CE Delft
Solutions for environment, economy and technology

Oude Delft 180
2611 HH Delft
The Netherlands
tel: +31 15 2 150 150
fax: +31 15 2 150 151
e-mail: ce@ce.nl
website: www.ce.nl
KvK 27251086

Aviation and maritime transport in a post 2012 climate policy regime

Report

Delft, December, 2006

Author(s): Jasper Faber (CE)
Bart Boon (CE)
Marcel Berk (MNP)
Michel den Elzen (MNP)
Jos Olivier (MNP)
David Lee (MMU)

Publication Data

Bibliographical data:
Jasper Faber (CE), Bart Boon (CE), Marcel Berk (MNP), Michel den Elzen (MNP), Jos Olivier (MNP), David Lee (MMU)
Aviation and maritime transport in a post 2012 climate policy regime
Delft, CE, 2006

Transport / International / Maritime Shipping / Aviation / Emissions / Policy / Measures / Analysis

Publication number: 06.7153.59

CE-publications are available from www.ce.nl

This study has been performed within the framework of the Netherlands Programme on Scientific Assessment and Policy Analysis for Climate Change (WAB)
Further information on this study can be obtained from the contact person Jasper Faber

© copyright, CE Delft, Delft

CE Delft

Solutions for environment, economy and technology

CE Delft is an independent research and consultancy organisation specialised in developing structural and innovative solutions to environmental problems. CE Delfts solutions are characterised in being politically feasible, technologically sound, economically prudent and socially equitable.

For the latest information on CE Delft check out our website: www.ce.nl.

This report is printed on 100% recycled paper.

Preface

Climate policy cannot be effective without addressing the climate impacts of aviation and maritime transport. This report shows how these sectors can be included in either a global policy regime or in regional policies. It has been performed within the framework of the Netherlands Programme on Scientific Assessment and Policy Analysis for Climate Change (WAB).

Many people have contributed to our understanding of the challenging issue on how to include aviation and maritime transport. The authors wish to thank the members of the EU expert group on bunker fuels and the members of the project steering committee for their valuable comments. Furthermore, we would like to thank Edwin Koekoek en Monique van Wortel for initiating this project. Of course, errors and shortcomings are only attributable to the authors.

The authors

Contents

Brief summary

Aim
This report explores ways to incorporate international aviation and maritime shipping in a climate policy regime. Currently, emissions from international transport are not included in climate policy targets under the Kyoto Protocol. One of the reasons is that it is not clear which country should be held accountable for which share of the emissions.

This project set out to develop concepts that are both founded on a sound scientific basis and in touch with current developments in international climate negotiations. For this purpose, the findings from the desk research stage have been presented to climate negotiators and other experts at several occasions, and comments have been fed back into the report.

Currently, much uncertainty exists with regard to the political will to agree on international action to combat climate change. This uncertainty and possible ways to engage countries in a global climate policy regime is not the primary subject of this report. Rather, this study addresses the issue *how* international transport could be incorporated in either an international or a regional climate policy, *assuming* that a sufficient number of parties agrees that such a policy is desirable.

Size of the problem
International aviation and maritime shipping account for approximately 1.5% and 1.8% of global CO_2 emissions, respectively. Because of its indirect climate impacts, aviation contributes more to global warming than is suggested by CO_2 emissions alone. Emissions from both sectors are rising, moreover, and especially emissions from aviation are rising fast. If that growth is not controlled, it threatens to offset much of the cuts in emissions from land-based sources.

Results
Three different types of policy regime have been explored for including international aviation and maritime transport in a post-2012 climate policy regime:
1 Allocation of responsibility for emissions to countries: each country is allocated a certain share of international transport emissions and this share is included in the national commitment.
2 Sectoral commitments: the international transport sectors take on a commitment to reduce their climate impact.
3 A regional start: international transport is not included in a global climate policy regime, but groups of countries, such as the EU, adopt policies addressing climate impacts of international transport.

In all, six concepts have been developed, two for each route:

Table 1 Concepts for the inclusion of bunker fuel emissions in climate policy

Routes	Concepts
1 Allocation of emissions to countries	A Route based allocation
	B Cargo based allocation
2 Sectoral commitments	C Sectoral approach with emission cap
	D Technology based sectoral approach
3 Regional start	E Inclusion of aviation in ETS
	F Inclusion of maritime shipping in existing policy instruments

In a multi-criteria analysis, three concepts score best. Below, the main characteristics of these concepts are laid out.

Concept A: Route-based allocation and stacked policies and measures

- Emissions are allocated to the country of arrival or departure of the vessel or aircraft and included in national totals.
- Industrialised countries are assigned absolute reduction targets, advanced developing nations relative targets (emissions per unit of GDP) and least developed countries no targets. These targets cover emissions from both land-based sources and international transport.
- Countries coordinate policies and measures (PAMs) to reduce emissions from international transport. To allow for differentiated commitments, PAMs are stacked: all countries introduce technology standards, on top of which advanced developing countries and industrialised countries introduce performance standards and emission charges, on top of which industrialised countries introduce emission trading.
- Only greenhouse gas emissions are targeted directly, but flanking policies could be introduced for indirect climate impacts.

Concept C: Sectoral approach with emission cap

- ICAO and or IMO take on a cap for greenhouse gas emissions or climate impacts of the sectors.
- ICAO and or IMO introduce cap-and-trade systems for aircraft operators and ship operators to fulfil their commitments. These systems can be linked to other emission trading schemes.
- The cap-and-trade systems allows for route-based differentiation.
- States are responsible for enforcing the compliance of aircraft and vessel operators with the international policies.

Concept E: A regional start for aviation: inclusion in ETS

- Emissions from aviation are included in the EU Emission Trading Scheme.
- Aircraft operators are made responsible for their emissions and are able to purchase additional allowances on the EU ETS market as necessary.
- If the scheme were extended to include other countries and/or routes, there could be differentiation between routes.

Executive summary

This report explores ways to incorporate international aviation and maritime shipping in a global climate policy regime. It develops concepts for their inclusion. At present these sectors' emissions are not included in a global climate policy regime, as the Kyoto Protocol excludes them from the national totals of Annex I countries that are to be reduced.

This situation gives way to debate. Emissions from international transport are growing rapidly and threaten to offset much of the cuts in emissions from land-based sources. Meanwhile, discussions on including emissions from aviation and maritime shipping in a global climate policy regime have reached a deadlock.

This report seeks to break out of the current situation by offering comprehensive options for including aviation and maritime shipping in climate policy regimes.

Of course, much uncertainty exists with regard to the political will to agree on international action to combat climate change. This uncertainty and possible ways to engage countries in a global climate policy regime is not the primary subject of this report. Rather, this study addresses the issue *how* international transport could be incorporated in either an international or a regional climate policy, *assuming* that a sufficient number of parties agrees that such a policy is desirable.

Background
International aviation and shipping make a significant contribution to climate change. In 2000, the last year for which reliable data are available, the CO_2 emissions of maritime shipping accounted for an estimated 1.8% to 3.5% of global emissions, with international aviation accounting for 1.5% and all aviation (including domestic) for 2.9%. The climate impact of aviation is greater than that of its CO_2 emissions alone, because of significant indirect effects (ozone formation from NO_x emissions, contrails, etc.). In the case of maritime shipping there are also indirect climate impacts, both positive and negative, with the latter probably predominating.

In recognition of the contribution of these international transport sectors, Article 2.2 of the Kyoto Protocol states that:

> The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.

However, in the nearly ten years since the Kyoto Protocol was signed by 84 countries in 1997, little progress has been made on this issue.

Until now Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have not been able to agree on a methodology to assign responsibility for greenhouse gas emissions from these sectors. The UNFCCC and its subsidiary body SBSTA have devoted much attention to the allocation of emissions to parties, but the discussion has not led to any agreement on an allocation option.

In addition, the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) have not been able to agree on actions to ensure effective implementation of mitigation policies to reduce greenhouse gas emissions from international aviation and shipping, other than agreeing on best practice in terms of air traffic management operations, in the case of ICAO. It is true that ICAO is currently investigating the scope for an open emissions trading scheme for aviation. It may even issue guidelines on implementing such a scheme, but on its own this move is not expected to lead to any significant emission cuts. The IMO, for its part, has issued guidelines for voluntary trials with a CO_2 index for ships, but it has not adopted any policies or even issued guidance on emissions abatement measures based on that index.

At a regional level some progress has been made. The European Commission has announced that it will issue a legislative proposal for including aviation in the European Emission Trading Scheme, one of the elements of the European strategy to meet the Kyoto target. Although this may reduce greenhouse gas emissions from aviation, however, it will do so only within a limited geographical scope.

In the meantime, the UNFCCC has started two processes to explore climate policy post-2012. The first, under the UNFCCC itself, is a “dialogue on long-term cooperative action to address climate change by enhancing implementation of the Convention”. It will engage parties in an exchange of experiences and an analysis of strategic approaches to long-term cooperative action to address climate change. The second, under the Kyoto Protocol, is “a process to consider further commitments for Parties included in Annex I for the period beyond 2012”. This is known as the Article 3.9 process, in reference to the relevant article of the Kyoto Protocol. Both the Dialogue and the Article 3.9 process will most likely consider the inclusion of emissions from bunker fuels. At this stage, it is impossible to assess what the possible outcomes of these processes may be.

Both the European Union and its Member States (including the Netherlands) have stated on various occasions that international aviation and maritime shipping should be included in a future global climate policy regime.

Problem analysis

It could be desirable that the discussion on inclusion of international transport is given new impetus, to overcome the current deadlock, and current discussions on post-2012 climate policy provide an excellent opportunity to that end.

In our view the current deadlock in establishing a global policy regime to address the climate impacts of international transport can be attributed to the following three factors:

- Policies and measures (PAMs) are discussed within ICAO and IMO, while allocation is discussed within UNFCCC SBSTA, with little coordination between the two. Effective climate policy requires agreement on both allocation and PAMs, though. In particular, it is difficult for parties to take responsibility for emissions in the absence of any internationally coordinated policy instruments to effectively limit those emissions.

- Under the Kyoto Protocol, only Annex 1 countries have quantitative targets and legally binding commitments, with other countries having no quantitative targets of any kind. Within IMO and ICAO, many non-Annex I countries have argued that it would be not be in line with current global climate policies to impose mitigation measures on their airlines and ship owners. However, since international transport is a global business, leaving out non-Annex I countries would lead to serious distortions of competitive markets. Worse, the environmental benefits would be extremely limited, for airlines and ship owners from non-Annex I countries would simply take over the business of their Annex I competitors, without any reduction of global emissions.
- Many proposals have been made on how to include advanced or rapidly growing developing countries like Brazil, South Korea, China and India in a global climate policy regime. As yet, however, these proposals have not addressed international transport in any great detail.

The present study

This report intends to bring current policy processes one step further by studying viable policy scenarios for overcoming the problems identified above. In the first place, the deadlock in the allocation discussions might be overcome by proposing policy regimes that incorporate PAMs, commitments and allocation simultaneously. Second, the study takes full account of the possibilities for differentiating target commitments between countries. In doing so, it builds on the so-called multi-stage approach, which assumes a gradual increase in the number of parties taking on mitigation commitments and in their level of commitment as they move through several stages according to participation and differentiation rules. Third, the study adds to our understanding of effective climate policies by addressing international transport in detail and linking it to an overall climate policy.

From these starting points, three different routes have been explored for including international aviation and maritime shipping in post-2012 climate policy:

1 Allocation of responsibility for emissions to countries.
2 Sectoral commitments.
3 A regional start.

For each of these routes, two concepts have been developed. These will be identified as concept A through F.

The study draws on literature on allocation, on policies and measures and on post-2012 climate policy. The study identifies the choices that will have to be made under the different regimes and the implications those choices may have.

Route 1: Allocation of responsibility for emissions to countries

In the case of emissions being allocated to countries, each country is made responsible for a certain share of global emissions from international aviation and maritime shipping, with the precise share depending on the allocation option adopted.

The basic assumption of this part of the study is that countries can only take responsibility for emissions they are in a position to control. The means available to states for this purpose are policies and measures, with different PAMs giving states control over varying fractions of global emissions. An essential first step is therefore to analyse the working of different kinds of PAMs.

Policies and measures

PAMs can be classified into three groups:

1 Technological PAMs, such as:
   a RD&D subsidies.
   b Technical standards.
   c Performance standards.
2 Taxes and charges, such as:
   a Fuel taxes.
   b Emission charges.
3 Cap-and-trade systems, such as:
   a Emission caps with tradable allowances.
   b Emission credits.

How do these PAMs enable states to control emissions? An analysis of their functioning shows the following:

In some cases technological PAMs can give states a measure of control over emissions from companies and/or vessels or aircraft registered nationally. RD&D subsidies, for example, may speed up the development and use of low-emission technologies. Other technological PAMs such as standards may give states control over either national companies and/or vessels, or over vessels and aircraft entering their jurisdiction. States could, for example, require vessels in their harbours to meet a certain technical or performance standard.

Technological PAMs may give countries some control over the relative emissions and climate impacts from transport (relative to transport volume), but are ill-suited for reducing emissions in absolute terms.

Taxes and charges allow states to control emissions within their jurisdiction, either directly (an emission charge) or indirectly (a fuel tax). By introducing emission charges, states would be able to control the emissions of all aircraft and vessels within their jurisdiction, regardless of their nationality.

Cap-and-trade systems allow states to control the total amount of emissions within the system. It depends on how the system is designed whether it is the emissions of national companies, nationally registered vessels or aircraft, or emissions within a certain region that are capped.

Allocation options

After analysing the working of policies and measures, various allocation options were analysed with regard to the amount of control they require, thereby restricting ourselves to those options still under discussion within UNFCCC SBSTA. Using the commonly accepted numbering of SBSTA, these are:

3 Allocation according to the country where the bunker fuel is sold.
4 Allocation according to the nationality of the transporting company, or to the country where an aircraft or ship is registered, or to the country of the operator.
5 Allocation according to the country of departure or destination of an aircraft or vessel; alternatively, emissions related to the journey of an aircraft or vessel shared by the country of departure and the country of arrival.
6 Allocation according to the country of departure or destination of passengers or cargo: alternatively, emissions related to the journey of passengers or cargo shared by the country of departure and the country of arrival.

Allocation option 3 implies that states have control over the amount of bunker fuel sold within their jurisdiction. Fuel taxes, emission charges and emission trading (in which case the fuel suppliers would have to be the trading entity) are the most direct ways of controlling the amount of bunker fuel sold. The applicability of each of these instruments may be reduced by existing legislation, such as Bilateral Air Service Agreements. Moreover, the effectiveness of fuel taxes may be hampered by changing the place to bunker.

For allocation option 4, states need to have control over the emissions of transporting companies, operators or ships or aircraft within their jurisdiction. Emission trading could be designed to give states this control, as could technical standards and performance standards. Stimulation of RD&D could be directed towards national transporting companies and operators.

Allocation option 5 requires that states have control over the emissions caused by aircraft or vessels travelling to or from harbours or airports within their jurisdiction. Emission trading and emission charges could be designed to give states such control. In aviation, control could also be exerted by means of fuel taxes, because tankering is subject to technical and economic constraints. Technology and performance standards could give states control over the level of emissions relative to transport performance.

Finally, allocation option 6 implies that states have control over the emissions caused by the transport of cargo or passengers entering or leaving their country. This resembles the control needed for allocation option 5. Emission trading and emission charges could be designed to give states such control.

Selection of allocation/PAM combinations
The analysis of PAMs and allocation options shows that the following combinations are possible (see Table 2).

Table 2 Combination of PAMs and allocation options

PAM	Gives states control over	Appropriate allocation options
RD&D	Rate of technological progress	4: Nationality of transporting company
Technology standard	Rate of technology adoption by aircraft and vessels within their jurisdiction	4: Nationality of transporting company 5: Departure / destination of vessel / aircraft 6: Departure / destination of passenger / cargo
Performance standard	Rate of technology adoption and performance by aircraft and vessels within their jurisdiction	4: Nationality of transporting company 5: Departure / destination of vessel / aircraft 6: Departure / destination of passenger / cargo
Fuel taxes	Emissions from fuel sold within their jurisdiction	3: Fuel sales
Emission-related charges	Emissions from aircraft and vessels within their jurisdiction	4: Nationality of transporting company 5: Departure / destination of vessel / aircraft 6: Departure / destination of passenger / cargo
Emission trading	Total emissions within the trading scheme	3: Fuel sales 4: Nationality of transporting company 5: Departure / destination of vessel / aircraft 6: Departure / destination of passenger / cargo

Several combinations can be discarded because of their limited environmental effectiveness or lack of feasibility.

Internationally coordinated fuel taxes are very hard if not impossible to implement, because states are very reluctant to give up sovereignty over their tax base and tariffs. Furthermore, fuel taxes, if differentiated, would lead to evasion. In the case of shipping, vessels would bunker fuel in countries with low tariffs. Although aviation has less scope for tankering than maritime shipping, there would still be scope for evasion.

Allocation on the basis of the nationality of the transporting company would distort the market if commitments were differentiated. In that case, transporting companies from countries with no commitments could take over the business of companies based in states with strict commitments. Alternatively, companies could relocate. Either way, the market distortion would lead to evasion and environmental effectiveness would be severely limited.

Differentiated commitments and allocation
The notion that commitments should be differentiated is enshrined in the UNFCCC. This is because greenhouse gas emissions correlate with economic development, so that strict targets for developing countries would hamper their economic development.

International transport contributes to economic development by linking different economies and allowing economies to exploit comparative advantages. The economic benefits of international transport result from the links with other economies, and thus from the movement of passengers and cargo, rather than from the nationality of the transporting company.

This analysis shows that route-based differentiation is more in line with the basic assumptions of the UNFCCC than differentiation based on the nationality of companies, registries of aircraft of vessel, or country of fuel sales. This conclusion is central to our analysis, both in this section and in others.

Phrased differently, we argue that a route based allocation allows for an equitable allocation of emissions, because developing countries can expand the benefit they derive from international transport and thus develop their economy, while industrialised countries could invest in cleaner transport systems. Compared to other allocation options, the market distortions and possibilities for evasion would be less under a route based differentiation.

Approaches to differentiated commitments

This report builds on the multi-stage approach to differentiating commitments. This is an incremental but rule-based approach that assumes a gradual increase in the number of parties taking on mitigation commitments and in their level of commitment as they move through several stages according to participation and differentiation rules. The multi-stage approach is being developed to ensure that countries with similar circumstances in economic, developmental and environmental terms have comparable commitments under the climate regime. It addresses some of the objections that certain countries currently have against the Kyoto Protocol, such as that the Annex I versus non-Annex I dichotomy leads to a distortion of competition.

In the multi-stage approach, industrialised countries are assigned absolute emission targets, advanced developing nations are assigned efficiency targets (to reduce the emission intensity of their economy, while allowing for economic growth), while the least developed countries are not required to limit their emissions.

Countries with different commitments would need different PAMs to fulfil them. This report advocates stacked PAMs as a means of differentiating commitments. For example, all countries could introduce technology standards, on top of which advanced developing nations and industrialised countries could introduce performance standards and emission charges, on top of which industrialised countries could introduce emission trading. The advantage of stacked PAMs would be that transport companies would face additional PAMs in some regions, but not PAMs that are incompatible. Given the international nature of aviation and maritime shipping, it is essential that PAMs be compatible.

Most feasible policy regimes in the case of allocation

Table 3 provides a summary review of the feasibility and data availability of the different potential policy regimes that entail allocation of emissions to countries.

Table 3 Feasibility of allocation options

Allocation and PAMs	Feasibility		Data availability and accessibility	
	Aviation	Shipping	Aviation	Shipping
3 – Fuel sales PAMs: Fuel tax Differentiation: different tax levels	Would require fuel tax, which would be hard to implement internationally.	Differentiated fuel tax would lead to evasion.	Good. Emissions associated with fuel sold can be easily calculated from fuel sales. These sales are available and accessible.	
4 – Nationality PAMs: LDCs: technology standards, CDM ADCs: technology standards, emission charges, sectoral CDM ICs: technology standards, emission trading	Differentiation in line with the multi-stage approach would lead to distortion of the competitive market.	Would lead to evasion: nationality of operators is not well defined, and the flag of a ship can be readily changed.	Availability: very good. Accessibility: good; airlines would be required to submit emission data to competent authority.	Availability: Flag: very good; Ship operator: nationality poorly defined. Accessibility: good; ship operators would be required to submit emission data to competent authority.
5 – Vessel or aircraft route PAMs: See above	Routes are well defined ex-post. Distortion of markets limited to ports and airports, provided that airlines (and ship operators) are treated in a non-discriminatory way, as required by the Chicago Convention.		Availability: Good. Accessibility: good; airlines would be required to submit emission data to competent authority	Availability: Good, but some ship operators may need to start monitoring emissions on a per-trip basis. Accessibility: good; operators would be required to submit emission data to competent authority
6 – Passenger or cargo route PAMs: See above	May be feasible, but requires solutions for the confidentiality of airline data under code-sharing agreements.	May be feasible provided that electronic Bills of Lading and IMO CO_2 index become the industry standard.	Availability: Poor. Accessibility: not relevant.	Availability: Currently poor with regard to emissions, but may improve in the near future. Accessibility: good; airlines would be required to submit emission data to competent authority

Note: ADC: advanced developing countries; IC: industrialised countries; LDC: least developed country; PAMs: policies and measures.

The conclusion is that allocation options 5 (and for shipping possibly also 6) would be best suited for differentiating commitments between countries. Differentiation under these two options would leave scope for economic growth in the least developed regions, while not distorting the competitive market by favouring transport companies from certain nations over others. It should be noted that these allocation options do not particularly favour certain PAMs over others.

Institutional arrangements

These policy regimes based on allocation would require institutional fulfilment of the following roles:

1 Agreement on allocation of bunker fuel emissions, based on assessment of policies and measures.
2 Agreement on stages, and rules for transition between stages.
3 Guidance on policies and measures.
4 Taking sector size and abatement potential into account when setting targets.
5 Allocating commitments to countries.
6 Implementing policies to ensure that commitments are fulfilled.
7 Enforcing compliance of states with overall target.

Apart from the third and the sixth task, all these roles could be fulfilled by the UNFCCC Conference of Parties (COP). They are in line with the roles the COP currently fulfils: it has agreed on the Kyoto protocol to the UNFCCC, which does set targets for various countries.

The third task could be fulfilled by ICAO and IMO for aviation and maritime shipping, respectively. This would be in line with the current role of these organisations. These organisations could ensure that the PAMs in place in various parts of the world are mutually compatible, so they do not hamper international transport. In the case of certain PAMs, ICAO and IMO may need to develop guidelines. PAMs may need to be stacked to allow the most developed countries to secure their absolute targets and developing countries their relative targets.

The sixth task would have to be fulfilled by states. States would also need to enforce actors' compliance with PAMs, much in the same way that compliance with international policies and standards is currently enforced.

For a policy regime based on allocating emissions to countries and making use of differentiated commitments, we judge the following two concepts most feasible (Table 4).

Table 4 Final concepts - allocation to countries

Concept	A Route-based allocation	B Cargo-based allocation
Allocation option number	5	6
Allocation	Allocation based on country of arrival or departure of vessel or aircraft.	Allocation based on country of origin or destination of cargo.
Sector	Aviation and/or maritime shipping.	Maritime shipping.
Responsibility for emissions	Countries	
Nature and level of commitment	In line with the multi-stage approach: Industrialised countries: absolute caps. Advanced developing countries: relative emission targets. Least developed countries: no commitments.	
Kinds of policy measures	Industrialised countries: RD&D, technology standards, emission charges, emission trading. Advanced developing countries: technology standards, emission charges, sectoral CDM. Least developed countries: technology standards, CDM.	
Coverage of the measures	CO_2 only. Other impacts could be addressed with technology standards	
Roles of Parties, Groups of Parties, UNFCCC, ICAO and IMO	UNFCCC COP sets national targets and enforces. ICAO and IMO develop guidance on policies and measures. States develop and implement policies and measures.	
Geographical scope	Industrialised countries and advanced developing countries.	

Route 2: Sectoral commitments

Under a sectoral commitment, emissions from international transport would not be allocated to countries, but the aviation and/or maritime shipping sectors would themselves assume responsibility for their climate impacts. many variants of this set-up are conceivable. This report focuses on two: one in which there would be an absolute cap for climate impacts or emissions, and one which would build on internationally co-ordinated technological action.

ICAO and/or IMO could decide to take on an absolute cap for emissions or climate impacts of aviation and maritime transport, respectively. ICAO and/or IMO would thus be responsible for the emissions of their respective sectors. To control those emissions, they could introduce a cap-and-trade system for aircraft and ship operators (other PAMs would either not lead to the required result or have to limit the amount of transport services offered or would have to be based on taxes and charges, which ICAO and IMO cannot levy).

ICAO and/or IMO could agree the cap on their emissions with the UNFCCC COP. In this way, the organisations could ensure that the underlying currency for emission trading would be the same in aviation, maritime transport and other emission trading systems. This would have the advantage that a large system could be created, which would lower the cost of reaching the target.

Alternatively, a sectoral commitment could consist of pledges by ICAO and IMO to contribute to mitigating climate change. These pledges could relate to the adoption of certain PAMs, or to some commitment or emission target. This institutional set-up would have at least two advantages. First, it would be in line with the current tasks and responsibilities of IMO and ICAO, and could therefore build on the existing organisational capacities of these organisations. Second, there would be no direct need for differentiating commitments, since the commitment could be made without reference to the UNFCCC, which has enshrined the principle of "common but differentiated responsibilities".

However, a set-up without an emission cap will most likely come at a price. The type of PAMs most likely to be introduced by ICAO and/or IMO would be of a technical nature (e.g. technical and performance standards), with potentially more stringent measures likely only on a voluntary basis, at best. Given the projected growth in emissions from international aviation and maritime shipping, a stabilisation or absolute reduction of emissions would be unlikely for a sectoral commitment outside the UNFCCC.

Sectoral approach with emission cap
In a sectoral approach with an emission cap, ICAO and/or IMO would set a cap on international transport emissions. They would create tradable allowances and distribute them among operators. It would be possible to differentiate operators' commitments according to their routes. For example, operators of routes between industrialised countries would have to hand over allowances, while operators of routes between least developed countries would not.

In order to reduce the cost of compliance, ICAO and/or IMO could allow operators to surrender JI or CDM credits, and link their emission trading systems to existing trading schemes. The latter would require agreement with the UNFCCC COP on the emission cap, in order to ensure that units in different trading systems are compatible.

Ultimately, enforcement would depend on states. ICAO and/or IMO could notify states if operators are not complying with the requirements of an emission trading scheme. States, in turn, could refuse landing rights or port entry to these operators' vessels or aircraft.

ICAO and IMO would, furthermore, provide guidance on policies and measures that could help the international transport sectors meet the cap.

Sectoral approach with technological PAMs
In contrast to the absolute commitments in a scheme with a cap, a technology-based scheme would most likely result in relative commitments. Ambitious relative commitments could be in the order of a 15% efficiency improvement for aviation and a 25% improvement for maritime shipping by 2050. In absolute terms, however, emissions would then continue to rise between 2000 and 2050, by 200% for international aviation and 110% for maritime shipping.

