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An analysis of options for including international aviation and marine emissions in a post-2012 climate mitigation regime

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Rapport in het kort

Analyse van opties voor het opnemen van internationale luchtvaart- en scheepvaartemissies in een post-2012 klimaatmitigatieregime

Een belangrijke conclusie van de analyse zoals gepresenteerd hier is dat het meenemen van bunkeremissies in nationale/regionale reductiedoelstellingen meer kosteneffectief is dan het niet meenemen en het voeren van apart sectorspecifiek beleid. De huidige snelgroeiende internationale lucht- en scheepvaartemissies zijn niet opgenomen in de nationale reductiedoelstellingen onder het Kyoto Protocol. Een analyse is gemaakt van opties om internationale lucht- en scheepvaartemissies in toekomstig klimaatbeleid op te nemen. Er is specifiek gekeken naar twee nationale/regionale allocatieopties die vanuit klimaatbeleid het meest efficiënt lijken: allocatie volgens de nationaliteit/registratie en allocatie volgens bestemming. De consequenties voor de regionale reductiedoelstellingen van deze allocatieopties voor deze zogenaamde bunkeremissies onder een post-Kyoto klimaatbeleid zijn geëvalueerd. Dit rapport presenteert een basisscenario voor de toekomstige bunkeremissies tot 2050 en een CO_2-reductiescenario voor deze specifieke sector gebaseerd op een verhoogde verbetering van de energie-efficiency en het gebruik van biobrandstoffen. De nationale/regionale allocaties onder verschillende allocatieopties worden geanalyseerd en de implicaties voor reductiedoelstellingen in de andere sectoren zijn verkend. Ook het beperkte potentieel voor de reductie van de bunkeremissies zelf is geëvalueerd.

Trefwoorden: scheepvaart, luchtvaart, emissies, CO_2, internationale bunkers, klimaatbeleid, reductiescenario

Contents

Summary

Analysis of options for including international aviation and marine emissions in a post-2012 climate mitigation regime

International aviation and shipping is projected to contribute significantly to international greenhouse gas emissions. These so-called bunker emissions are however not (yet) regulated by international policies under neither the UNFCCC nor its Kyoto Protocol. The aim of this study was to explore key options for dealing with including international bunker emissions in future climate policies, and to analyse their implications for regional emission allocations and global mitigation efforts.

The present analysis focuses on two options that seem most practical from a policy perspective: (1) allocation according to nationality/registration (SBSTA option 4) and (2) allocation according to destination (SBSTA option 6). The first option was selected as is fits in with the present regulatory regimes for international aviation and shipping in the context of the International Civil Aviation Organisation (ICAO) and International Maritime Organisation (IMO). The second, route-related option was selected because of the availability of data on imports of goods by shipping.

In exploring the implications of allocating bunker emissions under a post-2012 regime for future commitments the *Multi-Stage approach* has been chosen here. This is an incremental but rule-based approach for defining future emission abatement commitments, where the number of parties taking on mitigation commitments and in their level of commitment gradually increases over time. These increases over time are according to participation and differentiation rules which are related to the countries level of development and contribution to the problem.

The baseline scenario used is the updated IMAGE/TIMER implementation of the IPCC-SRES B2 scenario. The B2 scenario is based on medium assumptions for population growth, economic growth and more general trends such as globalisation and technology development.

This report presents a baseline scenario for future international bunker emissions up to 2050 and regional responsibilities under various regional allocation options. Next, various scenarios for dealing with the international bunker emissions in future international climate policy are analysed. The report looks both at options of regulating bunker emissions as part of the Multi-stage regime and separately on the basis of sector policies, and also explore the implications for mitigation targets for the other sectors when international bunkers emissions are being abated or left unabated. Here we also evaluate the consequences of including the relatively high impact of non-CO_2 emissions from aviation on radiative forcing in CO_2-equivalent emissions from international bunkers.

The main findings of this study are:

- Due to the high growth rates of international transport in the B2 baseline scenario by 2050 the share of unabated emissions from international aviation and shipping in total greenhouse gas emissions may increase significantly from 0.8% to 2.1% for

international aviation (excluding non-CO_2 impacts on global warming) and from 1.0% to 1.5% for international shipping. These shares may seem still rather modest, however, compared to total global allowable emissions in 2050 in a 450 ppm stabilisation scenario unabated emissions from international aviation have a 6% share (for CO_2 only) and unabated international shipping emissions have a 5% share. Thus, total unregulated bunker emissions account for about 11% of the total global allowable emissions of a 450 ppm scenario.

- However, since the total impact of aviation on radiative forcing is about 2.6 that of CO_2 only (*Radiative Forcing Index*, RFI), by 2050 the share of international aviation (including the RFI) in total greenhouse gas emissions in the baseline scenario will be about 5% instead of 2% for CO_2 only. For the 450 ppm stabilisation scenario by 2050, compared to total global allowable emissions the share of international aviation emissions increases from 6% to a 17%, and the share of international bunker emissions increases from 11% to about 20%.
- Incorporation of the non-CO_2 impacts of aviation on climate change (e.g. as represented by the *Radiative Forcing Index*) into the UNFCCC accounting scheme for greenhouse gas emissions should be considered, since aviation is a special case in this respect where the non-CO_2 impacts constitute a significant contribution. Moreover, aviation is expected to be one of the fastest growing sources and focussing solely on reducing CO_2 emissions from aviation would likely be counterproductive from a climate perspective: when improving the engine efficiency without further consideration and thus neglecting other climate pacts, e.g. NO_x emissions will increase and therefore the non-CO_2 impact of aviation on climate change.
- Given the limited (cost-effective) potential for greenhouse gas emission reductions in this sector (without substitution to biofuel), the inclusion of bunker emissions in an international emissions trading scheme seems to be a more effective and cost-effective way of having the aviation and maritime sectors share in overall emission reduction efforts as opposed to the development of sector-based policies. Inclusion in an international emissions trading scheme would provide the international transport sector the opportunity to compensate their emissions by purchasing emission reductions from other sectors instead of having to reduce their own emissions that are either very limited or very expensive.

More detailed findings on specific issues are:

Baseline developments

- Global international bunker emissions are projected to grow strongly in the period 2000–2050 (275% increase). The aviation sector is responsible for most of this growth.
- In 2050 the shares of the international aviation in total CO_2 bunker emissions increases from 45% to 60%. Including non-CO_2 contributions to radiative forcing the share is even higher: about 80% in 2050.

Allocation options

- Although the allocation of marine emissions to the flag states (Option 4) is not very robust, in practice the interchanges of registration to flag states over time have been limited during the past decades. At the present time, the registration of most ships is concentrated in the Bahamas, Panama, Liberia and Singapore as well as Greece, Malta and USA. However, for some ship types also China, Hong Kong, Norway, Germany and the Netherlands are among the most favourable flag states. Consequently, for those countries, an allocation to flag states can have a large effect on their total national GHG emissions.

Environmental penalty

- If international bunker emissions were to remain unregulated and uncompensated, this would result either in higher emission reduction targets for specific Annex I regions in order to still meet the global emissions pathway stabilising at 450 ppm, or in a significant surpassing of this emissions pathway – by about 3% by 2020 and 10% by 2050. These figures would double when the *Radiative Forcing Index* of aviation is included, implying that the stabilisation of greenhouse gas concentrations at 450 ppm CO_2-eq. by 2100 would become difficult.

Mitigation penalty

- If international bunker emissions are excluded in a Multi-Stage regime approach, and these unregulated international bunker emissions are compensated by more stringent reductions in the other sectors regulated in the international climate regime, this would result in higher emission reduction targets for particular Annex I regions in order to still meet the global emissions pathway stabilising at 450 ppm. Including the RF impact of non-CO_2 emissions from aviation would further increase the reduction targets. For example, for the EU, the reductions compared to 1990 levels can become more than 20% in 2020 (instead of 12%) and 90% in 2050 (in stead of 75%).

Regional emission commitments

- If international bunker emissions are included in a Multi-Stage regime approach, the impacts of different allocation rules are relatively small at the regional scale. However, this is not true for Central America, of which the amounts allocated have been shown to be very sensitive to the allocation rules used as the impact on allowable emissions is relatively small.
- If the bunker emissions are included in the regime, but remain unregulated, and other sectors included in the regime compensate the bunker emissions (via emissions trading), this leads to high reductions for the Annex I regions. The reductions are comparable with those under the mitigation penalty case, although even higher for the US, EU and Japan due to their high aviation emissions. Including the radiative forcing impact of non-CO_2 emissions from aviation would even imply zero-emission allowances for those regions.

Sector-based emission reduction policy

- The effectiveness of sector-based emission reduction policy scenarios on bunker emissions in terms of meeting emission reduction targets for stabilising at 450 ppm seems to be very modest due to the limited share of bunker emissions in overall emissions and the limited technical potential for mitigating international bunker emissions, at least on the short to medium term. However, for achieving a low overall emission level as needed for 450 ppm CO_2-eq. stabilisation, implementation of a large port folio of options in various sectors is necessary; excluding specific activities to contribute to emission mitigation will make it more difficult to achieve strong emission reduction targets.

1 Introduction

The international aviation and shipping sectors are projected to contribute significantly to global emissions of greenhouse gases (GHG), in particular carbon dioxide (CO_2). These so-called bunker emissions are, however, not (yet) regulated by international policies formulated by the United Nations Framework Convention on Climate Change (UNFCCC) or the Kyoto Protocol. In its Environmental Council decision in 2004 the European Union (EU) has indicated that international bunker emissions should be included in climate policy arrangements for the post-2012 period. Within this context, the aim of this report is to explore options for dealing with international bunker emissions in future climate policies and to assess their implications for regional emission allocations and mitigation efforts.

One of the reasons why international bunker emissions are not yet regulated is due to the unclear situation regarding who is responsible for these emissions. At the Conference of the Parties (COP) 1 in 1995 the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA) was requested to address the issue of allocation and control of emissions from international bunker fuels[1]. In 1996 the UNFCCC secretariat presented a paper at SBSTA 4 that included eight allocation options for consideration by the countries (Table 1):

Table 1. Concepts and SBSTA allocation options for international marine and aviation bunker fuel emissions.

Allocation concept	**SBSTA allocation option**
None	1. No allocation
Global bunker sales and associated emissions	2. In proportion to countries national emissions
	3. To the country where the bunker fuel is sold
Nationality based: specific trips made by a) transporting company (nationality), b) aircraft/vessel (registration country), or c) the operator (nationality)	4. To the nationality of the transporting company; to the country where an aircraft or ship is registered, or to the country of the operator
Route based: departure or ***destination*** of ***aircraft/vessel's*** trips	5. To the country of either departure or destination of an aircraft or vessel, or shared by the country of departure and the country of arrival
Cargo based: departure or ***destination*** of ***passengers/cargo*** transported	6. To the country of either departure or destination of passengers or cargo; or shared by the country of departure and country of arrival
Cargo based: origin of passengers/owner of cargo transported	7. To the country of origin of passengers or owner of cargo
National territory (airspace, sea under jurisdiction) *	8. To a party of all emissions generated in its national space

* E.g. territorial waters (12 mile zone), continental shelf, exclusive economic zone, national airspace.

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[1] For a more elaborate background on the process within the UNFCCC, consult its website at: http://unfccc.int/adaptation/methodologies_for/vulnerability_and_adaptation/items/3416.php (consulted January 19th, 2006).

The analyses presented here focussed on two allocation options that seem to be the most practical in terms of a policy perspective:

- allocation according to nationality/registration (SBSTA Option 4): flag state of vessels, national airline's aircraft activities; and
- allocation according to destination (SBSTA Option 6): imported goods and destination of passengers.

The first, nationality-based, option was selected for analysis as it fits in with the present regulatory regimes for international aviation and shipping within the framework of the International Civil Aviation Organisation (ICAO) and International Maritime Organisation (IMO), which are specialised agencies working with the UN to address policy issues on international transport. The second, cargo-based, option was selected since data is readily available on the import of goods by shipping route. At the regional level, this latter option is largely comparable to allocation according to the destination and departure of ships and airplanes, as intra-regional transit transport does not play a role at the regional level, while it does as at the national level. For Option 4 in aviation in this report the allocation of Option 5 (out-bound flights allocated to the country of departure and return flights to the country of destination) is used as a proxy, because no allocation was available for Option 4.

To explore the implications of allocating bunker emissions under a post-2012 regime for future commitments the *Multi-Stage approach* is chosen here, which is an incremental but rule-based approach for defining future emission abatement commitments. This approach assumes a gradual increase in both the number of parties taking on mitigation commitments and the level of commitment of the participating parties as the latter progress (graduate) through several stages in accordance to the rules for participation and differentiation (Berk and Den Elzen, 2001; Den Elzen et al., 2006c; 2006a). The Multi-Stage approach also appears to be the best method for fulfilling the various criteria (environmental, political, economic, technical, institutional) intrinsic to the multi-criteria evaluation of the approaches of Höhne et al. (2005) and Den Elzen and Berk (2003). The FAIR 2.1 model is used for the Multi-Stage analysis of regional emission allowances that are compatible with the long-term stabilisation of atmospheric greenhouse gas concentrations (Den Elzen and Lucas, 2005)[2].

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[2] The FAIR model is designed for the quantitative exploration of a range of alternative climate regimes with the aim of differentiating between future commitments compatible with the long-term stabilisation of atmospheric greenhouse gas concentrations (Den Elzen and Lucas, 2005). The model uses the IPCC SRES baseline scenarios for population, gross national product (GDP) and GHG emissions (excluding bunker emissions) for 17 global regions [i.e. Canada, USA, OECD-Europe, Eastern Europe, the former Soviet Union (FSU), Oceania and Japan; Central America, South America, Northern Africa, Western Africa, Eastern Africa, Southern Africa, Middle East and Turkey, South Asia (including India), South-East Asia and East Asia (including China)] from the integrated climate assessment model IMAGE 2.3 (IMAGE-team, 2001), including the energy model TIMER 2.0 (Van Vuuren et al., 2006b). The historical GHG emissions are based on various data sets. The historical regional CO_2 emissions from fossil fuel combustion and industrial sources are based on the IEA database (1970–2003) (IEA, 2005) and the EDGAR database developed by MNP, TNO and JRC (Van Aardenne et al., 2001). The CO_2 emissions from land-use changes are based on Houghton (2003) (1890–2000). The anthropogenic emissions of

The baseline scenario used for the analysis in this report is the updated IMAGE/TIMER implementation of the Intergovernmental Panel on Climate Change (IPCC) SRES B2 scenario (Van Vuuren et al., 2006b) (hereafter referred to as the 'B2 scenario'). The B2 scenario was selected since it is based on medium trend assumptions for population growth, economic growth and more general trends such as globalisation and technology development. In terms of quantification, the scenario roughly follows the reference scenario of the World Energy Outlook 2004 (IEA, 2004) and, after 2030, economic assumptions converge to the B2 trajectory (IMAGE-team, 2001). The population scenario is based on the UN Long-Term Medium Projection (UN, 2004).

The material presented in this report is structured as follows. Section 2 presents a baseline scenario for future international bunker emissions up to 2050 and regional responsibilities under various regional allocation options. Section 3 analyses various scenarios for dealing with the international bunker emissions in future international climate policy. Within this context, various options for regulating bunker emissions are explored, both as part of the Multi-Stage regime and separately on the basis of sector policies, as well as the implications for mitigation targets for the other sectors when international bunkers emissions are being abated or left unabated. In addition, the consequences of including the relatively high impact of non-CO_2 emissions from aviation on radiative forcing in CO_2-equivalent emissions from international bunkers are evaluated. To assess the sectoral emission reduction potential we have developed CO_2 mitigation scenarios based on the potential for energy efficiency improvement and the introduction of biofuels. The conclusions drawn from these analyses are presented in section 4.

This analysis was made as part of a study reported by Faber et al. (2006), for which three different types of policy regimes have been explored, for each of which two concepts were elaborated:

Table 2. Concepts for the inclusion of bunker fuel emissions in climate policy.

Type of policy regime	**Concepts**
1 ***Allocation of emissions to countries*** (each country is allocated a certain share and this share is included in the national commitment)	A Route-based allocation = SBSTA option 4 (marine; cf. flag states) and option 5 (aviation; cf. destination of aircraft)
	B Cargo-based allocation = SBSTA option 6 (destination of passengers/cargo)
2 ***Sectoral commitments*** (by the international transport sectors)	C Sectoral approach with emission cap
	D Technology-based sectoral approach
3 ***Regional start*** (not included in a global climate policy regime)	E Inclusion of aviation in EU Emission Trading Scheme (ETS)
	F Inclusion of maritime shipping in existing policy instruments

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the Kyoto non-CO_2 GHGs (CH_4, N_2O and the HCFCs, HFCs, PFCs and SF_6), other halocarbons (e.g. CFCs, HCFCs), sulphur dioxide (SO_2) and the ozone precursors (NO_x CO and VOC) are based on the EDGAR database (1890–1995).

2 Future projections of international marine and aviation emissions

The projection and allocation of emissions requires, firstly, the determination of the emissions in the starting year for the scenarios; secondly, a model to estimate the development of emissions over time; thirdly, an allocation of fuel consumption to countries. Each of these elements will be briefly discussed in this chapter. The differences in historical emissions estimates are discussed in more detail in text boxes, and details on the construction of the marine scenario are provided in the Appendix A. Historical CO_2 emissions from international shipping and aviation are surrounded by large uncertainties. For this reason, this report have estimated the emissions using two different methods – the top-down method based on national fuel sales statistics and the bottom-up method based on aircraft and shipping characteristics (specific fuel consumption, etcetera) and their statistics (numbers and length of voyage). Both approaches have advantages and disadvantages (see Boxes 1 and 2).

