be between -64 % and -91 % compared to 2005 emission levels, while the 2050 target for the shipping sector would range from -78 % to -94 % compared to 2005 emissions . If non-CO_2 impacts are taken into account, these targets would need to be even more stringent.

Taking into account the estimated mitigation potential within the sectors, it is unlikely that these targets can be achieved only by technological and operations improvements. In particular the targets which are compatible with the below 2°C objective are significantly below mitigation potentials within the sectors. As a result these potential targets should not be considered as sectoral caps. They rather indicate the extent to which both sectors contribute adequately to global GHG mitigation efforts. Achieving these targets may require both encouraging behavioural change which leads to reduced demand for international transport services and enabling the offsetting of climate impacts by financing emission reductions in other sectors. Moreover, it needs to be taken into account that particularly the non-CO_2 climate impacts of aviation will not be reduced if fossil fuels are replaced by hydrocarbons extracted from renewable energies. Only electrical propulsion, demand reduction (Bows-Larkin 2015) or offsetting remaining emissions will enable full decarbonisation of the aviation sector.

These considerations support the view that it is important to establish targets for international aviation and maritime transport which clearly indicate that emissions cannot grow unlimited and unregulated. Enhancing the stringency of the targets can be aimed at in a second step. Yet, aiming for ambitious targets in line with the approaches outlined above should not prevent agreement on targets which will trigger emission reductions sooner rather than later.

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ANNEX

Table 5: Summary of historic and projected emissions

			Unit	1990	2000	2010	2020	2030	2040	2050
Historic		int. Aviation	[Mt CO_2]	256	352	458				
		int. Maritime (bottom-up)	[Mt CO_2]	468	647	771				
		Bunker Fuels	[Mt CO_2]	724	999	1 229				
Projections	Int. Aviation	Baseline	[Mt CO_2]				752	1 195	1 751	2 716
		Techn. & op. Improvements	[Mt CO_2]				752	976	1 299	1 807
		High demand	[Mt CO_2]				800	1 366	2 160	3 443
		Low demand	[Mt CO_2]				651	833	1 066	1 438
		Lee et al. Baseline	[Mt CO_2]				625	883	1 233	1 644
	Int. Maritime	Baseline	[Mt CO_2]				890	1 100	1 600	2 100
		Techn. & op. Improvements	[Mt CO_2]				890	1 100	1 300	1 400
		High demand	[Mt CO_2]				910	1 200	1 900	2 800
		Low demand	[Mt CO_2]				870	971	1 100	1 200
	Bunker Fuels	Baseline	[Mt CO_2]				1 642	2 295	3 351	4 816
		Techn. & op. Improvements	[Mt CO_2]				1 642	2 076	2 599	3 207
		High demand	[Mt CO_2]				1 710	2 566	4 060	6 243
		Low demand	[Mt CO_2]				1 521	1 804	2 166	2 638
Share of global emissons (RCP2.6)	Int. Aviation	Baseline	[%]				2.0%	4.1%	9.5%	21.9%
		Techn. & op. Improvements	[%]				2.0%	3.4%	7.1%	14.6%
		High demand	[%]				2.1%	4.7%	11.7%	27.7%
		Low demand	[%]				1.7%	2.9%	5.8%	11.6%
	Int. Maritime	Baseline	[%]				2.4%	3.8%	8.7%	16.9%
		Techn. & op. Improvements	[%]				2.4%	3.8%	7.1%	11.3%
		High demand	[%]				2.4%	4.1%	10.3%	22.5%
		Low demand	[%]				2.3%	3.3%	6.0%	9.7%
	Bunker Fuels	Baseline	[%]				0.2%	2.6%	6.1%	11.2%
		Techn. & op. Improvements	[%]				0.2%	2.5%	5.4%	9.1%
		High demand	[%]				0.2%	2.9%	7.1%	13.6%
		Low demand	[%]				0.2%	2.3%	4.7%	7.7%
Share of global GHG budget for 2020-2100	Int. Aviation	Baseline	[%]				0.1%	1.3%	3.1%	5.9%
		Techn. & op. Improvements	[%]				0.1%	1.2%	2.6%	4.5%
		High demand	[%]				0.1%	1.5%	3.7%	7.2%
		Low demand	[%]				0.1%	1.0%	2.2%	3.7%
	Int. Maritime	Baseline	[%]				0.1%	1.3%	3.0%	5.3%
		Techn. & op. Improvements	[%]				0.1%	1.3%	2.8%	4.5%
		High demand	[%]				0.1%	1.5%	3.4%	6.4%
		Low demand	[%]				0.1%	1.3%	2.5%	4.0%
	Bunker Fuels	Baseline	[%]				0.2%	2.6%	6.1%	11.2%
		Techn. & op. Improvements	[%]				0.2%	2.5%	5.4%	9.1%
		High demand	[%]				0.2%	2.9%	7.1%	13.6%
		Low demand	[%]				0.2%	2.3%	4.7%	7.7%

Source: IEA 2014, IMO 2009, IMO 2014, ICAO 2013b, Lee et al. 2013, authors' own calculations.