The PAMs introduced would be mostly technical and operational, and ICAO and IMO could issue technical and operational standards. States would implement these and enforce them on ships sailing under their flag and on ships in their ports, and on aircraft at their airports and in their national fleet, much in the same way that standards are currently enforced. Pro-active states could choose to engage in RD&D

and/or implement market-based instruments to further technological progress and diffusion of innovation.

In this approach, all climate impacts could potentially be addressed. In the case of aviation, for example, NO_x emission standards, standards for the addition of bio-kerosene to fossil kerosene and possibly even fuel efficiency standards are conceivable instruments for reducing emission-related climate impacts. The impacts of contrails and cirrus clouds could be addressed by developing standards and rules for contrail-reducing ATM procedures.

Table 5 provides a schematic review of the potential policy regimes under the sectoral approach.

Table 5 Concepts for the sectoral approach

Concept	C Emission cap	D Technology based
Allocation	No allocation.	
Sector	Aviation and maritime shipping.	
Responsibility for emissions	ICAO, IMO.	ICAO and IMO would pledge to improve efficiency of transport systems.
Nature and level of commitment	Absolute target.	Relative commitment.
Kinds of policy measures	Technological policy measures, emission trading.	Technological policy measures.
Coverage of the measures	CO_2 only. Other impacts could be addressed with technology standards.	All impacts.
Roles of Parties, Groups of Parties, UNFCCC, ICAO and IMO	ICAO and IMO take on emission cap. Cap is agreed with UNFCCC COP. ICAO and IMO organise emission trading in their sectors. Operators surrender allowances. States enforce compliance of operators.	ICAO and IMO set standards. States implement standards and enforce compliance.
Geographical scope	Routes within and between industrialised countries and advanced developing nations.	All countries, ad hoc differentiation of measures possible.

Route 3: A regional start

This option proceeds from the idea of international transport emissions being be incorporated in EU policies and measures. Subsequently, these policies may be extended to larger geographical scopes through international agreements, thereby increasing the coverage of climate impacts of international aviation and maritime shipping.

A major advantage of this approach is that is does not depend on agreement being reached in a wider international context. Pro-active countries may together decide to set an example by reaching agreement on mitigating the climate impact of international transport, thus demonstrating they take climate policy seriously and possibly inducing less well developed countries to adopt measures, too.

The pivotal choice to be made in elaborating this idea is: which new or existing policy or policies can be implemented in a regional context to mitigate the greenhouse gas emissions of international transport?

A regional start for aviation

In the case of aviation we chose to focus on the possibility of including emissions in the EU emission trading system (ETS), in line with developments at the European Commission. This system would be a good example of a regional start, especially as it is official EU policy to extend the ETS to other countries and regions.

We consider three options for expanding such a scheme to include aviation:

1 Expanding the system in the European Economic Area (EEA).
2 Expanding the system parallel to EU enlargement.
3 Expanding the system to countries / regions that are not part of the EU.

All EEA States have agreed to implement EU legislation on social policy, consumer protection, the environment, statistics and company law. Directive 2003/87/EC, the Greenhouse Gas Emission Trading Directive, is among the directives that all EEA states will have to implement in their national legislation. This means that if the directive is amended in order to incorporate aviation emissions, EEA states will incorporate aviation as well.

When countries join the EU they must implement Directive 2003/87/EC as part of the *Acquis Communautaire*. This means that aviation emissions would be included in the same way they are in existing Member States.

Other Annex I signatory states of the Kyoto Protocol could in principle join the EU ETS and thereby include aviation in the ETS. To date, however, these parties have shown limited interest in joining the ETS. Extension of the scheme to non-Annex I parties, be they signatory states to the Kyoto Protocol or not, would not make sense under the current structure of the Protocol. After all, these states do not have emission targets, whereas the ETS is a cap-and-trade system, for which a cap (and therefore an absolute target) is essential.

A regional start for maritime shipping

In comparison with aviation, a coordinated regional EU policy to mitigate the climate change impact of maritime shipping is still further away. Any such policy would need to take account of the nature of greenhouse gas emissions and the nature of the maritime transport sector.

The main aspects are:

- Greenhouse gas emissions have global effects, which policies to mitigate them must take into due account. Policies limiting these emissions in one region while simultaneously increasing them in others are ineffective.

- Carbon dioxide emissions are the immediate result of fossil fuel combustion and cannot be mitigated by after-treatment of exhaust gases, as in the case of certain air pollutants. Low-emission propulsion systems are not currently available.
- States have jurisdiction over ships under their flag and in their ports, and over goods and persons within their territory. This means that policy instruments must target ships in EU ports, under EU flags, or the goods and people they carry, as measures based on other (wider) scopes are unenforceable.
- Ships can easily change flag, and often do so, and a policy covering only EU-flagged ships is therefore likely to lead to evasion and competitive distortions. Similarly, policies geared solely to ship owners, transport companies or operators from the EU could inflict competitive distortions and incentivise evasive behaviour, thereby undermining effectiveness.
- Ocean-going ships can typically bunker fuel for several trips. Moreover, it is common practice to refuel outside ports, at sea. This means vessels do not have to bunker in every port they visit. As a result, any local, national or regional tax on fuel taken in could easily be avoided and thus have a very limited effect on fuel consumption, for ships would choose to bunker fuel outside the tax area.
- Ships are often chartered by the owner of the cargo for transportation thereof, with typical lease contracts specifying that the cargo owner must pay for the fuel consumed. The owners or operators of ships may consequently have no incentive to reduce fuel consumption or emissions.

Because of these considerations, a large number of potential EU policies are ruled out. Policies that may be effective in mitigating greenhouse gas emissions from international maritime shipping would either target ships sailing or at berth within EU jurisdiction, or the cargo or passengers they transport.

New policies that could be introduced and existing policies that could be extended to create economic incentives to ships to mitigate greenhouse gas emissions are:
- Inclusion in the ETS.
- Charges (either differentiated existing charges or new charges).
- Performance standards.

None of these policies has any clear advantages over the others. Inclusion in the ETS could build on existing measures, but it may be hard to define the geographical scope of the emissions to be included in the system. This same difficulty could hamper the feasibility of charges. Performance standards would have the advantage of standards already being common in shipping, with the sector proving able to cope, but the metric is still very much in an experimental stage.

Table 6 summarises the feasible concepts for a regional start.

Table 6 Concepts for a regional start

Concept	E Aviation	F Maritime shipping
Allocation	No allocation.	No allocation.
Sector	Aviation.	Maritime.
Responsibility for emissions	Aircraft operators.	Ship operators.
Nature and level of commitment	Absolute target (cap).	Absolute target (cap) (ETS). Relative target (performance standard). Neither relative nor absolute (differentiated charges).
Kinds of policy measures	Emission trading.	Emission trading; differentiated charges or performance standard.
Coverage of the measures	CO_2 only; flanking instruments for other impacts.	CO_2 only (ETS and differentiated charges). All impacts (performance standard).
Roles of Parties, Groups of Parties, UNFCCC, ICAO and IMO	No roles for parties outside the EU, unless ICAO develops guidance prior to adoption of the legislative proposal.	No roles for parties outside the EU, unless IMO develops guidance prior to adoption of a legislative proposal (in case of ETS and differentiated charges). IMO develops performance standard (in case the EU chooses performance standard as a policy instrument).
Geographical scope	Intra-EU, all departures from EU airports or all arrivals at and departures from EU airports.	All voyages arriving in EU harbours.

Assessment of the policy regimes

In the final part of the report, the policy regimes presented under the three routes above are assessed on environmental, political, economic and practical criteria.

The environmental criteria include the coverage of climate impacts, the scope for evasion and the incentives for action. Although the technology based sectoral scheme has the potential to address all climate impacts, coverage is judged negatively because it is unlikely to effectively address the projected growth in emissions. In the regional start route, coverage is less than in a global climate policy regime because only regional emissions would be covered by the policy.

In developing the policy options, we have specified in such a way as to prevent evasion by flagging out. Another source of evasion arises from so-called border effect: policies differentiating between routes may induce transport via alternative routes. The allocation approach based on departure / destination of passenger / cargo and the technology based sectoral approach would not induce this kind of behaviour. All the other concepts may be hampered by the border effect.

All policy options have been specified such as to induce the least developed countries to take action, too, by allowing for CDM or sectoral CDM (CDM which is not project based, but sector based). Only in certain variants of the regional approach for maritime shipping is this incentive unavailable.

The political criteria adopted relate to equity and coherence with EU policy. The two concepts based on emissions being allocated to countries score best on equity, as these incorporate the climate impacts of international transport in multi-stage targets designed specifically to reflect the equity principles enshrined in the UNFCCC. The sectoral approach with an emission cap also distinguishes between regions that are capable of taking action and regions that are not. Depending on how this differentiation of commitments is implemented, this concept is also equitable. Concepts based on the regional start route suffer from the fact that some of the most developed nations may not take action. This hampers the equity of these concepts.

Coherence with EU policy relates both to allowance for growth and to the polluter pays principle. All concepts address emissions rather than transport levels. They therefore allow for maximum growth within the constraints of climate policy objectives.

Under most of the concepts developed, the polluter pays principle holds. Under the technology based sectoral approach, commitments are likely to be least stringent, and external costs will only be internalised to a minor extent.

The economic criteria adopted relate to efficiency and the potential for market distortions. Efficiency addresses the questions of whether measures are taken at lowest cost and whether climate impacts are in fact reduced. The regional start for aviation and the sectoral approach with a cap score well on this point, because they are based on cap-and-trade systems. So are, most probably, the concepts based on allocation. The technology based sectoral approach scores negatively, because technical standards do not create incentives to implement the cheapest options first. The same holds for the regional start for shipping that would be based on either technical or performance standards.

All options score well on the criteria of market distortions, because all concepts introduced either have no differentiation or a differentiation on routes.

The technical feasibility of the various concepts was assessed by considering data availability and enforceability. Fuel use data are generally available, although it may be necessary to further develop monitoring and reporting standards. The concept based on allocation to departure / destination of passenger / cargo scores poorly on this criterion, because different data sources would have to be combined. For the same reason, enforceability may be difficult for this option.

The results of this assessment are presented in Table 7.

Table 7 Assessment summary

	Allocation		Sectoral approach		Regional start	
	A Route of vessel or aircraft	B Route of passenger or cargo	C Emission cap	D Technology based	E Aviation	F Shipping
Environmental criteria						
Coverage	+	+	+	-	±	±
Evasion	-	+	-	+	-	-
Incentives	+	+	+	+	+	+/-
Political criteria						
Equity	+	+	+	-	±	±
Transport growth	+	+	+	+	+	+
Polluter pays	+	+	+	±	+	+
Economic criteria						
Efficiency	+	+	+	-	+	+/±
Market distortions	+	+	+	+	+	+
Practical criteria						
Data availability	+	-	+	n.a.	+	+
Enforce ability	+	-	+	+	+	+

(n.a. = not applicable)

In sum, the following three policy options score best.

Concept A: Route-based allocation and stacked policies and measures
Emissions are allocated to the country of arrival or departure of the vessel or aircraft. Differentiated responsibilities are reflected both in the type of commitment and the policy instruments introduced. Industrialised countries would have absolute caps, with advanced developing countries being assigned relative emission targets and least developed countries given no commitments. These least developed countries could be incorporated in the climate policy regime via CDM, while advanced developing countries could introduce technology standards, emission charges and sectoral CDM. The industrialised countries could apply a whole range of instruments, including RD&D, technology and performance standards, emission charging and emission trading. Only greenhouse gas (i.e. CO_2) emissions would be targeted directly, but flanking policies could be introduced for the other climate impacts. Alternatively, non-CO_2 climate impacts could be incorporated by means of a multiplier. The UNFCCC would set targets and enforce them, whereas ICAO and IMO would develop guidance on policies and measures. The countries themselves would be responsible for implementing the policies and measures.

Concept C: Sectoral approach with emission cap
The emissions of international transport would not be allocated to specific countries, but ICAO and IMO would be held responsible. They would take on a cap for these emissions and organise emission trading and the introduction of technological policy measures. The cap would be agreed with the UNFCCC COP in order to assure the

exchangeability of trading units within the sectoral trading systems and within other trading systems. Potentially, non-CO_2 climate impacts could be incorporated by means of a multiplier. Countries would enforce the compliance of aircraft and vessel operators with the international policies. Differentiation of commitments could be accounted for by only including emissions on routes within and between industrialised and advanced developing countries.

Concept E: A regional start for aviation: inclusion in the ETS
Emissions from aviation would be included in the EU ETS. This could hold for all flights departing from EU airports, or to an alternative geographical scope. Potentially, non-CO_2 climate impacts could be incorporated by means of a multiplier. Aircraft operators would be made responsible for emissions and could purchase additional allowances on the EU ETS market as necessary. In the event of the scheme being extended to other countries / routes, there could be differentiation between routes.

1 Introduction

1.1 Policy background

The international aviation and shipping sectors contribute significantly to climatic change and air pollution (IEA, 2005). In recognition of this fact, the Kyoto Protocol states in Article 2.2 that:

> The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.

However, in the almost ten years since the Kyoto Protocol was signed by 84 countries in 1997, very little progress has been made on this issue.

Until now Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have not been able to agree on a methodology to assign responsibility for greenhouse gas emissions from these sectors. The UNFCCC and its subsidiary body SBSTA have devoted much attention to the allocation of emissions to parties, but the discussion has not led to an allocation option which is favoured by many or most parties involved.

In addition, the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) have not been able to agree on any action to ensure effective implementation of mitigation policies to reduce greenhouse gas emissions from international aviation and shipping, other than agreeing on best practice in terms of air traffic management operations, in the case of ICAO. It is true that ICAO is currently investigating the possibilities of an open emissions trading system for aviation. It may even issue guidance for the implementation of open emission trading, but it is not expected that this alone will mitigate emissions. The IMO has issued guidelines for voluntary trials with a CO_2 index for ships, but has not adopted policies or even issued guidance on measures to reduce emissions based on the CO_2 index.

More progress has been made at a regional level. The European Commission has announced that it will issue a legislative proposal for the inclusion of aviation in the European Emission Trading Scheme, which is one of the policy measures of the European strategy to meet the Kyoto target. However, although this may reduce greenhouse gas emissions from aviation, it will do so only in a limited geographical scope.

In the meantime, the UNFCCC has started two processes to explore climate policy post 2012. The first, under the UNFCCC, is a ‘dialogue on long-term cooperative action to address climate change by enhancing implementation of the Convention’. It will engage parties in an exchange of experiences and an analysis strategic approaches for long-term cooperative action to address climate change. The second, under the Kyoto Protocol, is ‘a process to consider further commitments for Parties included in Annex I for the period beyond 2012 in accordance with Article 3, paragraph 9, of the Protocol'[1]. Both the Dialogue and the Article 3.9 process will most likely consider the inclusion of emissions from bunker fuels.

This report is intended to add to the current processes by showing viable ways to include aviation and navigation in a post 2012 climate policy regime. Furthermore, it explores the possibilities to mitigate emissions from bunker fuels without bringing them under a global climate policy, for example by a regional start.

1.2 Problem analysis

In our view, the current deadlock in addressing the climate impacts of international transport globally can be attributed to the following factors:

- Policies and measures are discussed within ICAO and IMO, whereas allocation is discussed in SBSTA. These discussions are hardly linked. But an effective climate policy would require agreement on both allocation and policies and measures.
- Under the Kyoto Protocol, only Annex 1 countries have quantitative targets and legally binding commitments. Within IMO and ICAO, many non Annex I countries have argued that it would be not be in line with the current global climate policies to impose mitigation measures on their airlines, shipowners. However, since international transport is a global business, leaving out non Annex I countries could lead to serious distortions of competitive markets.
- Many proposals have been brought forward on ways to include advanced or rapidly growing developing countries, such as Brazil, South Korea, China and India in a global climate policy regime. However, to date, these proposals have not addressed international transport in full detail.

1.3 Goal of the study

The goal of the study is to develop policy regimes on the basis of three basic ideas: allocation to countries, a sectoral approach and a regional start. It draws on literature on allocation, on policies and measures and on post 2012 climate policy. The study will show which choices have to be made in the different regimes and what the pros and cons of the different choices are.

The current study aims to overcome the first part of the problem analysis by incorporating policies and measures, commitments and the differentiation of targets and commitments simultaneously. It does so along three routes:

1 Allocation of emissions to countries. Emissions are allocated to countries by the UNFCCC and are included in national emission reduction targets. It is up to the countries to decide on how emissions will be limited. In case this takes place in coherence with work through ICAO and IMO on the field of measures and instruments, countries will know at the moment of taking responsibility, how emissions can be limited and the potential for limitation.

---

[1] Article 3.9 states that in 2005 at the latest, the 'consideration' of 'commitments' for Annex I parties for the post 2012 periods shall begin, and that they shall have the form of Annex B of the Kyoto Protocol, which currently lists a quantified emission limitation or reduction commitment for each Annex I country as a percentage of the emissions in a base year or period.

2 Sectoral commitments. The emissions of international transport are allocated to the aviation and maritime sector. Both sectors take on commitments or targets. The UNFCCC determines the target and the timetable, whereas ICAO and IMO set the policy measures.
3 A regional start. Emissions from international transport will be incorporated into EU policies and measures. Subsequently, these policies may be extended to a larger regional scale through international agreements, thereby enhancing the geographical coverage of climate impacts from aviation and navigation.

In order to overcome the second and third part of the problem analysis, this report envisages a different architecture of a global climate policy regime than the Kyoto Protocol. It builds on the so-called Multi Stage approach, an incremental but rule-based approach, which assumes a gradual increase in the number of parties taking on mitigation commitments and in their level of commitment as they move through several stages according to participation and differentiation rules (Berk and Den Elzen, 2001). The Multi-Stage approach has been selected because it fulfils best the various criteria (environmental, political, economic, technical, institutional) in the multi-criteria evaluation of the approaches of Höhne and Den Elzen and Berk (2003).

The Multi Stage approach is being developed to ensure that countries with similar circumstances in economic, developmental and environmental terms have comparable commitments under the climate regime. It addresses some of the current objections that some countries have against the Kyoto Protocol, such as that the Annex I versus non-Annex I dichotomy leads to a distortion of competition. The Multi Stage approach has not been designed to overcome the problems with international transport. However, since a future climate policy regime is likely to include more groups of countries than just Annex I countries, and since commitments could well take different forms, this reports takes the Multi Stage approach as a starting point. It adds to the current thinking on the Multi Stage approach by incorporating international transport.

Currently, much uncertainty exists with regard to the political will to agree on international action to combat climate change. This uncertainty and possible ways to engage countries in a global climate policy regime is not the primary subject of this report. Rather, this study addresses the issue *how* international transport could be incorporated in either an international or a regional climate policy, *assuming* that a sufficient number of parties agrees that such a policy is desirable.

1.4 Outline of this report

This report first presents an analysis of the climate impacts of aviation and maritime transport, based on the current scientific understanding. After that, chapters 3 through 5 develop concepts for the inclusion of aviation and maritime transport in a future climate policy. Chapter 3 starts from the basic idea that emissions are allocated to countries and included in the national totals. Chapter 4 develops concepts on the basis of allocation to sectors. And chapter 5 explores the possibilities of a regional start. The final chapter assesses the concepts.

2 Current and future climate impacts

The climate impacts of aviation and maritime transport are not limited to emissions of greenhouse gases covered by the Kyoto Protocol[2]. Both activities give rise to other climate impacts, some of which contribute to global warming, while others reduce the greenhouse effect. Not all of the climate impacts can be addressed in the same way as greenhouse gas emissions. Section 2.1 describes the different types of impacts and the implications of the existence of indirect impacts for policy. The main conclusions of this section are that there are significant non-greenhouse gas climate impacts, but because there is no good metric to compare these impacts to the impacts of greenhouse gases, and because the impacts are qualitatively different, it is very hard, if not impossible, to address these impacts by current climate policies.

Section 2.2 quantifies the size of the impacts of CO_2 emissions (which is the impact that can be quantified best) and develops scenarios for future development of the climate impacts. It shows that the climate impacts of aviation and maritime transport are likely to increase considerably in the near future. Therefore, leaving them out of a climate policy regime aimed at preventing dangerous anthropogenic interference with the climate system would put a large burden on land based sectors.

2.1 Climate impacts of aviation and maritime transport

Aviation effects on climate have been the most studied of transportation sectors being considered since the early 1970s (Lee, 2003) although the subject has had more extensive study since the mid 1990s. Shipping effects have been under discussion more recently, for approximately the last 10 years, and are less well studied.

'Radiative forcing' (in units of Watts per square metre) is the climate metric used in science (*cf* policy metrics) and is defined as the globally averaged perturbation to the Earth-atmosphere energy system. Radiative forcing (RF) is used as a metric because many GCM (General Circulation Model) experiments have shown that there is an approximately linear response between the change in global average RF (ΔRF in W m^{-2}) and the change in global average surface temperature response (ΔT_s in K), with some proportionality constant, the 'climate sensitivity parameter', λ in K (W $m^{-2})^{-1}$, i.e:

$$\Delta T_s \approx \lambda \, \Delta RF \qquad [2]$$

More recent detailed work has challenged this assumption for some climate forcings (e.g. Joshi, 2003; Hansen, 2005) but to a first-order, the linearity assumption is robust and a λ value warranted.

2 Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulphur hexafluoride (SF_6).

For long-lived greenhouse gases (GHGs), it is necessary to consider the *history* of the emissions as this will affect the current-day RF. For the shorter-lived effects, such as those from particles or ozone (O_3), the instantaneous forcing is an adequate descriptor. Because of the long lifetime of, e.g. carbon dioxide (CO_2), the current-day forcing does not describe the ultimate forcing or its temperature response, as this will be reached at some time in the future. Simple calculations where aviation CO_2 emissions cease, or are kept at constant levels, illustrate this point (see CE Delft, 2005). In both cases, the calculations show that the temperature response will continue to rise for some time.

Whilst the usage of RF and other climate metrics (see Fuglestvedt, 2003) is generic issue, RF is currently still the appropriate metric to quantify present and potential future climate impacts for various scenarios of aviation and shipping emission, and will be used in the following sections to describe and quantify their relative effects. The Global Warming Potential (GWP) is quite a different metric and was designed to provide equivalence between future effects of emissions, over a given time-frame. Thus, GWP is suited for issues such as emissions trading and is essentially a *forward-looking* metric: RF is used for quantification of effects (to date, or at some future date) and is essentially *backward-looking*.

Individual and overall effects of aviation on climate

The most definitive overall assessment of knowledge of aviation emissions and their effects remains the Special Report of the Intergovernmental Panel on Climate Change (IPCC), '*Aviation and the Global Atmosphere*' (IPCC, 1999). This report provides a wealth of detail on aviation emissions, their effects, and the underlying technologies that affect emissions. One of the principal – and most used – outputs of IPCC (1999) was the RF charts that quantify aviation's effects for 1992 and 2050.

The individual RFs for present-day aviation (the reference year was 2000, *cf* 1992 for IPCC) have been recently been re-assessed by Sausen (2005), since some components needed updating in the light of improved models and data within the FP5 project 'TRADEOFF'. Sausen (2005) quantified aviation RF (total and its component parts) for the year 2000. This showed that whilst traffic had increased over the period 1992 (IPCC baseline) and 2000 and that this was reflected in fuel use and therefore CO_2 RF, other forcings had not changed proportionally since either models or underlying science (or both) had improved over the intervening period between IPCC and TRADEOFF. The updated assessment of aviation's total RF according to Sausen (2005) was 47.8 mW m^{-2}, representing 2.1% of total man-made forcing in 2000[3].

The individual components of aviation's effects on RF and their origins are summarized qualitatively in the text and quantitatively in Figure 1.

Carbon dioxide is produced in direct proportion (~3.16) to (kerosene) fuel usage and has a positive RF (warming) effect. In terms of calculating RF at any given point in time, it is necessary to consider historical emissions (e.g., see Sausen and

[3] Calculated using the total RFs presented by IPCC (2001) for which best estimates were provided (see Chapter 6, Table 6-11 of IPCC, 2001), correcting the contrail forcing for the revised assessment of Sausen (2005).

Schumann, 2000) because of the lifetime of the gas. The year 2000 CO_2 forcing of 25.3 mW/m^2 (*c.f.* 18 mW/m^2) is in line with aviation growth since 1992.

Ozone is produced from emissions of nitrogen oxides (NO_x=NO+NO_2) via complex tropospheric chemistry. Ozone is a GHG and has a positive RF (warming). Ozone production at cruise altitudes is particularly efficient and removal (sink) terms are smaller than at the earth's surface resulting in a longer lifetime than O_3 produced there (e.g. see Gauss, 2006). In addition, O_3 has a stronger RF effect at altitudes than at the earth's surface, so the resultant O_3 RF from NO_x emissions is greater than NO_x sources at the earth's surface (see, e.g. Forster and Shine, 1997). The O3 RF calculated by IPCC (1999) was 23 mW/m^2 whereas the more recent estimate made by Sausen (2005) was 21.9 mW/m^2: it is considered that this smaller RF than might be expected from increased traffic is the result of better chemistry transport models (CTMs) with increased horizontal and vertical resolutions.

Methane (CH_4) arising from other emissions sources (e.g. agriculture, land-use, coal mine gas leakage, etc.) is *reduced* from aviation NO_x emissions. This is because of the complex interaction of additional NO_x emissions with tropospheric chemistry. This is effectively a negative RF or cooling effect. IPCC (1999) estimated the reduction of ambient CH_4 concentrations to be approximately 2%. Similarly to the O_3 RF, this has not changed in line with traffic. IPCC (1999) estimated this to be -14 mW/m^2, whereas Sausen (2005) estimated -10.4 mW/m^2. It is likely (although not tested rigorously) that this smaller RF is also the result of improved resolution of CTMs.

Water vapour (not to be confused with contrails) has a direct positive RF (warming) effect. Water vapour is also produced in direct proportion to fuel usage but the addition of H_2O on the natural hydrological cycle is small, and consequently has a small RF effect. Note that this would be different in the case of supersonic aircraft that would fly in the (dry) stratosphere (IPCC, 1999). Consequently, the RF estimate of Sausen (2005) of 2 mW/m^2 (over 1.5 mW/m^2 of IPCC, 1999) is a simple result of an increase in traffic

Sulphate particles are emitted as a result of the presence of sulphur in the fuel. Fuel sulphur is thought to be largely emitted as sulphur dioxide (SO_2) and a fraction converted quickly within the plume from S^{IV} to S^{VI} (essentially sulphuric acid – H_2SO_4 – or some hydrated form) or more slowly within the ambient atmosphere. The H_2SO_4 either self nucleates or coats pre-existing particles and has a small (at levels emitted) negative RF (cooling) since the particles scatter incoming solar radiation. Since the emission factor scales with fuel usage, the magnitude of the negative RF has increased from -3 mW/m^2 (IPCC, 1999) to -3.5 mW/m^2 (Sausen, 2005).

Soot particles are emitted as a product of the combustion process. These particles (at levels emitted) have a small positive RF (warming). The emission factor(s) for soot is not well known and a small decrease in RF has resulted from 3 mW/m^2 (IPCC, 1999) to 2.5 mW/m^2 (Sausen, 2005).