2.1 International marine transport scenario

Very few source-specific scenarios exist for the emissions of international shipping. Although the emissions scenarios by Eyring et al. (2005b) are very detailed, they focus primarily on NO_x emissions and other non-CO_2 compounds and pay little attention to specific fuel consumption and the trend in specific fuel consumption over time. Also, these scenarios do not provide a regional split in their emission projections.

With respect to international shipping, which in some studies is considered to be equivalent to ‘ocean-going ships’, different top-down and bottom-up data sets on historical fuel consumption and CO_2 emissions exist. While the principal causes of differences between these data sets are known – for example, a significant fraction of domestic shipping may be included in the bottom-up estimates, as explained in Box 1 – it is currently not possible to implement precise corrections in either of the data sets. Consequently, the regional emissions scenarios presented here, which are based on IEA data for global total emissions in 2000 minus an amount estimated by Corbett and Köhler (2003) for military fuel use, should be considered to be a fair estimate and, as such, to be sufficiently accurate for analysing how the allocation options work out in practice.

Therefore, for the reasons discussed above we chose to develop a Baseline (trend) scenario, which is in line with the baseline B2 scenario (medium scenario) and which is based on historical data on the capacity per ship type in Dead Weight Tonnes (DWT) of tankers, bulk carriers, container ships, general cargo, among others, from the United Nations Conference on Trade and Development (UNCTAD, 2006b) . The following assumptions are made:

- The specific fuel consumption per DWT per major ship type remains constant over time (as suggested by historical data; see Appendix A);

- The historical fuel consumption trends were determined per type of shipping using DWT capacity per region and the definitions below;
- The regional 2000–2030 growth trends are based on historical regional capacity growth trends in the 1985–2003 period and linear extrapolation of the growth trend in the 2020s for the 2030–2050 period (with a few exceptions in cases of extreme high growth rates).

Box 1: Approaches used to estimate fuel consumption of international shipping

For international shipping, which in some studies are considered to be equivalent to ‘ocean-going ships’, different data sets on historical fuel consumption and CO_2 emissions exist. The methodologies for deriving these data sets on emissions can be characterised as either top-down or bottom-up. Top-down approaches rely on national statistics on marine bunker sales as the basis for estimating global total fuel use by fuel type for international marine transport (IEA, 2005), whereas bottom-up estimates are based on data assembled on ship types, ship numbers, number and type of engines, average hours of operation, among others (Eyring et al., 2005b). The basic data on ship numbers by type and number and type of engines per ship are reasonably well known for the world ship fleet. However, the determination of the fraction actually engaged in international transport (as defined by the UNFCCC), the number of hours per year of operation of the engines and the average load factors are based on best estimates. These factors contribute significantly to the uncertainty of the bottom-up estimates. In addition, a portion of the ocean-going ships is engaged in domestic activities – for example, local, coastal and short sea traffic and trips to and from the mainland and islands belonging to the same country – which may be a substantial fraction of the domestic freight transport [e.g. about 40% for Japan and EU-15, 30% for Canada and 17% in USA (OECD, 2006)]. Furthermore, the amount of international transport through internal waterways (rivers, canals), which is not accounted for in the ocean-going fleet, is very difficult to estimate on a global level. However, the accuracy of the top-down estimates is also limited, since duty-free marine bunker fuels may also be sold to ships actively used in the domestic transport sector, as defined by the UNFCCC (e.g. fisheries). Military activities may also be included. Eyring et al. (2005b) provide an overview of elements that cause differences between these two types of estimations and of the national estimates that comply with UNFCCC definitions. For international marine transport this report assumes that the top-down estimate from the IEA (2005) is the best estimate for the following reasons:

- Although top-down estimates include military vessels and fishing boats, which account for about 14 and 6% of total fuel consumption (Corbett and Köhler, 2003), respectively, these estimates are probably still more accurate than the bottom-up calculations in which many parameters have to be estimated and which also include a significant fraction of internal navigation (e.g. coastal or short-sea shipping);
- The post-1990 historical trend in IEA data set is quite accurately reproduced using the trend in Dead Weight Tonnes (DWT) per ship type according to UNCTAD (2006a) when assuming that military fuel use is constant over time, based on the estimate of Corbett and Köhler (2003), and that there is a constant specific fuel consumption per DWT (a unit of shipping capacity) (see Appendix A).

As shown in Table 3, these data limitations and different source aggregations result in different estimates of the national and global estimates of fuel consumption from this source category (i.e. precisely as defined by UNFCCC); this is particularly evident between the top-down and bottom-up methods, which differ by up to a factor of two (without corrections for differences in definitions).

Table 3. Top-down and bottom-up estimates for CO_2 emissions from global international marine transport.

Inventory	**Type**	**Base year**	**CO_2 (Tg)**
Corbett et al. (1999)	bottom-up	1993	451
Endresen et al. (2003)	bottom-up	1996	461
EDGAR 3.2 FT2000	top-down	2000	428
IEA (2005)	top-down	2001	442
Corbett and Köhler (2003)	bottom-up	2001	913
Eyring et al. (2005b)	bottom-up	2001	813

In constructing the scenarios, two types of regional groupings/allocations were used for the historical trend and for projections of fuel consumption and CO_2 emissions per ship type:

- As defined by flag of the country of registration corresponding with Option 4 of section 1: allocation according to the country where the ship is registered (*hereafter also designated as* ***flag state***);
- As defined by the import value per country (based on UNCTAD (2006a)) of goods that are generally transported by ships, using statistics for the major commodities per ship type to estimate the associated CO_2 emissions; this corresponds with Option 6 of section 1: allocation according to the country of destination of the cargo or passengers (*hereafter also designated as* ***imported goods***).

Although both regional groupings result in somewhat different global total emission projections, they are basically projections (extrapolations) of historical trends of capacity per ship type. The resulting differences in the two projections were removed by scaling both groupings to the same global total values. The reader is referred to Appendix A for more details on the historical trends and the methodology used for making the CO_2 emission projections.

When the historical trends of ship capacity are used for projecting CO_2 emissions from 2000 onwards, the result is a more than 40% increase in emissions by 2020 and an approximately 180% increase by 2050. As suggested by the differences in regional shares and trends in the registration of DWT capacity per flag country and by the value of imported goods (in USD), which are presented in Appendix A.1 (and illustrated in Figures A.1 and A.3), these different allocation methods also result in the development of highly different regionally allocated future CO_2 emissions (Figure 1). Notable exceptions are OECD Europe and South-East Asia, which show rather similar trends in both cases. When the global trends are compared with the four scenarios of Eyring et al. (2005b), the projected increases in the 2000–2020 period of 41–46% are very similar to the baseline (‘Business-As-Usual’) scenario. However, the projected increase in 2050 is somewhat higher than the largest projected increase in the Eyring scenarios, which is about 250%. These differences in regional allocations that originate from the differences between Option 4 (allocation to flag nation, measured in DWT) and Option 6 (allocation to imported goods, expressed in USD) in the base year 2000 (Figure 2). The largest absolute differences are, once again, seen in the CO_2 emissions from Central America (i.e. the Caribbean) and Western Africa, with both of these regions showing much higher emissions in Option 4 (flag nations), and from the USA, OECD Europe, Middle East and Japan, all of which show much higher emissions in Option 6 (imported goods).

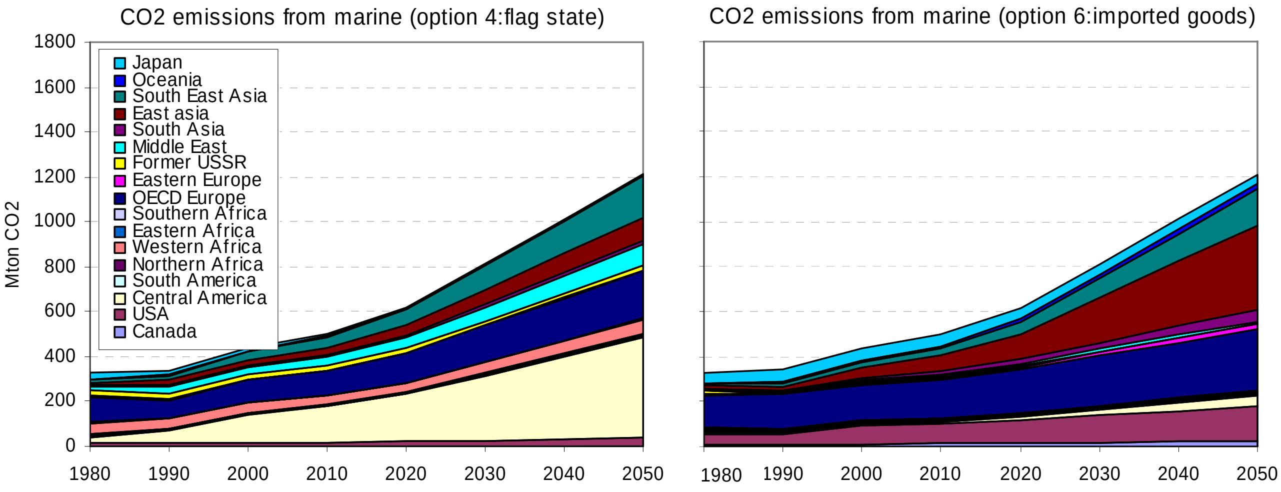

Figure 1. Baseline (trend) scenario for regional CO$_2$ emissions from marine transport using Option 4 (flag state) (left) or Option 6 (imported goods) (right). Source: this study.

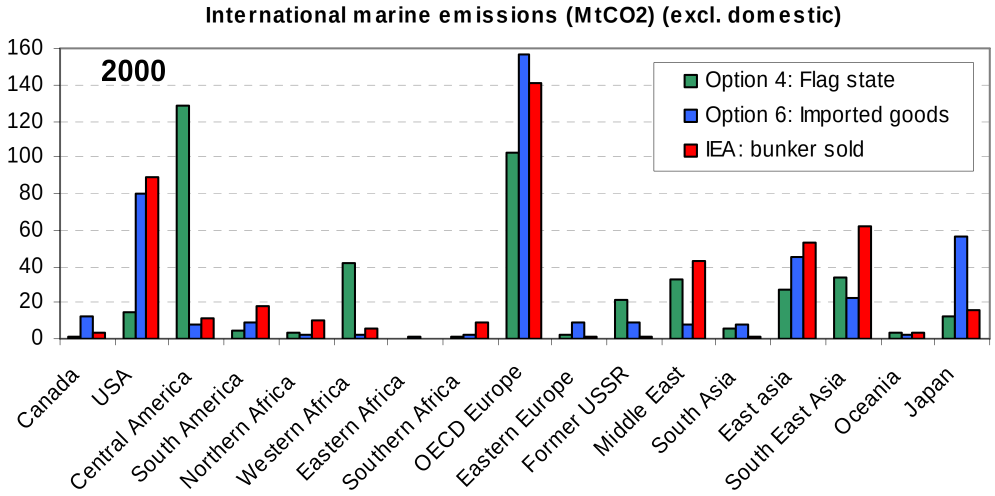

Figure 2. The effect of different allocation options – Option 3 (bunker sold), Option 4 (flag state) or Option 6 (imported goods) – on international marine emissions based on data from UNCTAD (2006). The IEA bunker sales data are also depicted here for comparison purposes. Source: this study.

It should be noted that in contrast to most other emission sources, the allocation of maritime emissions to the flag countries where ships are registered is not very robust and may change significantly over time, since ship fleet owners may easily change the country of registration if national ship policies change substantially (e.g. administrative or tax regulations). In practice, however, the registration of most ships (in DWT capacity) is concentrated in a limited number of countries – the Bahamas, Panama, Liberia and Singapore in particular, but also Greece, Malta and USA. For some ship types, China, Hong Kong, Norway, Germany and the Netherlands can also be included in the list of most favourable flag states. However, since flag states play a key role in the implementation of IMO treaties, as do port and coastal states, and given the fact the interchanges of registration to flag states have been limited over time, we have elaborated on the regional subdivision in the scenarios to identify any key specific differences between the two allocation options.

In addition, when considering inter-regional differences presented in this report one should keep in mind that regional totals are reported as the direct sum of imports by all countries within the regions and thus include intra-regional transport between countries. As such, net imports to the EU-25 as a region, for example, will actually be smaller than the figures presented here, which are the direct sum of imports of every member state. Moreover, the import value may include goods that are transported across countries using trucks (and rail and air). Nevertheless, the aggregation to regions using national import figures for goods that are mainly transported by ships provides a reasonably proxy for making comparisons.

2.2 International aviation baseline scenarios

Several emission scenarios for aviation are reviewed in IPCC (1999). However, only few data sources exist which have separated out the emissions from international aviation and allocated historical fuel consumption and related CO_2 emissions for international aviation according to various options (see Box 2).

Owen and Lee (2005) calculated the amount of emissions from international aviation for the period 2005–2050 for the IPCC B2 scenario, which are used here. In their calculations, these authors used a very detailed bottom-up method, allocated to Parties, when working out allocation options 2, 3, 4, 5, 6 and 8 (section 1):

- *Option 4: Nationality of airline* – Under this option emissions were first estimated using the FAST model (see the description of Option 3a above). Emissions were then allocated according to the nationality of the airline. The feasibility of the alternative options under SBSTA Option 4 (allocation to the country in which the aircraft is registered or to the country from which the airline is operated) was considered to be uncertain and, consequently, allocation to nationality of the airline was selected. Although feasible for 2000, ownership of airlines is becoming progressively more complicated *(designated hereafter also as **national carrier**).*
- *Option 5: Country of destination or departure of aircraft* – Emissions were first calculated using the FAST model. The emissions from out-bound flights were then allocated to the country of departure and those from return flights to the country of destination. In other words, flight emissions were allocated to the country from which the aircraft ‘originally’ departed *(designated hereafter also as **destination aircraft**).*
- *Option 6: Country of departure or destination of passengers or cargo* – This is an alternative option in which emissions related to the journey of passengers or cargo are shared by the country of departure and the country of arrival. This implies that states have control over the emissions caused by the transport of cargo or passengers that enter or leave their country and, consequently, the control needed for this option resembles that needed for allocation Option 5. Emission trading and emission charges

could be designed to give states this control *(designated hereafter also **destination passenger**).*

Box 2: Approaches to estimate fuel consumption of international aviation

In aviation, similar causes of differences exist between top-down and bottom-up estimates of fuel consumption and CO_2 emissions. Top-down international statistics, such as those from the IEA, are based on fuel sales and include military aircraft. Bottom-up estimates of global flights, which are based on the Official Airline Guide (OAG), may underestimate actual fuel consumption when they do not include charter flights (which are particularly important in Europe), do not use real flight distances (non-optimal routes, circling around airports) and assume neutral winds for the complete flight. Owen and Lee (2005) provide an overview of elements that cause differences between these two types of estimations. It is also acknowledged that in energy statistics fuel consumption for domestic aviation may occasionally correspond to all fuel purchases of domestically based airlines regardless of the flight destinations. However, for international aviation this report assumes that the top-down estimate – for example, that of IEA (2005) – is the best estimate because:

- Although it includes military aircraft, it is probably more accurate than the bottom-up calculation, for which many parameters have to be estimated and which also excludes a significant fraction of fuel consumption from non-scheduled flights (e.g. charters and general aviation);
- Bottom-up estimates generally use great circle distances between airports and specific fuel consumption for estimating total fuel consumption, whereas in practice actual distances flown and air conditions may differ considerably from these idealised assumptions. According to Owen and Lee (2005), this difference could be up to 15%.

Table 4 shows that the differences between both methods are substantial.

Table 4. Top-down and bottom-up estimates for CO_2 emissions from global aviation (estimates for international aviation are given in parenthesis).

Inventory	Type	Base year	CO_2 (Tg)
NASA	bottom-up	1999	404
FAST-2000 (OAG)	bottom-up	2000	480 (266)
AERO2K	bottom-up	2002	492
EDGAR 3.2 FT2000	top-down	2000	654
IEA	top-down	2000	672 (358)

Sources: Owen and Lee (2005); Olivier et al. (2005); IEA (2005).

This report used the allocation of Owen and Lee’s Option 5 as proxy for Option 4 because no allocation was calculated for Option 4, and the ‘growth’ element of Option 4 is simply reflected in the FAST-2000 B2 scenario for Option 5 (D.S. Lee, personal communication, 2006). However, the scenario emissions were calculated using a bottom-up model requiring a large number of additional estimates, and these are likely to result in a considerable bias (see Box 2). Therefore, these emissions are scaled to match the international aviation CO_2 emissions in 2000 estimated in IEA (2005). This scaling results in a global increase in 2000 of about 35% compared to the calculated FAST emissions. The largest absolute differences are seen in the emissions of OECD Europe (about 35%), the former USSR (a factor of 6 higher) and the USA (about 25% higher) (see Figure 3). Figure 3 also clearly shows that emissions of OECD Europe and the USA are much larger than those of the other regions presented. However, the emissions in the IEA data set allocated to the former USSR appear to be suspiciously high (D.S. Lee, personal communication, 2006), which reflects the generally much higher uncertainty in the statistics for economies in transition. However, please note that the IEA total international bunker estimates also contains some uncertainty, as the IEA bunker data include military emissions, and countries do not always report their statistics in accordance to the definition requested.