Table 6: Summary of emission targets

				1990	2000	2010	2020	2030	2040	2050
2050 target proposals	Int. Aviation	ICAO Baseline	[Mt CO_2]	256	352	458	752	1 195	1 751	2 716
		ICAO techn. & op. Improvements	[Mt CO_2]				752	976	1 299	1 807
		Constant share of 2020 global emissions (RCP 4.5)	[Mt CO_2]				752	822	850	831
		Constant share of 2020 global emissions (RCP 2.6)	[Mt CO_2]				752	582	368	248
		EU target path (min)	[Mt CO_2]				752	602	351	150
		EU target path (max)	[Mt CO_2]				752	602	313	38
		Carbon neutral growth 2020	[Mt CO_2]				752	752	752	752
		Industry proposal	[Mt CO_2]				752	752	481	209
		Budget approach	[Mt CO_2]				752	506	261	15
	Int. Maritime	IMO Baseline	[Mt CO_2]	468	647	771	890	1 100	1 600	2 100
		IMO techn. & op. Improvements	[Mt CO_2]				890	1 100	1 300	1 400
		Constant share of 2020 global emissions (RCP 4.5)	[Mt CO_2]				890	973	1 005	983
		Constant share of 2020 global emissions (RCP 2.6)	[Mt CO_2]				890	689	436	294
		EU target path (min)	[Mt CO_2]				890	712	415	178
		EU target path (max)	[Mt CO_2]				890	712	371	45
		Carbon neutral growth 2020	[Mt CO_2]				890	890	890	890
		Industry proposal	[Mt CO_2]				890	1 139	1 388	1 637
		Budget approach	[Mt CO_2]				890	599	309	18
	Bunker Fuels	Baseline	[Mt CO_2]	724	999	1 229	1 642	2 295	3 351	4 816
		Techn. & op. Improvements	[Mt CO_2]				1 642	2 076	2 599	3 207
		Constant share of 2020 global emissions (RCP 4.5)	[Mt CO_2]				1 642	1 796	1 855	1 814
		Constant share of 2020 global emissions (RCP 2.6)	[Mt CO_2]				1 642	1 272	804	542
		EU target path (min)	[Mt CO_2]				1 642	1 314	766	328
		EU target path (max)	[Mt CO_2]				1 642	1 314	684	82
		Carbon neutral growth 2020	[Mt CO_2]				1 642	1 642	1 642	1 642
		Industry proposal	[Mt CO_2]				1 642	1 891	1 869	1 846
		Budget approach	[Mt CO_2]				1 642	1 106	569	33
Share of global emissons (RCP2.6)	Int. Aviation	ICAO Baseline	[%]	0.9%	1.2%	1.3%	2.0%	4.1%	9.5%	21.9%
		ICAO techn. & op. Improvements	[%]				2.0%	3.4%	7.1%	14.6%
		Constant share of 2020 global emissions (RCP 4.5)	[%]				2.0%	2.8%	4.6%	6.7%
		Constant share of 2020 global emissions (RCP 2.6)	[%]				2.0%	2.0%	2.0%	2.0%
		EU target path (min)	[%]				2.0%	2.1%	1.9%	1.2%
		EU target path (max)	[%]				2.0%	2.1%	1.7%	0.3%
		Carbon neutral growth 2020	[%]				2.0%	2.6%	4.1%	6.1%
		Industry proposal	[%]				2.0%	2.6%	2.6%	1.7%
		Budget approach	[%]				2.0%	1.7%	1.4%	0.1%
	Int. Maritime	IMO Baseline	[%]	1.7%	2.2%	2.1%	2.4%	3.8%	8.7%	16.9%
		IMO techn. & op. Improvements	[%]				2.4%	3.8%	7.1%	11.3%
		Constant share of 2020 global emissions (RCP 4.5)	[%]				2.4%	3.3%	5.5%	7.9%
		Constant share of 2020 global emissions (RCP 2.6)	[%]				2.4%	2.4%	2.4%	2.4%
		EU target path (min)	[%]				2.4%	2.4%	2.3%	1.4%
		EU target path (max)	[%]				2.4%	2.4%	2.0%	0.4%
		Carbon neutral growth 2020	[%]				2.4%	3.1%	4.8%	7.2%
		Industry proposal	[%]				2.4%	3.9%	7.5%	13.2%
		Budget approach	[%]				2.4%	2.1%	1.7%	0.1%
	Bunker Fuels	Baseline	[%]	2.6%	3.5%	3.4%	4.4%	7.9%	18.2%	38.8%
		Techn. & op. Improvements	[%]				4.4%	7.1%	14.1%	25.8%
		Constant share of 2020 global emissions (RCP 4.5)	[%]				4.4%	6.2%	10.1%	14.6%
		Constant share of 2020 global emissions (RCP 2.6)	[%]				4.4%	4.4%	4.4%	4.4%
		EU target path (min)	[%]				4.4%	4.5%	4.2%	2.6%
		EU target path (max)	[%]				4.4%	4.5%	3.7%	0.7%
		Carbon neutral growth 2020	[%]				4.4%	5.6%	8.9%	13.2%
		Industry proposal	[%]				4.4%	6.5%	10.1%	14.9%
		Budget approach	[%]				4.4%	3.8%	3.1%	0.3%

Source: IEA 2014, IMO 2009, IMO 2014, ICAO 2010, ICAO 2013b, van Vuuren, D. P. et al. 2011, IATA 2013; Thomson et al. 2010, ICS 2015, IPCC 2014, authors' own calculations.

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