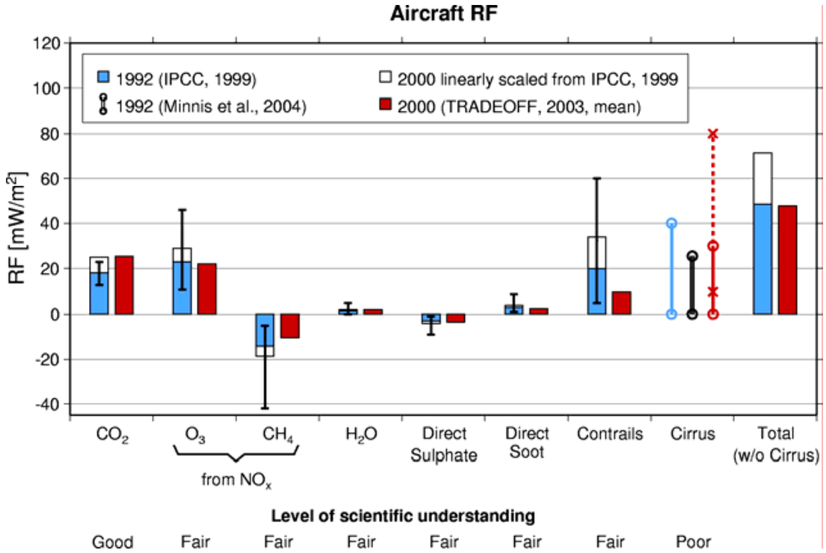
Contrails are formed initially from the water vapour and particles emitted in the exhaust of the aircraft engine. Persistent contrails only form when environmental conditions of temperature and ice-supersaturation favour their formation and development; thus, the aircraft 'triggers' the formation of these ice clouds and the bulk of the water in a persistent contrail is from the background atmosphere. Contrails give rise to both positive and negative RFs, i.e. cooling from backscatter of incoming solar radiation and warming from long-wave radiation (and thus, particularly at night). The magnitude of the two effects is a product of time of day, and overall results in a positive RF (warming). The magnitude has been under some investigation and a wide range of estimates has been made (3.5 – 20 mW m^{-2}) and this remains an effect of uncertain magnitude. Model calculation have been improved with revised assumptions on optical thicknesses of contrails which strongly influences the calculated RF. Sausen (2005) provided a mid-range estimate of 10 mW/m^2.

Cirrus clouds are a natural phenomenon but may be enhanced by aviation, primarily from spreading persistent contrails; also, it is possible that an indirect effect of seeding of the upper atmosphere with particles also enhances cirrus cloud formation. There is no estimate of RF from this 'contrail-cirrus' effect that has the degree of robustness that other aviation RF effects has. Estimates are generally given as a range and could be 0 through to 80 mW m^{-2} (Sausen, 2005; Stordal, 2005).

In both the cases of IPCC (1999) and Sausen (2005), the potential RF from enhanced cirrus cloudiness caused by aviation was excluded in the total. However, whilst the estimate of contrail-cirrus by IPCC (1999) had only a large uncertainty range and no best estimate, there is now a much better evidence base for this effect from analyses of satellite data of cirrus cloud trends (e.g. Zerefos, 2003; Stordal, 2005). Stordal (2005) whilst acknowledging remaining large uncertainties, bounded the contrail-cirrus RF between 10 and 80 mW m^{-2}, with a 'mean' (not a best estimate) RF of 30 mW m^{-2}.

More recently, Mannstein and Krebs (2006) have presented tentative analyses of contrail-cirrus forcing of 300 mW/m^2 (Mannstein and Krebs, 2006). The uncertainties are given as being very large (±300 mW/m^2) and are based upon scaling regional coverages and estimated forcings, so should currently be viewed as provisional.

Figure 1 RF [mW/m^2] from aviation for 1992 and 2000, based on IPCC (1999) and TRADEOFF results.



Note: The whiskers denote the 2/3 confidence intervals of the IPCC (1999) value. The lines with the circles at the end display different estimates for the possible range of RF from aviation induced cirrus clouds. In addition the dashed line with the crosses at the end denote an estimate of the range for RF from aviation induced cirrus. The total does not include the contribution from cirrus clouds.

Individual and overall effects of shipping on climate

The state of science for shipping effects upon climate is not as advanced as it is for aviation, and no detailed assessment has been undertaken[4]. However, a body of research work reported in the scientific literature has become available, along with some preliminary calculations of RF which are summarized here.

The individual effects of shipping emissions on climate are similar in many respects to those of aviation in that there are direct GHG emissions, other GHGs affected by NO_x emissions, particles and cloud effects. However, some of these effects (particularly clouds) are quite different in nature and potentially have large *negative* RF effects. These are summarized below.

Carbon dioxide is produced in direct proportion to (diesel[5]) fuel usage and has a positive RF (warming) effect. As is the case for aviation, it is necessary to consider historical emissions in order to calculate concentrations and resultant RF because of the lifetime of the gas.

Ozone is produced from emissions of nitrogen oxides (NO_x=NO+NO_2) via complex tropospheric chemistry. Ozone is a GHG and has a positive RF (warming). Ozone production at the earth's surface is less efficient than in the upper troposphere/lower stratosphere (UT/LS). However, shipping emissions of NO_x often occur in 'clean air'

4 In this context, a recently awarded Strategic Support Action (SSA) of the European Commission, 'ATTICA' (European Assessment of Transport Impacts on Climate Change and Ozone Depletion) will provide assessments of aviation, land transportation and shipping impacts on climate. In addition, it will provide an assessment of metrics and an overarching cross-sectoral comparison. The project commenced 1st June 2006 and the coordinator is DLR, Institut für Physik der Atmosphäre, Oberpaffenhofen. DSL is leading the aviation assessment, providing input to the shipping and metrics assessments. See place-holder web page; http://www.pa.op.dlr.de/attica/

5 Most of the fuel used in shipping is diesel-fuel oil.

regions, where the production rate of O_3 (per NO_x molecule) is greater than that in polluted areas. Moreover, the dry deposition 'sink' term is less over the ocean than over vegetated land, so that it is possible that marine boundary layer O_3 has a longer lifetime than that formed over land. The resultant forcing from O_3 is also smaller (for O_3 at the Earth's surface): however, the O_3 produced can be vented to more radiatively effective altitudes through convection and approaching frontal systems (so-called 'warm conveyor belts').

Methane (CH_4) is both emitted by shipping (0.2 Tg yr^{-1}, according to Eyring, (2005a)) and consumed by shipping emissions of NO_x via tropospheric chemistry. Whilst the emission of CH_4 from shipping is very small component part of the global emission term (~700 – 800 Tg yr^{-1}), this may offset a fraction of the 'negative' CH_4 forcing from NO_x effects on tropospheric chemistry.

Water vapour will be emitted from shipping in proportion to the fuel usage. However, it is very unlikely that this will have any RF effect as it will be an extremely small fraction of the hydrological cycle.

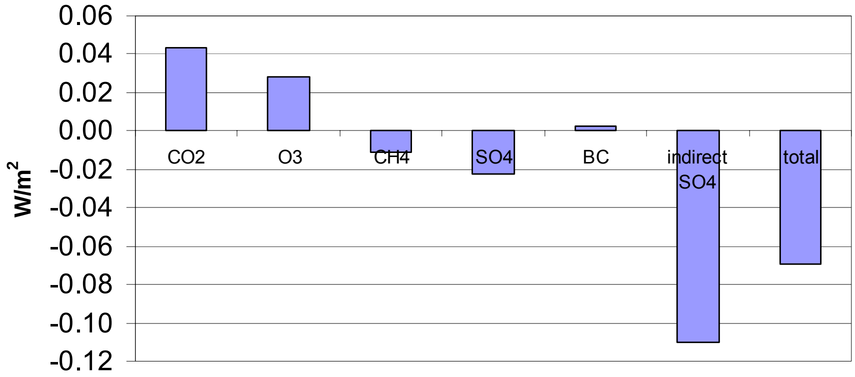
Sulphate particles are emitted as a result of the presence of sulphur in the fuel, as is the case for aviation. The fuel sulphur content of shipping fuel is greater than for aviation (which has limits) and therefore it is likely that the direct (negative) RF will be much larger than it is for aviation.

Soot particles are emitted as a product of the combustion process. These particles (at levels emitted) have a small positive RF (warming).

'Ship tracks' are clouds formed from emissions of water vapour and particles in the marine boundary layer which can form line-shaped persistent stratiform clouds that are clearly visible from satellite imagery. This addition of particles to the marine atmosphere is thought to have a strong negative (cooling) RF, which is often referred to as the 'indirect cloud effect'. It should be noted that the 'cloud-effects' of aviation and shipping, i.e. contrails/contrail-cirrus and ship tracks have different overall effects – aviation warming; shipping cooling. Aviation contrails (and contrail-cirrus) are calculated to warm overall since there are two competing effects of back-reflected solar (shortwave) radiation and downward reflected infrared (longwave) radiation. Broadly speaking, contrails cool during the day and warm at night. The overall balance is in favour of warming (Meerkötter, 1999). Ship tracks, by contrast, provide a cooling effect because they increase albedo (reflectivity of solar shortwave radiation) but have little effect on the longwave radiation balance since they are so shallow.

Overall shipping radiative forcing. There is no reliable and thorough published assessment of shipping RF. However, Berntsen (2004) has presented a 'best guess' assessment of shipping RF. Presented in Figure 2 below is a similar chart as presented by Berntsen (2004) but also including some independent preliminary CO_2 and O_3 RF calculations from Lee (2006) which include updated calculations of shipping CO_2 and O_3.

Figure 2 Best guess RF [mW/m^2] from shipping for 2000



Source: Lee, 2006 for CO_2 O_3, CH_4, SO_4, Capaldo, 1999 for indirect sulphate and Berntsen, 2004 for BC (black carbon/soot)

The shipping CO_2 RF estimate of Lee (2006) represents a substantial (30 – 50%) increase in previously estimated forcing as it combines the historical emissions estimations of Eyring (2005) (1960 – 2000) and Endresen (2006) (1870 – 2000). It is critical in calculating CO_2 RF that a complete time history of emissions is included, which this study has done for the first time. These calculations result in a CO_2 RF in 2000 that is approximately 1.7 times that of aviation (43 mW/m^2, *cf* 25 mW/m^2). Eyring (2006) presented results of O_3 perturbations with a suite of CTMs and calculated an O_3 RF of 12.5 mW/m^2. Lee (2006) calculated O_3 RF from shipping by a simplified methodology of 28 mW/m^2. However, these different results are not necessarily in conflict: Eyring's (2006) study used emissions that were approximately half those used by Lee (2006). Moreover, Eyring (2006) found a linear response between global NO_x emissions from ships and O_3 burden. Given that O_3 burden should scale linearly to a first order with RF, a shipping O_3 RF of 28 mW/m^2 is reasonable. Clearly, the source of the discrepancy is the emissions estimates, which remain very uncertain (particularly for NO_x) for shipping. Lee (2006) also calculated the CH_4 response which was found to be negative. Whilst shipping (unlike aviation) emits small amounts of CH_4 – which should result in a positive forcing – the ratio of NO_x to CH_4 emission is large, such that the chemistry of the NO_x results in some ambient CH_4 destruction that overwhelms its own CH_4 emission term.

Currently, very little is known about the RF terms from shipping for sulphate particles and ship tracks – this is the subject of ongoing research. Simple estimates of the direct (sulphate) and indirect (ship tracks) effects are available from Endresen (2003) of -20 mw/m^2 and Capaldo (1999) of -110 mW/m^2, respectively.

In conclusion, there is more uncertainty about the climate impacts of shipping than those of aviation. The current scientific understanding suggests that overall, shipping may have a negative global mean RF, which implies a global mean cooling effect. This cooling effect is mainly attributed to sulphur emissions although the effects of reducing sulphur levels in fuel on ship track (cloud) formation, is not yet known. This is discussed in more detail in Section 2.1.1.

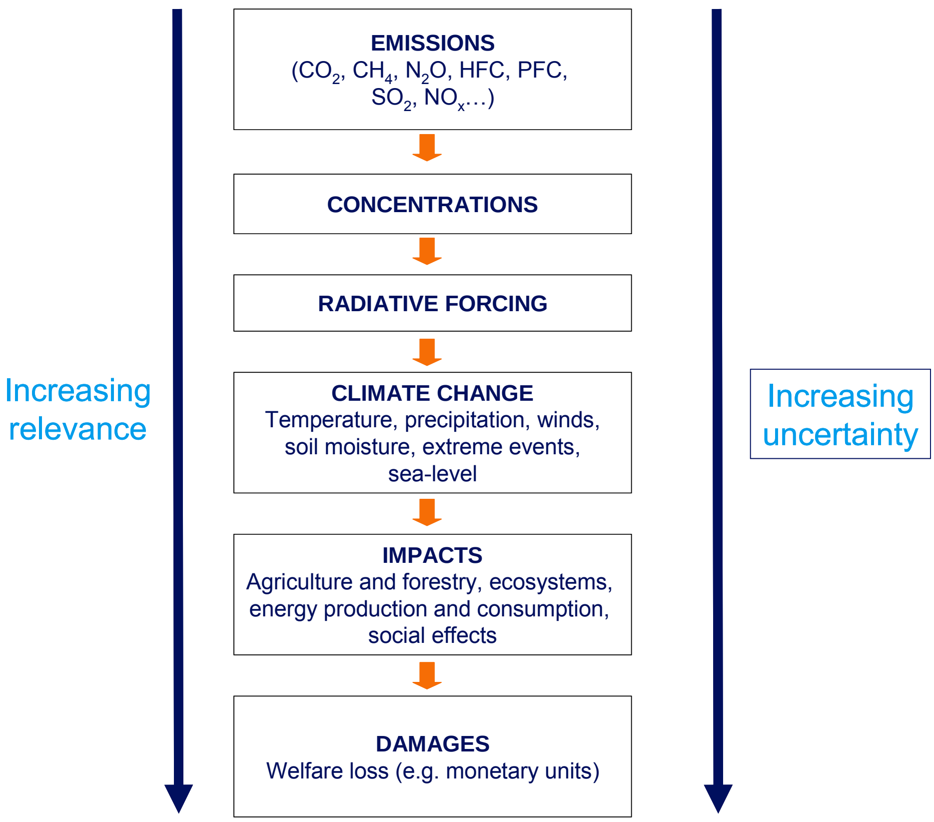
2.1.1 Climate impacts of aviation and maritime transport that can be included in a future policy regime

Climate metrics

In order to include aviation and maritime shipping in a future climate policy regime, their climate impacts have to be made comparable to the climate impacts of ground-based emissions. In other words, the metrics used to express the climate impacts need to be comparable. This section deals with climate metrics.

The subject of climate metrics is a complex one. Currently, there are broadly two metric types in usage; scientific metrics and policy-oriented metrics. Radiative forcing underlies both. Radiative forcing is a suitable metric for quantifying the effects of a range of emissions and changing conditions (such as changes in albedo from, e.g. land use change or cloud cover change) for the reasons given in Section 1.1. The sequence of events from emissions to economic impacts is summarized in Figure 3 below.

Figure 3 Overview of chain between emissions and 'damage'



Source: Fuglestvedt, 2003 and IPCC, 2001, Chapter 7.

Figure 3 not only illustrates a view of the 'chain' of events from emissions to environmental damage but the points at which different things may or may not be quantified usefully. Also, it is clear – as is illustrated – that as the quantification becomes more relevant, the more uncertainty is inherent in the calculations.

Most conceivable forms of a future climate policy regime would require:

- Quantification of emissions.
- Calculation of their effects (in some way).
- ‘Equality’ of quantification.

Quantification of emissions might generally be considered to be the essential first step but, as will be shown for some forcings from aviation and shipping, this may not be relevant. Next, *calculation of their effects* may or may not be possible, depending upon the state of knowledge and scientific understanding. Lastly, some metric needs to be invoked that allows quantification of ‘effect’ in an *equitable way*, e.g. some weighting factor that may be necessary.

It would be very attractive to use the same metric for all the Kyoto greenhouse gases (CO_2, CH_4, N_2O, HCFCs, PFCs and SF_6) and for the climate impacts of aviation and shipping. For the Kyoto gases, the metric used is the Global Warming Potential (GWP). The history, advantages and shortcomings of GWPs have been discussed in detail elsewhere (for a convenient review of the literature, see Fuglestvedt, 2003) so that only the basis will be dealt with here. The GWP was devised to provide a simple, transparent ‘weighting’ function of different greenhouse gas *emissions* over some timescale. Essentially, this is the time-integrated radiative forcing of a unit pulse emission of a gas divided by that of a reference gas (by convention, CO_2). The timeframe is effectively an arbitrary choice: however, it should be noted that the choice of longer or shorter time horizons than the generally accepted one of 100 years, alters the value of GWPs for different gases. Note that it is not possible to formulate a GWP without a reference time frame. Referring to Figure 2, it is seen that the GWP invokes an association between step 1 (emissions) through to step 2 (concentrations) and finally step 3 (RF): these – depending on the gas considered – may be non-trivial calculation steps so that a metric that associates equivalent emissions with RF is useful, even acknowledging any potential shortcomings.

Unfortunately, it has been shown that it is not possible to express a GWP for the climate impacts of aviation and shipping. The principle problem is that the GWP only works well for long-lived species and not short-lived species that are highly variable in space and time and, as a result, have highly variable RFs. Moreover, the non-linearity of the formation of some climate agents, e.g. O_3, means that even in terms of its formation, an emissions equivalency does not exist. That is, the same unit emission of NO_x will form different amounts of O_3 depending upon the background conditions of a wide variety of other species and removal process, therefore by latitude, longitude and altitude (Berntsen, 2005).

However, it may be possible to include aviation and maritime transport in a different way. Emissions of Kyoto gases can be included in the same way as Kyoto gases from ground based sources. Suggestions for accommodating other impacts include weighting functions and the use of additional policy (‘flanking’) instruments. In tackling environmental impacts from particular sources, there are many examples of the usage of different policy instruments to tackle different effects. A simple example of this might be, e.g. sulphur dioxide (SO_2): some sources have emission rate controls (or even a cap); many countries have ambient air quality standards for ambient concentrations of the gas; international protocols may limit the emission rate (on a country basis) to reduce ‘acid rain’ (strictly, wet and dry deposition of S species); lastly, even trading between sources within a country. This range of policy tools and instruments has found to be necessary to tackle one particular emission type. Similarly, it has been recognized that a uniform metric may not be possible to tackle the range of aviation and shipping effects on climate. For aviation, this has been set out in some detail by CE Delft (2005).

The principal point being made here is that there is no historical precedent from other sectors of source categories that dictates that a single instrument is either the best way forward or the most effective. In this sense, there is nothing 'different' about aviation or shipping that disallows the policy maker/regulator to makes use of a range of policy instruments that are quite different in approach, e.g. applying a mix of regulation and market-based approaches.

2.1.2 Consideration of shipping in post 2012 policy regimes

Aviation
Aviation's effects on climate with reference to GWP as a single metric for a future policy regime can be usefully considered according to the criteria stated above, i.e.:

- Quantification of emissions.
- Calculation of their effects (in some way).
- 'Equality' of quantification.

The above criteria are summarized and commented upon in Table 2, which describes whether the emission/effect can be quantified and with what quality[6]; how the effect can be quantified (e.g. a concentration which can then be quantified by RF); and lastly, whether a GWP equivalence can be calculated. Each entry provides some explanatory comment.

From Table 1, it can be deduced that most non-CO_2 effects can only be calculated with either moderate or large uncertainties (or in the case of contrail-cirrus, only with a range) and that only one effect, namely that of NO_x emissions upon O_3 can be calculated with a GWP. However, such a calculation remains highly contentious in the scientific literature (IPCC, 1999; Fuglestvedt, 2003; CE Delft, 2005).

Multipliers. The possibility of using a single 'multiplier' has frequently been raised in the policy debate. The idea is that a single number might be used to weight CO_2 emissions to capture the non-CO_2 effects for either aviation or shipping. The most frequently-cited candidate for this is the Radiative Forcing Index (RFI), which is the sum of the sectoral forcings divided by the CO_2 forcing (note, not emissions). This concept was rejected by CE Delft (2005) on technical and scientific grounds, and again more recently by Forster (2005).

The possibility of calculating equivalence with an alternative metric, the Global Temperature Index (GTI) as a modification and extension of the Global Temperature Potential (GTP, Shine, 2005) has been raised by CE Delft (2005). This has the advantage of potentially providing a single 'multiplier' on CO_2 *emissions* through

---

6 A subjective evaluation of 'large', 'moderate', and 'low' uncertainty is ascribed. Note that these uncertainties do not equate to 'levels of scientific understanding' as given in Figure 1; they relate to specific aspects of quality of the emissions and effect quantifications.

temperature response, which is where RFI fails for a number of reasons explained in detail by CE Delft (2005). However, as emphasized by CE Delft (2005), the GTI metric is not yet mature nor has it been extensively tested. Moreover, getting a new climate metric accepted and embedded in the policy process would be a major challenge.

Whether a single multiplier metric is possible and robust begs the question of whether it is *desirable*. It is conceivable that even if a robust multiplier was devised for aviation (or shipping) emissions, it may be undesirable as it could result in a large effort to reduce the emission that is being multiplied (CO_2) with the potentially perverse effect of resulting in increased other emissions. This is particularly the case for NO_x for both shipping and aviation, where there is generally a technological tradeoff between fuel efficiency and NO_x production (see footnote 9 below). However, whilst this is a potentially correct argument from the technical standpoint, it may be a specious argument from the practical standpoint. Aircraft engine manufacturers continue to need to comply with ICAO NO_x Engine Emissions Certification regulations[7] and CAEP's Working Group 3 has demonstrated that to approximately ±10-15% uncertainty, NO_x LTO stringency scales to cruise NO_x. The more real concern is that a multiplier would have the effect of pushing for greater levels of fuel efficiency than would have been the case otherwise (in the absence of an ETS), which consequently increases overall pressure ratios. The ICAO-CAEP NO_x stringency regulations allow for higher NO_x at higher overall pressure ratios (OPRs), so that the issue of whether OPRs would increase as a result of an ETS is the crux of the argument, *not* that engine manufacturers would 'abandon' NO_x control since it is 'covered' under the multiplier. There is an ongoing international requirement from ICAO to improve NO_x performance during the LTO for air quality reasons.

Flanking instruments. CE Delft (2005) also considered other ('flanking') policy instruments to capture the effects of non-CO_2 effects of aviation, and as proposed above, this is not without precedent in other sectors. To summarize their work, they considered:

- An *en route* NO_x charge, which was considered effective but politically difficult to implement.
- An ICAO-determined cruise NO_x certification regime, which was rejected for Europe on the basis that it was subject to the long timeframe deliberations of ICAO and because other political influences could jeopardize its introduction, and – as has emerged more strongly from ICAO's relevant working groups since the publication of CE Delft (2005) – cruise NO_x is likely to be effectively controlled by the existing LTO NO_x certification regime for current technologies within an acceptable margin, such that a cruise NO_x certification regime is likely to be abandoned by ICAO.
- An LTO NOx *mass* landing charge as a proxy for reducing NO_x emissions. This last instrument was favoured as it does not suffer from the current ICAO NO_x regulatory regime's metric, Dp/foo[8], which is allowed to be higher for greater OPR[9] engines. However, there is the possibility that for technologies that may be

7 See: http://www.icao.int/cgi/goto_m_atb.pl?/icao/en/env/aee.htm.

8 Dp/foo is the mass emission of NO_x in a static sea-level test at maximum thrust (kg NO_x/kN).

9 Overall Pressure Ratio of the engine: basically, NO_x control becomes increasingly difficult for higher OPR engines, which is the current technology trend. At higher OPRs, combustor temperatures and pressures

used in the future (such as staged combustors), the relationship between LTO NO_x and cruise NO_x may not be the same as it is for current technologies, such that *in extremis*, controlling LTO NO_x could conceivably increase cruise NO_x. This possibility has not been investigated or proven.

Since the publication of the report of CE Delft (2005), there is no reason to change the above conclusions, other than where outlined above.

Maritime transport

The consideration of shipping within a post 2012 policy regime is more difficult to address than for aviation since less work has been committed to shipping effects on climate, and most climate policy issues focus on international bunkers, and therefore CO_2. Nonetheless, many of the issues associated with international shipping are similar to those for aviation.

For example, CO_2 emissions are not well quantified and there is still disagreement on global CO_2 and NO_x emissions rates (e.g. Endresen, 2003; Eyring, 2005a). The same arguments on climate metrics for aviation also broadly apply to shipping, i.e. an RFI metric would not work as a simple multiplier – additionally, use of an RFI may imply a *negative* multiplier.

Given the uncertain sign and magnitude of shipping RF on climate, this raises the question as to whether any policies should be developed either for non-CO_2 effects of shipping, or for shipping at all. A simplistic view would be that with a negative total RF, shipping is benign.

However, there are more scientific and policy issues at stake. Even disregarding the uncertainties of the potential magnitude of shipping negative RFs (from sulphate particles and ship tracks), it is not clear that an inhomogeneous (local) negative RF cancels a homogenous (global) positive RF from CO_2 in terms of climate response. Moreover, if the source of the forcing were removed, the CO_2 forcing and temperature response would increase and decay only very slowly, whereas the forcing from sulphur-induced effects would disappear with a year and the temperature response equilibrate much faster (than for CO_2). So, as with all sources of CO_2 forcing, the full effect of historical emissions is not 'felt' until sometime in the future. This point is simply illustrated below in which the emissions from shipping are 'turned off' in 2000 and the RF and temperature response is shown to damp only slowly.

increase (for reasons of fuel efficiency) and the regulatory metric allows for this in that the regulatory cut-off line is sloped allowing higher Dp/foo for higher OPRs.

Figure 4 Hypothetical scenario where shipping emissions of CO_2 cease in 2000, illustrating damping response of radiative forcing and temperature response

Note: Model is that of Lim (2006) and as applied in Lee (2006) for shipping.

Figure 4 illustrates the 'unreleased potential' of shipping CO_2 emissions from 1870 to 2000, in which it can be seen that forcing damps after cessation of emissions in 2000 only slowly and temperature response continues to *increase* after 2000, until 2023 and then damps even more slowly than RF.

The above description of the behaviour of CO_2 RF and temperature response is important in considering whether shipping emissions should be considered in a policy regime at all. Sulphur emissions have other more localized effects on air quality and acidification and are therefore a potential candidate for future emissions control. This is most likely to be effected through lowering the allowable levels of sulphur in the fuel, or through exhaust gas desulphurization techniques. The International Maritime Organization (IMO – the shipping analogue of ICAO) has limited sulphur levels in fuels through MARPOL Annex VI and allows for the provision of designated SO_x Emission Control Areas.

If sulphur emissions from ships are reduced in the future, it is clear that the direct (negative) RF effect from sulphate particles will diminish. However, it is not so clear how the formation of ship tracks will respond to reductions in sulphur in fuels. It is likely that in order to reduce cloud formation, it would also be necessary to control total particulate source, i.e. sulphates and black carbon (soot). This is a subject for urgent scientific research. In the case of NO_x emissions, the available research indicates that they enhance tropospheric O_3 (e.g. Endresen, 2003; Eyring, 2006; Lee, 2006) and that there is a positive RF which is of the same order or greater than that of aviation. Emissions of NO_x are also problematic to control in shipping: the same basic technology problem exists for marine diesel engines in that if they are optimized for fuel efficiency, this makes NO_x control more difficult. This is sometimes referred to as the 'diesel dilemma'.