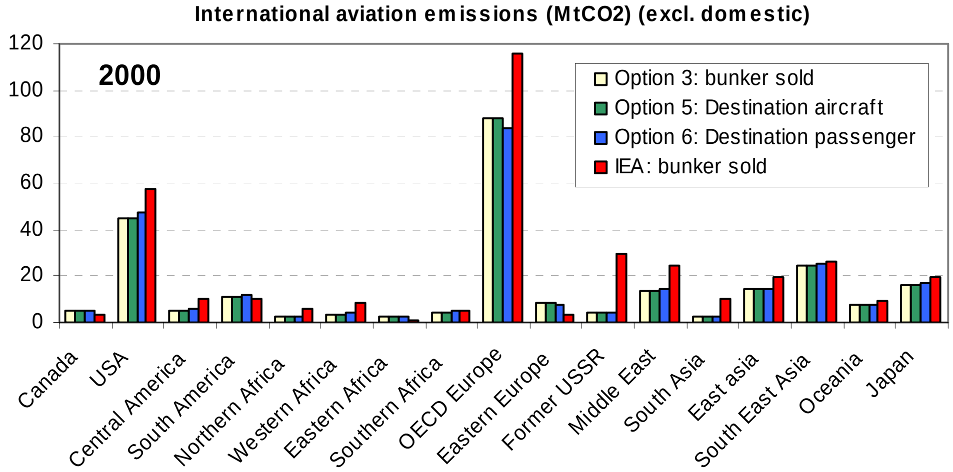

Figure 3. The effect of three different allocation options on international aviation emissions: Option 3 (bunker sold), Option 4 (flag state) or Option 6 (imported goods). Emissions are based on data of Owen and Lee (2005). For comparison, IEA data are also depicted.

This report does not go into the specific outcomes of the different allocation methods here. The main conclusion of Owen and Lee (2005) is that the options favoured by SBSTA (Options 3, 4, 5 and 6) are in close agreement[3]. This is also shown in Figure 3. Therefore, the choice of one of these options over another does not appear to introduce a significant bias or distortion into the system (in contrast to clearly different systems, such as Options 2 and 8). However, in terms of some of the countries with relatively few emissions allocated, the allocation options can have a substantial impact on the amount of emissions allocated.

The FAST B2 scenario is based on a scheduled air traffic projection by the Forecasting and Economic Support Group (FESG) of ICAO for revenue passenger kilometres up to 2020 and a logistic model of revenue passenger kilometres relating to GDP growth assumptions of the IPCC SRES B2 scenario. The GDP growth assumptions are an annual increase of 3.2% until 2010, followed by a decrease to 2.5% in the 2040–2050 period. Improvement in specific fuel consumption due to engine/airframe factors, which was not included in the FESG projections, were included based on historical trends; these amount to 1.3% per year for 2000–2010 and 1.0% per year for 2010–2020, whereas 0.5% per year was used for the 2020–2050 period

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[3] This does not necessarily imply that this would remain so after an allocation method has been decided upon. Under some options, strategic actions to avoid inclusion under a stringent regime may be conceivable. This is analogous to the situation for sea shipping where vessels may be diverted to flag countries with less stringent commitments.

(Owen and Lee, 2005). More details on the regionalisation of the scenario (regional CAEP-6 forecasts up to 2020 and regional breakdowns up to 2050 according to the proportions in the CAEP-6 projection data) can also be found in this report.

The projection of the FAST B2 emission scenario for CO_2 emissions from *international* aviation from 2000 onwards shows an almost 100% increase in emissions by 2020 and an approximate 400% increase by 2050 (Figure 3). The FAST B2 emission scenario for *total* aviation results in about 2000 Tg CO_2 for 2050, which is well within the range of 1500–5300 Tg CO_2 projected by the group of scenarios for aviation presented in the IPCC Special Report on Aviation (excluding the four most extreme, less probable ones). As suggested by the small differences in regional shares in 2000 (Figure 3), the allocation methods of Option 4 and Option 6 result in a rather similar development in terms of the regionally allocated CO_2 emissions (Figure 4).

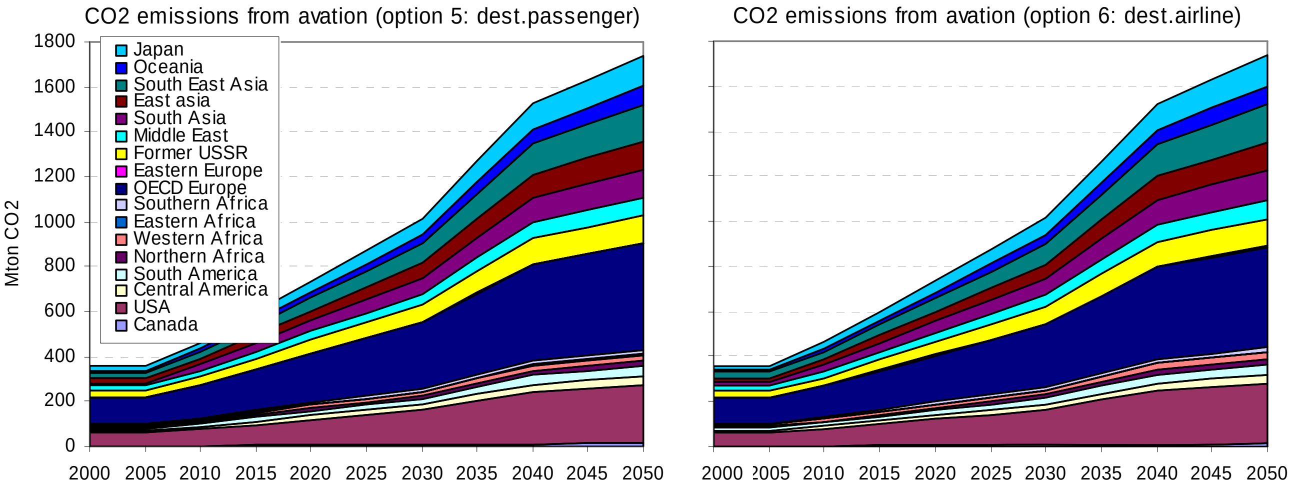

Figure 4. Baseline B2 (trend) CO_2 emissions scenario for international aviation allocated using Option 5 (destination/departure of passengers/cargo; used in analysis as proxy for Option 4) (left) or Option 6 (destination/departure of aircraft) (right) Source: historical data from IEA and scenario from Owen and Lee (2005).

However, we should recall the discussion on the accuracy of the national and global estimates of fuel consumption from this source category within the context of its exact definition by the UNFCCC (see Box 2), with particular reference to estimates based on top-down and bottom-up methods, which differ by up to a factor of two (without corrections for differences in definitions) (Table 4). Although the principal causes for these differences are known (e.g. a significant fraction of domestic aviation may be included in the bottom-up estimates), precise corrections in both types of data sets can not be made. Also note that the adjustment of the FAST emissions to IEA total international bunker estimates of 35% for fuel consumption that is not accounted for in the bottom-up FAST model also contains some uncertainty, as the IEA bunker data include military emissions, and reporting countries may not always report their statistics in accordance to the definition requested.

2.3 International bunker emissions

Without specific emission abatement, combined future bunker emissions from the aviation and maritime sectors are projected to grow in the baseline B2 (trend) scenario from about 800 Mt CO_2 in 2000 to about 1350 Mt by 2020 and nearly 3000 Mt in 2050 (Figure 5.) This is equivalent to an increase of approximately 70% in 2020 and 275% in 2050 compared to 2000. The aviation sector is responsible for most of this growth. While the shares of international shipping and aviation in 2000 in terms of total CO_2 bunker emissions are both about 50%, in 2050 this has shifted to 40% for shipping versus 60% for aviation. However, when the *Radiative Forcing Index* (RFI) is applied to the CO_2 emissions projection for aviation – a measure to estimate and include the impact of specific non-CO_2 emissions on climate: the ratio of the total radiative forcing (RF) by all aviation emissions to that of CO_2 from aviation alone, which is about 2.6 (see Box 5 in section 3.4.4) – the share of aviation in the bunker total increases from about two thirds in 2000 to 80% in 2050 (without specific abatement). The RFI value of 2.6 is based on IPCC (1999), which analyses the following contributions of aviation to radiative forcing: CO_2, NO_x, (via ozone changes and via methane changes), contrails and stratospheric water vapour, sulphur and black carbon aerosols, cirrus cloud formation induced by aircraft emissions. In particular the contribution from NO_x emissions appeared significant; the impact on cirrus cloud formations is considered to be very uncertain. In a more recent study by Sausen et al. (2005) a new estimate of the RFI value was presented, which as somewhat lower than the IPCC estimate mainly because of a reduced estimate of the RF from contrails. However, they estimate the the potential range for the RF contribution from aviation induced cirrus clouds, which is not included in their estimate, much larger than the IPCC did.

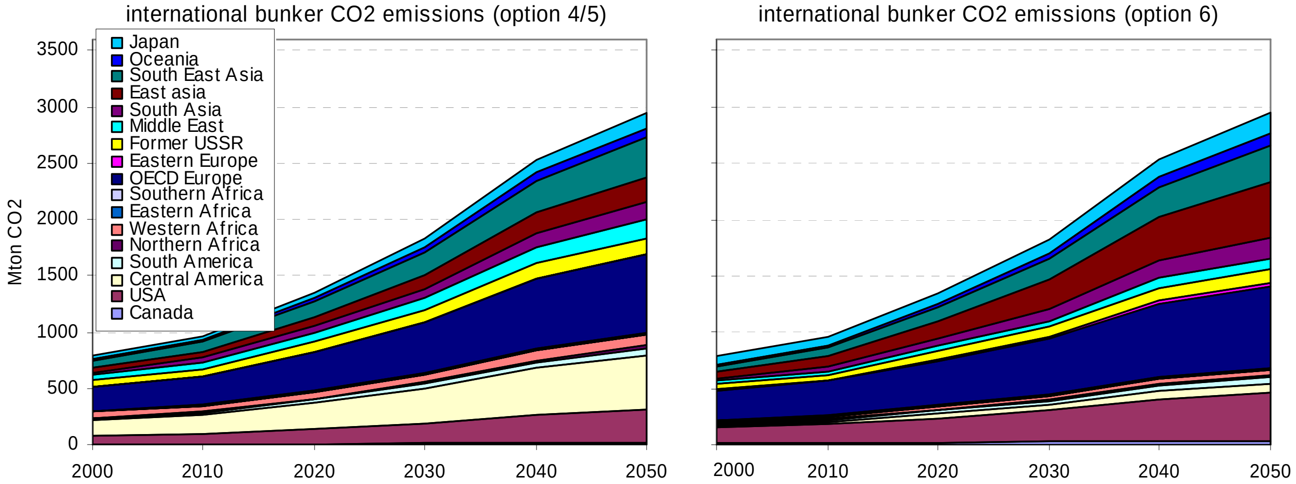

Figure 5. The international bunker emissions for the IPCC SRES baseline B2 scenario as constructed for this study for Option 4/5 [i.e. Option 4 for marine (flag state) and Option 5 for aviation (destination aircraft)] (left) and Option 6 marine and aviation (destination passenger/cargo) (right). Source: this study.

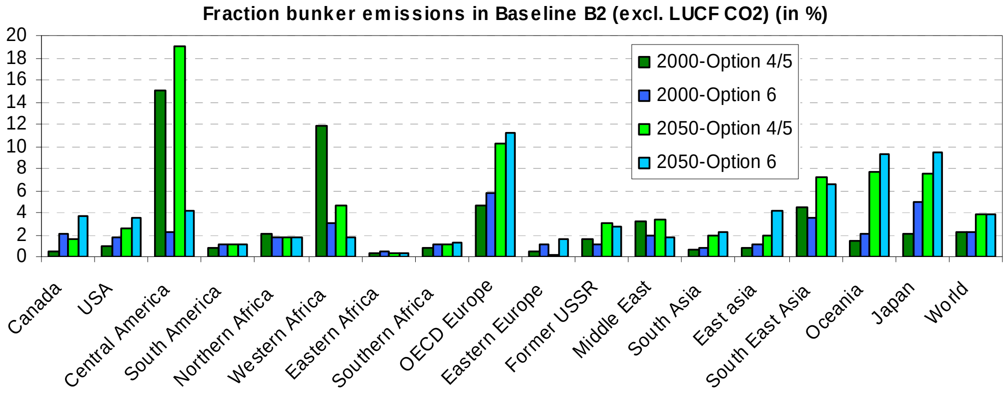

Figure 6. Fraction of the bunker emissions in the overall regional and global anthropogenic CO_2-equivalent emissions for the B2 baseline scenario in 2000 (green) and 2050 (blue) for Option 4/5 (i.e. Option 4 for marine and Option 5 for aviation) and Option 6 marine and aviation). Source: MNP-FAIR model.

With respect to the regional projections, Figure 6 clearly shows that there are large differences for some regions depending on whether emissions are allocated according to nationality/flag or route/destination of passengers and goods. This is particularly true for Central America and Western Africa and, to a lesser extent, for Canada, Eastern Europe, Middle East, Japan (in the short term) and East Asia (China) (in the long term).

In summary, the main findings of this analysis are:

- Although the allocation of marine emissions to flag states is not very robust since the registration of most ships is concentrated in a limited number of countries and the country of registration may change easily over time, in practice the changes in registration to flag states over time have been limited during the past decades (see Appendix A).
- Using the Option 6 allocation (imported goods/aircraft destination), in 2050 the fraction of projected bunker CO_2 emissions in total fossil CO_2 emissions increases substantially in OECD Europe, South-East Asia, Japan and Oceania from about 5% to shares of about 10%. The fraction in East Asia increases to about 5%, whereas the fraction in Western Africa decreases from over 10% to less than 5%.
- Using the Option 4/5 allocation (flag state/departing aircraft), in 2050 the fraction of projected bunker CO_2 emissions in total fossil CO_2 emissions increases substantially in OECD Europe, Japan and Oceania to shares of between 5 and 15%, whereas the share of Western Africa decreases from over 25% to less than 10%. The fraction in Central America remains high (between 15 and 20%), whereas the fraction in Eastern Africa decreases from about 5% to about 1%.
- The flag state allocation of marine emissions, which plays a key role in the implementation of IMO treaties, has a very large effect on the fraction of total bunker emissions to total fossil fuel-related CO_2 emissions of a country. At the present time, the registration of most ships is concentrated in the Bahamas, Panama, Liberia and

Singapore as well as Greece, Malta and USA. However, for some ship types, China, Hong Kong, Norway, Germany and the Netherlands are also among the most favourable flag states. For those countries in particular, an Option 4 allocation of marine CO_2 emissions would have a very large impact on their total national greenhouse gas emissions.

- The shares of international shipping and aviation in total CO_2 bunker emissions, which at the present time are both about 50%, will shift in 2050 to 40% for shipping versus 60% for aviation. When the *Radiative Forcing Index* (RFI) for aviation is applied to include the non-CO_2 contributions, the share of aviation in the bunker total increases from about 70% in 2000 to 80% in 2050 (without specific abatement).

3 Mitigation scenarios

3.1 International aviation and marine emissions in climate mitigation scenarios

In this section a quantitative approach is used to evaluate a number of scenarios in terms of how they deal with future bunker emissions. The first step will be to assess the implications of allowing bunker emissions to remain formally unallocated. In such a scenario, the bunker emissions would remain outside a future multi-lateral international climate regime, such as the Multi-Stage approach, and would grow unabated, as projected in chapter 2 of this report. This assessment will shed some light on both the additional mitigation burden for the regulated emission sectors (mitigation penalty) as well as on how total emissions would exceed the emission caps for stabilisation if the bunker emissions are not compensated for (environmental penalty) (section 3.2.). Section 3.2 will also examine how actual regional emission allocations would develop if bunker emissions are accounted for in accordance with rules for allocating bunkers emissions (implicit allocations). Section 3.3 evaluates a number of cases in which bunker emissions are formally allocated and included in a future multi-lateral international climate regime, which at this time is the Multi-Stage approach. The aim of this evaluation is to explore the implications of different allocation rules for future emission reduction/limitation targets for the Annex I and non-Annex I regions under a multi-stage regime by 2020 and 2050. Section 3.4 examines a number of cases in which bunker emissions are not included in a future multilateral international climate regime but are instead regulated directly within the sectors themselves (e.g. as part of coordinated policies and measures within the guidelines established by the IMO and ICAO). As such, the level of reductions in projected future bunker emissions is assessed that may be feasible up to 2050 and what this level would imply for the level of emissions reductions required for the (other) sectors regulated under the international climate regime. Table 5 provides an overview of all cases.

In all of the cases assessed here the medium growth baseline scenario – baseline B2 – is used as background for the analyses. The trend-based projections for the international shipping sector fit in well with this scenario. In addition, the policy cases use the global emission pathway (ceiling) for stabilising GHG emissions at 450 ppm CO_2-equivalent, as described in Den Elzen et al. (2006b). Finally, in those cases in which international bunker emissions are allocated, the allocation is carried out for both aviation and shipping emissions either according to nationality/flag or according to destination/import. Although other combinations are possible in principle, these rules seem to be most consistent with a sovereignty-oriented approach or route-oriented approach to the allocation of responsibility for international bunker emissions. All analyses were performed for 17 global regions, but for the purpose of clarity, the results are reported for ten aggregated groups of these regions. Given its high sensitivity to the allocation rules, Central America has been singled out as a separate region. Emissions up to 2010 are estimated as follows: it is assumed that Annex I countries implement their Kyoto targets by 2010 and that all Non-Annex I countries follow their reference scenario until 2010.

Table 5. Overview of policy cases explored.

Case	Climate policy	Allocation of bunker emissions *	Abatement of bunker emissions	Compensation of bunker emissions
1. Baseline	No	No	No	No
2a. Mitigation penalty	Yes	No	No	Yes
2b. Environmental penalty	Yes	No	No	No
3a. Bunkers in climate regime (MS)	Yes	Yes	Yes	n.a.**
3b. Bunkers in climate regime unabated	Yes	Yes	No	Yes
4. Sector-based approach	Yes	No	Yes	n.a.**

* Including bunker emissions in regime

** Not applicable

Note: These cases are the subsequent graphs labelled as follows: 2a: compensation (excl.); 2b: no compensation (excl.); 3a: (incl.) reduced bunker; 3b: (incl.) unlimited bunker; 4: policy – compensation (excl.).