Thus from a scientific point of view, there are good reasons to include shipping emissions into climate policy regimes from a precautionary principle. This is because the warming effect from CO_2 and NO_x emissions is likely to continue, whilst some unknown fraction of the total direct and indirect negative RF effects arising from sulphur in the fuels may diminish with further potential fuel standards and emission abatement regulations brought in for reasons of protecting air quality and reducing acidification.

There are other, economic reasons for the inclusion of shipping into climate policies: its non-inclusion might bring about market distortions that would tend to favour shipping as a means of freight transportation. Furthermore, if external costs of shipping would not be internalised, this would lead to an overconsumption of shipping and a decrease of welfare.

CO_2 only policies. For CO_2 (only) effects of shipping, there is no reason to consider that different instruments to other sectors would be invoked. This can either be done through emissions standards – which is rare for CO_2 – or through incentives for fuel economy, or – most likely – emissions trading. The shipping sector is similar to aviation that it is a growing sector dealt with via a UN Agency (IMO) at an international aviation. Thus, the introduction of emissions trading will bring its own host of problems associated with allocation of emissions and inclusion/non-inclusion of emissions for regional ET schemes.

Multipliers. In terms of a policy instrument for accounting for non-CO_2 effects, the use of a multiplier is dubious on scientific grounds. In the first instance, the reasons elaborated by CE Delft (2005) as to the unsuitability of the usage of an RFI for aviation on scientific grounds equally apply to shipping with the added difficulty that the RFI is likely to be negative. Even if a temperature response metric were used, as tentatively suggested by CE Delft (2005) and in Section 2.3.1 as a possibility for aviation, this would also be potentially problematic. Currently, there are not enough data to be able to calculate a potential Global Temperature Index for shipping as was done by CE Delft (2005) for aviation. Moreover, because of the mix of strong positive and negative RFs, it is possible that a globally-averaged climate response is an inappropriate metric. This would need further scientific consideration.

Flanking Instruments. There are a number of potential flanking instruments that could be invoked for shipping, including: tighter IMO NO_x standards for new engines; NO_x and SO_2 differentiated harbour and fairway dues; regional restrictions on NO_x and SO_2 emissions; SO_2 reduction by lowering sulphur content of the fuel.

There are a number of advantages and disadvantages to these potential flanking instruments that closely parallel the problem with aviation which may be summarized as follows:

- Tighter IMO standards require international agreement at the global level through a consensual process – this is inevitably slow and requires much international effort.
- NO_x and SO_2 differentiated harbour dues (an analogue to an aviation ‘landing charge’) may be possible to implement locally although its potential knock-on effects have not been studied.

- Regional restrictions on NO_x and SO_2 shipping emissions may be possible through existing regional acidification protocols, e.g. UNECE-LRTAP or via a modification of the European Union's National Emissions Ceilings Directive.

Lastly, one of the easiest restrictions – in terms of technical feasibility – may be to reduce sulphur levels in fuel. This undoubtedly will have economic implications for fuel production and market supply. Moreover, it is likely that this will continue to have to be enacted though the IMO.

Table 8 Summary of aviation effects and quality of emission quantification, effect quantification and equivalence

Effect	**Emission quantification**	**Notes**	**Effect calculation**	**Notes**	**Equivalency (GWP)**	**Notes**
CO_2	Yes	Relatively easy – scales with fuel; **low** uncertainty	Concentration, RF	Requires historical emissions data; **moderate** uncertainty	Reference gas	
O_3	No	Secondary species formed from NO_x emissions	Concentration, RF	Secondary species formed from NO_x emissions: model-dependent, **large** uncertainty	Possible	O_3 GWPs can be calculated but remain contentious
CH_4	No	Secondary species affected by NO_x emissions	Concentration (reduction), RF	Secondary species affected by NO_x emissions: model-dependent, **large** uncertainty	No	Concept of negative GWPs not used
H_2O	Yes	Relatively easy – scales with fuel; **low** uncertainty	Concentration, RF	Water vapour concentrations not well characterized in UTLS; **moderate** uncertainty	No	Short-lived species
Sulphate	Yes	Relatively easy if S content of fuel is known; consequentially **moderate** uncertainty	Concentration, RF	S content of fuel not well characterized. Calculation of RF model dependent, requires assumptions on size distribution; **moderate** uncertainty	No	Short-lived species
Soot	Yes	Engine/combustor dependent, poorly characterized from measurements; **large** uncertainty	Concentration, RF	Concentrations and size poorly characterized; **large** uncertainty	No	Short-lived species
Contrails	No	Occurrence of contrails relatively easy to calculate if suitable data available	Coverage, RF	Coverage is model-dependent, RF model requires assumptions (size/shape); **large** uncertainty	No	A contrail cannot be quantitatively related to a mass emission
Cirrus	No	No current methodology for measurement/modelling	Enhancement or coverage, RF	Coverage model/data dependent, poorly characterized optical properties; **large** uncertainty	No	Contrail-cirrus cannot be quantitatively related to a mass emission

2.2 Current and future size of climate impacts of aviation and maritime transport

This section highlights current emissions from bunker fuels and trends. It is based on (MNP 2007), which can be found in Appendix **Fout! Verwijzingsbron niet gevonden.**.

2.2.1 Current bunker emissions

Historical and current emissions from international shipping and aviation are surrounded by large uncertainty. Therefore, here they have been estimated by using two different methods, top-down from national fuel sales statistics and bottom-up from aircraft and shipping characteristics (specific fuel consumption, etc.) and their statistics (numbers and length of voyage). Both approaches have their advantages and disadvantages (see textbox below).

Box 1: Approaches to estimate fuel consumption of international shipping

For international shipping, also sometimes considered equivalent to 'ocean-going ships', different datasets on historical fuel consumption and CO_2 emissions exist. The methodologies for deriving these emission data can be characterised as either top-down or bottom-up. Top-down approaches rely on national statistics on marine bunker sales to estimate global total fuel use by fuel type for international marine transport (IEA, 2005), whereas bottom-up estimates are bases on data on ship types, ship numbers, number and type of engines, average hours of operation, etc. (Eyring, 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) and 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, part of ocean-going ships is engaged in domestic activities, e.g. local coastal and short-sea traffic and trips to and from the mainland to islands belonging to the same country, which may be a substantial fraction of 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), not accounted for in the ocean-going fleet, is very difficult to estimate on a global level. However, also the accuracy of he top-down estimates is limited, since duty-free marine bunker fuels may also be sold to ships which activities are defined by the UNFCCC as domestic transport, e.g. fisheries. Also military activities may be included. Eyring (2005b) provide an overview of elements causing differences between these two types of estimations and with the national estimates that comply with UNFCCC definitions. For international marine transport we assume that the top-down estimate from the International Energy Agency (IEA) (2005) is the best estimate for the following reasons:

- Although top-down estimates includes military vessels and fishing boats accounting for about 14% and 6% of total fuel consumption (Corbett and Köhler, 2003), respectively, these 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 historical trend since 1990 of the IEA dataset is quite accurately reproduced using the trend in deadweight tonne (DWT) per ship type according to UNCTAD (2005), when assuming military fuel use to be constant over time based on the estimate of Corbett and Köhler (2003) and assuming a constant specific fuel consumption per DWT, a unit of shipping capacity.
- As shown in Table 9 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), in particular between top-down and bottom-up methods, which differ up to a factor of two (without corrections for differences in definitions).

Table 9 gives an overview of various top-down and bottom-up estimates for CO_2 emissions from global international marine transport. These show substantial differences. While the principal causes for these differences are known (e.g. a significant fraction of domestic shipping may be included in the bottom-up estimates), precise corrections in both type of datasets cannot be made.

Table 9 Top-down and bottom-up estimates for CO_2 emissions from global international marine transport

Inventory	Type	Base year	CO_2 (Tg)
Corbett (1999)	BU	1993	451
Endresen (2003)	BU	1996	461
EDGAR 3.2 FT2000	TD	2000	428
IEA (2005)	TD	2001	442
Corbett and Köhler (2003)	BU	2001	913
Eyring (2005b)	BU	2001	813

Note: BU = Bottom-Up (based on activity data of vessels); TD = Top-Down (based on bunker fuel sales).

In aviation, similar causes of differences exist between top-down and bottom-up estimates of fuel consumption and CO_2 emissions (see Figure 7). Owen and Lee (2005) provide an overview of elements that are causing differences between these two types of estimations. Top-down international statistics such as from the IEA are based on fuel sales and include military aircraft, whereas bottom-up estimates of global flights 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, and do not use real flight distances (non-optimal routes, circling around airports) and assume neutral winds for the complete flight. We therefore assume that the top-down estimate, e.g. from IEA (2005), is better than the bottom-up estimate.

Figure 7 shows that the differences between both methods are substantial.

Table 10 Top-down and bottom-up estimates for CO_2 emissions from global aviation (between brackets: international aviation)

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

Note: BU = Bottom-Up (based on activity data of vessels); TD = Top-Down (based on bunker fuel sales)

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

2.2.2 International bunker emissions under a baseline scenario

Maritime transport

For emissions of international shipping only very few source-specific scenarios exist. Although the emissions scenarios by Eyring. Eyring (2005b) are very detailed, they focus on NO_x emissions and other non-CO_2 compounds and pay little attention to the specific fuel consumption and its trend over time. Also, they do no provide a regional split in their emission projections. Thus for developing an international bunker baseline scenario, first a baseline scenario for maritime bunker emissions was developed. For this purpose, it was decided to make use of historical data on the capacity per ship type (Dead Weight Tonnes (DWT) of tankers, bulk carriers, container ships, general cargo and other) from UNCTAD (2006) and the following assumptions:

- The specific fuel consumption (SFC) per DWT per major ship type remains constant over time (as suggested by historical data, see (Den Elzen, 2007)).
- The historical fuel consumption trends were determined per type of shipping using DWT capacity per region using 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).

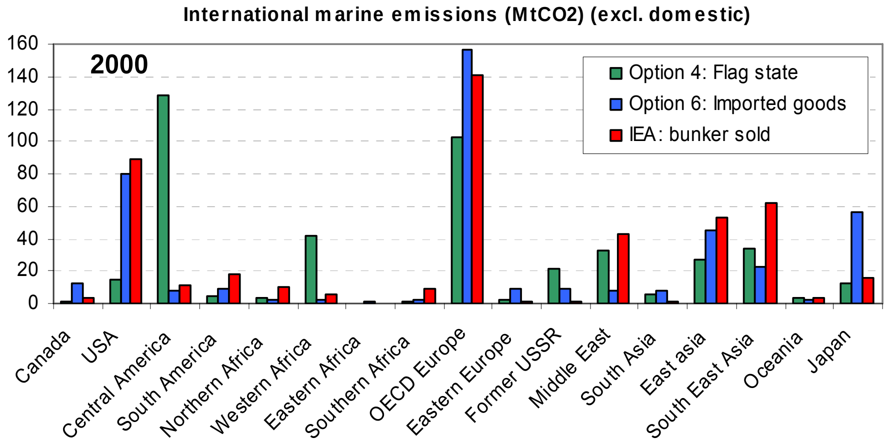
In constructing scenarios with regional detail it was necessary to allocate emission. Here, two types of regional allocations were used for the historical trend and for projections of fuel consumption and CO_2 emissions per ship type:

- As defined by flag of the country of registration; this corresponds with the STBA's *Option 4: Allocation according to the country where the ship is registered.*
- As defined by the import value per country from UNCTAD (2006) of goods which are generally transported by ships, using statistics for the major commodities per ship type to estimate the associated CO_2 emissions; this corresponds with SBSTA's *Option 4: Allocation according to the country of destination of the cargo or passengers.*

It is acknowledged 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, registration of most ships (in DWT capacity) is concentrated in a limited number of countries, in particular the Bahamas, Panama, Liberia and Singapore and also Greece, Malta and USA. For some ship types also China, Hong Kong, Norway, Germany and the Netherlands are among the most favourable flag states. However, since flag states play a key role in the implementation of IMO treaties, besides port and coastal states, and the interchanges of registration to flag states have been limited over time, we have elaborated this allocation rule in the scenarios to identify any key specific differences between the two allocation options.

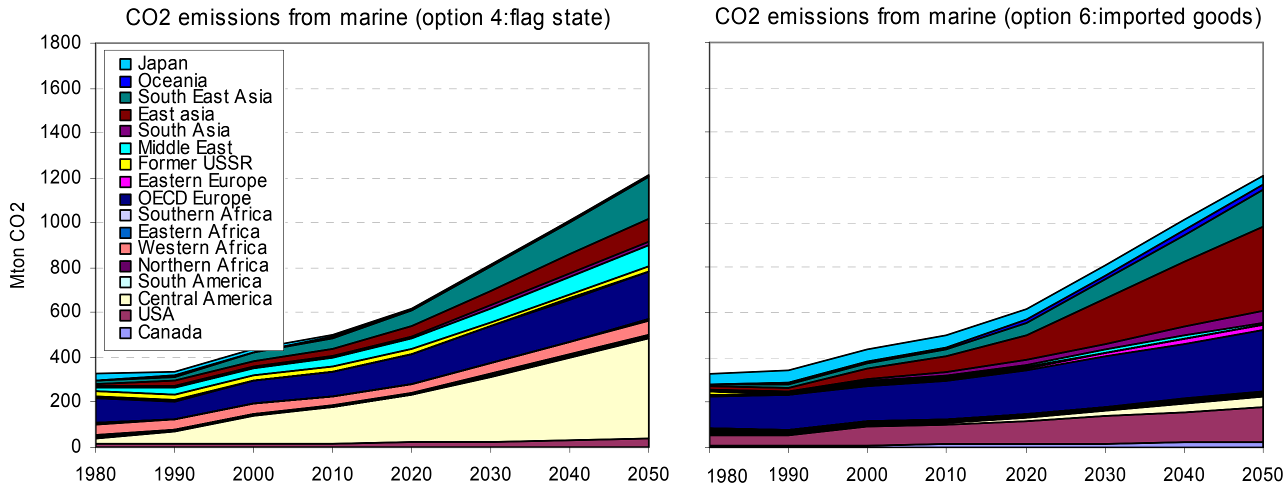
Using the historical trends of ship capacity for projecting of CO_2 emissions from 2000 onwards shows over 40% increase in emissions by 2020 and about 180% by 2050. As suggested by the differences in regional shares and trends of registration of DWT capacity per flag country and the value of imported goods (in USD) as shown described in (Den Elzen, 2007), these different allocation methods also result in much different development of the regionally allocated CO_2 emissions (Figure 5). Notable exceptions are OECD Europe and Southeast Asia, which show rather similar trends in both cases. When comparing the global trends with the four scenarios of Eyring (2005b), the projected increases in the 2000-2020 period of 41 to 46% are very similar to our business as usual scenario. However, our increase in 2050 is somewhat higher than the largest increase of about 250% in the Eyring scenarios. These differences in regional allocations 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 6). The largest absolute differences are, again, seen in the CO_2 emissions from Central America (i.e. the Caribbean) and Western Africa that show much more emissions in Option 4 (flag nations) and in USA, OECD Europe, Middle East and Japan that show much higher emissions in Option 6 (imported goods).

Figure 5 The effect of different allocation options, i.e. option 3 (bunker sold), option 4 (flag state) or option 6 (imported goods), for international marine emissions based on data from UNCTAD (2006). For comparison also the IEA bunker sales data are depicted here



Source: Den Elzen, 2006, Den Elzen 2007.

Figure 6 Baseline (trend) scenario for regional CO_2 emissions from marine transport using option 4 (flag state) (left) or option 6 (imported goods)



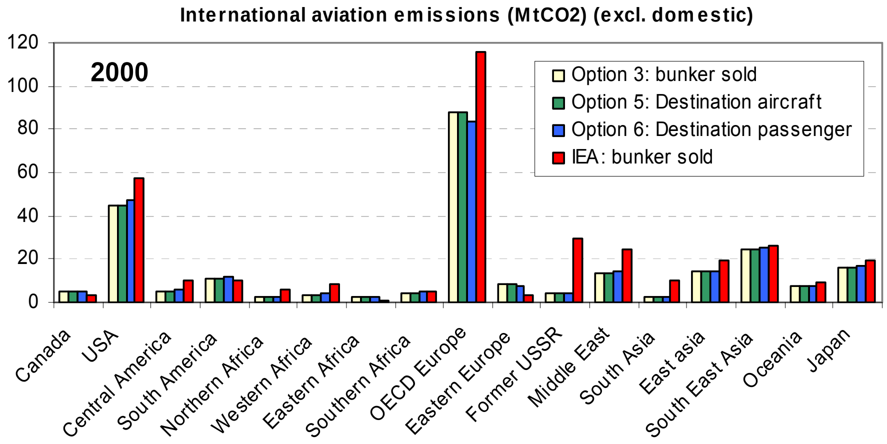
Source: Den Elzen, 2006, Den Elzen 2007.

When interpreting interregional differences please note that regional totals are the direct sum of imports by all countries within the regions and thus include intraregional transport between countries, so e.g. net imports to the EU-25 as a region will be smaller than the figures presented here, that are the direct sum of imports of every member state. Also, 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.

Aviation
Several emission scenarios for aviation have been reviewed in IPCC (1999). However, only few data sources exist which have separated out international aviation and have allocated historical fuel consumption and related CO_2 emissions for international aviation according to various options. Owen and Lee (2005) calculated the amount of emissions from international aviation, using a very detailed bottom-up method for allocating aviation emissions to Parties according to allocation options 2, 3, 4, 5, 6 and 8 of SBSTA.
We used the allocation of Owen and Lee's option 5 (*Country of destination or departure of aircraft)* as proxy for Option 4, because for Option 5 no allocation was calculated and the 'growth' element of Option 4 is simply reflected in the FAST-2000(OAG) B2 scenario for option 5. However, the scenario emissions were calculated using a bottom-up model requiring a lot of additional estimates and that is likely to contain a considerable bias. Therefore, we scaled these emissions to match with the international aviation CO_2 emissions in 2000 estimated in IEA (2005). This 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%), former USSR (factor 6 higher) and the USA (about 25% higher) (see Figure 6). However, it appears that

the emissions in the IEA dataset allocated to the former USSR are very high. The reason could be the higher uncertainty of statistics for economies in transition.

Figure 7 The effect of the different allocation options, i.e. option 3 (bunker sold), option 5 (destination aircraft) or option 6 (imported goods), for the international aviation emissions based on data of Owen and Lee (2005). For comparison also the IEA data are depicted here

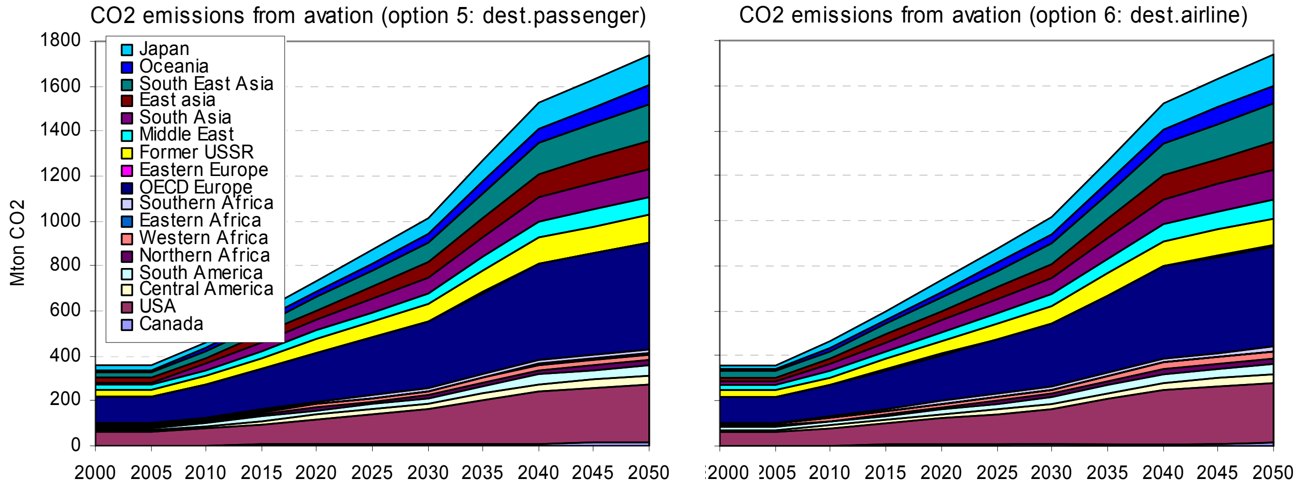


Source: Den Elzen, 2006, Den Elzen 2007.

As shown in Figure 7, the allocation options 3, 5 and 6 are in close agreement. This is also the main conclusion of Owen and Lee (2005)[10]. However, for some of the countries with relatively few emissions allocated, the allocation options can have a substantial impact on the amount of emissions allocated.

[10] 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 analogue to the situation for sea shipping where vessels may be diverted to flag countries with less stringent commitments.

Figure 8 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 (2005abc)



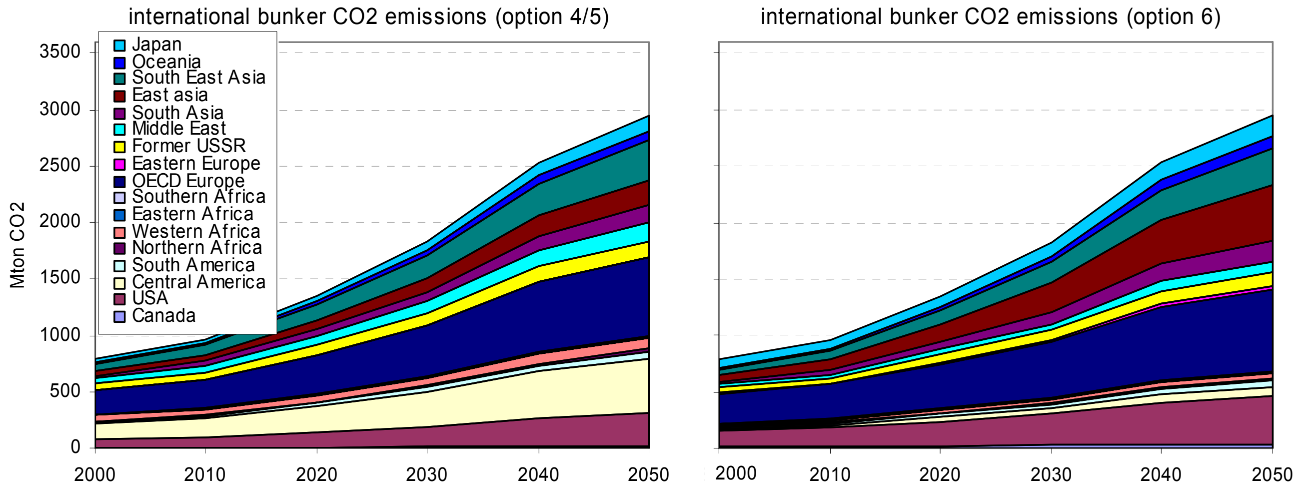
Source: Den Elzen, 2006, based on historical data from IEA and scenario from Owen and Lee (2005a).

Using the FAST B2 emission scenario for projecting CO_2 emissions for *international* aviation from 2000 onwards shows an almost 100% increase in emissions by 2020 and about 400% increase by 2050 (Figure 8). The FAST B2 emission scenario for *total* aviation results in 1996 Tg CO_2 for 2050. This is well within the range of 1,500 to 5,300 Tg CO_2 of the group of scenarios 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 as shown in Figure 5, the allocation methods of Option 4 and Option 6 result in a rather similar development of the regionally allocated CO_2 emissions.

International bunker emissions

Combined future bunker emissions from the aviation and maritime sectors are projected to growth in the Baseline B2 (trend) scenario from about 800 Mt CO_2 in 2000 to about 1,350 Mt by 2020 and nearly 3,000 Mt in 2050 (Figure 9) This is equivalent to an increase by about 70% in 2020 and 275% in 2050 compared to 2000. The aviation sector is responsible for most of this growth.

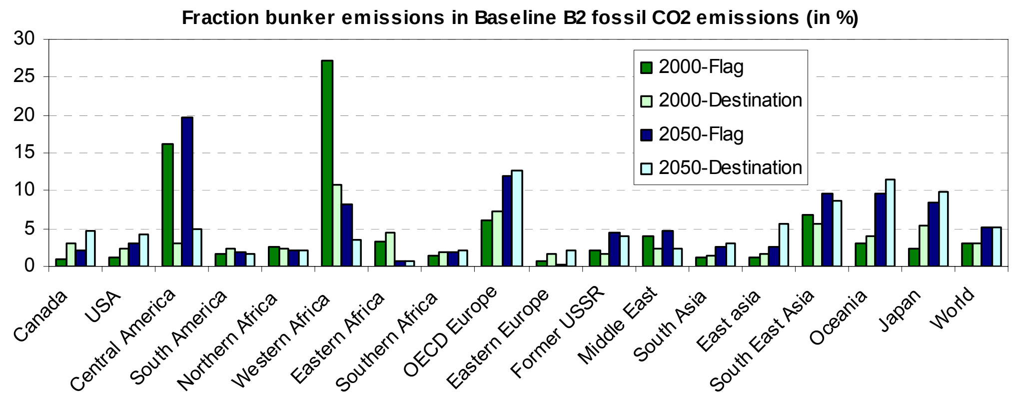
Figure 9	The international bunker emissions for the IPCC SRES baseline B2 scenario as constructed for this study for the option 4/5 (i.e. option 4 for marine (flag state) and option 5 for aviation (destination aircraft)) (left) and option 6 marine and aviation (destination passenger/cargo) (right)



Source: Den Elzen, 2006, Den Elzen 2007.

With respect to the regional projections, it is clear from Figure 10 that for some regions there is large difference depending on whether emissions are allocated according to nationality/flag or route/destination of passengers and goods. This is particularly true for Central America, Western Africa and to a lesser extent for Canada, Eastern Europe, Middle East, in the short-term for Japan and in the long-term for East Asia (China).

Figure 10	Fraction of the bunker emissions in the overall regional and global anthropogenic CO_2-equivalent emissions for the B2 baseline in 2000 (green) and 2050 (blue)



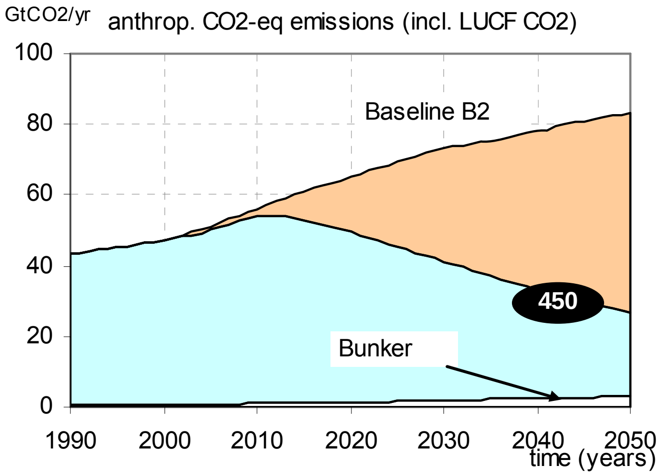
Source: MNP-FAIR model, Den Elzen, 2006, MNP 2007 (appendix **Fout! Verwijzingsbron niet gevonden.**).

2.3 International bunker emissions and allowable emission levels for stabilisation at 450 ppm

This section will explore the implications if the projected development of bunker emissions for international climate policy. In particular it will look into the case when international bunkers would formally remain unallocated and unabated. This sheds some light at both the additional mitigation burden for the regulated emission sectors (*mitigation penalty*), as well as how total emissions would exceed the emission caps for stabilisation if the bunker emissions are not compensated for (*environmental penalty*).

Figure 11 shows the development of global CO_2 equivalent greenhouse gas emissions under the B2 scenario, the projected growth in international bunker emissions and the pathway for stabilising concentration in the atmosphere at 450 ppm by 2100. The emissions pathway allows overshooting, i.e. concentrations peak at 510 ppm before stabilizing at 450 ppm later on. Global GHG emission 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.

Figure 11 The share of (unabated) international bunker emissions (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) (blue area)



Source: adapted from Den Elzen (2006b), Den Elzen 2007.

While global international bunker emissions are projected to growth strongly in the 2000-2050 period (375%), their share in total greenhouse gas baseline emissions will remain in the order of a few percent (3 gigatonne from bunkers versus a total of about 80 gigatonne CO_2 eq. by 2050).

If, however, global greenhouse gas concentrations would need to be stabilised at 450 ppm by 2100 in order to limit global warming to 2 degrees above pre-industrial levels, the share of bunker emissions in allowable emissions would grow to over 12% by 2050. Moreover, as discussed above, particularly in the case of aviation their contribution to global warming may be more substantial due to their indirect impacts on the radiative balance of the atmosphere.

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. Under a multi-stage regime, this would result in more stringent emission reduction targets for particularly Annex I parties.

If international bunker emissions would remain unabated and not compensated for this would result in a significant exceedance of the allowable emission pathway by about 8% by 2020 and 15% by 2050. This could imply that stabilising greenhouse gas concentrations at 450 ppm CO_2-eq. by 2100 will be come more difficult, if still possible at all.

More detailed analyses of the emission implications of including or excluding and compensating or not compensation for international emissions on the regional level can be found in Den Elzen (2007).

3 Allocation to countries

3.1 Introduction

This chapter starts from the assumption that each country will be allocated with a share of the climate impacts of aviation and maritime transport. This share would become a part of the national totals of these countries, and would fall under the commitment that these countries would have in a future global climate policy regime. The basic idea is formulated as:

> Emissions are allocated to countries by the UNFCCC and are included in national emission reduction targets. It is up to the countries to decide on how emissions will be limited. In case this takes place in coherence with work through ICAO and IMO on the field of measures and instruments, countries will know at the moment of taking responsibility, how emissions can be limited and the potential for limitation.

Allocation of responsibilities to countries would have the advantage that countries can decide on the distribution of their reduction targets over sectors. They may, for example, choose to bring down emissions in the residential sector in order to create room for international transport to grow. Or they could choose, for example, to treat the aviation sector as a whole stringently in order to create room for industrial development.

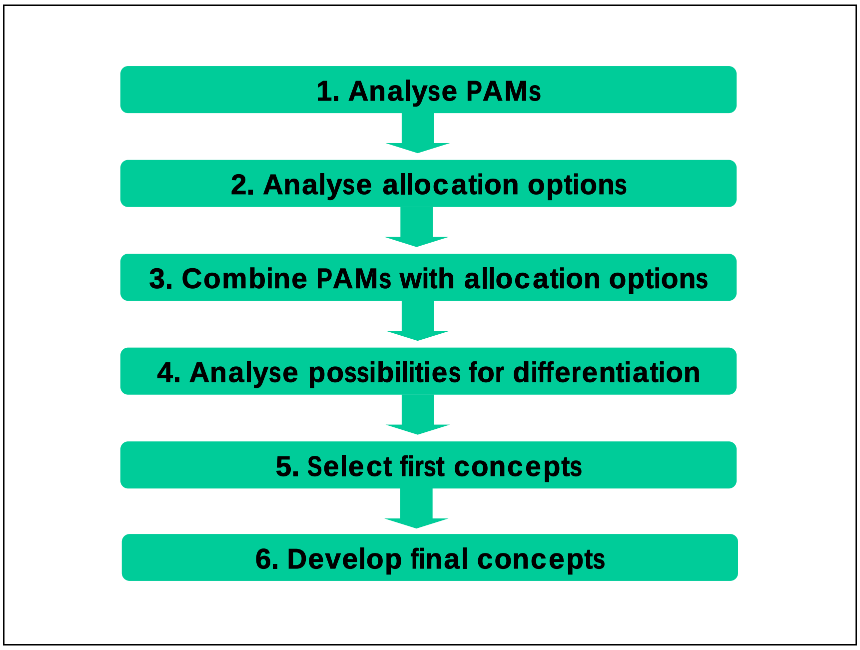
Hitherto, the allocation of emissions from international aviation and maritime transport to countries has been discussed within the UNFCCC context. Not much progress has been witnessed in recent years. Nor is it expected that a major breakthrough will take place in the near future. One of the main reasons for this is that allocation is discussed in isolation from policies and measures, which are discussed in IMO and ICAO[11]. If a decision were to be taken on allocation, Parties would be faced with responsibilities without an existing framework for mitigative policies and measures, which, to be effective, require to a large extent international coordination. Countries may be expected to be reluctant to take on responsibilities without a clear prospect of how to meet potential obligations.

This chapter takes an alternative approach. Instead of looking at the allocation decision in isolation from the discussion on co-ordinated policies and measures and the discussion on commitments, we will focus on working out complete policy regimes, combining the allocation decision with (internationally coordinated) policies and measures and emission reduction commitments. By negotiating integrated regimes, countries will be able to assess their commitment and their possibilities to fulfil the commitment simultaneously. This approach leads to a six step process, which is represented in Figure 12.

---

[11] See also Oberthur, S. Interactions of the climate change regime with ICAO, IMO and the EU burden-sharing agreement, project deliverable no. D 3, final draft (February 2003).

Figure 12 Development of the first concepts – allocation to countries



Section 3.2 starts by analysing which combinations of policies and measures and allocation options enable states to control the emissions they will be given responsibility for. Section 3.3 explores ways to differentiate commitments. After a selection of the first concepts in section 3.4, section 3.5 fills in the blanks and develops full concepts. 3.6 summarises and concludes.

3.2 Policies, measures and allocation options

This section explores which combinations of policies and measures on the one hand and allocation options on the other enable states to control the emissions allocated to them. To that end, the section first analyses the control that various policies and measures enable. Second, the allocation options are discussed: which control do states require to assume responsibility for the emissions assigned to them? Finally, on the basis of these two analyses, logical combinations of PAMs and allocation options are made.

3.2.1 Policies and measures

This section provides a brief overview of policies and measures. Because of the international nature of aviation and maritime transport, the focus will be on internationally coordinated policies and measures. Unilateral policies are generally not as effective, because the environmental scope is much smaller, they may be evaded and may lead to distortions of the competitive market.

Internationally coordinated policies and measures can take many forms. The following PAMs have received broad attention in relation to mitigation of GHG emissions from international transport:

- Policies and measures based on technology:
  - Research and development investments.
  - Technology standards.
  - Performance standards.
- Taxes and charges.
- Emissions trading, and mechanisms to equalise abatement costs between sectors and regions.

Coordination of all these PAMs could take place within ICAO and IMO. Such coordination can be analogous to the current coordination of environmental issues within ICAO and IMO. Agreements, once ratified by the Member States, are enforced by the Member States.

R&D investments, technology standards and performance standards

Technological policies and measures enable states to reduce the relative climate impact of aviation and maritime transport by increasing the pace of technological development and / or deployment. Research & development (R&D) subsidisation may accelerate technological development at manufacturers. Policies aimed to diffuse new technologies may increase the speed of adoption. Technology standards may increase the speed of introduction of new technology in practice. And performance standards may introduce new operational practices[12], in addition to increasing adoption of new technologies.

The main advantages of technology and performance standards are (Barrett, 2001):

- Standards are well fit to ensure compliance and participation.
- Standards could be self enforcing, if enough countries adopt the standards, other countries and their industries would follow to ensure market access, economies of scale in production and network effects.
- Common standards can ensure an international level playing field.
- Standards provide incentives for investment in climate-friendly technologies.

Technological policies and measures also have important shortcomings. These are (Den Elzen en Berk, 2004):

- The environmental outcome of these PAMs is not certain because the amount of traffic would not be directly controlled.
- These instruments do not provide an incentive beyond the standards.
- Governments may not accurately know the most cost-effective measures, and may possibly increase the cost of reducing emissions by prescribing costly technologies.
- Technology standards may lead to lock in effects.

[12] The difference between technology and performance standards is that the former prescribe the use of a certain technology, whereas the latter set an objective performance level without prescribing how this should be achieved.

It should be noted that many of the disadvantages relate particularly to the prescription of specific techniques (technology standards). Most disadvantages do not relate to performance standards. However, performance standards are in general more difficult to monitor.

Research and development (R&D) investments, stimulation of adoption of new technologies, technology standards and performance standards could be implemented separately or as part of a larger Technology protocol (see e.g. Ecofys, 2005).

Such a protocol could be characterised as either effort-based or result-based. Effort-based policies focus on the input to action (e.g. money or policies to implement new technologies), result-based policies on the output of action. R&D investments and stimulation of adoption fit well into effort-based policies, whereas technology and performance standards match well with result-based policies. Note that effort-based measures generally focus on the development and supply of new technologies, while result-based policies more directly impact the demand for and deployment of new technologies.

Both in aviation and maritime transport technology and performance standards have played an important role in reducing environmental impacts. Aircraft noise has been reduced due to noise standards for aircraft induced by airports in response to local noise problems. Technology standards for oil tankers within the MARPOL[13] convention have reduced the risk of large oil spills (Barrett, 2001). In a more general sense, both aviation and maritime transport are used to the measure of standards. ICAO's environmental policy has been largely conducted with standards, and the IMO MARPOL convention is also standard-based.

Although technological improvements could significantly reduce emissions and climate impacts relative to transport volume, it is unlikely they will result in absolute emission reductions in the near future. In aviation, the European manufacturing industry has set a goal to reduce CO_2 emissions of new aircraft by 50% per passenger kilometre in 2020 compared with 2000. This goal is generally regarded as ambitious, although in the long run larger reductions may be achieved (Royal Aeronautical Society, 2005). The ACARE target implies an average improvement of performance of 2% per annum. Since air traffic is expected to grow at a pace of about 5% per annum, and since new aircraft will only gradually enter the fleet, it means that total emissions are likely to continue to rise. So, in order to even stabilise the contribution of aviation to global warming, technological development would need to accelerate well beyond the current ambitious goals that the manufacturing industry has committed itself to.

Performance standards could add to the gradual improvement of aircraft technology. It is estimated that better air traffic management may reduce fuel burn by 8% (ELFAA, 2006). Furthermore, there are indications that contrail formation may be reduced by up to 80% at a fuel penalty of around 4%, which would reduce the climate impact of aviation (Royal Aeronautical Society, 2005).

---

13 The International Convention for the Prevention of Pollution from Ships (MARPOL).

And finally, recent research suggests that the reduction of evening and night flights may significantly reduce the negative climate impacts of contrails (Stuber, 2006). Like aircraft technology, aircraft performance may be improved further, provided that the proper incentives are given to the aviation sector.

In maritime transport, there may be more scope for absolute emission reductions, for two reasons. First, shipping grows at a slower rate than aviation, which makes the technological gap to be bridged to reduce emissions smaller. From 1970 to 2000, shipping grew at an average annual rate of 2.9% in terms of tonnes of cargo transported (UNCTAD, 2005). Since ships have increased in size, and larger ships are more fuel efficient than smaller ships, emissions have grown at a lesser rate. What this rate is, is not clear, however, because there are large discrepancies between different estimation methods of fuel use. Estimates range from 0.8% annually over the period 1971-2001 (IEA, 2003) to 2.8% annually over the period 1970 – 2000 (Eyring, 2005)[14]. The growth of maritime transport for the coming years is not expected to exceed 4% per annum, and emissions will rise at a slower, albeit unknown, rate. Second, fuel economy has not been at the centre stage of ship design[15]. It is estimated that applying existing technology to new ships may reduce CO_2 emissions by 5% - 30%, and applying existing technology to existing ships may reduce CO_2 emissions by 4% - 20% (Marintek, 2000). The development of new technologies could lead to even higher emission reductions. If the shipping industry would set itself goals comparable to those of aviation, technological development could offset the growth of maritime transport and as a consequence reduce emissions.

In sum, technological policies and measures may give states control over the relative emissions and climate impacts from transport. They are, however, ill suited to reduce the absolute amount of emissions or the absolute climate impacts, which are expected to increase considerably in the coming decades.

Taxes and charges

Taxes and charges[16] may take many forms. New taxes may be introduced on previously untaxed activities, such as emitting greenhouse gases. Existing charges may be differentiated, such as differentiated harbour and fairway dues. Taxes or charges may either be imposed on emissions, on fuel, or on other bases, such as ticket prices or freight rates. Taxes and charges affect emissions in several ways. First, by raising the price of emissions, they depress demand for

[14] The difference is caused by a different estimation methodology. The IEA figures are based on bunker fuel statistics, whereas Eyring use activity based methods.

[15] After the first and especially the second oil crisis, several indicators show that ships improved their fuel efficiency: design speeds of new ships declined (T&E, 1996) and installed power dropped (GL, 2006). Since 1985, however, both design speeds and installed power have risen again. Several observers of the industry have noted that the emphasis has been more on reducing labour costs than on increasing fuel efficiency. With the current high oil prices, fuel efficiency may become a more important factor again.

[16] ICAO policies make a conceptual difference between taxes and charges, as follows (see Resolutions adopted by the Assembly, provisional edition December 2004, at: http://www.icao.int/icao/en/assembl/a35/a35_res_prov_en.pdf, consulted January 12, 2006): ‘a charge is a levy that is designed and applied specifically to recover the costs of providing facilities and services for civil aviation, and a tax is a levy that is designed to raise national or local government revenues which are generally not applied to civil aviation in their entirety or on a cost-specific basis’.

polluting activities. Second, taxes and charges provide an incentive to reduce emissions as long as the associated costs are below the charge level. Thus, taxes or charges may steer innovation towards lower greenhouse gas emissions (Jaffe, 2002). They may further help to ensure that mitigation costs are equal across countries. The introduction of an international carbon tax has been put forward as a means to level mitigation costs across countries.

Taxes and charges have the advantage that they help to internalise external costs, and thereby contribute to economic efficiency. Furthermore, compared to other PAMs the cost of compliance and administrative burden are relatively low (although this depends in part on their actual design).

Taxes and charges have a serious deficiency as well. Because countries generally claim sovereignty over their tax base and tax levels, a co-ordinated introduction of taxes or charges is hard to achieve. Without co-ordination, however, (unilateral) introduction generally has a small environmental impact and may lead to legal disputes, if they are to apply to foreign vessels and aircraft[17].

In aviation, many Bilateral Air Service Agreements (BASAs) currently explicitly rule out taxation of bunker fuels for international transport[18]. In maritime shipping, the general practice of tankering may significantly reduce the environmental impact of fuel taxes when introduced unilaterally or regionally[19].

Neither in aviation, nor in maritime transport are taxes or charges widely used in the environmental domain. However, some examples exist, such as airport NO_x charges in Sweden and the UK, which were introduced to reduce air pollution. Also in Sweden, harbour and fairway dues have been differentiated according to NO_x emissions of ship engines. Very few countries have a fuel tax for domestic aviation, among which the US and the Netherlands.

Taxes and charges may enable states to control emissions in many ways, depending on the tax or charge base. A fuel tax would enable states to reduce emissions in their national totals based on fuel sales. Emission charges would incentive emission reductions within the scope of the scheme. A ticket charge or

---

17 And if, on the other hand, they only apply to national vessels and aircraft, substantial economic distortions between carriers from different countries may occur.

18 Contrary to what is often stated, the Chicago Convention, on the basis of which ICAO was founded in 1944, does not forbid the taxation of bunker fuel sold. In Article 24, it forbids taxation of fuel on board, not fuel bunkered: “Aircraft on a flight to, from, or across the territory of another contracting State shall be admitted temporarily free of duty, subject to the customs regulations of the State. Fuel, lubricating oils, spare parts, regular equipment and aircraft stores on board an aircraft of a contracting State, on arrival in the territory of another contracting State and retained on board on leaving the territory of that State shall be exempt from customs duty, inspection fees or similar national or local duties and charges.”

19 The only documented introduction of a bunker fuel tax shows this clearly. In 1991, California imposed a 8.5% sales tax on bunker fuels. At that time, 4.5 million barrels of bunker fuel were sold in the Los Angeles/Long beach Harbour area monthly. After the introduction of the tax, many shipping companies decided to tanker in Panama instead, reducing the volume of the Los Angeles market to 1 million barrels. And although there were additional reasons for the bunker fuel price to rise in Los Angeles, such as the introduction of the Oil Pollution Act, many stakeholders blamed the tax for the collapse of the market. As a consequence, the tax was abolished within a year (Michaelis, Lauri, 1997: Special Issues in Carbon / Energy Taxation: Marine Bunker Fuel Charges, Paris: OECD, OCDE/GD(97)77).

freight charge would primarily affect demand and thus enable states to reduce emissions by lowering transport demand.

Taxes and charges have both a supply side effect and a demand side effect. The supply side effect comprises the change to low-emission engines and aircraft and operational measures to abate emissions. If at least some of the additional costs are passed on to the consumer, there is a demand side effect as well. This effect is the reduced demand for air travel or sea transport as a consequence of higher ticket prices or transport fares. In theory, the effects can vary from zero to a very large reduction of emissions, depending on the level of the tax or charge. For aviation, CE Delft (2002) has estimated the potential environmental effects for a range of tax / charge levels, which are represented in Table 11.

Table 11 Estimated CO_2 emission reductions resulting from emission charge, as a percentage of total emissions in EU airspace in 2010

valuation of CO_2 / NO_x, €/tonne/kg	Supply side, %	demand side, %	Total	
			%	Mtonne
10 / 0	-0.9%	-1.0%	**-1.9%**	-2.2
30 / 0	-2.9%	-3.1%	**-5.9%**	-6.9
50 / 0	-4.6%	-4.9%	**-9.3%**	-10.9
10 / 1.2	-1.5%	-1.7%	**-3.1%**	-3.6
30 / 3.6	-4.4%	-4.5%	**-8.7%**	-10.2
50 / 6.0	-6.6%	-7.2%	**-13%**	-15.6

Source: CE Delft, 2002.

The table is included for illustrative purpose only. At other levels for the tax or charge, environmental impacts would be different. A tax level of € 50 per tonne of CO_2 could reduce CO_2 emissions by 9%. CE Delft (2002) has also calculated the effects of a revenue neutral charge. (The proceeds of a charge would be ploughed back into the sector as opposed to a tax, of which the proceeds would be added to the general budget). The effects of charges are some 40% to 50% lower than the effects of taxes. For shipping, we are not aware of the existence of studies on the environmental effects of charges or taxes.

In sum, taxes and charges may give states control over emissions and climate impacts of emissions in their jurisdiction or emissions from fuels sold under their jurisdiction. Some countries are however very reluctant to agree to internationally controlled charges and taxes, partly because they do not want to lose control over their tax base and want to have authority over tax and charge levels.

Emission trading, equalisation mechanisms

Emission trading is designed to minimise the costs of reducing emissions. It can be implemented in many ways, but the most common is by distributing a limited number of emission allowances among emitters and allowing trade. The number of allowances, the cap, can be set to the desired environmental effect. By allowing trade, the system in fact allows entities to pay for emission reductions by other entities. The market should then ensure that emission reductions are realised were they are cheapest, thereby minimizing the costs of emission abatement.

Emission trading can be supplemented by trading with entities outside the scope of the system. Under the Kyoto Protocol, there are two ways in which this can be done: through the Clean Development Mechanism (CDM) in developing countries, or in developed countries through Joint Implementation (JI). Emission reductions realised through either CDM or JI can be transferred to entities within the emission trading system. In this way, cheap abatement options outside the system can be used to lower the price of emission allowances within the system.

Emission trading has several advantages. First, the cap ensures that the environmental goal is realised. Second, the market ensures that this is done at the lowest cost possible.

However, there are disadvantages to emission trading as well. For a start, external costs are not necessarily internalised, such as can be the case with taxes and charges. Internalisation of external costs increases welfare. Second, it is not well suited for all sectors. In sectors with many small emitters the transaction costs may become very high.

Several emissions trading systems currently exist. The EU has an emission trading system for CO_2, and so does Norway. The US has a system for SO_2. No emissions trading systems currently exist in the maritime transport sector. In aviation, British Airways participates in the voluntary UK Emission Trading Scheme. ICAO has advocated open emissions trading as a way to reduce the climate impact of aviation[20].

In sum, emissions trading, whether or not complemented with mechanisms designed to equalise costs with sectors or regions outside the system, may give states control over the total amount of emissions within the system. An open emissions trading scheme is not suited to target emission reductions within specific sectors.

3.2.2 Allocation options

Having discussed different options for internationally coordinated policies and measures, we now turn to a discussion on allocation options for allocating responsibility to countries. After providing a background on allocation options (this section), we will relate the above discussed policies and measures with specific allocation options (section 3.2.3). As it will turn out, some policies and measures relate better to specific allocation options than others.

A number of allocation options have been discussed inside and outside the UNFCCC. This subsection reviews the options that have been discussed and rejects some options because they are not feasible or have other disadvantages.

---

[20] Open emission trading allows for trading with other sectors of the economy, as opposed to closed emission trading, which is emission trading within the aviation sector only.

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[21]. The UNFCCC secretariat presented a paper at SBSTA 4 (1996), including eight allocation options for consideration. These options were:

1 No allocation.
2 Allocation of global bunker sales and associated emissions to parties in proportion to their national emissions.
3 Allocation according to the country where the bunker fuel is sold.
4 Allocation according to the nationality of the transporting company, or to the country where an aircraft of ship is registered, or to the country of the operator.
5 Allocation according to the country of departure or destination of an aircraft or vessel; alternatively, emissions related to the journey of an aircraft or vessel shared by the country of departure and the country of arrival.
6 Allocation according to the country of departure or destination of passengers or cargo: alternatively, emissions related to the journey of passengers or cargo shared by the country of departure and the country of arrival.
7 Allocation according to the country of origin of passengers or owner of cargo.
8 Allocation to a party of all emissions generated in its national space.

Later, SBSTA decided that the options 1, 3, 4, 5 and 6 should be the basis of further work. The three discarded options have several important disadvantages. To name a few: option 2 would not be equitable and would lead to practical problems, such as assigning maritime emissions to land locked countries that have no control over them; option 7 would suffer from heavy data requirements; and option 8 would leave emissions on and over the high seas outside the responsibility of any party.

In this section we will focus on the allocation options that are still under discussion. We therefore exclude options 2, 7 and 8. We furthermore exclude option 1 from further discussion, as it forms the basis for chapter 4.

Allocation option 3, 'according to the country where the bunker fuel is sold', implies that states have control over the amount of bunker fuel sold within their jurisdiction. This can be done in a number of ways. Among the policies and measures discussed in the previous subsection, fuel taxes, emission charges, and emission trading (in which case the fuel suppliers would have to be the trading entity) are the most direct ways to control the amount of bunker fuel sold.

For allocation option 4, 'according to the nationality of the transporting company, or to the country where an aircraft of ship is registered, or to the country of the operator', states need to have control over the emissions of transporting companies, operators, or ships or aircraft within their jurisdiction. Emission trading could be designed to give states this control, as could technical standards

[21] 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 Jan. 19th, 2006).

and performance standards. Stimulation of R&D could be directed towards national transporting companies and operators.

Allocation option 5, ‘according to the country of departure or destination of an aircraft or vessel; alternatively, emissions related to the journey of an aircraft or vessel shared by the country of departure and the country of arrival’ requires that states have control over the emissions caused by aircraft or vessels travelling towards or from harbours or airports within their jurisdiction. Emission trading and emission charges could be designed to give states this control. In aviation, control could also be exerted by fuel taxes, because tankering is restricted by technical and economical constraints. Technology and performance standards could give states control over the amount of emissions relative to transport performance.

Finally, allocation option 6, ‘according to the country of departure or destination of passengers or cargo: alternatively, emissions related to the journey of passengers or cargo shared by the country of departure and the country of arrival’ implies that states have control over the emissions caused by the transport of cargo or passengers that enter or leave their country. This resembles the control needed for allocation option 5. Emission trading and emission charges could be designed to give states this control.

Box 2: Is allocation option 6 feasible?
Allocation option 6 is often discarded because of the heavy data requirements. However, it appears that both in aviation and in maritime transport, the data are available or can be made available at little additional cost.

In maritime transport, the Bill of Lading contains information on port of departure, port of destination, shipper, vessel, amount of cargo, owner of cargo, et cetera. So on the basis of this document, which is increasingly becoming an electronic document, ship movements can be linked to country of destination or origin of cargo. If vessels would register their fuel use on a per trip basis, this registry could be coupled to the Bill of Lading to calculate the amount of emissions associated with the transportation of the cargo.

Current experiments with the IMO CO_2 index show that the additional cost or administrative burden of registering fuel consumption per trip is very small. Many shipping companies have these data available, and for those who do not, a simple procedure exists for which a ship crew can monitor fuel use per trip.

When the Bill of Lading would be available in electronic format and stored in a central confidential database, and ship operators would be required to submit data on fuel use to a central confidential database, a combination of these data would allow to calculate emissions.

In aviation, aircraft operators register the airport of departure and ultimate destination of both passengers and freight. In an increasing number of cases, they are obliged to share this information with authorities on security grounds. Furthermore, they register fuel use of their aircraft and occupancy. These data could be combined to calculate emissions per passenger and per amount of freight.

However, under code sharing agreements airlines frequently transport each others customers. The transporting airline may not always be aware of the final destination of the passenger. Conversely, the airline that has sold the ticket may not have information on the fuel use and load factor on the trip legs that are carried out by other airlines. A calculation of the emissions per passenger may require that airlines share information on trip, fuel use, and load factor, which they may consider to be confidential. Perhaps this can be overcome by the establishment of a central, confidential database.

3.2.3 Combining PAMs with allocation options

In Table 12 the most logical combinations of policies and measures on the one hand and allocation options on the other hand are presented. It furthermore makes clear over what states have control when introducing the policy instrument.

Table 12 Environmental effects of emission taxes

PAM	Gives states control over	Appropriate allocation options
R&D	Rate of technological progress	Nationality of transporting company, operator or country of registration
Technology standard	Rate of technology adoption by aircraft and vessel within jurisdiction	Nationality of transporting company, operator or country of registration Country of departure or destination of trip Country of departure or destination of cargo
Performance standard	Rate of technology adoption and performance by aircraft and vessel within jurisdiction	Nationality of transporting company, operator or country of registration Country of departure or destination of trip Country of departure or destination of cargo
Fuel taxes	Emissions from fuel sold within its jurisdiction	Country of fuel sales
Emission related charges	Emissions from aircraft and vessels within its jurisdiction	Nationality of transporting company, operator or country of registration Country of departure or destination of trip Country of departure or destination of cargo
Emission trading	Total emissions within the trading system	Country of fuel sales Nationality of transporting company, operator or country of registration Country of departure or destination of trip Country of departure or destination of cargo

R&D investments influence the speed of technological development. These combine most logically when the companies that might benefit from increased technological development are located nationally. Only in allocation option 4 is there a link with nationality.