3.2 The implications of excluding bunker emissions from future climate policy

3.2.1 The implications of emission reductions when compensating for the exclusion of bunker emissions in a Multi-Stage regime

Figure 7 shows the global CO_2-equivalent greenhouse gas emissions pathway for stabilising concentrations in the atmosphere to be 450 ppm by 2100. The emissions pathway allows for overshooting; that is, the concentrations peak at 510 ppm before stabilising at 450 ppm at a later date. Global GHG emissions can still increase by about 20% above 1990 levels up to 2015 before they need to be reduced to 45% below 1990 levels by the middle of the century. If unabated, the share of international bunker emissions in allowable global emissions (including land use-related emissions) would increase from about 2% in 2000 to about 11% of the allowable emissions by 2050. Thus, over time, they would consume a substantial part of the allowable emissions. This does not include the additional impact of non-CO_2 emissions from aviation to radiative forcing, which enhances the impact by a factor of about 2.5 compared to CO_2 only. The inclusion of all emissions affecting radiative forcing by aviation would increase the share of international aviation emissions in allowable global emissions from 6 to 17%, thereby effectively doubling the share of total international bunker emissions to almost one quarter (21%).

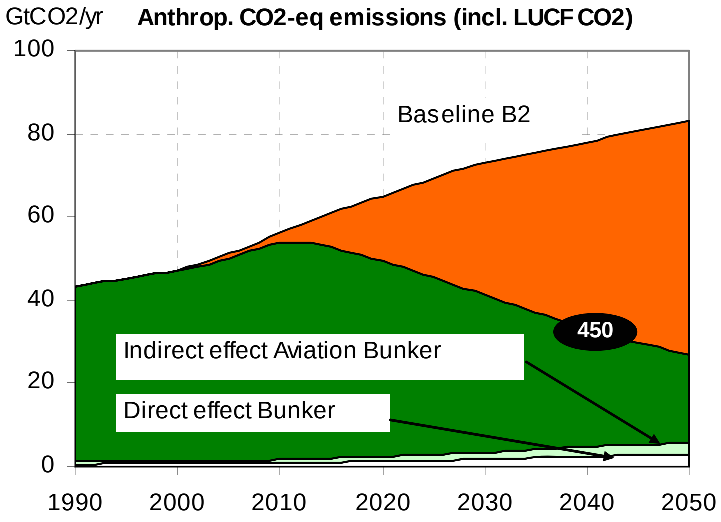

Figure 7. The share of (unabated) international bunker emissions(only the direct effects, used in the default calculations) (white area) in the B2 scenario (red area) compared to allowable emission levels for the stabilisation at 450 ppm CO_2-equivalent concentrations (hereafter S450e emissions pathway) (green area). For comparison also the additional indirect effect of the non-CO_2 emissions is included (light-green). Source: adapted from Den Elzen et al. (2006b).

In order to still comply with the global emission constraint for stabilising at 450 ppm, bunker emissions would need to be compensated for by more stringent emission targets for the other sectors regulated under the international climate regime. The ‘compensation (excl.)’ case (case 1) in Figures 8 and 9 shows the *mitigation penalty* of leaving international bunker emissions outside the climate regime and leaving them unabated, respectively. In the case shown, the international bunker emissions have been subtracted from the global emissions cap before the regional emission targets under the Multi-Stage regime were calculated (for details see Box 3 in section 3.3).

Evidently case 1 leads to higher reductions for all countries compared to the default case (not accounting for the bunker emissions in the calculations, as described in Den Elzen et al. (2006c)), as all countries need to compensate the increasing global bunker emissions. If the additional impact of non-CO_2 emissions from aviation to radiative forcing is included, the reductions for most of the Annex I countries become as high as 90% of the baseline emissions. For example, for the EU, the reductions compared to 1990 levels can become more than 20% in 2020 (instead of 12%) and 90% in 2050 (in stead of 75%).

Compared to the case in which bunker emissions are included (see Figure 10 below: case 3a), i.e. the case in which the global bunker emissions are not been subtracted from the global emissions cap, the results of the analysis show that compensating for increasing global bunker emissions leads in particular to higher emission reduction targets in both the short term (2020) and long term (2050) for the Annex I regions, such as North America and the EU. However, if the unabated bunker emissions are added to the regional emission targets according to the allocation rules of nationality and destination (import) – the ‘compensation (incl.) case' (case 2b) in Figures 8 and 9 – the de-facto emission allowances would be larger and thus their reduction targets lower (compare case 2b with case 1). Some regions would de-facto profit from excluding bunkers, while still compensating for them, such as Central America and South-East and East Asia, in particular. Compared to the inclusion of international bunkers in the Multi-Stage regime (case 3b) (see Figure 10), some regions would gain somewhat in the case of allocation to flag state, most notably the EU and Japan/Oceania, South-East Asia and, in particular, Central America. The differences seem small, but are likely to be more substantial at the national level (not shown here).

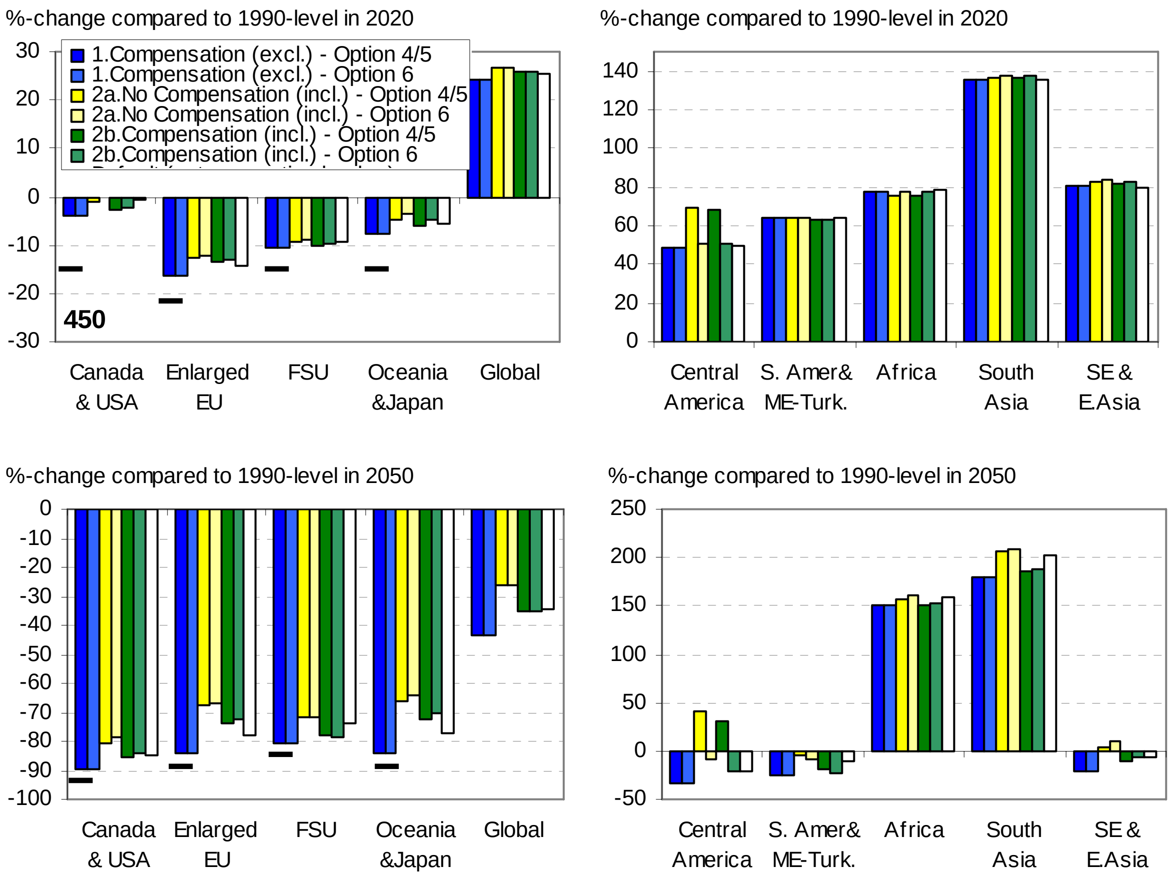

Figure 8. Percentage change in the CO_2-equivalent emission allowances relative to the 1990 emissions level for the *excluding* bunkers case in 2025 and 2050 for the S450e emissions pathway for Option 4/5 (i.e. Option 4 for marine and Option 5 for aviation) and Option 6 (marine and aviation). For comparison also the default case (not accounting for bunker emissions) is included. The lines included in the left column represent the outcomes when including the non-CO_2 effects. Source: MNP-FAIR model.

3.2.2 The environmental implications of not compensating for excluding bunker emissions in a Multi-Stage regime

There is an environment penalty if there is no compensation for the unregulated increase in international bunker emissions in that emissions will then overshoot the emission pathway for meeting the 450 ppm stabilisation target. The 'no-compensation case in Figure 8 shows that global emissions would exceed the global ceiling by about 8% by 2020 and 15% by 2050. The implications of this overshoot are that stabilisation at 450 ppm CO_2-eq. would become more difficult and probably result in an even larger initial overshoot of this target, even above the 510 peak that is assumed for the default pathway (see Den Elzen et al., 2006b). Concurrently, the lack of compensation for the increase in bunker emissions would result in less stringent mitigation targets, particularly for the Annex I regions.

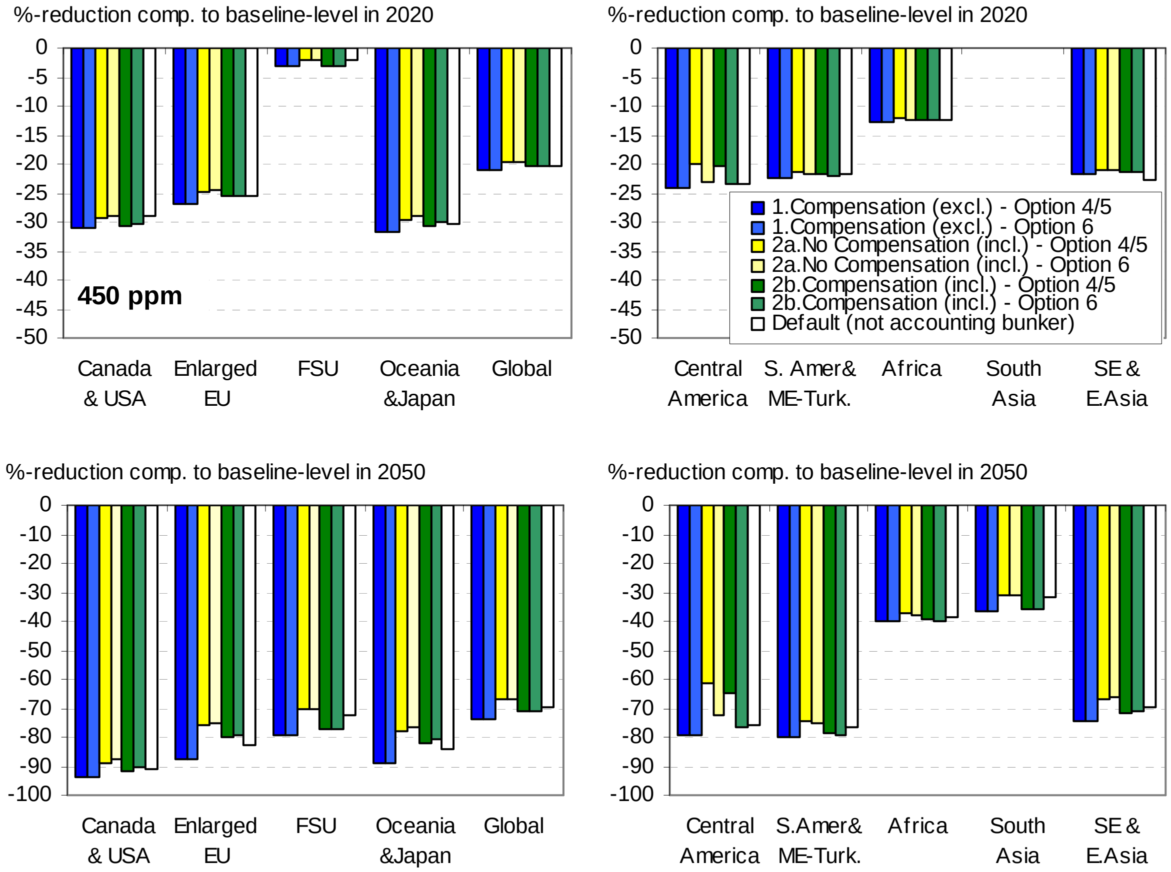

Figure 9. Percentage change in the CO_2-equivalent emission allowances relative to the B2 baseline scenario emissions level for the case of *excluding* bunkers in 2025 and 2050 for the S450e emissions pathway for Option 4/5 (i.e. Option 4 for marine and Option 5 for aviation) and Option 6 (marine and aviation). For comparison also the default case (not accounting for bunker emissions) is included. Source: MNP-FAIR model.

Box 3. Multi-Stage approach

The Multi-Stage approach consists of a system in which the number of countries involved and their level of commitment increase gradually over time. It is based on pre-determined participation and differentiation rules that determine when a (non-Annex I) country moves (graduates) from one stage to the next and how its type and level of commitment changes. The aim of this system is to ensure that countries in similar economic, developmental and environmental circumstances have comparable commitments under the climate regime. The Multi-Stage approach therefore results in an incremental evolution of the climate change regime. The approach was first developed by Gupta (1998) and subsequently elaborated (Berk and Den Elzen, (2001) Den Elzen, (2002) into a quantitative scheme for defining mitigation commitments under global emission pathways that are compatible with the UNFCCC objective of stabilising greenhouse gas concentrations. Höhne *et al.* (2005) extended the Multi-Stage approach with a pledging stage for Sustainable Development Policies and Measures, while Den Elzen et al. (2006c) developed a simpler version with some new types of participation thresholds.

Here, the Multi-Stage approach is based on three consecutive stages for the commitments of non-Annex I regions beyond 2012. These are: Stage 1 – no commitment (baseline emissions); Stage 2 – emission limitation targets (intensity targets); Stage 3 – absolute reduction targets. In Stage 3, the total reduction effort to achieve the global emission pathway is shared among all participating regions on the basis of a burden-sharing key, which, in turn, is based on an equal weighting of greenhouse gas emissions per capita (in tCO_2-equivalents per capita) and per capita GDP income [in purchasing power parity (PPP) €1000 per capita] (e.g. Den Elzen et al., 2006a).[4] Annex I regions are assumed to be in Stage 3 after 2012. Participation thresholds are used for the transitions between stages and are defined as the sum of per capita GDP income and per capita CO_2-equivalent emissions, thereby reflecting responsibility for climate change. Because it combines variables with different characteristics, this composite index should in principle be normalised and/or weighted. It happens, however, that one-to-one weighting combined with normalisation (to make it 'unit-less') produces satisfactory results. Current (2000) index values vary widely between countries, ranging from below 2 for Eastern and Western Africa, 4 for India and 8 for China to as high as 29 for the Enlarged-EU (EU-25) and 25 for the USA.

Table 6. Entry date in Stages 2 and 3 for the non-Annex I regions for the 450 ppm stabilisation scenario (e.g. Den Elzen et al., 2006a)

	Regions	Central America	South America	Northern Africa	Western Africa	Eastern Africa	Southern Africa	Middle East	South Asia	East Asia	South-East Asia
S450	**Entry to Stage 2**	----	----	----	2015	2065	2015	----	2015	----	----
	Entry to Stage 3	2015	2015	2020	>2050	>2050	2020	2015	2040	2015	2015

Source: MNP-FAIR model.

3.3 Bunker emissions in a Multi-Stage approach: the influence of bunker allocation rules

The inclusion of international bunker emissions in the international climate regime will, in principle, provide more certainty in terms of the environmental effectiveness of the regime. In the Multi-Stage approach (see Box 3), only the emissions of those countries/regions in Stage 2 and 3 are regulated (see Table 6): countries in Stage 2 have emission limitation targets (intensity targets), while countries in Stage 3 adopt absolute reduction targets. The

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[4] This leads to more balanced reduction targets for all regions compared to a burden-sharing key solely based on per capita emissions, such as those used in Den Elzen et al. (2005; 2006c).

stringency of the limitation and reduction targets is dependent on the overall global emissions ceiling. In such a regime, international bunker emissions are added to the overall emissions and, as such, the allocation rule for international bunkers affects the distribution of (regional) emissions limitation and reduction commitments in different manners. First, the allocation of many emissions to countries in Stage 1 and 2 implies – under a global emissions ceiling – more stringent commitments for those countries in stage 3. Second, if the thresholds for graduating from one stage to the other are (partly) based on (per capita) emission levels (e.g. per capita emissions or emission intensity of economy), the inclusion of international bunker emissions can accelerate the graduation of a country to a different stage with commitments. In the Multi-Stage case used here, the threshold is based on a composite index of per capita emissions and per capita income; as such, it is to some extent sensitive to the allocation rules for international bunkers. Finally, the allocation rules affect the differentiation of commitments between countries within the same Stage, with countries allocated a larger share of the international bunker emissions having relatively more stringent commitments with the inclusion of these sources than when these sources are excluded [whether compensated for or not (Figures 8 and 9)].

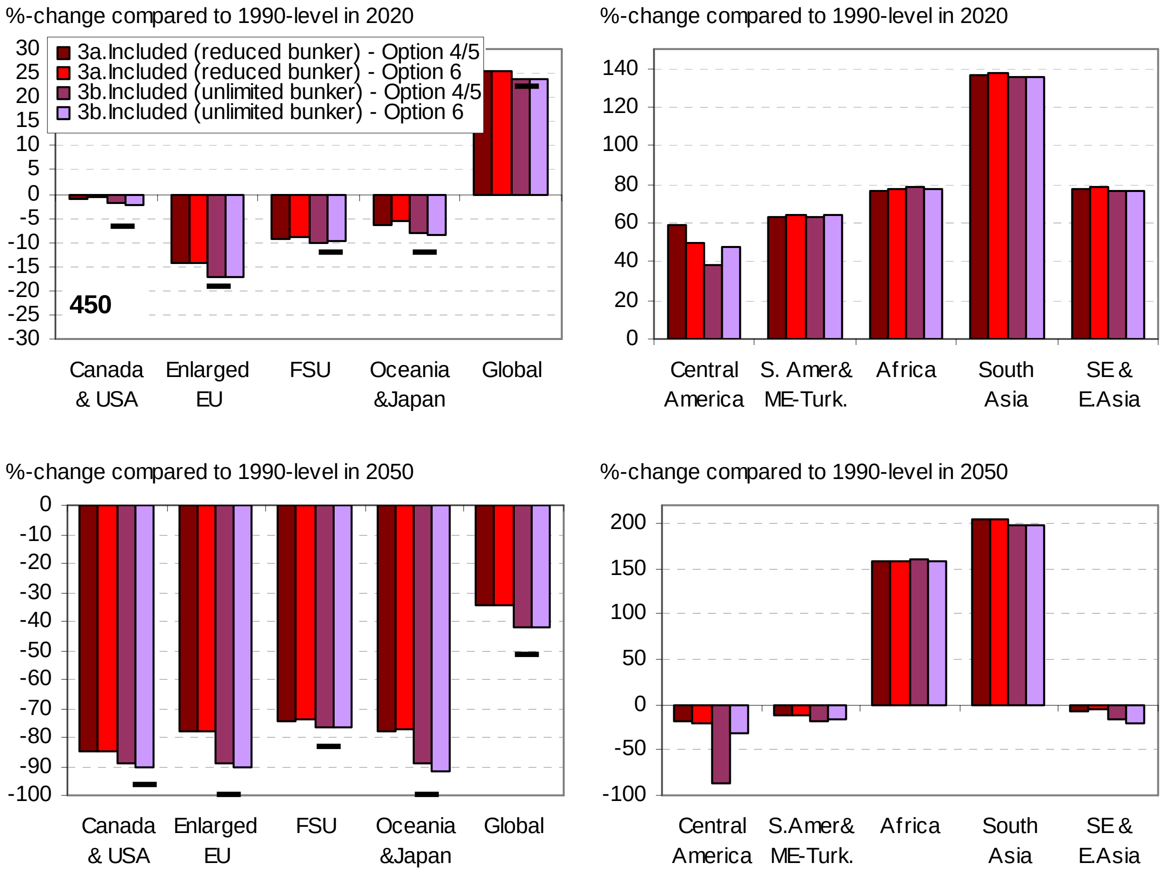

Figure 10. Percentage change in the CO_2-equivalent emission allowances relative to the 1990 emissions level for the *including* bunkers case in 2025 and 2050 for the S450e pathway for Option 4/5 (i.e. Option 4 for marine and Option 5 for aviation) and Option (6 marine and aviation). The lines included in the left column represent the outcomes when including the non-CO_2 effects. Source: MNP-FAIR model.

Figures 10 and 11 show the regional emission limitation and reduction (Annex I) commitments that result from the inclusion of international bunker emissions in a Multi-Stage regime that includes the allocation of bunker emissions according to nationality/flag or destination/import.

At the regional scale, the implications of using different allocation rules for bunkers are, in general, very small, except for Central America, which has been shown to be very sensitive to the allocation rules used, the impact on allowable emissions is relatively small. The reason for this small effect is that the bunker emissions are now added up with the other emissions before emission reduction or limitation targets are set for them. For Central America, which has been shown to be very sensitive to the allocation rules used, the impact of allocation on the basis of nationality/flag state on allowable emissions are much larger, and this leads to substantially more stringent targets (almost 100% compared to baseline emissions instead of 80%). However, at a lower level of scale, in particular the country level, the differences between the allocation rules may still be substantial.

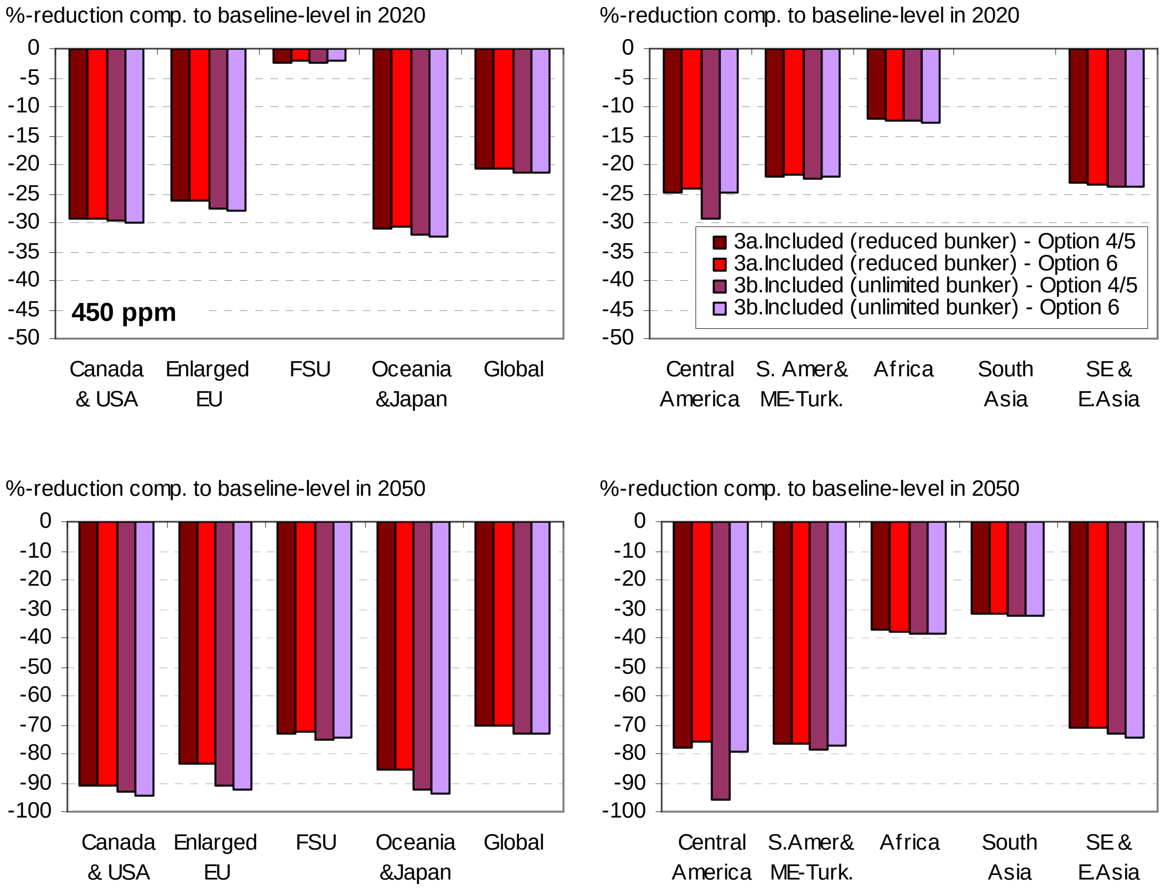

Figure 11. Percentage change in the CO$_2$-equivalent emission allowances relative to the B2 baseline emissions level for the *including* bunkers case in 2025 and 2050 for the S450e pathway for Option 4/5 (i.e. Option 4 for marine and Option 5 for aviation) and Option 6 (marine and aviation). Source: MNP-FAIR model.

One of the factors for problems with allocating international bunker emissions (or including in the regime) – and thus in terms of taking the responsibility for the allocated emissions– is the perceived difficulty involved in reducing these emissions, even though the technical potential for such reductions do exist (see section 3.4). If reducing bunker emissions would indeed be difficult and/or expensive, the inclusion of these sources in overall climate regimes and national targets would result in other sectors having to reduce even more. Depending on the national allocation of emission reduction targets or emission permits, this would result in higher abatement costs for other sectors or the sale of emission reductions to the shipping and aviation sectors. Ex-ante analyses on the impact of including aviation in the European Emission Trading System demonstrate that with the aviation sector becoming a buyer at the emission market (Tuinstra et al., 2005), there would not be much impact on the overall carbon price (ICF, 2006).

The ‘inclusion (unlimited bunker)’ cases (case 3b) in Figures 10 and 11 illustrate the implication for the emission reduction targets for all other sectors when bunker emissions are included in a Multi-Stage regime, but are also left de facto unabated. This case is somewhat comparable with the mitigation penalty case discussed in section 3.2, with the primary difference being that here the bunker emissions are being first allocated according to either flag/nationality or destination/import. For the Annex I regions, this case particularly results in higher reduction targets for the EU, Oceania and Japan, with a relative large share of bunker emissions in overall emissions and lower shares for regions with relatively few bunker emissions, such as the Former Soviet Union. The reduction targets would be even lower here than the compensation case in section 3.2. For the non-Annex I regions, such as Central America, the implications for allocation on the basis of nationality/flag state are much larger; South-East Asia and East Asia would be also faced with substantially more stringent targets.

If the additional impact of non-CO_2 emissions from aviation to radiative forcing are included, the reductions for most of the Annex I countries (except FSU) become as high as 95-100% of the baseline emissions, so basically they have no emission allowances left.

3.4 Sector-based reduction of bunker emissions and the implications for overall emission reductions

An alternative approach to regulating international bunker emissions as part of an overall climate mitigation regime is to regulate them on the sector level, i.e. only supply side measures: increased efficiency and biofuels and technical standards for new and existing ships and fuels. The emissions from international transport would then be allocated to the aviation and maritime sectors, with both sectors taking on commitments or targets. The UNFCCC could determine or provide guidance on the overall targets and the timetables, whereas the ICAO and IMO would set the policy measures. In such a case, these policies would mainly relate to supply-side measures only, such as the increased efficiency and use of bio-fuels via improved technical standards for new and existing aircraft, ships and fuels. This section will explore the possible contribution of the international aviation and maritime sectors to reducing global emissions and the implications of such a contribution to the other sectors. To this end, a mitigation scenario for these sectors up to 2050 is developed.

3.4.1 High-Efficiency scenario for international marine transport

In the High-Efficiency scenario, a limited energy improvement of 10% in 2020 and 25% in 2050 is assumed. From the technical and policy options listed in Box 4, which were identified by RMI (2004), we can conclude that these assumptions take reasonable account of the practical limitations to further efficiency improvements. In fact, these fuel efficiency improvements are moderate assumptions in comparison with the 15–16% fuel efficiency improvement (gross/revenue) made by the Canadian fleet during the period 1990/1995–2004 (King, 2006). Key factors in the efficiency improvement programme of the Canadian fleet were, among others, fore body investments, widening investments, dry dock painting, maximum draft changes and the elimination of steamships, whose fuel efficiency is only about 40% of that of diesel ships. Teekay Shipping reported that an improvement in the performance by the optimisation of engine operation and in the voyage by vessel reporting and automation may result in a 7% efficiency improvement (Taylor, 2005). Furthermore, two autonomous developments that will improve the average fuel efficiency are the phase out of steamships (CEF, 2000; RMI, 2004) and the phase out of cruise ships built in the 1990s that were outfitted with gas turbines (Taylor, 2005), as both of these ship types are much less efficient than ships using diesel engines. These are not included in the frozen fuel efficiency baseline B2 (trend) scenario but are part of the High-Efficiency scenario.

In conclusion, a 10% efficiency improvement should be possible without any or – at most – only very limited costs (performance improvement, the two phase-outs). Further efficiency improvements are possible through technical changes to the engine, propeller or vessel, which may increase the improvement yet further to between 15 and 30%. This is reflected in the High-Efficiency scenario with a global fleet efficiency improvement of 10% in 2020 and 25% in 2050 compared to the baseline B2 (trend) scenario.

3.4.2 High-Efficiency-Biofuels scenario for international marine transport

The High-Efficiency-Biofuels scenario assumes an overall CO_2 efficiency improvement (i.e. fossil fuel efficiency and CO_2 efficiency improvement) of 15% in 2020 and 40% in 2050 as compared to the 10 and 25% improvement, respectively, assumed in the High-Efficiency scenario. This estimate is based on a 5% share of biofuels in 2020, increasing to 20% in 2050, combined with a somewhat more limited energy improvement in 2050 – 20% versus the 25% estimated in the High-Efficiency scenario. In the IMAGE/TIMER scenario for stabilisation of greenhouse gas concentrations at 450 ppm (Van Vuuren et al., 2006a), the total transport sector is assumed to use about 40% biofuel by 2050 (i.e. notably in road transport). However, the introduction of biofuel in road transport is more competitive than in shipping and, consequently, we assume a lower use of biofuel in this sector: on average, about half that of the road transport sector in 2050. Other considerations for assuming a lower fraction of biofuels in marine transport are (1) efficiency improvement per tonne-kilometre provides an alternative approach for reducing the CO_2 intensity; (2) not all countries may start using biofuels in international shipping. If biofuels are used, the overall improvement in fuel efficiency is assumed to be somewhat less in 2050 than that estimated in the High-Efficiency scenario, since part of the incentive for improving fossil fuel efficiency will be shifted towards using biofuels as a means to reduce CO_2 intensity.

Box 4. Options for energy efficiency improvement in marine transport

Technical options for energy efficiency improvement

Although the costs of most marine diesel fuels are relatively low, which is especially true for heavy fuel oil, fuel costs represent a large fraction of the total costs made in marine transport (about one third for oil tankers; Taylor, 2005). Thus, currently operational diesel engines already run at a high efficiency. Most modern diesels have efficiencies of about 46–47% peak load and 36% part load, while older diesel engines may have efficiencies of about 35% peak load and 28% part load (CEF, 2000). According to the Clean Energy for the Future (CEF) study 'assuming that most freighters use their engines at peak load during the greater part of their journeys, the diesel drive train aboard a modern freighter may obtain greater than 40% efficiency: 45% engine, 97% reduction gear and shafting yields 42% efficiency from engine to propeller.'

Consequently, technological improvements to the engine and the rest of the propulsion system may be limited in their energy efficiency improvement potential – e.g. only 5–8% (RMI, 2004; Eyring et al., 2005a). In contrast, the technical potential may be even as high as 22% (RMI, 2004). However, there are a number of other measures that can be taken to improve the overall efficiency:

- propeller maintenance (<5% improvement in fuel use)
- coating and antifouling paint (3-4%)
- weather routing (4%)
- adaptive autopilot (2.5%)
- changes in hull shape (3%)
- larger ships (to 30% for doubling size)

Although enlarging the ship size has a high potential for efficiency improvements, port and lock limitations are likely to limit this option to about half of its potential. RMI (2004) has calculated for the energy efficiency improvement a potential for 2025 a low estimate of 16% and a high estimate of 28%. This is based on a stock turnover of 50% by 2025, so the estimated technical potential for efficiency improvement is twice that of the estimated improvement in energy efficiency. These estimates include an engine improvement of 8 and 22%, respectively. In addition, the switch to bio-diesel would reduce fossil CO_2 emissions significantly.

Policy options for improving the fuel efficiency

According to RMI (2004): 'OECD has identified a number of policies that could be used to improve ship efficiency, including charges and fees varying by efficiency; direct regulations; voluntary agreements; best practice programs such as EPA's Energy Star Program; technology prizes (golden carrots); and increased RD&D through government programs or tax incentives. Programs like voluntary agreements, best practice programs, and increased RD&D fit in well with the Moderate Scenario definition; direct regulations and efficiency-based charges and fees could be added for the Advanced Scenario.' (see RMI report for explanation of scenarios).

3.4.3 Comparison of scenarios for marine transport

In the B2 baseline scenario an extrapolation of the trends of the past decade project that, in comparison to 2000, CO_2 emissions from global marine bunker fuels increase by about 41% in 2020 and about 180% in 2050. For 2020, this is very close to projections made by Eyring et al. (2005a), but for 2050 the estimate is somewhat higher than their highest estimate. The projected increase in 2050 – relative to 2000 – by the High-Efficiency policy scenario falls within the range of that projected by the Eyring scenarios. The Eyring scenarios were made for Average Vessel Movement, which is slightly lower than sea trade volume (in tonnes), and were based on IPCC SRES GDP trends and the observation that these trends are highly correlated to GDP, and a 5% decrease in fuel efficiency in 2050 (and none in 2020).

The resulting trends in global CO_2 emissions in the baseline scenario and in the two policy scenarios are shown in Figure 12. The two policy scenarios reduce the 180% growth projected for 2050 (relative to 2000) to 110 and 65% of that projected in the High-Efficiency and High-Efficiency-Biofuels scenarios, respectively. This corresponds to emission increases of 0.8, 0.5 and 0.3 Pg CO_2, respectively.