Technology standards impact the technology on board of the vessel or aircraft. This could be controlled by regulations for registration of vessels / aircraft or when they call at national ports. Therefore allocation options 4, 5 and 6 combine most directly with this instrument.

Performance standards control the relative emissions. They can only be installed on vessels / aircraft within a country's jurisdiction. Information would not only be required for the last trip, but for the performance over a longer time period. The transporting company may be best suited to provide this information. Therefore allocation options 4 combines best with this instrument.

An internationally agreed tax on carbon would logically combine with allocation based on the country of fuel sales. It would be easiest to collect the tax at the moment of fuel sale (taxing imported fuel is not allowed) and the country inning the tax would be the country responsible for the emissions it is aimed to regulate.

Emission charges impact the emissions from vessels and aircraft, primarily within the geographical scope of the scheme. Allocation should be such that governments have jurisdiction over the emissions that fall under the scope. Therefore, they most logically combine with allocation options 4, 5 and 6.

Emissions trading controls the total amount of emissions, either by the sector or within the trading scheme. This instrument combines well with any of the allocation options. Country of fuel sales and country of departure / destination would both be appealing because of the availability of data. On the other hand, the transporting company could be made to report on this.

3.3 Differentiation of national commitments and targets

Under the UNFCCC, countries have 'common but differentiated responsibilities'. As set out in the introduction (chapter 1), this report starts from the Multi Stage approach, which elaborates the concept of differentiated responsibilities into three different types of commitments: absolute, relative, and no commitments. When emissions of international transport are allocated to countries, these emissions will be included in the national commitments and would therefore fall under different types of commitments.

The following section analyses whether a differentiation of commitments is possible for the allocation options discussed in section 3.2.2. Section 3.3.2 analyses how policies and measures enable a differentiation of commitments.

3.3.1 Differentiation and allocation

A major complication in dealing with emissions from maritime transport and aviation within the context of the UNFCCC is the principle of differentiated responsibilities and capabilities between developed and developing countries. According to this principle the developed countries should take the lead on mitigation emissions. For this reason, it is not possible to simply combine allocation concepts with sector PAMs and (national) commitments in a logical and pragmatic way. The issue of equity needs to be addressed as well. Clearly, the problem here is that international aviation and maritime shipping entails many entities competing on international markets. Treating these entities differently could lead to substantial economic distortions. Therefore a balance needs to be struck between international equity in climate policy and fair competition. In the next section we discuss the feasibility of differentiating responsibilities under the different allocation options. Thereafter, we discuss which policies and measures can be differentiated in stringency between countries. Several general aspects of differentiation between countries are discussed subsequently.

Allocation according to country of fuel sales

If emissions are allocated according to the country of fuel sales (option 3), differentiation of responsibilities is likely to decrease the environmental effectiveness for maritime transport. Responsibilities in developed countries may be reflected in fuel prices. If developing countries have less responsibilities, not only the development of the country itself may be enhanced (as intended by the differentiated responsibilities clause). Vessels may be fuelled up in countries with little responsibilities (and lower prices). This practice of tankering might cause a substantial amount of leakage from the scheme.

For aviation the problem is less substantial. The so-called fuel penalty[22] is relatively large, preventing tankering across large distances. However, if countries with different responsibilities are located close to another, some tankering may occur.

Allocation according to nationality of transporting company

In case of allocation according to nationality of transporting company, operator or registration (option 4), differentiation is not possible for maritime transport. It would not result in an effective climate policy. Vessels frequently change of registration country. Operators can relocate their business. Faced with different stringencies of policy measures, operators could choose to register their vessel in a country with the least stringent targets, or register their company there. This evasive behaviour would not lead to an effective reduction of climate impacts.

In the aviation sector, the situation is different. International aviation does not operate in a liberalised market, but is bound by Bilateral Air Service Agreements (BASA) between countries. A BASA entitles operators registered in the countries in question to carry out commercial flights between those countries. Without a BASA, operators cannot engage in commercial traffic between countries[23]. Change the nationality of an operator therefore has substantial consequences, and as a result, the nationality of aircraft operators is much more stable than the nationality of a ship operator or the country of registry of a ship. Furthermore, the nationality of operators is clearly defined under international regulation and operators cannot easily change their nationality. The Air Operator's Certificate (AOC), which is required to operate an aircraft on a commercial basis, states the nationality of the owner of the certificate.

So in aviation, in contrast to maritime transport, a differentiation of commitments under allocation option 4 would be possible and effective. It would, however, not be unproblematic. After all, some developing countries have very advanced airlines, which are allowed by BASAs to compete with airlines of industrialised countries on certain routes. Now when the airline of country A would fall under a different climate policy regime than the airline of country B, while competing with

---

22 The costs associated with transporting additional fuel on board an aircraft.

23 In the EU, the internal market has been liberalised and the EU is negotiating ASAs with non-EU countries, which would apply to all European aircraft operators.

each other on routes between country A and B, or between countries C and D, substantial distortions of the market would occur. This would reduce the environmental effectiveness of the policy, since the airline with the least stringent commitments would be able to grow at the expense of the airline with the more stringent commitments.

Therefore, we conclude that a differentiation of commitments is not compatible with allocation option 4, because it would lead to a distortion of the competitive market and a decrease in environmental effectiveness.

Allocation according to country of departure or destination of vessel or aircraft

In the case of allocation to the country of departure / destination of vessel or aircraft (option 5), a differentiation of responsibilities and commitments appears more feasible. The reason is that no distortions of competition will take place between different transporting companies on the same route[24]. However, there may arise some competition between airports (or ports) that are geographically close but fall under different stringencies in commitments. In the aviation sector, this appears to be a viable way of differentiating commitments. For the maritime transport sector it is slightly more complicated. The reason is that vessels sometimes change destination while at sea. If the policy regime depends on the route taken, it might thus change at open sea. One way to solve this problem would be to allocate emissions entirely to the country of destination.

Allocation according to country of departure or destination of passengers or cargo

When emissions are allocated to the country of departure or destination of passengers or cargo (allocation option 6), a differentiation of commitments is as feasible as under allocation option 5. In case the ultimate destination of cargo can be determined, there wouldn't even be a distortion in the markets between airports or ports, since the commitment would be entirely determined by the country of destination, and not by the route taken.

Conclusion

The concept of allocation to country of departure / destination of either vessel and aircraft, or cargo and passengers seems best suited for differentiating commitments between industrialised countries, advanced developing countries and least developed countries. It gives room for economical growth in the least developed regions, while it would not distort the competitive market by favouring certain nationalities over others, or lead to evasion because of increased tankering.

---

[24] This differentiation would also appear to be most in line with the idea behind the 'common but differentiated responsibilities'. They were introduced so not to put too much burden on developing states. Climate policy for vessels under the flag of a developing state would however hardly impede the economic development of the state. Arguably a slightly larger impact on the development would occur if commitments would be tied to nationality of the transporting company or operator. Exempting transport from or to the country would enable lower transport prices, promoting trade.

3.3.2 Policies and measures for differentiation

Policies and measures can be stacked in order to achieve a differentiation of commitments. This could be in line with the overall differentiation of national commitments and targets, as set out in section 3.3.

For example, building on a division of countries into three groups: Industrialised Countries (ICs), Advanced Developing Countries (ADCs) and Least Developed Countries (LDCs), which would have absolute emission targets, relative emission targets and no commitments, respectively, one could design the following technology regime. ICs would be required to invest in R&D, and apply technology and/or performance standards. ADCs could apply the same or similar standards and possibly engage in a sectoral Clean Development Mechanism (S-CDM) if they surpass the standards. And LDCs would be able to engage in CDM.

PAMs could be stacked in other ways as well in order to differentiate them. See Table 13 for three examples.

Table 13 Differentiated commitments, allocation options and PAMs

<table>
<tr><td>National Commitments</td><td>Type of PAMs</td><td>Differentiation of PAMs</td></tr>
<tr><td rowspan="3">ICs: Absolute fixed or Absolute with price cap
ADCs: Dynamic targets or Dual targets or no-lose target
LDCs: no commitments</td><td>Technological</td><td>ICs: R&D, Technology standards and performance standards
ADC: technology standards and sectoral CDM
LDCs: sectoral CDM and CDM</td></tr>
<tr><td>Technological, charges and trading</td><td>ICs: R&D, Technology standards, performance standards, emission charges and emission trading
ADC: Technology standards, emission charges and sectoral CDM
LDCs: CDM</td></tr>
<tr><td>Taxes, charges and trading</td><td>ICs: taxes, charges and emission trading
ADC:, taxes, charges (possibly at a lower level)
LDCs: -</td></tr>
</table>

Conclusion

The concept of allocation to country of departure / destination seems best suited for differentiating commitments between industrialised countries, advanced developing countries and least developed countries. It gives room for economical growth in the least developed regions, while it would not distort the competitive market by favouring certain nationalities over others, or lead to evasion because of increased tankering.

This allocation options could be combined with a number of PAMs, which could be stacked in order to share the burden of the PAMs in an equitable way.

3.3.3 Accounting for the size of the sectors when setting the targets

When emissions from aviation and maritime transport are allocated to countries, some countries will face a large increase in emissions for which they are responsible, while other countries will not. Because of these differences, countries may be reluctant to take responsibility for aviation or maritime transport emissions, without agreeing on the target simultaneously[25].

One way to overcome this barrier is to calculate national targets from a set of sectoral targets and the structure of a countries economy. Sectoral targets can be set by estimating how much emissions can be reduced within a sector at a price that is considered fair. Consider for example that it has been established that countries can reduce emissions from aviation by 5% and emissions from shipping by 25% at a given price and with a specified set of policies and measures. This reduction potential can be multiplied by the amount of emissions allocated to a country in order to calculate the target for the sectors. The sectoral targets are added to calculate the overall target that a country is given. In this way, countries with large emissions from international transport will not be disadvantaged or advantaged compared to countries with hardly any emissions from bunkers.

It is beyond the scope of this project to work out the details of such an arrangement, but some principles can be explored. One way would be cost based. When the marginal abatement cost curves are known for different sectors, one could set a target for the aviation sector and maritime transport so that the sectors would face costs that are equal to abatement costs in other parts of the economy. This principle could be applied both to absolute targets as to intensity targets, provided that the marginal abatement cost curves are known. Another principle could be rooted in history: e.g. the requirement that the international transport sectors emissions will not increase further in the short term, and will start decreasing in the medium to long term.

3.4 Selection of first concepts

This section selects first concepts, which will be developed further into final concepts in the second stage of this project.

The analyses above have shown that allocation of emissions according to the country of fuel sales does not logically combine with other policies and measures than fuel taxes or emission charges. These taxes or charges would have to be imposed internationally in order to minimise evasion and ensure environmental effectiveness. But international fuel taxes or emission charges would be very difficult to implement, given the weight countries place on their sovereignty. We therefore propose not to work out this option any further.

---

25 This is not a new idea, in setting targets both in the Kyoto Protocol and the EU Burden Sharing Agreement, consideration was given to reduction potentials of countries, as well as to other factors, such as need for economic development. This is one of the reasons why the targets for Annex I countries under the Kyoto Protocol differ.

Allocation on the basis of the nationality of the transporting company (option 4) would be feasible in aviation, where the nationality is clearly defined and stable. However, differentiation of commitments on this basis and in line with a multi stage approach would lead to distortions of the competitive market and to evasion. Therefore, the environmental effectiveness of this allocation option would be limited. In maritime transport, the nationality of the transporting company is not as well defined as in aviation. The flag state, however, is well defined, but ships can easily change flag. Therefore, allocation to the flag state in combination with a differentiation of commitments would lead to evasion.

Allocation to the country of departure or arrival of aircraft of vessel would not lead to evasion and would not distort the competitive market, at least not as much as allocation option 4. This option seems feasible both in aviation and in maritime transport. There are no data issues which would make this allocation impossible.

Allocation to country of departure or arrival of passengers or cargo would not lead to evasion and would not distort the competitive market. Of all the options considered, it would probably be the one which is most in line with the polluter pays principle. Provided that electronic Bills of Lading and IMO CO_2 indexes become the industry standard and provided that ship operators would be willing to submit data to a common database, this option would be feasible for maritime transport. It would also be feasible for aviation when the confidentiality of data on fuel use, load factors and trips can be guaranteed, e.g. by a central, confidential database.

Table 14 summarises the arguments used to select first concepts.

Table 14 Arguments for the selection of first concepts - allocation to countries

	Feasibility		Data availability	
	Aviation	Maritime transport	Aviation	Maritime transport
3 – Fuel sales	Would require fuel tax, which would be hard to implement internationally		Good	
		Differentiated fuel tax would lead to evasion		
4 – Nationality	Differentiation in line with the multi stage approach would lead to distortion of the competitive market	Would lead to evasion: nationality of operators is not well defined, and the flag of a ship can be changed easily	Very good	Flag: very good; ship operator: poor
5 – Vessel or aircraft route	Routes are well defined ex-post. Distortion of markets limited to ports and airports		Good	Good, but some ship operators may need to start monitoring emissions on a per trip basis
6 – passenger or cargo route	May be feasible, but requires solutions for the confidentiality of airline data under code sharing agreements	May be feasible provided that electronic Bills of Lading and IMO CO_2 index become the industry standard	Good	Currently poor with regard to emissions, but may improve in the near future

Table 14 shows that there are two first concepts that seem in line with the notion of common but differentiated responsibilities, are feasible and that do not lead to evasion (they are labelled A and B, respectively):

A. For both aviation and maritime transport: Allocation based on country of departure or arrival of a vessel or an aircraft. This allocation option can be combined with PAMs like emission trading, emission charges or technological PAMs.
B. Allocation based on country of origin or destination of cargo or passengers. This allocation option can also be combined with PAMs like emission trading, emission charges or technological PAMs.

3.5 Further development of the concepts

This section takes the two concepts above and develops them further into full concepts for the inclusion of aviation and maritime transport in a post 2012 climate policy regime. This chapter continues to look at concepts based on allocation to countries. Other concepts are dealt with in chapters 4 (sectoral commitments) and 5 (a regional start).

3.5.1 Kind and level of commitment

When emissions of international transport are allocated to countries, countries have no specific commitment or target for international transport. Rather, the emissions from international transport allocated to them fall under the commitment of the country. Countries could decide themselves how they would distribute their commitment over their economic sectors. In principle, they could choose to allow unrestricted growth of aviation and maritime transport, but they would have to cut emissions more stringently in other sectors.

The kind and level of these commitments could vary with the economic development of a country. In the multi stage approach, the most economically developed nations would have absolute emission reduction targets. Advanced developing countries would have relative targets: they should reduce their emissions per unit of GDP. Least developed countries would have no commitments, but could participate in the global climate policy through CDM. Countries could move from one group to another when their wealth increases or decreases.

A multi stage approach can be designed in various forms, all of which would result in different groupings of countries and different targets for the various stages. For illustrative purposes, commitments for various groups of countries are presented here based on Den Elzen (2006). The current Annex I countries would all be in stage 3 (absolute commitments) in 2012. They would have to reduce their total emissions (including the allocated emissions of aviation and maritime transport) by 30% to 40% in 2025, and by 70% to 80% in 2050, respectively. 1990 would still be the reference year. Furthermore, depending on the precise rules for transition into more advances stages, the Middle East and South America could also be in stage 3. Their emissions could grow 40% to 80% above 1990 levels in 2025, and reduce thereafter to 1990 levels in 2050.

Stage 2 countries, which would have relative targets, would include Central American countries, East Asia and South East Asia, and North Africa and South Africa. They would have to reduce the emission intensity of their economy by 3% per year at most. This means that when their economy grows with 3% per annum, the emissions should not grow. In absolute terms, South East and East Asia, for example, could double their emissions in 2025 compared to 1990, and then enter stage 3.

West Africa and East Africa would remain in stage 1 until at least 2055, and not have any targets until then. Western Africa could see its emissions raise by well over 400% in 2050 and still be in stage 1.

Table 15 indicates which groups of countries are forecasted to be at which stage in the coming decades, and, if they are expected to be in stage 3, what their emission targets are in relation to their 1990 baseline emissions.

Table 15 Indicative overview of stages and targets under a multi stage approach

	2010	2020	2030	2040	2050	2060
		2025 target		2050 target		
USA		-30%	-40%		-80%	
Canada		-30%	-40%		-80%	
OECD Europe		-30%	-40%		-70%	
Eastern Europe		-30%	-40%		-70%	
Former USSR		-40%	-50%		-80%	
Oceania		-30%			-70%	
Japan		-30%			-70%	
Central America					0%	
South America		+40%	+80%		0%	
Northern Africa						
Western Africa						
Eastern Africa						
Southern Africa					+70%	
ME & Turkey		+70%	+90%		0%	
South Asia						
SE Asia					+30%	
East Asia		+100%	+140%		+30%	
Stage 1: no targets						
Stage 2: relative targets						
Stage 3: absolute targets						

Note: This approach aims at stabilizing GHG concentrations at 550 ppmv CO_2-equivalent.
Source: Den Elzen, 2006.

As explained in section 3.3.3, it could be desirable to take the size of aviation and maritime transport in a country into account when assigning a commitment to a country. It could also be desirable to do based on certain principles, such as the abatement costs and potentials in these sectors as compared to the marginal abatement costs in other sectors of the economy.

3.5.2 Roles of organisations and parties

The concepts chosen in this chapter require the fulfilment of the following roles:
1 Agreement on allocation of bunker fuel emissions, based on assessment of policies and measures.
2 Agreement on stages and rules for transition between stages.
3 Guidance on policies and measures.
4 Taking sector size and abatement potential into account when setting targets.
5 Allocating commitments to countries.
6 Implementing policies to ensure that commitments are fulfilled.
7 Enforcing compliance of states with overall target.

Apart from the third and the sixth task, all roles could be fulfilled by the UNFCCC COP. They are in line with the roles the COP currently fulfils: it has agreed on the Kyoto protocol to the UNFCCC, which does set targets for various countries.

The third task could be fulfilled by ICAO and IMO for aviation and maritime transport, respectively. This would be in line with the role that these organisations currently fulfil. These organisations could ensure that the policies and measures in various parts of the world are compatible with each other, so that they do not hamper international transport.

ICAO and IMO may have to develop guidance for several policies and measures. As analysed in section 3.3.1, policies and measures may need to be stacked to allow stage 3 countries to reach their absolute targets and stage 2 countries to meet their relative targets.

The sixth task would have to be fulfilled by countries. Countries would also need to enforce compliance of actors with policies and measures, much in the same way that compliance with international policies and standards is currently enforced.

3.5.3 Coverage of climate impacts

The climate impact of both aviation and shipping is caused by a range of emissions and physical effects: greenhouse gas emissions, indirect effects of non-greenhouse gas emissions, contrails, ship tracks and cirrus cloud formation (see section 2.1). This fact raises two important issues for the allocation of emissions (or impacts) to countries. First, should all impacts be allocated to countries, and if so, how? Second, can all impacts be addresses with the same policies and measures, or are different policies and measures necessary? This section analyses how the multiple impacts can be addressed within the concepts selected above (section 3.4).

Allocation of impacts to countries
In order to allocate the impacts to countries, it has to be clear what is allocated. Climate policy regimes allocate quantified amounts of greenhouse gas emissions to countries. However, many of the climate impacts of aviation and shipping (and of other sectors, for that matter) cannot be expressed in the same metric as the greenhouse gases (see section 2.1). There are a number of reasons for this. One is that the effects may be very time and place dependent. Another reason is that the common metric of global warming potential (GWP) is not suited to express the climate impact of short-lived phenomena such as contrails and ship tracks. Therefore, if each of these impacts would be allocated to countries, they would have to be allocated apart from the allocation of other greenhouse gas emissions. Unless a new metric would be designed that would allow comparison of the impacts, it would not be possible to offset growth of these impacts by a decrease of greenhouse gas emissions.

Furthermore, in these concepts, climate impacts would be allocated to countries based on country of departure or arrival of a vessel or an aircraft or based on country of origin or destination of cargo or passengers. The allocation would have to be based on impacts of actual flights in order to allow countries to reap the benefits of the widest array of policies and measures aimed at reducing the impacts. This, however, could be very hard. CO_2 and NO_x emissions can be monitored and attributed to flights and voyages with a reasonable accuracy. Ship tracks and contrails, however, cannot. Contrails, for example, can be caused when aircraft fly at a certain distance from each other. The second aircraft may show contrails, but these would not be there if the first aircraft would not have flown there. In this case, it would be impossible to determine which plane has caused the contrails to be formed.

An alternative would be to use a multiplier on the emissions of the main greenhouse gas: CO_2. This multiplier would be the quotient of the total climate impact of aviation or shipping and the CO_2 emissions. However, such a multiplier could lead to negative trade-offs and would furthermore force the technological response to climate policy down one single path. This would most probably increase the costs of measures.

Special consideration should be given to the inclusion of negative climate impacts (cooling effects of e.g. CH_4 decomposition by NO_x and indirect sulphate effects). Since most of these effects result from emissions that pollute the air and/or may cause acidification, it would create a perverse incentive to reward these emissions in climate policy. On the other hand, it would not be fair to include only warming effects and leave the 'positive' contribution of these sectors out of a climate policy regime.

We propose to include only the direct emissions of greenhouse gases in a global climate policy regime for three reasons. First, inclusion of all impacts in a climate policy regime is impossible because there is no common metric. Second, using a multiplier is undesirable because is may lead to negative trade-offs. And third, the inclusion of emissions with cooling effects is problematic, since it may create perverse incentives for environmental policy.

Other climate impacts are important, but they are probably better dealt with outside the scope of the UNFCCC. NO_x emissions of both jet engines and maritime engines, for example, can be brought down by take-off and landing charges, harbour dues, or by increasingly tighter international standards. Likewise, contrail formation can be prevented to a certain extent by contrail-conscious air traffic management.

This solution has one disadvantage. In some cases, there may be trade-offs between the different climate impacts. For example, it is possible to fly at lower altitudes to reduce contrail formation (Greener by Design 2005). Such a measure would result in higher CO_2 emissions. The overall result, however, would be a reduction of the climate impact. When only the impacts of CO_2 are included in a climate policy regime, it might be harder to explore this trade-off.

In sum, only the climate impacts of direct greenhouse gas emissions should be allocated to countries and thus included in a global climate policy regime. Other impacts should be dealt with, but outside the scope of the UNFCCC.

3.6 Conclusion: concepts for the inclusion of international transport based on allocation of emissions to countries

This chapter has analysed the possibilities for the inclusion of international transport in a global climate policy regime that is based on allocation of emissions to countries.

Starting from the assumption that countries can only take responsibility for emissions when they have the means to control them, this chapter started to analyse policies and measures for the kind of control they give states over emissions. A separate analysis showed which control countries need for the various allocation options. Based on these analyses, allocation methods were combined with policies and measures.

Countries were given the means to differentiate commitments by introducing stacked commitments. Furthermore, roles were analysed and assigned to organisations and parties.

This resulted in two concepts for the inclusion of maritime transport and aviation in a global climate policy regime.

Concept A: Route-based allocation and stacked policies and measures
Emissions are allocated to the country of arrival or departure of the vessel or aircraft. Differentiated responsibilities are reflected both in the type of commitment and the policy instruments introduced. Industrialised countries would have absolute caps, with advanced developing countries being assigned relative emission targets and least developed countries given no commitments. These least developed countries could be incorporated in the climate policy regime via CDM, while advanced developing countries could introduce technology standards, emission charges and sectoral CDM (CDM which is not project based, but sector based) (Figueres 2006). The industrialised countries could apply a whole range of instruments, including RD&D, technology and performance standards, emission charging and emission trading. Only greenhouse gas (i.e. CO_2) emissions would be targeted directly, but flanking policies could be introduced for the other climate impacts. The UNFCCC would set targets and enforce them, whereas ICAO and IMO would develop guidance on policies and measures. The countries themselves would be responsible for implementing the policies and measures.

Concept B: Cargo-based allocation and stacked policies and measures
Emissions are allocated to the country of arrival or departure of the *passengers* or *cargo*. The other aspects of this concept are very much like the one described above.

Table 16 summarises the final concepts based on allocation of emissions to countries.

Table 16 Final concepts - allocation to countries

Concept	A Route based allocation	B Cargo based allocation
Allocation	Allocation based on country of arrival or departure of a vessel or an aircraft	Allocation based on country of origin or destination of cargo
Sector	Aviation and/or maritime transport	Maritime transport
Responsibility for the emissions	Countries	
Kind and height of commitment	In line with multi-stage approach: Industrialised countries: absolute caps Advanced developing countries: relative emission targets Least developed countries: no commitments	
Kinds of policy measures	Industrialised countries: R&D, Technology standards, performance standards, emission charges, emission trading Advanced developing countries: Technology standards, emission charges, sectoral CDM Least developed countries: CDM	
Coverage of the measures	CO_2 only	
Roles of Parties, Groups of Parties, UNFCCC, ICAO and IMO	UNFCCC sets targets and enforces ICAO and IMO develop guidance on policies and measures States implement policies and measures	
Geographical scope	Industrialised countries and advanced developing countries	

4 Sectoral commitments or targets

This chapter starts from the assumption that mitigation of climate impacts of aviation and maritime transport will not be the responsibility of countries, but rather of the sectors themselves. The sectors themselves, or rather, the international organisations governing aviation and maritime transport (ICAO and IMO), would be responsible for mitigating the climate impacts. The basic idea was originally formulated as:

> The emissions of international transport are allocated to the aviation and maritime sector. Both sectors take on commitments or targets. ICAO and IMO ensure that commitments are fulfilled.

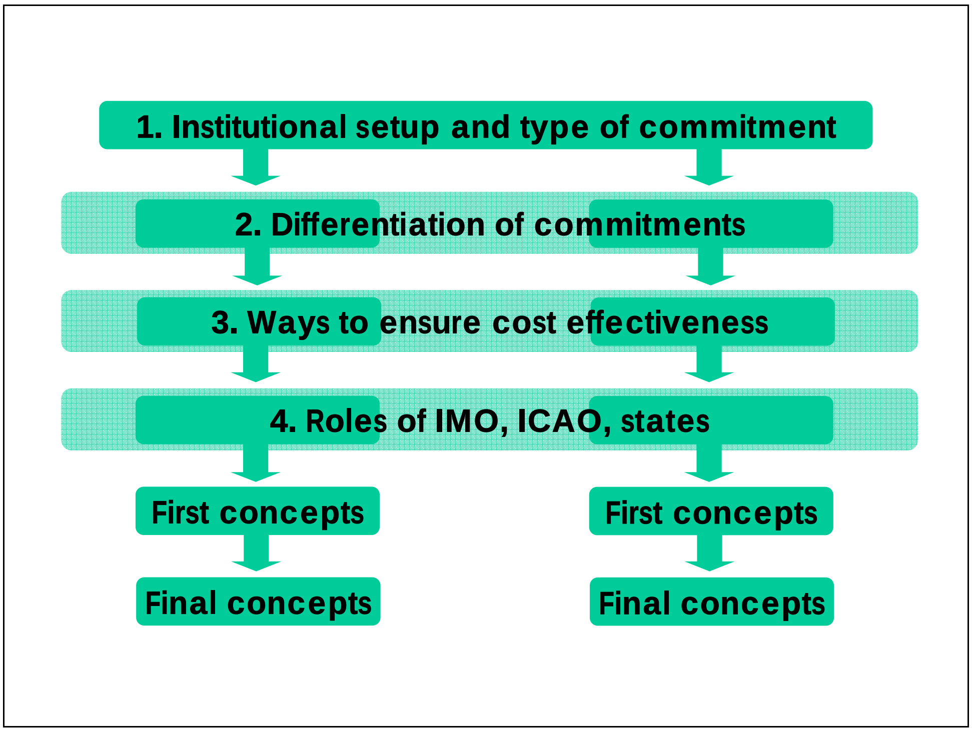
When emissions are allocated to the sectors, it means that they are not allocated to countries. In that way, this chapter can be seen as building on allocation option 1: no allocation.