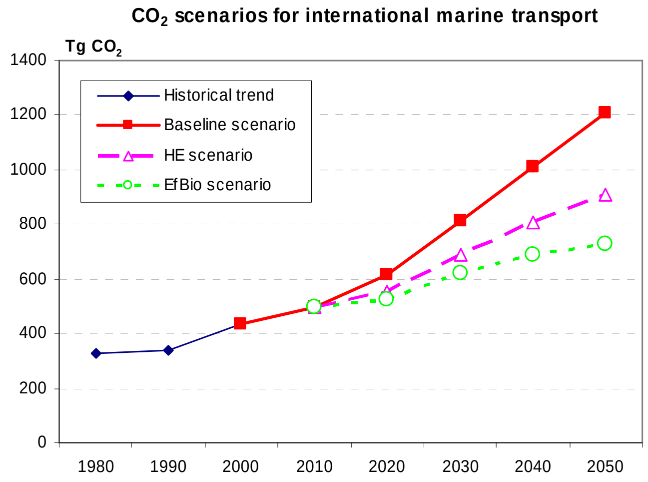

Figure 12. Comparison of scenarios for CO_2 emissions from international marine transport during the period 1980–2050: B2 baseline (trend) scenario, High-Efficiency scenario and High-Efficiency-Biofuels scenario.

3.4.4 High-Efficiency scenario for international aviation

The High-Efficiency scenario assumes an additional energy improvement of 0.5% per year from 2020 to 2050, which is equivalent to an improvement of 15% in 2050 compared to the baseline scenario. In the scenarios of Lee et al. (2005) and the IPCC SRES, the annual fuel efficiency improvement is strongly reduced after 2020 to 0.5% and 0.75%, respectively. For the High-Efficiency scenario, however, we assume an additional improvement from 2020 onward of 0.25% per year for engine/aircraft efficiency improvements and another 0.25% per year from more efficient routing and shorter hold-ups near airports. In terms of total annual energy improvement, this amounts to 0.5% per year from 2020 to 2050, which is equivalent to an improvement of 15% in 2050 compared to the projection in the baseline scenario.

However, the total contribution of air traffic to radiative forcing – including non-CO_2 effects – is about 2.6 times the contribution of CO_2 emissions only, with a significant fraction of the former originating from NO_x emissions (through ozone formation). Consequently, the current contribution of aviation to radiative forcing is 3.5% instead of about 1% for CO_2 emissions only (see Box 5). When aviation activities are not included in future climate change mitigation protocols, their contribution to climate change will increase to about 6 to 16%, depending on the scenario (in the case of a fourfold increase in expected aviation emissions by 2050, as suggested in the baseline scenario).

Box 5. The contribution of aviation to radiative forcing

In 1992, the total impact of aviation to radiative forcing (RF) is estimated to have been **+0.05 Wm^{-2} or 3.5%** of the total anthropogenic radiative forcing of 1.4 Wm^{-2}. This is the sum of the following contributions:

- CO_2 +0.018 Wm^{-2}
- NO_x +0.023 Wm^{-2} (via ozone changes)
- NO_x –0.014 Wm^{-2} (via methane changes)
- Contrails and stratospheric H_2O both: +0.002 Wm^{-2}
- S and BC aerosols: 0 (–0.003 and +0.003 Wm^{-2} , respectively)
- Cirrus clouds: negligible or potentially large, in the range of 0–0.04 Wm^{-2}.

Thus, the contribution of non-CO_2 to radiative forcing is larger than that of CO_2. In particular, the net contribution by NO_x is significant, as it appears to be difficult to optimise the engine design simultaneously for both CO_2 and NO_x emissions.

The future RF from aviation was estimated for some scenarios:

- For 2015: +0.11 Wm^{-2} for NASA-2015* scenario;
- For 2050: +0.19 Wm^{-2} for IS92a (Fa1) scenario, including +0.074 for CO_2 and +0.10 for contrails.

The so-called Radiative Forcing Index (RFI) is the ratio of total RF to that of CO_2 alone; for aircraft, it is 2.7 in 1992 and 2.6 in 2040 for the Fa1 scenario. The RFI ranges from 2.6 to 3.4 for 2050 for various scenarios discussed in the IPCC Special report on Aviation. In a more recent study by Sausen et al. (2005)) a new estimate of the RFI value was presented, which was somewhat lower than the IPCC estimate mainly because of a reduced estimate of the RF from contrails.

Source: IPCC Special Report on Aviation (IPCC, 1999)

With respect to aircraft engine designs, there is a trade-off between improving fuel efficiency and reducing NO_x emissions (IPCC, 1999). Although there are major uncertainties surrounding the numbers used in the different scenarios, if climate change mitigation policies for aviation would only focus on CO_2 mitigation through changes in the design of the aircraft engine, the result will likely be a non-optimal mitigation of total radiative forcing from aircraft (Box 5). Consequently, in terms of climate change mitigation, the aim of the mitigation policy should not be minimising of CO_2 emissions exclusively, but rather minimising of total radiative forcing from aviation – that is, determination of an optimal balance between engine design in terms of fuel efficiency (reduction of CO_2) and of reducing NO_x emissions. For this purpose, the use of the *Radiative Forcing Index* as discussed above may be an efficient means – just like the concept of ‘Global Warming Potential’ is used to weigh different greenhouse gases – to find the physical optimum where the impact from aviation on climate change is minimised. This does not, however, relate to reducing specific fuel consumption per passenger-kilometre by improving non-engine parameters, such as the size and aerodynamic shape of the aircraft, load factors and route optimisation, all of which reduce both CO_2 and NO_x emissions simultaneously (and by the same fraction).

3.4.5 High-Efficiency-Biofuels scenario for international aviation

In the High-Efficiency-Biofuels scenario, we assumed an overall CO_2 efficiency improvement (i.e. fossil fuel efficiency and CO_2 efficiency improvement) of 0% in 2020, increasing to 20% in 2050 (or to 0.6% annual reduction from 2020 to 2050) as compared to the 15% improvement in 2050 in the High-Efficiency scenario. This is based on a 5% share of biofuels in 2050 (equivalent to 0.15% per year).

IPCC (1999) fuel property restrictions limit the proportion of biofuel (biodiesel) that can be blended into jetfuel to 2%. However, a number of recent studies (Saynor et al., 2003; Anderson et al., 2006; Daggett et al., 2006) indicates that a further increase to 10% or even higher (20%) may be technically feasible within due time. Nevertheless, it must be borne in mind that mixing mineral kerosene with biodiesel may compromise the effectiveness of kerosene as an aviation fuel at cold temperatures at high altitudes, even when the proportion of biodiesel is small. One possible alternative for biodiesel would be synthetically produced bio-kerosine based on the Fischer-Tropsch process (Saynor et al., 2003). This form of kerosene is chemically and physically similar to mineral kerosene and could therefore fully replace it. However, due to its lack of aromatic molecules and very low sulphur content, this bio-kerosine would require additives to improve its poor lubricity. Given the very strict safety rules on aviation and the additional, possibly costly, fuel processing steps to arrive at the required fuel quality, a rather conservative estimate is assumed, i.e. a 5% replacement of mineral kerosene by biofuels by 2050 with a phasing in by 2020.

3.4.6 Comparison of scenarios for international aviation

In the B2 baseline (trend) scenario, which is an extrapolation of the trends of the past decade, results in the projection that CO_2 emissions from global aviation bunker fuels will increase by about 100% in 2020 and by about 375% in 2050 as compared to 2000 (Owen and Lee, 2005). Figure 13 shows the resulting trends in global CO_2 emissions in the baseline scenario and in the two policy scenarios. The two policy scenarios reduce the projected 375% growth by 2050 in the baseline scenario to 300% (High-Efficiency scenario) and about 250% (High-Efficiency-Biofuels). Relative to 2000, this corresponds to emission increases of 1.3, 1.1 and 0.9 Pg CO_2 for the baseline, High-Efficiency and High-Efficiency-Biofuels scenarios, respectively.

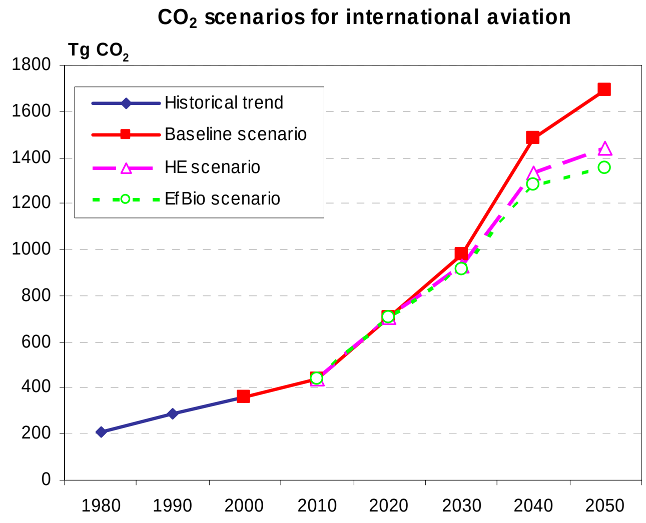

Figure 13. Comparison of scenarios for CO_2 emissions from international aviation for the period 1980–2050: B2 baseline (trend) scenario, High-Efficiency scenario and High-Efficiency-Biofuels scenario.

3.4.7 *Comparison of scenarios for total international transport*

Figure 14 shows the resulting trends in global CO_2 emissions in the baseline scenario and in the two policy scenarios. The two policy scenarios reduce the 270% growth projected by the baseline scenario in 2050 – relative to 2000 – to about 200% (High-Efficiency scenario) and about 150% (High-Efficiency-Biofuels scenario). This corresponds to emission increases in 2050 of 2.5, 2.0 and 1.6 Pg CO_2, respectively. However, the policy scenarios reduce the projected growth of 65% by 2020 at maximum to only 55% (in the High-Efficiency-Biofuels scenario).

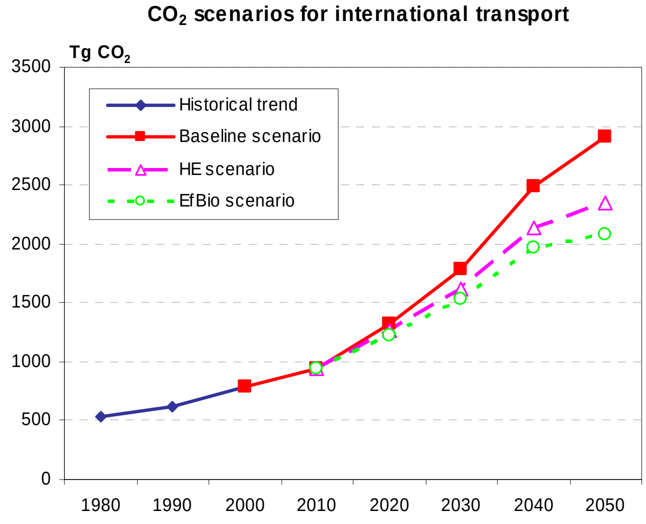

Figure 14. Comparison of scenarios for CO_2 emissions from international marine and air transport in the period 1980–2050: B2 baseline (trend) scenario, High-Efficiency scenario and High-Efficiency-Biofuels scenario.

3.5 Sector-based reduction scenario and implications for emission targets for sectors in a Multi-Stage regime

Figure 15 shows the implications of the most stringent sector-based reduction scenario (i.e. High-Efficiency-Biofuels scenario) on the allowable regional emissions for the other sectors under the Multi-Stage regime. The effectiveness of the sector-based emission reduction policy scenario in reducing the global emissions for meeting the 450 ppm stabilisation profile is very modest: only about 1% by 2020 and only a few per cent by 2050. The foremost reason for these modest reductions is the relatively small share of bunker emissions in present and future emissions (when considering CO_2 only), although the limited number of technically feasible reductions also plays a role. The findings are very similar at the regional level, although the impact will be more substantial at the national level for specific countries (e.g. important maritime flag states and countries with relatively high volumes of aviation).

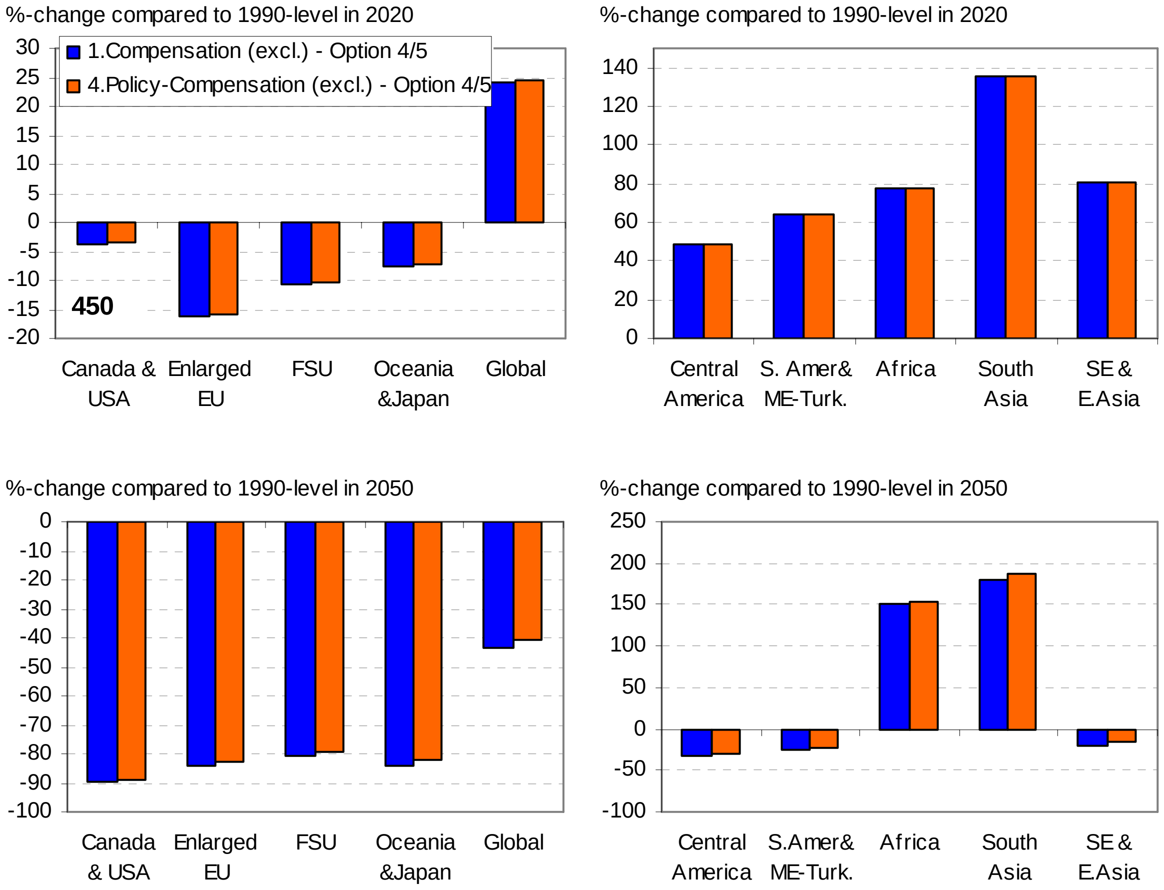

Figure 15. Percentage change in the regional CO_2-equivalent emission allowances relative to the 1990 emissions level for the sectors covered under the Multi-Stage approach with sector-based abatement of bunkers (policy-compensation) versus no abatement of bunker emissions (compensation) in 2025 and 2050 for the S450e emissions pathway. Source: MNP-FAIR model.

The technical reductions that currently appear to be feasible in the maritime and aviation sector are rather limited compared to the overall reduction efforts required. To secure a cost-effective approach – one that avoids too expensive measures – and to make the aviation and maritime sectors share in the costs of mitigation in other sectors, a logical step would seem to be the linking of these sectors by way of emission trading schemes. Such a policy is easily conceivable when international transport is integrated in the overall climate regime. This would provide the international transport sector the opportunity to compensate their emissions by purchasing emission reductions from other sectors. However, the establishment of integrated emission trading schemes may be more complex if a sector-based approach for international transport is taken.

4 Findings

The aim of this study was to explore key options for dealing with the inclusion of international bunker emissions in future climate policies and to analyse the implications of this inclusion on regional emission allocations and global mitigation efforts. The presented analyses focus on two options that seem to be the most practical from a policy perspective: (1) allocation according to nationality/registration and (2) allocation according to destination. The first option was selected because it fits in with the present regulatory regimes for international aviation and shipping in the context of the ICAO and IMO even though in the case of international shipping the designation of flag states may not be very stable. The second, route-related option was selected because of the availability of data on the import of goods by shipping. At the regional level, this option is largely comparable to allocation according to the destination and departure of ships and airplanes, as intra-regional transit transport does not play a role at the regional level, while it does as at the national level.

The present analysis focussed on a number of policy questions:

- *Baseline developments* in international bunker emissions;
- *Allocation options* of international bunker emissions;
- The environmental implications of excluding bunker emissions from GHG abatement policies (*environmental penalty*);
- The implications of excluding bunker emissions from GHG abatement policies on (compensating) abatement efforts of other sectors (*mitigation penalty*);
- The implications of allocating bunker emissions for *regional emission commitments* under a future climate policy regime based on the *Multi-Stage approach;*
- The effectiveness of *sector-based emission reduction policy* scenarios;
- The consequences of including the relatively high *impact of non-CO_2 emissions from aviation on radiative forcing* in CO_2-equivalent emissions from international bunkers.

Table 7. Shares in 2020 and 2050 of bunkers in baseline B2 and in total allowable emissions for 450 ppm stabilisation: (a) CO_2 emissions of aviation only; (b) Including non-CO_2 impact of international aviation.

Year	2000			2020			2050		
Source	Bunkers	BAU-B2*	450 ppm*	Bunkers	BAU-B2*	450 ppm*	Bunkers	BAU-B2*	450 ppm*
Unit	Gt CO_2	Gt CO_2-eq.	Gt CO_2-eq.	Gt CO_2	Gt CO_2-eq.	Gt CO_2-eq.	Gt CO_2	Gt CO_2-eq.	Gt CO_2-eq.
Emission (Gt)	0.8	43.8	43.8	1.3	65.1	47.7	2.9	83.3	26.9
Shares (a)	Gt CO_2	% of total	% of total	Gt CO_2	% of total	% of total	Gt CO_2	% of total	% of total
Int. shipping	0.4	1.0%	1.0%	0.6	0.9%	1.3%	1.2	1.5%	4.5%
Int. aviation	0.4	0.8%	0.8%	0.7	1.1%	1.5%	1.7	2.1%	6.4%
Total bunkers	**0.8**	**1.8%**	**1.8%**	**1.3**	**2.1%**	**2.8%**	**2.9**	**3.5%**	**10.9%**
Shares (b)									
Int. shipping	0.4	1.0%	1.0%	0.6	0.9%	1.3%	1.2	1.5%	4.5%
Int. aviation * RFI **	0.9	2.1%	2.1%	1.9	2.9%	4.0%	4.5	5.4%	16.8%
Total bunkers	**1.4**	**3.1%**	**3.1%**	**2.5**	**3.9%**	**5.3%**	**5.7**	**6.9%**	**21.3%**
o.w. non-CO_2	*0.6*	*1.3%*	*1.3%*	*1.2*	*1.8%*	*2.5%*	*2.8*	*3.3%*	*10.3%*

* Total anthropogenic emissions (incl. CO_2 from LUCF), excluding the non-CO_2 RF impacts of aviation.

** RFI = Radiative Forcing Index = ratio of total radiative forcing (including non-CO_2 contributions) to that of CO_2 alone. For aviation an RFI = 2.6 has been assumed.

The main findings of this study are (see Table 7):

- Due to the high growth rates of international transport in the B2 baseline scenario – the combined projected growth is 275% – by 2050 the share of unabated emissions from international aviation and shipping in total greenhouse gas emissions may increase significantly from 0.8% to 2.1% for international aviation (excluding non-CO_2 impacts on global warming) and from 1.0% to 1.5% for international shipping. These shares may seem still rather modest, however, compared to total global allowable emissions in 2050 in a 450 ppm stabilisation scenario, which assumes a 2/3 reduction in 2050 compared to the baseline, unabated emissions from international aviation have a 6% share (for CO_2 only) and unabated international shipping emissions have a 5% share. Thus, total unregulated bunker emissions account for about 11% of the total global allowable emissions of a 450 ppm scenario.
- However, the global warming impacts of aviation are much higher than accounting for by CO_2 emissions, since the total impact of aviation on radiative forcing is about 2.6 that of CO_2 only (*Radiative Forcing Index*, RFI). This means that by 2050 the share of international aviation (including the RFI) in total greenhouse gas emissions in the baseline scenario will be about 5% instead of 2% for CO_2 only. For the 450 ppm stabilisation scenario by 2050, compared to total global allowable emissions the share of international aviation emissions increases from 6% to a 17%, and the share of international bunker emissions increases from 11% to about 20%.
- Incorporation of the non-CO_2 impacts of aviation on climate change (e.g. as represented by the *Radiative Forcing Index*) into the UNFCCC accounting scheme for greenhouse gas emissions should be considered, since aviation is a special case in this respect where the non-CO_2 impacts constitute a significant contribution. Moreover, aviation is expected to be one of the fastest growing sources and focussing solely on reducing CO_2 emissions from aviation would be likely be counterproductive from a climate perspective: when improving the engine efficiency without further consideration and thus neglecting other climate pacts, e.g. NO_x emissions will increase and therefore the non-CO_2 impact of aviation on climate change.
- Allocating bunker emissions according to one of the options discussed (e.g. to nationality/registration of ships and aircraft or to destination/departure of goods and passengers) will have a significant impact on the group of countries that has a relatively high share in these activities versus other countries with relative low shares. However, when the present status of not allocated bunker emissions continues, the growing bunker emissions need to be incorporated in any global greenhouse gas mitigation scheme. If the reductions required compensating for these global unallocated and unregulated emissions were to be distributed over countries, this would be beneficial for countries with a high share in bunker emissions and at the cost of other countries. This lead to more stringent reduction targets in the other sectors included in the mitigation regime, and if compensating the radiative forcing of the non-CO_2 emissions from aviation, it may even imply zero-emission allowances for some Annex I regions.

- Given the limited (cost-effective) potential for greenhouse gas emission reductions in this sector (without substitution to biofuel), the inclusion of bunker emissions in an international emissions trading scheme seems to be a more effective and cost-effective way of having the aviation and maritime sectors share in overall emission reduction efforts as opposed to the development of sector-based policies. Inclusion in an international emissions trading scheme would provide the international transport sector the opportunity to compensate their emissions by purchasing emission reductions from other sectors instead of having to reduce their own emissions that are either very limited or very expensive.

More detailed findings on the policy questions mentioned above are:

Baseline developments:

- Global international bunker emissions are projected to grow strongly in the period spanning 2000–2050 (275% increase). The emissions are projected to increase from about 800 Mt CO_2 in 2000 to about 1350 Mt by 2020 and to nearly 3000 Mt in 2050. The aviation sector is responsible for most of this growth.
- In 2050 the shares of the international aviation and shipping sectors in terms of total CO_2 bunker emissions will be about 60% and 40%, respectively. At present they are both about 45% and 55%. Including non-CO_2 contributions to radiative forcing the share of aviation in the bunker total is even higher: about 80% in 2050.
- The share of international bunker emissions in total greenhouse gas B2 baseline emissions will remain in the order of a few percentage points (3.5% of a total of about 83 Gigaton CO_2-eq. by 2050). However, when including the RFI for non-CO_2 impact from aviation, the share of bunker emissions increases to 7% of the baseline and to about 20% of the allowable global emissions in 2050 for achieving stabilisation of GHG concentrations at 450 ppm CO_2-eq.

Allocation options:

- Although the allocation of marine emissions to the flag states (Option 4) is not very robust since the registration of most ships is concentrated in a limited number of countries and the country of registration may change easily over time, in practice the interchanges of registration to flag states over time have been limited during the past decades. At the present time, the registration of most ships is concentrated in the Bahamas, Panama, Liberia and Singapore as well as Greece, Malta and USA. However, for some ship types also China, Hong Kong, Norway, Germany and the Netherlands are among the most favourable flag states. Consequently, for those countries, an allocation to flag states can have a large effect on their total national GHG emissions.
- In both allocation Option 4/5 (flag state/departing aircraft) and Option 6 (imported goods/aircraft destination), the fraction of projected total bunker CO_2 emissions in total fossil CO_2 emissions increases substantially in 2050 in OECD Europe, Japan and Oceania to shares of about 5–15%. However, only in Option 4/5 does the fraction in

Western Africa strongly decrease – from 25% to less than 10% – while the fraction in Central America remains high (between 15 and 20%). The fractions in South-East Asia and East Asia also increase in Option 6 to about 5%.

Environmental penalty:

- If international bunker emissions were to remain unregulated and uncompensated, this would result either in higher emission reduction targets for specific Annex I regions in order to still meet the global emissions pathway stabilising at 450 ppm, or in a significant surpassing of this emissions pathway – by about 3% by 2020 and 10% by 2050. These figures would double when the *Radiative Forcing Index* of aviation is included; implying that the stabilisation of greenhouse gas concentrations at 450 ppm CO_2-eq. by 2100 would become difficult.

Contribution of non-CO_2 emissions from aviation to global warming:

- The total contribution of air traffic to radiative forcing (i.e. to global warming) is about 2.6 times the contribution of CO_2 emissions only (so-called RF index), of which a significant fraction originates from NO_x emissions (through ozone formation). This results in a present total contribution of aviation to anthropogenic radiative forcing of 2%. When aviation activities are not included in future climate change mitigation protocols, their contribution to total CO_2-eq. emissions (using a RFI of 2.6) will increase to about 6 to 16% by 2050, depending on the scenario (in the case of a fourfold increase of expected aviation emissions by 2050, as suggested in the baseline scenario).
- Moreover, since there is a trade-off between improving fuel efficiency and reducing NO_x emissions from aircraft, it is important to include the total impact of aviation activities on climate change when aircraft emission policies are being developed.

Mitigation penalty:

- If global greenhouse gas concentrations need to be stabilised at 450 ppm by 2100 in order to limit global warming to 2°C above pre-industrial levels, the share of bunker emissions in allowable emissions would grow from about 2% in 2000 to over 20% by 2050. As such, over time they would consume a substantial part of the allowable emissions.
- Moreover, particularly in the case of aviation, the contribution of their emissions to global warming may be more substantial due to their indirect impacts on the radiative balance of the additional impact of non-CO_2 emissions from aviation to radiative forcing enhances the impact by a factor of about 2.6 compared to the case of CO_2 only. The inclusion of the global warming impact of non-CO_2 emissions from aviation would increase the share of international aviation emissions in allowable global emissions in 2050 (for stabilisation at 450 ppm) from 6 to 17%, thereby effectively doubling the share of total international bunker emissions in allowable emissions in 2050 to 21%.
- If international bunker emissions are excluded in a Multi-Stage regime approach, and these unregulated international bunker emissions are compensated by more stringent

reductions in the other sectors regulated in the international climate regime, this would result in higher emission reduction targets for particular Annex I regions in order to still meet the global emissions pathway stabilising at 450 ppm. Including the RF impact of non-CO_2 emissions from aviation would further increase the reduction targets. For example, for the EU, the reductions compared to 1990 levels can become more than 20% in 2020 (instead of 12%) and 90% in 2050 (in stead of 75%).

Regional emission commitments:

- If international bunker emissions are included in a Multi-Stage regime approach, the impacts of different allocation rules are relatively small at the regional scale. However, this is not true for Central America, of which the amounts allocated have been shown to be very sensitive to the allocation rules used as the impact on allowable emissions is relatively small.
- However, even at a lower level of scale, in particular, the country level, the differences between the allocation rules may still be substantial. This case refers in particular to countries that are regional hubs for international passenger or goods transport (as opposed to Option 2, which is very sensitive to countries which have major marine bunker stations, e.g. Singapore, Gabon, the Netherlands, Uruguay, United Arabic Emirates).
- If the bunker emissions are included in the regime, but remain unregulated, and other sectors included in the regime compensate the bunker emissions (via emissions trading), this leads to high reductions for the Annex I regions. The reductions are comparable with those under the mitigation penalty case, although even higher for the US, EU and Japan due to their high aviation emissions. Including the radiative forcing impact of non-CO_2 emissions from aviation would even imply zero-emission allowances for those regions.

Sector-based emission reduction policy:

- The effectiveness of sector-based emission reduction policy scenarios on bunker emissions in terms of meeting emission reduction targets for stabilising at 450 ppm seems to be very modest due to the limited share of bunker emissions in overall emissions and the limited technical potential for mitigating international bunker emissions, at least on the short to medium term. However, for achieving a low overall emission level as needed for 450 ppm CO_2-eq. stabilisation, implementation of a large port folio of options in various sectors is necessary; excluding specific activities to contribute to emission mitigation will make it more difficult to achieve strong emission reduction targets.

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Appendix A Trends and trend scenario for international shipping

The first part of this appendix provides background information on the historical trends in international shipping and analyses how CO_2 emissions are related to specific fuel consumption (SFC) per main ship type. These trends per ship types are grouped/allocated to the country/region to which the ships are registered (flag states) and to the country/region that imports the goods. This is followed by a more detailed description of the construction of the trend scenario (‘Business-As-Usual’).

A.1 Historical trends in international shipping

The capacity of the global merchant fleet increased during the period 1980–2004 by one third (UNCTAD, 2006a). Analysis of the trends in shipping capacity [expressed in Dead Weight Tonnes (DWT)] per flag region (Option 4) reveals that the shipping capacity of Central America (i.e. the Caribbean) increases steadily (about 500% since 1980) and that since the mid-1990s it is the region with the largest share (about 31%), followed by OECD Europe (22%) which, however, shows a much smaller growth since the late 1980s. Since the late 1990s, East Asia (notably China), South-East Asia (notably Singapore) and the USA also show significant growth rates (Figure A.1).

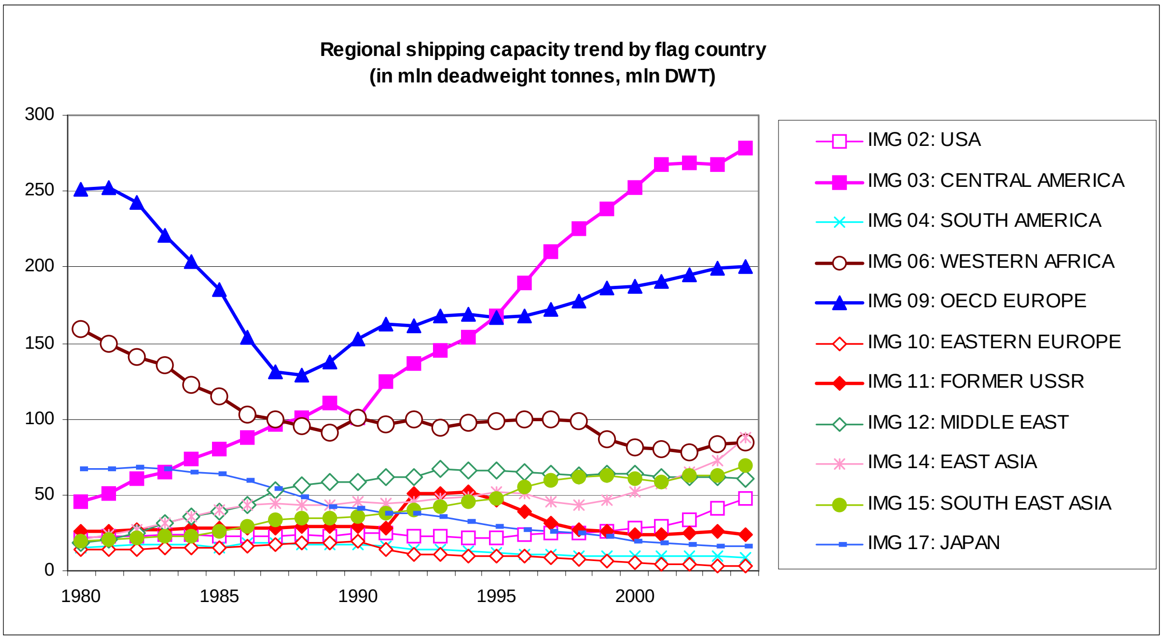

Figure A.1. Trends in regional shipping capacity in the period 1980–2004 (in million DWT). Source: UNCTAD (2006a).

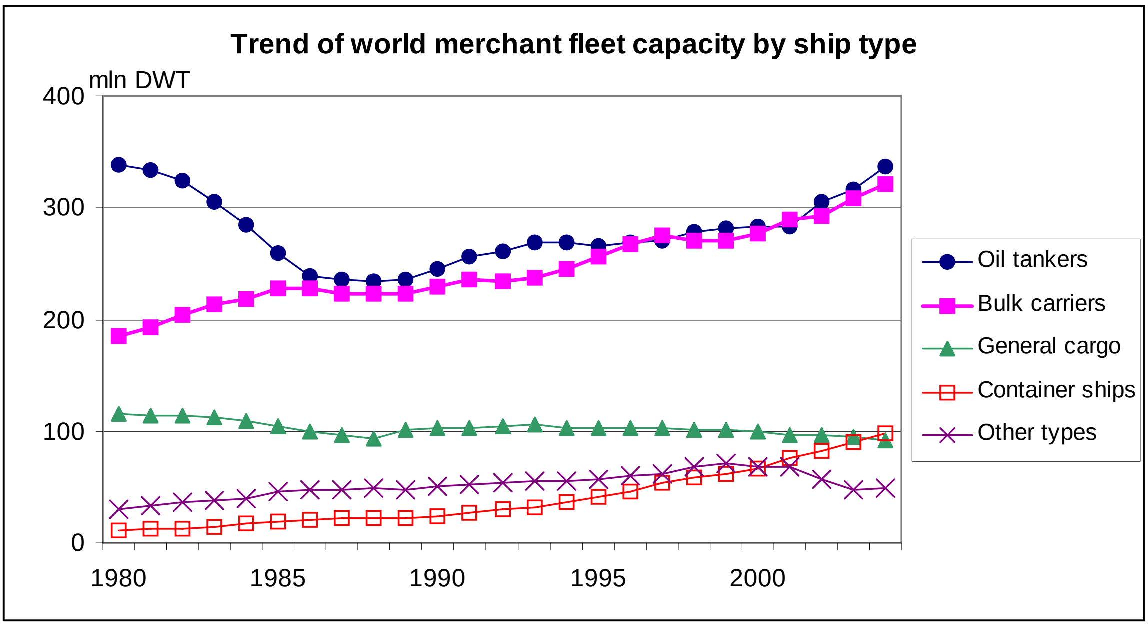

Figure A.2. Global trends in the shipping fleet by ship type (in million DWT). Source: UNCTAD (2006a).

Disregarding regional trends, UNCTAD global ship statistics reveal that oil tankers and bulk carriers show steadily increasing capacities, with respective shares of 38 and 36% at the present time, thereby accounting for almost 75% of the shipping capacity of the world fleet. Although the share in shipping capacity of container ships and general cargo is each about 10%, the former show an absolute increase in capacity since 1985 that is about as large as that shown by oil tankers and bulk carriers (Figure A.2). However, when the shipping capacity is expressed in the value of goods imported, container ships have a global share of about 75% at the present time. When the trends in imported goods (Option 6) are examined, as illustrated in Figure A.3, OECD Europe, the USA and East Asia (i.e. China) are found to show a steady increasing trend in the value of the imports since the mid-1980s, with exceptionally rapid increases in 2003 and 2004 that led to the shares of these regions reaching 40, 20 and 15%, respectively, in 2004. Most of these goods relate to the import of goods in container ships, indicating that OECD Europe imports a great volume of goods, most of which will be transported in containers. With respect to the interpretation of inter-regional differences, the reader should note that regional totals are the direct sum of imports by all countries within the regions and, therefore, also include intra-regional transport between countries. As such, the figures for net imports to the EU-25 as a region will be smaller than the figures presented here, which are the direct sum of imports of every member state.