The development of the original idea to the first concepts deals with the following issues:

- The form of the commitment and the institutional setup. Will there be absolute or relative targets, and will the burden of meeting these targets be shared with entities outside the sector or not? And which organisations are capable of setting targets and timetables, and of monitoring and enforcing them?
- Linking international transport with other sectors in a post 2012 policy regime. How can the principle of common but differentiated responsibilities for different sets of nations be combined with a sectoral approach?
- The principles for target setting and the cost-effectiveness of climate policy. How can both sectors be given equitable targets and what can be done to ensure that the costs for meeting these targets are neither excessive nor negligible in relation to the costs that other sectors bear? (If these costs would be much higher or lower than in other sectors, this could lead to macro-economically inefficient allocation of resources).

This chapter starts with a section in which the current institutional setup of environmental policy in both sectors is discussed (4.1). Then, the first concepts are developed in four stages, as illustrated in Figure 13. First, section 4.2 analyses the form of the commitments and the institutional setup. Second, ways to ensure cost-effectiveness are sketched in section 4.3. Third, 4.4 selects the first concept, on the basis of which full concepts are developed in section 4.5. Finally, 4.6 summarises and concludes.

Figure 13 Development of the first concepts – sectoral commitments



4.1 Current institutional setup

Both in aviation and in sea shipping, several international agreements exist on technology standards and environmental performance of ships and aircraft. These agreements are often legally binding on the states that have signed them. Signatory states enforce compliance with these agreements while aircraft or ships are within their jurisdiction, in ports or airports.

Currently, most international sector agreements on environmental issues are in the form of technical standards, stringency or procedures. Enforcement and compliance are not problematic when parties agree on the interpretation of the legal texts. Extension of these institutional arrangements to market based options is not straightforward, but it is possible provided the political exists.

Both aviation and maritime transport have taken some first steps towards a contribution of the sector to climate policy within ICAO and IMO, respectively. However, progress has been slow. The main obstacle to progress is the fact that non Annex I countries in both organisations object to being subject to climate policy measures. A future climate policy regime may not have the current Annex I – non-Annex I dichotomy, but it may still exclude some countries from any commitments. If a sectoral approach is to succeed, it will have to take into account the common but differentiated responsibilities, and differentiate commitments according to the level of development. Otherwise, the current deadlock might not be broken.

This next two subsections describe international agreements and their enforcement for aviation and sea shipping, respectively. The institutional arrangements may serve as a template for a possible inclusion of sectors in a post 2012 climate policy regime.

4.1.1 Aviation

A number of international organisations issue rules and regulations on safety and environmental aspects of aviation[26]. Most prominent among these organisations is ICAO, the International Civil Aviation Organization. It sets standards on, for example, noise and NO_x and other emissions of aircraft engine during the landing and take-off cycle. It has made the standards more stringent several times, and this has resulted in a market driven production cut-off of high NO_x emission engines[27].

States which are parties to ICAO enforce the standards agreed on by the General Assembly of ICAO and laid down in Annexes to the Chicago Convention. Annexes to the Chicago Convention are international treaties which supersede national law[28].

States are able to enforce ICAO regulations (and other national and international regulations) when aircraft are in airports. It is common practice that aircraft which do not comply with national law are refused landing rights. If national law defines non compliance as an offence or a crime, states may apply sanctions such as charges or fines, and ultimately refuse an aircraft to take off. Problems do occur, however, when states disagree on the interpretation of the legal texts. This may result in complicated legal procedures and political disputes.

Apart from or on top of international rules, states may require aircraft registered nationally to observe additional norms.

Agreements of ICAO and other international organisations may and do extend into the environmental field (see Box 3). Currently, legally binding ICAO agreements are mostly technical standards or operating procedures.

---

26 Rules and regulations in the Netherlands, for example, stem from ICAO; the Joint Aviation Authorities (JAA); the European Aviation Safety Agency (EASA); the EU and from national law.

27 High NO_x engines are still being used, and will only be phased out when their economical life has ended.

28 Personal Communication Mr. Hans Pulles (Dutch Ministry of Transport), 19.6.2006.

Box 3: ICAO and aircraft engine emissions

ICAO (International Civil Aviation Organization) is a specialised agency of the United Nations that was founded in 1944 through the signing of the Chicago Convention on Civil Aviation. The environmental activities of the ICAO are undertaken largely by the Committee on Aviation Environmental Protection (CAEP).

Every three years, the ICAO Council revises and updates a version of the 'Consolidated Statement of continuing policies and practices related to environmental protection', to be adopted by the triennial ICAO Assembly. The present version was adopted at the 35th Assembly in October 2004 (ICAO, 2004).

Aircraft are required to meet the engine certification standards adopted by the Council of ICAO. These are contained in Annex 16 - Environmental Protection, Volume II - Aircraft Engine Emissions to the Convention on International Civil Aviation. These were originally designed to respond to concerns regarding air quality in the vicinity of airports. As a consequence, they establish limits for emissions of oxides of nitrogen (NO_x), carbon monoxide, unburned hydrocarbons, for a reference landing and take-off (LTO) cycle below 915 metres of altitude (3,000 ft). There are also provisions regarding smoke, vented fuel and noise.

4.1.2 Maritime transport

In the maritime sector, several organisations set up rules and laws for different jurisdictions[29]. Of these organisations, the International Maritime Organisation (IMO) has the broadest scope. IMO is a UN agency responsible for improving maritime safety and preventing pollution from ships. It currently has 166 Member States.

IMO's most important agreements on environmental protection are laid down in the International Convention for the Prevention of Pollution from Ships (MARPOL) and its annexes. Annex VI, for example, which entered into force on 19 May 2005, sets limits to emissions of SO_2 and NO_x[30]. MARPOL Annexes are legally binding for the states that have ratified them. States that have not ratified a specific Annex do not have to transpose it into national law, let alone enforce it. Ships have to comply with MARPOL or its Annexes when sailing under a flag of a state that has ratified them, or when entering the jurisdiction of a state that has ratified them.

Any violation of the MARPOL 73/78 Convention within the jurisdiction of any Party to the Convention is punishable either under the law of that Party or under the law of the flag State. It is the responsibility of flag States or states with ports to ensure that ships comply with MARPOL regulations.

With the exception of very small vessels, ships engaged on international voyages must carry on board valid international certificates which may be accepted at

---

29 For example, ships in Dutch waters or ports have to comply with rules from IMO and the EU. Moreover, ships sailing under a Dutch flag have to comply with Dutch maritime law.

30 SO_2 (or formally SO_x) emissions are limited by introducing a global cap on the sulphur content of fuel oil (4.5%). Furthermore, Annex VI contains provisions allowing for special SO_2 Emission Control Areas (SECAS) to be established with more stringent controls on sulphur emissions. In these areas, the sulphur content of fuel oil used onboard ships must not exceed 1.5%. Alternatively, ships must fit an exhaust gas cleaning system or use any other technological method to limit SO_2 emissions. The Baltic Sea Area is designated as a SO_2 Emission Control area in the Protocol. The North Sea was adopted as SO_2 Emission Control Area in July 2005. NO_x emissions from diesel engines are also limited. A mandatory NO_x Technical Code defines how this shall be done.

foreign ports as prima facie evidence that the ship complies with the requirements of the Convention.

If, however, there are clear grounds for believing that the condition of the ship or its equipment does not correspond substantially with the particulars of the certificate, or if the ship does not carry a valid certificate, the authority carrying out the inspection may detain the ship until it is satisfied that the ship can proceed to sea without presenting unreasonable threat of harm to the marine environment.

In practice, ships are inspected when entering a port. In most North American and European countries, 25% of individual ships are inspected, in accordance with the Paris Memorandum of Understanding on Port State Control[31]. In case a ship is not in compliance, inspection authorities have a number of possible measures to ensure compliance, varying from fines to detention.

Current procedures on the determination of IMO rules and their enforcement are best suited for technical standards. In the maritime sector, however, many abatement options are operational. Within the current framework of IMO, it is hard to address operational factors, although the current work on the IMO CO_2 index could perhaps be seen as a first step (see Box 4).

[31] Mr. Vink, Inspectie Verkeer en Waterstaat, personal communication 21 November 2005.

Box 4: IMO work on policy to reduce greenhouse gas emissions
Following the call by the Kyoto Conference of Parties to the UNFCCC to pursue the limitation of greenhouse gas emissions from ship bunker fuels (Article 2.2 of the Kyoto Protocol), attention has also been given to GHGs. IMO started work on this topic in 1998 by commissioning a study on ship GHG emissions in 2000 to a consortium led by Marintek (IMO, 2000). In addition, a correspondence group was established by the Marine Environment Protection Committee (MEPC), which was asked to collate any information received, prepare an IMO Strategy/Policy on GHG emissions from ships and to draft an IMO Assembly resolution to that effect. GHG reduction in international shipping has since been on the agenda of the MEPC meetings.

In 2003, IMO's General Assembly adopted a resolution (A.963(23)) which urges the MEPC to establish a GHG emission baseline, to develop a methodology to determine the GHG emission index for ships, to develop guidelines for practical implementation of the GHG emission indexing scheme, and to evaluate technical, operational and market-based solutions.

Although several countries have since then put forward proposals to mitigate emissions, any progress on this issue has been halted by key non Annex I countries, such as China, India and Saudi Arabia. These countries argue that a global approach to reduce greenhouse gas emissions would not adhere to the principle of common but differentiated responsibilities for the developed and developing countries as formulated by the UNFCCC. Annex I countries such as Norway, however, argue that any GHG policies should be applicable to all ships, irrespective of their nationality. Their main arguments are that:

a The Kyoto Protocol is aimed at domestic emissions, while the characteristics of international shipping emissions require fundamentally different treatment.
b The IMO has a strong tradition of developing mechanisms that do not discriminate between Member States.

In 2004, MEPC52 agreed to focus at technical issues only at this stage. The elaboration of a CO_2 index was given priority. The CO_2 index is defined as the amount of CO_2 emissions per amount of transport work. The index is determined by both technical and operational factors. In 2005, MEPC53 agreed on draft interim guidelines for voluntary ship CO_2 emission indexing and to invite industries and other organizations to start working with the guidelines in order to gain experience. The issue of possible instruments to reduce greenhouse gas emissions, based on this index, was postponed.

4.1.3 Conclusion

Both in sea shipping and in aviation a large number of international agreements exist which are enforced by the states that have ratified the agreement. Most of these agreements focus on technical or operational standards.

4.2 Target and institutional setup

Sectoral commitments or targets can either be absolute or relative to transport performance. This section explores both possibilities in order to analyse the implications and the potential barriers. As this section will show, the form of the commitment has a bearing on the institutional setup. The discussion of the environmental effectiveness of absolute and relative targets is postponed to section 4.5.1.

4.2.1 Sectoral commitments or targets with an emission cap

The first alternative, sectoral commitments or targets with an absolute cap, would imply that ICAO and/or IMO take on an absolute target for their sectors, just like industrialised nations take on an absolute commitment in the UNFCCC COP (in a future climate policy regime, other commitments than absolute targets are conceivable). This alternative would have the advantage that the commitments of the international transport sectors would be brought in line with the commitments of states.

In principle, ICAO and IMO can ensure the fulfilment of their commitment in two ways. First, they can redistribute the assigned amount to their member states. This would imply some form of allocation of emissions, like in chapter 3, although the grouping of countries would not necessarily have to coincide with the UNFCCC grouping for emissions from ground based sources. In this case, the question has to be solved how the assigned amount would be allocated to countries. Second, ICAO and IMO could create allowances for emission trading in line with their cap, which they could distribute directly to aircraft operators or ship operators. These operators could then engage in emission trading. Since the first option is only slightly different than the options discussed in chapter 3, we will develop only the second option here.

When ICAO and IMO agree their cap with the UNFCCC COP, the organisations could mutually recognise their cap or assigned amount, as caps are called in the UNFCCC. This would have the advantage that emission allowances based on the cap would be mutually exchangeable, and that emission trading systems could be linked.

As described in section 4.1, ICAO and IMO have no direct enforcement power, neither can they force their members to implement specific policies and measures. This has two implications. First, ICAO and IMO would have to delegate the implementation of policies and measures and their enforcement to member states. States could, for example, ultimately refuse landing rights to airlines that have not surrendered enough allowances for their emissions, or that have not reported their emissions to ICAO. In maritime transport, states could require ships to surrender allowances before leaving the harbour.

The second implication of the lack of direct enforcement power is that neither ICAO nor IMO can be held accountable for not fulfilling their commitment or not reaching their target. After all, even if only one of the aircraft operators or ship operators would not surrender enough allowances, the sectoral commitment may not be fulfilled. Neither IMO nor ICAO currently have the power to force operators to comply with resolutions. However, in a future climate policy regime, ICAO and IMO may cancel the permit of an operator to engage in emission trading. In that case, the operator could not engage in flights for which he would have to surrender allowances. This may turn out to be a strong enforcement action.

Differentiation of commitments

From the current discussions within ICAO and IMO, it can be understood that it will be very hard, if not impossible, to impose a cap on aviation or maritime transport of a country that does not have a commitment under the UNFCCC, because they claim that it could be a infringement of the principle of common but differentiated responsibilities. The reason why these countries have no target is that they are allowed to develop their economies, which results in higher emissions. This argument holds for the international transport sectors as well as for other economic sectors.

Therefore, ICAO and IMO would probably have to adhere to the principle of 'common but differentiated responsibilities' (UNFCCC), even though this principle is not enshrined in the Chicago Convention or the IMO Convention. Not adhering to this principle would mount opposition from countries without commitments, which would frustrate negotiations on policy measures. Differentiating responsibilities would not be without precedents, however. ICAO has given developing countries more time to implement noise regulation, and IMO has agreed with a regional implementation of sulphur exhaust limits.

How could ICAO and IMO implement the 'common but differentiated responsibilities'? The differentiation could be based on:

- The nationality of the airlines.
- The routes flown.
- The nationality of the passengers transported.
- The ultimate destination of the cargo.

The latter two options suffer from heavy data requirement. The first option would be the easiest to implement, but is could seriously distort the competitive market. Consider for example a route between an airport in a Least Developed Country and an Industrialised Country. In many cases, this route will be served by at least two airlines, one based in the LDC, the other based in the IC. If the first would have different commitments than the latter, this would distort the competitive market on that route. The LDC airline would grow at the expense of the IC airline, but if the total transport performance would remain the same, this would have no economic benefit for either the LDC or the IC. Therefore, we consider a route-based differentiation the best option; it balances ease of implementation and data requirements with market efficiency.

It must be recognised that a route-based differentiation and route-based policies associated with it would constitute a shift from the current practice within ICAO and IMO. Although both organisations do have regional differentiation in at least some of their policies (sulphur emission policies in IMO and noise abatement policies in ICAO), most of their policies are implemented on a global level. Furthermore, in most cases, states in which vessels or aircraft are registered are held responsible for implementation of these policies. A route based differentiation would probably shift the responsibility to harbour and airport states.

One way of implementing this differentiation would be to require operators to surrender emission allowances on specific routes only. Another way would be to require operators to surrender allowances for all their emissions on routes in or between Industrialised countries, for a part of their emissions on routes in or between advanced developing countries, and no allowances for routes in or between least developed countries. A third option, allocating more allowances to operators on routes from LDCs, would be less feasible, since it would require intricate rules on redistributing allowances when operators change their routes[32]. In aviation, route schedules exist but are subject to change. In contrast, in many segments of shipping, there are no scheduled routes.

Whichever method of differentiation would be chosen, ICAO and IMO would have to make sure that there are no perverse incentives, e.g. fly or sail longer distances in order to avoid the costs of mitigation.

Conclusion
In sum, this analysis shows that sectoral commitments with an emission cap are possible. ICAO and IMO would create allowances on the basis of a cap and distribute them over operators. They, in turn, can participate in emission trading (see section 4.5.2). The cap could be agreed with national caps set by the UNFCCC (assigned amounts). This would have the advantage that emission trading systems could be linked, thereby increasing the efficiency of climate policy.

4.2.2 Technology based sectoral commitments

Technology based sectoral commitments would basically consists of pledges of ICAO and IMO to contribute to the mitigation of climate change in certain ways. The organisations could pledge for example to adopt certain policies and measures, or to take on other types of commitments and targets, if mandated to do so by their members.

This institutional arrangement would have two main advantages. First, it would be in line with the current tasks and responsibilities of IMO and ICAO, and could therefore build on the existing organisational capacities of these organisations. Second, agreement with other international bodies would not be necessary.

This comes at a price, however. It is not to be expected that ICAO and IMO could engage in the development of policies and measures that would be very costly to all its member states. This would lead to resistance from states that have no target or commitment in a post 2012 climate policy regime. Neither can measures be expected from ICAO and IMO that significantly reduce demand.

The policies and measures available for ICAO and IMO would be predominantly of a technical nature: technical and performance standards. Other policies and measures are hardly conceivable. It is unlikely that ICAO and IMO could implement taxes and charges or agree on their implementation by their member

32 In any case, if ICAO would choose to grandfather allowances, the distribution could cause problems when ICAO would opt for a route-based differentiation. An auction of allowances would not have these problems, but in that case the question would have to be solved how the proceeds would be used.

states, for the same reasons why the UNFCCC cannot agree on taxes and charges (see section 3.2.1).

Policies and measures could in theory be differentiated in much the same way that IMO and ICAO currently differentiate measures. IMO, for example, has agreed on measures that will only affect shipping in certain regions[33]. Extension of such a scheme to greenhouse gas emissions will not be straightforward, however. ICAO has issued guidance for the regionally differentiated phase-out of noisy aircraft types, thereby enabling a regional differentiation in aircraft noise. This could be extended to e.g. measures of fuel efficiency, although ICAO has continuously laid emphasis on a balance between environmental protection and possible market distortions. Since fuel efficiency requirements would be harder to meet for some airlines than for others, this could distort the market and therefore not gain enough support within ICAO. So, although regionally differentiated commitments exist in other environmental fields, extension to greenhouse gas emissions may prove to be problematic.

Since the commitments would be based on technical policies and measures, they would most likely be relative targets (see section 3.3.1). Since all countries would have to agree on the commitments and the policies and measures, they have to be acceptable to countries without a commitment under the future climate policy regime, which means that the commitments will most likely not be too stringent. Furthermore, IMO and ICAO could only take supply side measures. The demand for aviation and maritime transport can hardly be addressed by technical policies and measures.

What could the sectoral approach look like? To name a few items it could include: In shipping, environmental indexing could be developed further to the point where it would constitute a basis for CDM of Sectoral CDM. In addition, NO_x standards could be tightened both for new and existing ships, which could mitigate the indirect climate effects of shipping. In aviation, ICAO could offer guidance on best practices in air traffic management to reduce fuel consumption and the formation of contrails, further reduce engine NO_x emissions through increasing standards, et cetera. Furthermore, it could explore the possibilities for CDM in aviation.

Most of these measures would lead to a reduction of the climate impacts relative to transport volume. Because transport demand is forecasted to increase significantly, these measures would probably result in slower increase of the climate impacts of international transport, not in a stabilisation or decrease (Den Elzen, 2007).

[33] Under MARPOL Annex VI, certain areas can de assigned the status of Sulphur Emission Control Area, requiring ships sailing in these regions to limit their sulphur emissions.

4.2.3 Conclusion

A sectoral approach could either be based on an emission cap or on a efficiency pledge. An technology based approach – without a cap for the sector and without necessity for differentiating commitments – would have the advantage that it is compatible with the current practice in IMO and ICAO. Some form of differentiation could be possible. The measures taken by IMO and ICAO would probably lead to a reduction of the climate impacts relative to transport performance. But absolute climate impacts would probably continue to rise.

An approach with a cap could open up the possibility of linked trading systems. ICAO and IMO could \allocate allowances to operators, that could be used in emission trading. This could be combined with a route based differentiation.

4.3 Ensuring cost-effectiveness

In a sectoral approach, cost-effectiveness of policies in different sectors could diverge. This may have negative impacts on welfare. Two issues are at stake here. First, it could be desirable to ensure that the cost-effectiveness of climate change action in aviation and sea shipping is not completely out of line with other sectors. And second, one could want to ensure that the cost-effectiveness of measures taken by different actors in the sector are comparable.

One way to ensure that the cost-effectiveness in the international transport sectors will not grow out of line with the cost-effectiveness in other sectors is to introduce emission trading or credit trading (in case of relative targets). Should the marginal costs to reduce emissions in shipping or aviation be lower than in another sector, then shipping or aviation would sell emission allowances or intensity credits to that other sector. If the costs are higher, these sectors would buy. By doing so, the marginal cost to reduce a unit of emissions or intensities would be equal in all sectors of the economy[34]. Emission or credit trading would also ensure that the cost-effectiveness is equal within the sector.

All other policy instruments would not by their nature ensure an equal marginal cost-effectiveness among sectors (except for emission taxes, which are not feasible). Neither would they ensure that the most cost-effective measures to reduce emissions are taken first. And they do not equalise cost-effectiveness within the sector.

4.4 Selection of first concepts

This chapter shows that two concepts of sectoral commitments are conceivable. Their main difference is their institutional setup.

---

34 Since allowance trading and credit trading would not be mutually compatible, differences in marginal cost-effectiveness would exist between the regions of the world with absolute targets and the regions with relative targets. This would not be considered a problem, since the starting point of differentiation of commitments was that different regions have differentiated responsibilities.

One first concept would be a sectoral commitment with an emission cap. We label this **concept C**. ICAO and IMO would take on this cap, which would be agreed with the UNFCCC. ICAO and IMO would create emission allowances which they would distribute among aircraft or ship operators. These could engage in emission trading. The differentiation of responsibilities would be route based: on routes between the least developed countries, operators would not have to surrender allowances for their emissions, whereas on routes between industrialised countries, operators would have to surrender allowances. There would be mutual recognition of emission allowances in different systems, both sectoral systems and regional or national systems.

Another first concept is a technology based sectoral commitment. In that case, ICAO and IMO would pledge to take on a certain commitment. This concept is labelled **concept D**. These commitments would be relative targets at most, since they would be based on technical and operational measures.

4.5 Further development of the concepts

In order to develop the concepts further, a number of issues have to be addressed: the kind and level of the commitment that the sectors would take on, the kinds of policy measures that they would implement, and the coverage of climate impacts. Furthermore, the roles of organisations and parties needs to be described in more detail. This section addresses these issues.

4.5.1 Kind and level of commitment

In a sectoral approach with a cap, the sectors would take on an absolute cap of emissions. The height of the cap should be in line with the stated goal of all climate policy, viz. to prevent ‘dangerous anthropogenic interference with the climate system’. This means that the cap would have to be well below the business as usual forecasted emissions, unless ground based sources would decrease their emissions even more than currently foreseen. For the same reason, a cap which would be relative to transport performance would not have the desired environmental effect.

In a technology based sectoral approach, only technical and operational measures on the supply side can be taken. Therefore, the commitments will be relative to transport performance. The analysis in Den Elzen (2007) shows that very ambitious commitments could mean a reduction of emissions relative to transport performance of 41% in 2050 for aviation[35] (relative to 2000 levels) and 25% for maritime transport. In absolute terms, the emissions would continue to rise, with respectively 200% for aviation and 110% for maritime transport until 2050.

---

[35] This is based on a baseline annual increase of 1.3% from 2000 through 2010; a baseline increase of 1% from 2011 through 2020; a baseline 0.5% plus an additional 0.5% from 2021 through 2050.

4.5.2 Kind of policy measures

In a sectoral approach with an emission cap, emissions of operators would be capped on certain routes. An inflexible cap is undesirable, however, since it would distort the competitive market and may lead to large differences in cost-efficiency of meeting the cap between operators. In order to allow some flexibility, the climate policy regime should therefore give room for trading of assigned amount units between countries. Furthermore, the regime could allow pooling aviation emissions with emissions from ground based sources and even creating a bubble of aviation emissions and ground emissions of a number of countries. Under such a regime, it would be logical for operators to engage in emission trading.

International transport operators could trade without problems in trading systems in countries with absolute targets. Trading in countries with relative targets is not straightforward. There are, however, several solutions. First, if aviation would be a net buyer of emission allowances, it could do two things:

1 Buy CDM credits in countries without commitments.
2 Engage in CDM-like projects in countries with relative commitments. In that case, the baseline would not be a business as usual emission baseline, but rather a business as usual plus increased efficiency baseline. For example, when a country is committed to increasing its emission efficiency by 3% per year, it could decide to hand over emission reduction credits for every emission reduction below the 3% per annum increase in efficiency. The baseline could, of course, also be made sector specific in order to allow some sectors to contribute more to the overall commitment.

Second, if aviation would be a net seller of allowances, it could:

1 Sell allowances to trading entities in countries with a relative commitment. When the decrease in emissions in aviation would not have an impact on economic output, this would create no accounting problems. When there would be GDP effects, these could be taken into account by converting absolute emissions into relative emission credits that would be emission decreases below a business as usual plus emission efficiency baseline.

In a technology based sectoral approach, the policy measures would be mostly technical and operational. R&D into increasing fuel efficiency of new and existing aircraft and ships; R&D into operational measures that would decrease fuel efficiency; R&D into biofuels for shipping and aviation; dissemination of the results; stimulation of adoption of innovations; and, of course, designing new standards in international co-ordination and enforcing them.

Apart from these technical policy measures, states could use some market-based instruments to induce technological development and diffusion of innovations. Differentiated tariffs and emission charges could create powerful incentives to invest in low-emission vessels or aircraft. A scrapping bonus could take the least efficient vessels and aircraft out of the fleet before their economic life would have ended. This would improve the fuel efficiency of the fleet.

4.5.3 Roles of organisations and parties

In a sectoral approach with a cap, ICAO and IMO would set a cap for emissions of their respective sectors. They would agree this cap with the UNFCCC. ICAO and IMO would provide guidance for policies and measures on technical and operational measures that could facilitate the international transport sectors in meeting the cap. Furthermore, IMO and ICAO would organise emission trading systems: they would distribute allowances among operators, set rules for the surrender of allowances and enforce compliance. When emission trading systems would include more sectors that just international transport, the UNFCCC could issue guidance on the combination of absolute targets for aviation and relative commitments for some countries.

The enforcement could be organised as follows. Operators would report emissions and surrender allowances to ICAO and IMO. In case of non-compliance, these organisations would notify their member states. These, in turn, could take action against operators. Furthermore, in case allowances would be grandfathered, operators that are not in compliance could be issued with less allowances in the next trading period.

In a technology based sectoral approach, ICAO and IMO would issue standards. States would implement these standards and enforce them on ships sailing under their flag and on ships in their ports, much in the same way that standards are currently enforced.