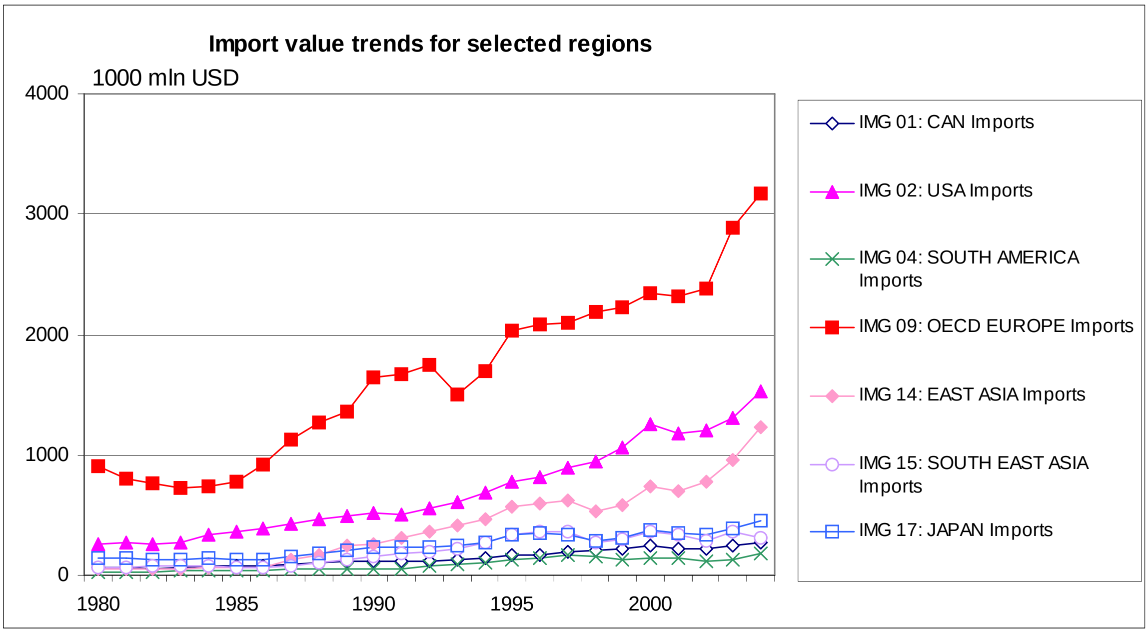

Figure A.3. Trend in regional imports for selected regions (including intraregional trade) (in million 1000 USD). Source: UNCTAD (2006a).

A.2 Trend CO_2 scenario for international shipping

A baseline (trend) scenario was constructed based on historical data available on the shipping capacity per ship type [Dead Weight Tonnes (DWT) of tankers, bulk carriers, container ships, general cargo, among others] from UNCTAD (2006). The following assumptions are made:

- The specific fuel consumption (SFC) per DWT per major ship type remains constant over time (as suggested by historical data, see above);
- The historical trends in fuel consumption trends are determined per type of ship based on DWT capacity per region using two allocation schemes (flag and destination).

For the 2000–2030 period, regional growth trends are based on historical regional average annual capacity growth trends in the 1985–2003 period (with a few exceptions in cases of extreme high growth rates). Since 1990 SFC appears to have remained rather constant, while prior to 1985 there is a mismatch between actual fuel consumption/CO_2 emissions and the calculation of these variables based on from ship capacity trends (Figure A.4). An explanation for this discrepancy may be the oil crisis that occurred during the period prior to 1985: a decrease in oil demand may have resulted in a lower utilisation rate by oil tankers, and the SFC may have decreased as a result of energy efficiency improvements that were implemented following the doubling of oil prices. Moreover, a shift in the vessel mix (fewer tankers, more 'other types') may also have played a role.

Since the match for 1990–2003 is quite good, it is concluded that for medium-term projections we may use the specific fuel consumption (SFC) calculated from 2001 data on DWT and shares per ship type from UNCTAD and total marine bunker fuel consumption from the IEA.

In order to apply the SFC data on importing/exporting goods, the use of monetary trends reported in the UNCTAD statistics for import/exports related to these five ship types (oil tankers, bulk carriers, general cargo, container ships, other types) also needs to be evaluated. As shown in Figure A.5, the trends in calculated and reported CO_2 closely follow the trends per ship type of monetary value of imports and SFC. Since 1985 the average CO_2/US$ import has decreased – i.e. the energy efficiency has increased by 16% in the 1985–2002 period, which is 1.0% annually. Since the average SFC per DWT has not significantly improved (see analyses above), this development must be due to the increasing share of high-value shipments (i.e. in US$ per tonne), which consist primarily of manufactured goods [Standard International Trade Classifications (SITC) 5 to 8 of less 68]. The value per tonne for these manufactured goods is much higher than that for other cargo types, and the share of the former in global total imports has been strongly increasing, reaching 75% in 2003. On average, the import value/DWT ratio almost tripled in this 18-year period.

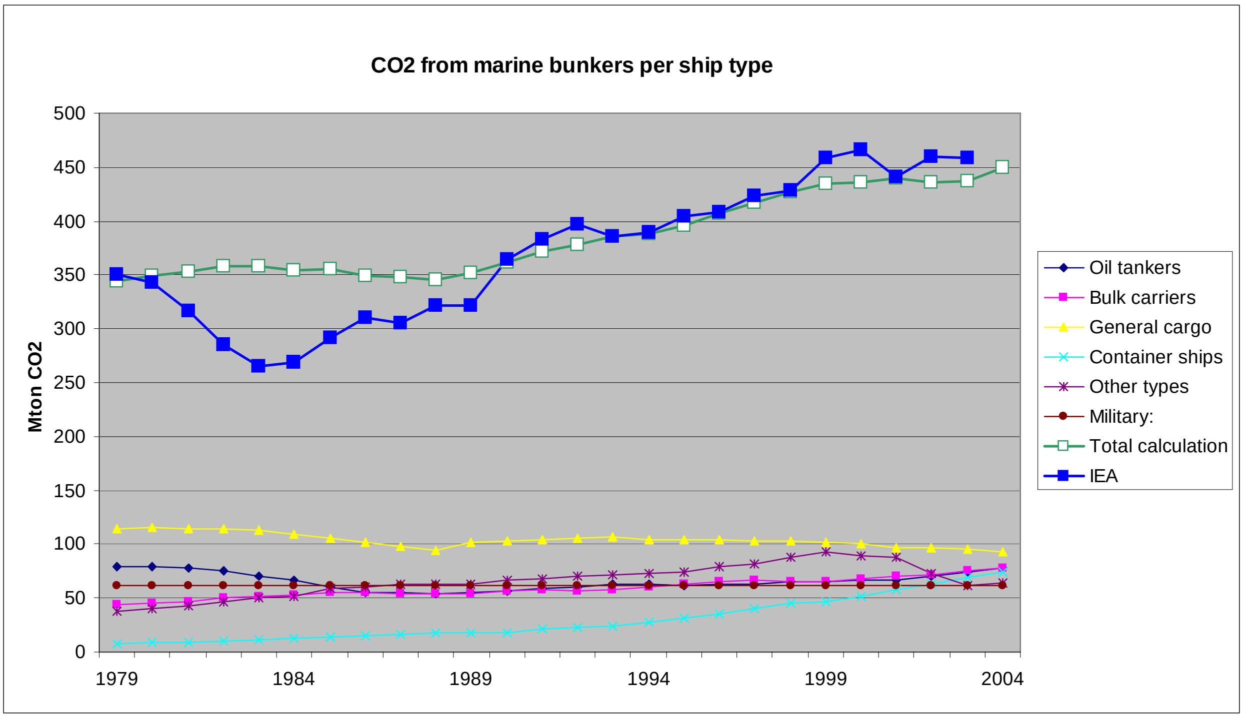

Figure A.4. Comparison of CO_2 emissions reported by IEA (2005) and calculated from DWT volume per ship type (UNCTAD, 2006), assuming constant specific fuel consumption (GJ/DWT, calculated for 2001).

For the 2030–2050 period a linear extrapolation of the growth trend in 2020–2030 is applied to avoid a continued exponential increase, which seems to be unrealistic in view of other published shipping scenarios. The resulting trend in the CO_2 emissions scenario is presented in Figure A.6. This trend is dominated by the strong growth in container ships, of which the share in fuel consumption increases from 15% at the present time to about 40% in 2050.

This feature will have a particularly large effect on the trends of flag states that show a large increase and have a high share in container ships and on the trend of importing countries that import a large portion of their goods by container ships.

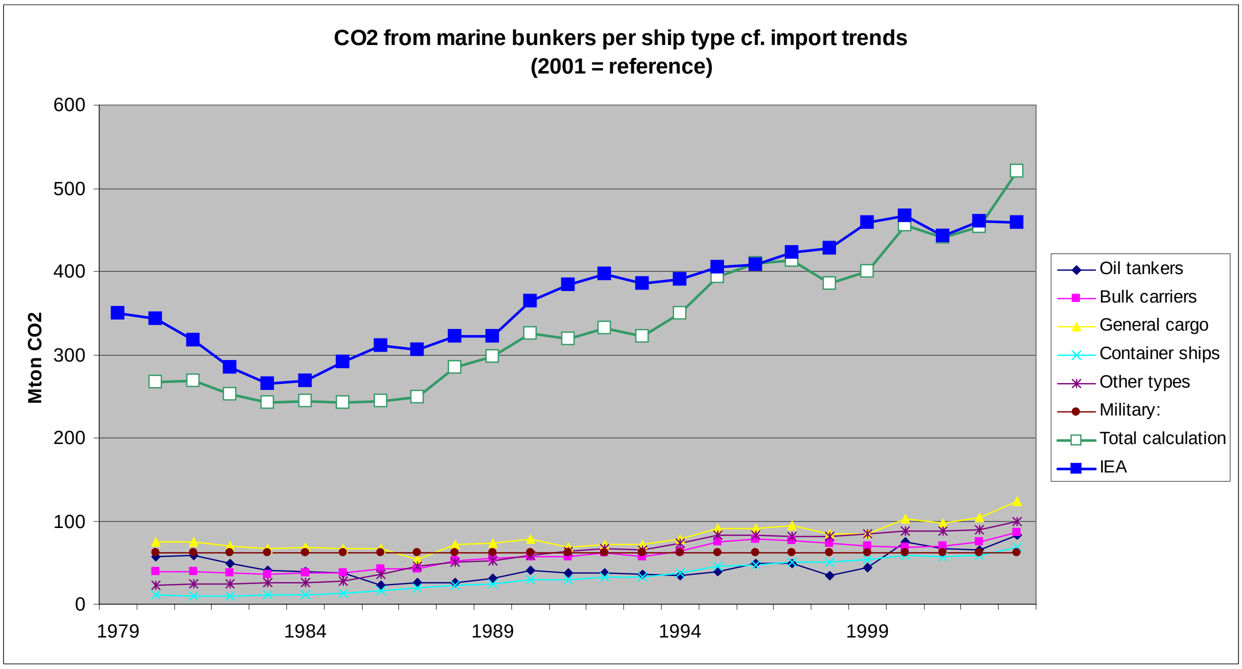

Figure A.5. Comparison of CO_2 emissions reported by IEA (2005) and calculated from import values per ship type (UNCTAD, 2006), assuming constant specific fuel consumption (GJ/US$, calculated for 2001).

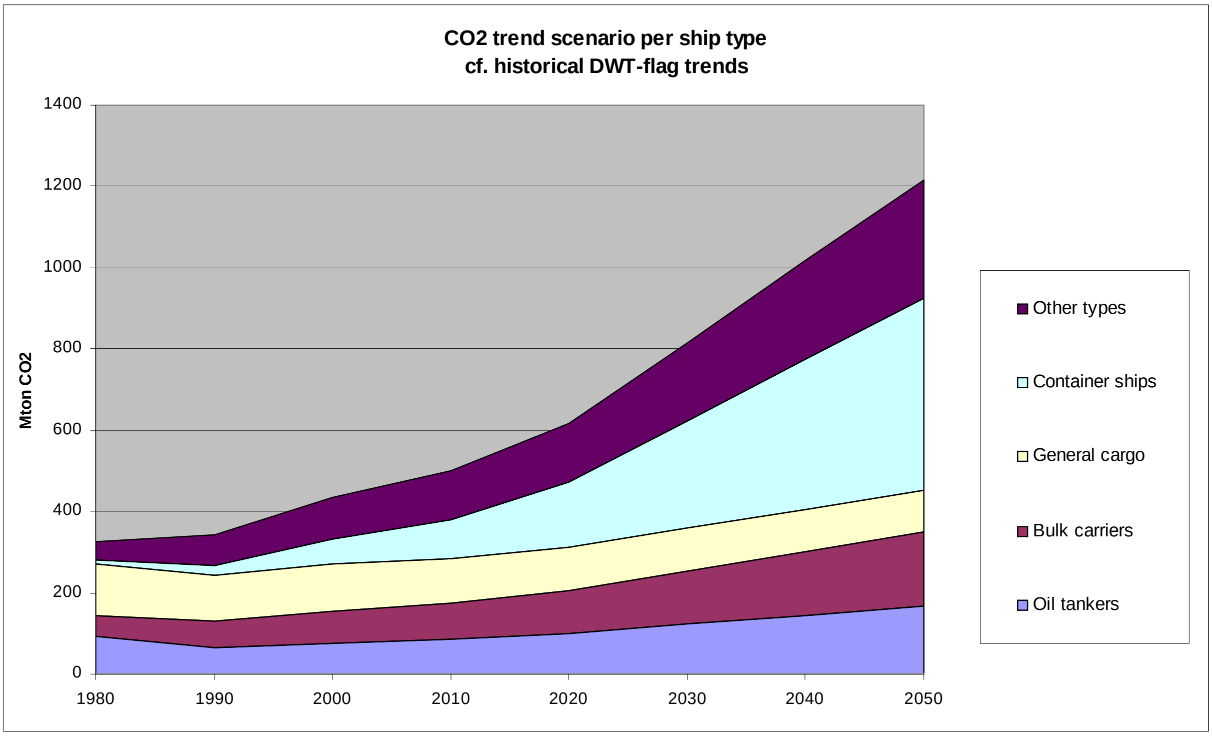

Figure A.6. Trend scenario for CO_2 emissions per ship type based on historical DWT trends per ship type.

Appendix B Detailed results of the cases

Table B.1. Overview of the cases: reductions (in %) compared to the baseline emissions (numbers are rounded off to the nearest zero-decimal number).

2020	Global	Canada &USA	Enlarged EU	FSU	Oceania &Japan	Central America	S.America & ME-Turkey.	Africa	South Asia	SE & E.Asia
1.Compensation (excl.) - Option 4/5	-21	-31	-27	-3	-32	-24	-22	-13	0	-22
1.Compensation (excl.) - Option 6	-21	-31	-27	-3	-32	-24	-22	-13	0	-22
2a.No Compensation (incl.) - Option 4/5	-20	-29	-25	-2	-30	-20	-21	-12	0	-21
2a.No Compensation (incl.) - Option 6	-20	-29	-25	-2	-29	-23	-22	-12	0	-21
2b.Compensation (incl.) - Option 4/5	-20	-31	-26	-3	-31	-20	-22	-12	0	-21
2b.Compensation (incl.) - Option 6	-20	-30	-25	-3	-30	-23	-22	-12	0	-21
3a.Included (reduced bunker) - Option 4/5	-21	-29	-26	-2	-31	-25	-22	-12	0	-23
3a.Included (reduced bunker) - Dest	-21	-29	-26	-2	-31	-24	-22	-12	0	-23
3b.Included (unlimited bunker) - Option 4/5	-21	-30	-28	-2	-32	-29	-22	-12	0	-24
3b.Included (unlimited bunker) - Dest	-21	-30	-28	-2	-32	-25	-22	-13	0	-24
4.Policy-Compensation (excl.) - Option 4/5	-21	-31	-27	-3	-31	-24	-22	-13	0	-22

2050	Global	Canada & USA	Enlarged EU	FSU	Oceania &Japan	Central America	S. Ame.& ME-Turk.	Africa	South Asia	SE & E.Asia
1.Compensation (excl.) - Option 4/5	-74	-94	-87	-79	-89	-80	-80	-40	-36	-75
1.Compensation (excl.) - Option 6	-74	-94	-87	-79	-89	-80	-80	-40	-36	-75
2a.No Compensation (incl.) - Option 4/5	-67	-89	-76	-70	-78	-61	-75	-38	-31	-67
2a.No Compensation (incl.) - Option 6	-67	-88	-75	-70	-77	-72	-75	-38	-31	-66
2b.Compensation (incl.) - Option 4/5	-71	-92	-80	-77	-82	-65	-78	-39	-36	-72
2b.Compensation (incl.) - Option 6	-71	-91	-79	-77	-81	-76	-79	-40	-36	-71
3a.Included (reduced bunker) - Option 4/5	-70	-91	-84	-73	-85	-78	-77	-37	-32	-71
3a.Included (reduced bunker) - Dest	-70	-91	-84	-72	-85	-76	-76	-38	-32	-71
3b.Included (unlimited bunker) - Option 4/5	-73	-93	-91	-75	-92	-96	-78	-38	-32	-73
3b.Included (unlimited bunker) - Dest	-73	-94	-92	-75	-94	-79	-77	-39	-32	-75
4.Policy-Compensation (excl.) - Option 4/5	-73	-93	-86	-78	-88	-78	-79	-40	-35	-73