Pro-active states could choose to engage in R&D and/or implement market based instruments in order to further technological progress and diffusion of innovation (see section 4.5.2).

4.5.4 Coverage of climate impacts

The concept for the sectoral approach for the inclusion of international transport in a global climate policy regime with a cap would imply allocation of emissions to operators (see section 4.2.1). In section 3.5.3 it has been argued that in that case, only emissions of greenhouse gases can be included in the climate policy regime. There are three main reasons for this:

- There is currently no metric that allows for treatment of short lived phenomena such as contrails and greenhouse gas emissions on an equal basis.
- Indirect effects of emissions can hardly be attributed to individual flights or airlines, which makes allocation of these impacts to countries problematic.
- Negative climate impacts (cooling), which are indirect effects of emissions, are hard to incorporate.

So in the sectoral approach with a cap, only CO_2 emissions of aviation can be included in the climate policy regime.

In the technology based sectoral approach, the situation is different. In that case, all climate impacts can be addressed. For example, in the case of aviation, NO_x

emission standards, standards for the addition of bio-kerosene to fossil kerosene and possibly even fuel efficiency standards are conceivable instruments to reduce the emission-related climate impacts. The impacts of contrails and cirrus could be addressed by developing standards and rules for contrail reducing ATM procedures.

So the technology based sectoral approach could, in principle, address most climate impacts of both aviation and shipping. Still, negative climate impacts (cooling effects) of air polluting emissions would continue to pose a problem to the integration of climate policy with air pollution policy.

4.6 Conclusion: concepts for a sectoral approach to the inclusion of international transport

This chapter has developed concepts for the inclusion of aviation and maritime transport in a global climate policy regime without allocating emissions to countries. Rather, the sectors themselves are responsible for mitigating their climate impacts. The international organisations governing these sectors play a pivotal role. They take the responsibility to limit the climate impacts. The limit can either be stringent, an absolute cap, or less stringent, in the form or an efficiency target or a set of policies and measures. Both options are briefly described below.

Concept C: Sectoral approach with emission cap
The emissions of international transport are not allocated to specific countries, but ICAO and IMO take responsibility for them. They take on a cap, in agreement with the UNFCCC. ICAO and IMO organise emission trading and the introduction of technological policy measures. Emission trading systems of these organisations recognise units from other systems, and this recognition is mutual. Countries enforce the compliance of aircraft operators and ship operators with the international policies. Differentiation of commitments is accounted for by only including emissions on routes within and between industrialised and advanced developing countries.

Concept D: Technology based sectoral approach
ICAO and IMO pledge to decrease the climate impact of aviation and maritime transport relative to transport performance. They do so by introducing a set of policies and measures aimed at reducing the climate impacts. These policies could comprise NOx emission standards, fuel efficiency standards, Air Traffic Management procedures aimed at reducing contrails, performance standards, et cetera. States would implement the policies and enforce compliance.

Table 17 Concepts for the sectoral approach

Concept	With emission cap	Technology based
Allocation	No allocation	
Sector	Aviation and maritime	
Responsibility for the emissions	ICAO, IMO	No formal responsibility; ICAO and IMO would pledge to improve efficiency of transport systems
Kind and height of commitment	Absolute target	Relative commitment
Kinds of policy measures	Technological policy measures, emission trading	Technological policy measures
Coverage of the measures	CO_2 only	All impacts
Roles of Parties, Groups of Parties, UNFCCC, ICAO and IMO	ICAO and IMO take on cap and organise emission trading UNFCCC recognises caps Operators surrender allowances States enforce compliance of operators	ICAO and IMO set standards States implement standards and enforce compliance
Geographical scope	Routes within and between industrialised countries and advanced developing nations	All countries, ad hoc differentiation of measures possible

5 A regional start

The previous two chapters have explored ways to integrate emissions from international transport in a global climate policy by allocating emissions to countries and to sectors. A global approach to mitigate climate impacts from these international sectors has major advantages, because it could minimise distortions of markets while maximising the environmental effect. However, in case a global solution is not possible, a regional start could be envisaged.

This chapter develops the first concepts of a regional start for the inclusion of international aviation and maritime transport in a regional post 2012 climate policy regime. The basic idea from which these concepts are developed was originally formulated as:

> Mitigation by regional agreements. Emissions will be incorporated into EU policies and measures which may later be expanded to a larger regional scale through international agreements.

A major advantage of this approach is that is does not necessarily depend on agreement being reached in a wider international context. Pro-active countries may together decide to set an example by reaching agreement on mitigation of climate effects of international transport. This way these countries can demonstrate that they take climate policy seriously and may induce countries that are less well developed to also adopt measures.

The pivotal choice to be made for the elaboration of this idea is: which new or existing policy or policies can be implemented in a regional context to mitigate greenhouse gas emissions from international transport?

For aviation, we have made the choice to focus on inclusion of emissions from aviation into the EU emissions trading system (ETS). The European Commission aims to put forward a legislative proposal by the end of 2006 on how to include aviation in the EU ETS (COM(2005) 459 final). This system would be a good example of a regional start, especially since it is official EU policy to extend ETS to other countries and regions.

For maritime transport, this chapter also focuses on the EU. Since there are currently no propositions for policies and measures for abating greenhouse gas emissions from maritime transport, we start from the beginning by discussing all possible options.

This chapter will first address the possibilities for a regional start of aviation, and discuss maritime transport subsequently.

5.1 A regional start for aviation

In its communication of September 2005 (COM(2005) 459 final), the European Commission announces that it plans to take forward the idea of emission trading for international aviation. Meanwhile, it intends to keep open alternative measures to limit the climate impact of aviation 'in the event that complementary measures are required alongside emissions trading to address the full climate impact of aviation'.

There are already some initiatives on alternative and complementary measures in Europe. Emissions from domestic aviation are included under a voluntary emissions trading scheme in the UK. A small-scale initiative directed at fuel taxation on domestic flights exists in the Netherlands, and is under discussion in Germany. This could potentially be expanded to flights between these countries. And although not directly related to climate impacts but to all environmental effects of aviation, Sweden has announced to levy an environmental tax on air tickets from mid-2006. The tax will also apply to international flights[36],[37].

In this section we will mainly focus on the developments with respect to including aviation in the EU ETS. First, we will briefly outline the current developments with respect to including aviation in the EU ETS. Next, three possible means of expanding the system under development are discussed:

- Expanding the system in the EEA.
- Expanding the system parallel to EU enlargement.
- Expanding the system to countries / regions that are not part of the EU.

Account shall be taken of the possibilities to increase support by making use of differentiated responsibilities.

5.1.1 Current state of affairs regarding aviation and the EU ETS

Currently the European Commission is studying the design parameters for inclusion of aviation in the EU ETS. The Commission believes that the objective of the scheme should be to provide a workable model for aviation within emission trading in Europe that can be extended or replicated worldwide.

Under the European Climate Change Program (ECCP) 2, an Aviation Working Group has been set up representing EU Member States and different stakeholders. This group is to advise the Commission on how the climate impact of aviation can be incorporated in the EU ETS. As stated in the Communication (COM(2005) 459 final), the Commission aims to put forward a legislative proposal by the end of 2006.

---

36 See http://www.regeringen.se/sb/d/5973/a/55595 (consulted January 18th, 2006).

37 Apart from these measures that directly relate to the environment, France (alongside 12 other countries) has taken the initiative to introduce a charge on airline tickets to raise money for development aid. As of July 1st, France will raise a levy of € 1 will be raised on EU flights and € 4 on long haul flights. Business class travelers face a levy of € 10 to € 40 for EU and long haul flights respectively.

In this section we will briefly describe the outline of the scheme under development. Because there is of yet no legislative proposal, the nature of this section is by definition speculative. Where possible, we will make clear the standpoint of the Commission[38] and whether there appears to be agreement on this among stakeholders or not.

It is intended to include the emissions from aviation into the EU emissions trading scheme. Because it is fundamental that the *entity* made responsible is the one with the most direct control over the type of aircraft in operation and the way is which they are flown, the Commission considers that aircraft operators should be the entities made responsible within the EU ETS. There is wide agreement on this point among stakeholders.

The *coverage* of the trading scheme has not yet been decided upon. The Commission is of the opinion that both the CO_2 and non-CO_2 impacts of aviation should be addressed to the extent possible. Pending scientific progress regarding some non-CO_2 impacts, a pragmatic approach is needed according to the Commission, either by:

- Introducing a multiplier; aviation would have to surrender a number of allowances corresponding to its CO_2 emissions multiplied by a precautionary average factor reflecting other impacts.
- Introducing initially flanking instruments to assure no negative trade offs occur. An example would be differentiated airport charges according to NO_x emissions.

Some airports have already introduced NO_x landing and take off (LTO) charges to provide incentives to airlines to fly cleaner aircraft, so to have minimal impact on local air quality.

Monitoring is likely to be based on actual fuel consumption data. In this way, aircraft operators would receive maximum incentives to reduce fuel consumption. Moreover, they would be most flexible in their way to respond.

Regarding the type of flights covered, the sector's overall emission limitation, and the allocation procedure of allowances it is more difficult to predict the Commission's proposal.
To prevent competitive distortions between operators, the starting point of the Commission is that all aircraft operators on certain routes should be included in the scheme. So if EU carriers would be liable to the scheme on a certain route, so would non-EU carriers on this route. This would ensure minimal competitive distortions on routes.
There are several '*geographical scopes'* under consideration. First of all, the scheme could apply to intra-EU routes only. The Commission does not favour this option, because it would limit the environmental impact of the scheme, compared to other options. Many aircraft operators are however in favour of starting with this option initially. They fear that under a larger geographical scope, competitive distortions will arise, because the Commission will not succeed in

---

[38] The Commissions standpoints are mostly derived from COM(205) 459 final.

imposing the scheme on non-EU carriers. This is less of a problem in an intra-EU scheme, because the market share of non-EU carriers on intra-EU flights is very limited[39].
The Commission appears to favour the option of including the emissions from all flights departing from EU airports for its larger environmental impact.
There are two alternative options still under consideration. This is a scheme in which emissions from all flights either landing or departing from EU airports are included. Finally, a system including all emissions in European airspace is considered. This would have some complicating factors, regarding the actual fuel consumption within EU airspace and overflights[40].

As regards calculating and apportioning aviation's overall *emission limitation*, the Commission is of the opinion that rules already in place for participants in the EU scheme are not necessarily suitable for aviation. This could be taken to understand that the Commission is considering formulating overall emission limitation in different means than referring to 1990 emission levels. However, we are not aware of any official Commission standpoint on this issue.
The Commission and many other stakeholders appear to favour a harmonised (or possibly central) allocation mechanism, which could prevent competitive distortions. In case of a central mechanism, emissions need not necessarily be first allocated to countries, but can be allocated to aircraft operators directly.
It is not clear which position the Commission takes regarding the allowance distributing mechanism. Generally, allowances could be grandfathered, possible based on benchmarking, or auctioned.

Having explained briefly the potential structure of emission trading for aviation, we will now turn to how the scheme could be expanded.

5.1.2 Expanding emissions trading for aviation

This section discusses three possible means of expanding the system under development:

- Expanding the system in the EEA.
- Expanding the system parallel to EU enlargement.
- Expanding the system to countries / regions that are not part of the EU.

Account shall be taken of the possibilities to increase support by making use of differentiated responsibilities.

Expanding the system in the EEA
The European Economic Area (EEA) unites the 25 EU Member States and the three EEA EFTA States (Iceland, Liechtenstein, and Norway) into an Internal Market governed by the same basic rules. All EEA States have agreed to implement EU legislation on social policy, consumer protection, the environment, statistics, and company law. Directive 2003/87/EC, the Greenhouse Gas

39 Non-EU carriers require special freedom rights to operate intra-EU flights. These are granted very restrictively.
40 Flights that do not land at EU airports but cross EU airspace on route from and to non-EU airports.

Emission Trading Directive, is among the directives that all EEA states will have to implement in their national legislation. This means that when the directive is amended in order to incorporate aviation emissions, EEA states will incorporate aviation as well.

Expanding the system parallel to EU enlargement
When countries join the EU, they will have to implement Directive 2003/87/EC as part of the *Acquis Communautaire*. This means that aviation emissions will be included in the same way as aviation emissions in the existing Member States.

The countries that may join the EU ETS in the coming years exist of acceding countries (Bulgaria and Romania), candidate countries (Turkey, Croatia, and Macedonia) and potential candidate countries (Albania, Bosnia and Herzegovina, Serbia and Montenegro, and Kosovo under UN Security Council Resolution 1244).

Expanding the system to countries / regions that are not Member of the EEA
Apart from the countries discussed above, it is possible that the policy regime for aviation will be expanded to countries that are currently not Member of the EEA and are not considering to join the EU. These countries may or may not have an emission reduction commitment under the Kyoto Protocol[41].

Switzerland is Member of the EFTA but not of the EEA. Switzerland aims at obtaining access to the internal market by negotiating bilateral sector agreements. Switzerland has continued its policy of negotiating bilateral agreements since the negative outcome of the referenda with respect to opening accession negotiations with the EU in 2001. One of the bilateral agreements between Switzerland and the EU covers land and air transport. Currently, there are no negotiations with Switzerland on joining ETS. Without an agreement on ETS, Swiss aviation is unlikely to join the EU aviation in this policy measure.

Other Annex I signatory states of the Kyoto Protocol could in principle join the EU ETS and thereby include their aviation in the ETS. However, to date, these parties have shown limited interest in joining ETS. Inclusion of aviation is therefore not likely in the near future. Furthermore, for some countries, such as Canada, inclusion of its aviation in ETS would possibly cause large distortions of the competitive market. For example, expending an intra-EU scheme to include Canada would potentially give rise to larger distortions on flights between the EU and Canada, which would potentially receive increased competition from flights departing from US airports close to the border of Canada. Alternatively, in a scheme that includes emissions from all arriving and departing flights, competition will not arise on flights between Canada and the EU, but on Canada – US flights, where people close to the US border could opt for an intra US flight.
Extension of the scheme to non Annex I parties, be it signatory states to the Kyoto Protocol or not, would not make sense under the current structure of the

[41] Or a newly negotiated post 2012 Treaty. For the analysis here, we will assume that a future Treaty involves emission reduction obligations similar to the Kyoto Protocol and that these obligations do not cover emissions from international air transport.

Kyoto Protocol. After all, these states do not have emission targets, whereas ETS is a cap and trade system, for which a cap (and therefore an absolute target) is essential.

Feasible differentiated responsibilities
Independently of whether there may be a need to differentiate responsibilities, we will now address the question whether it would be possible to do so[42]. In theory, there are different types of differentiation possible. Differentiation could be incorporated in the allowance distributing mechanism or in the strength or type of commitment[43]. Moreover, differentiation could relate to:
- Carriers.
- Routes[44].

We discuss these options briefly. First, differentiation between carriers could lead to large economic distortions on routes. If, continuing the previous example, Canadian carriers would receive beneficial treatment, they would be able to undercut other carriers. It appears to us that this could not be justified on competitive arguments in relation to the US, in this case, nor on the economic state of development of a country. Moreover, not allowing competitive distortions on routes is one of the starting-points of the aviation scheme under development.

Differentiation based on routes does not have the same distortive effect on the competitive market as differentiation based on nationality. Route-based differentiation could take two forms: differentiation of allowance distribution or differentiation of allowance surrender.

Under the first option, more allowances could be distributed to the aircraft operator flying on certain routes. For example, aircraft operators could receive allowances for 100% of the baseline[45] emissions on certain routes instead of, say, 90% on all other routes. The potential environmental impact of the beneficial treatment is known beforehand. If the beneficial treatment leads to increased growth, operators could be under the same regime for this additional growth as operators on other routes and would thus have to purchase allowances.
It should be noted that this option may give rise to competitive concerns, albeit probably to a smaller degree than when differentiation would take place at carrier level. This, however, is a complicated issue, depending also on the level of competition on the route.

The second alternative is differentiating allowance surrender for different routes. Instead of distributing a larger share of the Business as Usual (BaU) required

---

[42] Obviously, given that the lay out of the aviation scheme is not known yet, it is hard to speculate on how it could be altered.

[43] We refrain here from discussing the possibility of alternative policies and measures, such as an performance target or technical standard. In our view, that would not be constitute an expansion of the emission trading system for aviation.

[44] Differentiation to country may appear a third option. However, depending on how this is applied, it would either result in differentiation to carrier (country where carrier is based) or to route (country of departure / destination). Therefore, this option is not treated separately.

[45] The baseline could either refer to Business as Usual (BaU) emissions or to some historic emission level.

allowances for the route, operators could be made responsible for a smaller share of the emissions on the route. For example, on routes between Canada and the EU, aircraft operators would have to turn in only 90% of the normally required allowances. In this case, there would still remain incentives to reduce emissions as long as a positive share of the normally required allowances has to be turned in.

The first option, differentiating the distribution of allowances, can ensure the environmental goals are reached. The second option, differentiating the surrendering of allowances cannot. For different numbers, it may happen under the first option that more allowances are allocated to an airline than will actually be required on the route. The airline is likely to use the allowances for other routes than, or may sell them. This cannot happen under the second option, thus decreasing the risk of competitive distortions.

5.2 A regional start for maritime transport

In comparison to aviation, a coordinated regional EU policy aiming to mitigate the climate change impact from maritime transport is much further away still. In fact, the discussion on the desirability of such a regional start and the possible policies and measures has just begun[46]. In principle, a large number of policies and measures may be extended to cover greenhouse gas emissions from maritime transport. In practice the list will be short, since the policies and measures have to take the nature of greenhouse gas emissions from maritime transport into account.

---

46 In 2005, the EC commanded a research project to assess and design several options. In this project, the EC asks the consultant to look into the following options:

1 Voluntary commitment(s) with EU-based ship operators and/or EU-flagged ships and/or EU-based shippers (manufacturers), to reduce actual CO_2 emissions or the CO_2 index of new and/or existing ships.
2 Requirement for all EU-based ship operators and/or EU-flagged ships to use the IMO CO_2 index and report results annually to Member State Administrations and/or the European Commission.
3 Requirement for EU-based ship operators and/or EU-flagged ships and/or EU-based shippers to meet a unitary CO_2 index limit or target.
4 Inclusion of refrigerant gases from shipping in the EU regulation in future, and/or in an indexing system parallel to the CO_2 index.
5 Inclusion of a mandatory CO_2 element in the proposed EU-wide regime for port infrastructure charging on the basis of tonnes emitted en route, or a differentiation of the charge on the basis of CO_2 index performance.
6 Inclusion of CO_2 emissions in the EU emissions trading scheme, for journeys to or from EU ports.
7 Allocation of ship emissions to Member States, in addition to their national emissions totals as currently applicable under the Kyoto Protocol.

The results of this study will not be available before the end of 2006.

From the list of options it may be inferred that the Commission is thinking along the following lines:

1 Voluntary commitments.
2 New technical standards (the CO_2 index requirement).
3 Allocation of emissions and target setting.
4 Economic instruments:
   a Harbour dues.
   b Inclusion in ETS.

The main aspects are:

- States have jurisdiction over ships under their flag and in their ports, over goods and over persons within their territory. This means that policy instruments have to target ships in EU ports, under EU flags, or the goods and people that ships transport, because measures cannot be enforced for other (wider) scopes.
- Greenhouse gas emissions have global effects, which policies to mitigate them have to take into account. Policies that limit greenhouse gas emissions in one region, but simultaneously increase emissions in other regions are not effective.
- Carbon dioxide emissions are the immediate result of fossil fuel combustion and cannot be mitigated by after-treatment of exhaust gasses, as some air pollutants can. Currently, low emission propulsion systems are not available.
- Ships can easily change flag, and often do. Therefore, a policy which only covers EU-flagged ships would lead to evasion and competitive distortions. Similarly, policies related to ship owners, transport companies or operators from the EU only could inflict competitive distortions and incentivise evasive behaviour[47], thereby undermining the effectiveness.
- Maritime ships can typically bunker fuel for several trips. Moreover, it is common practice to refuel outside ports on sea. This means that they do not have to bunker in every port they visit.
- Ships are often chartered by the owner of the cargo to transport it. Typical lease contracts specify that the owner of the cargo has to pay for the fuel used. Therefore, ship owners or operators may have no incentive to reduce fuel consumption and emissions.

Because of the first aspect, policies related to permit or flag regulations would lead to evasive behaviour and would not be effective. After all, permits and flag regulations would apply only to ships with a EU-flag, and flags can easily be changed.

Because of the second and third aspect, current policies aimed at reducing air pollutant emissions are not directly suited to mitigate greenhouse gas emissions. Examples of current policies to reduce sulphur dioxide emissions include the use of shore electricity when at berth[48], the use of low sulphur fuel, and possibly exhaust gas cleaning. Strengthening current NO_x standards might even lead to negative trade-offs with fuel use and hence to increased CO_2 emissions. In general, there is no direct relation with the emissions of greenhouse gases and local air pollutants and separate policies and measures are required.

Because of the fifth aspect, any local, national or regional tax on fuel taken in could easily be avoided and thus have a very limited effect on fuel consumption; ships would choose to bunker fuel outside the tax area.

---

47 Ship owners can relatively easy move to a location outside the EU.

48 It should be noted that there is some evidence that use of shore side electricity can reduce CO_2 emissions associated with in port operations by some 50%. (Entec, 2005, shore side electricity report).

This brief analysis rules out a large number of EU policies. Policies that could be effective to mitigate greenhouse gas emissions from shipping would either target ships sailing or at berth within EU jurisdiction, or the cargo or passengers they transport.

New policies that could be introduced and existing policies that could be extended to give economic incentives to ships to mitigate greenhouse gas emissions are:

- Emissions trading.
- Differentiated port infrastructure charges.
- Emission charges.
- Technical standards.
- Performance standards.

The following subsections discuss how ETS, Port Infrastructure Charging and technical standards can be used as instruments to mitigate greenhouse gas emissions from maritime ships.

5.2.1 ETS and maritime transport

One way to mitigate the climate impacts of shipping would be to include shipping in ETS. This could be done in many ways. This section briefly discusses the following design choices, which are in line with the choices studied for aviation in the CE Delft (2005) feasibility report:

1. Coverage of climate effects.
2. Geographical scope.
3. Trading entity.
4. Interplay with the Kyoto Protocol.
5. Allocation rules.
6. Allocation method; and
7. Monitoring method.

At this stage, this study does not intend to cover all these aspects extensively. Only the aspects that determine the basic feasibility will be discussed here. These are the geographical scope, the trading entity, the monitoring method and the coverage of climate effects, in so far this is relevant for monitoring compliance. Other aspects are either mainly relevant for the economic impacts (allocation rules and methods) or are not specific for shipping (interplay with the Kyoto Protocol).

Coverage of climate effects and monitoring method
The climate effects of emissions from maritime transport are diverse. Some emissions, such as carbon dioxide and refrigerant gases, contribute to global warming. Others, such as sulphur aerosols and soot, may have a cooling effect. Not all effects are well understood. Neither is monitoring of all emissions possible. The climate effect that is probably best understood is the global warming caused by carbon dioxide.

Emissions of carbon dioxide can form a good basis for coupling maritime transport with ETS, since ETS is based on emissions of the same substances from large, land based combustion installations.
Emissions of carbon dioxide can in principle be monitored effectively en efficiently. As a general rule, ships register their fuel intake for managerial purposes. Furthermore, ships entering ports of States that have ratified MARPOL Annex VI need to be able to show bunker delivery notes and fuel samples to the port State control. These notes and samples show the type of fuel used, from which its carbon content can be inferred or analysed.

In practice, not all ships may be able to show their fuel consumption per trip. When they are unable to do so, they could be forced to surrender allowances amounting to the calculated emissions of a similar ship with a relatively poor fuel efficiency. This would provide ships with an incentive to start registering their fuel consumption per trip.

Geographical scope

Which part of maritime transport should be included in ETS? There is a large number of options conceivable. To name the most important:
- Only intra EU shipping.
- All shipping in EU territorial waters.
- All shipping to and from EU ports.
- All shipping to or from EU ports.

Inclusion of **only intra EU shipping** (ships sailing from one port inside the EU to another port inside the EU) has comparable to other options the least environmental impact. Only a small part of global emissions would be liable to the scheme. Furthermore, the possibilities for evasion could be relatively large in some areas bordering non-EU states, such as the Mediterranean and the Baltic Sea. Therefore, this should be considered a fall back option, in case other options fail. In that case, the possibilities for evasion should be assessed more thoroughly.

Inclusion of **all shipping in EU territorial waters** would be hard to enforce. It would be problematic to force ships that pass through EU waters on a trip between two non-EU ports to surrender emission allowances. Moreover, monitoring based on actual fuel use would be complicated. Therefore, we propose not to study this option further.

Inclusion of **all shipping to and from EU ports** would potentially have the largest environmental effect. There could be a problem, though. It is not uncommon that ships change their destination while at sea. The reason may be that the cargo is sold to another entity, or that the owner of the cargo needs it at another location. This option may lead to evasive behaviour depending on which emissions precisely are included. For example, including all emissions between the last port call before the EU and up to the first call after calling at a EU port, may induce additional calls at ports close to the EU. This would minimise the emissions under the scope. For these reasons, inclusion of shipping *from* EU ports would not be straightforward.

Shipping *to* EU ports can be included in ETS. For ships that arrive at EU ports, it can clearly be established what their point of departure was. For ships that pass several ports on their way to the EU, it will have to be decided how to deal with this. The last port before the EU can be used as departure point, but this may lead to evasive behaviour by vessels making an additional intermediate stop. An alternative solution that may be considered is to use the port that is farthest away, or the port where most cargo has been loaded.

Trading entity
The trading entity should have control over emission reduction measures, otherwise inclusion in ETS will have a limited effect. Furthermore, the port State authorities should be able to force the trading entity to surrender allowances. Based on these considerations, we think that the ship operator is the best option as trading entity.

5.2.2 Port Infrastructure Charging or Emission Charge and maritime transport

The climate impacts of shipping could be mitigated by giving financial incentives to ship operators to reduce emissions. The incentives could be linked to existing charges, such as port charges, or a new emission charge could be introduced. Several design issues of both incentives would be similar. Therefore, both incentives are discussed in combination.

The difference between a differentiation of port charges is that this scheme would not raise additional revenues. The current charge structure would be adapted such to provide incentives for emission reduction, leaving the total revenues unchanged. Relatively big emitters would pay more port charges than under the current scheme, ships that emit only a little would pay less.

In a system of emission charges, small emitters would pay little, while big emitters would pay a substantial amount. These charges would be levied in addition to current port charges. The use of revenues would have to be discussed. These could for example be recycled back to the maritime transport sector, or alternatively be used to finance emission reductions elsewhere or to fund R&D in ship fuel efficiency.

The difference in charge levels between large and small emitters would provide an incentive for the use of low emission ships, or the introduction of low emission operational procedures.

We discuss here three parameters of differentiated port or emission charges[49]:
1 Levy point: which entity pays the differentiated charge at which place to whom?
2 Incentive base: what is the basis for the calculation of the differentiated charge?
3 Incentive level: by how much will the charges be differentiated?

[49] See also (CE Delft, 2004): Charges for barges? Preliminary study of economic incentives to reduce engine emissions from inland shipping in Europe, Delft: CE Delft.

We will discuss each parameter below.

Levy point
The charge has to be paid by the same entity that pays the undifferentiated port charge now. It is paid to the port authorities. In the case of emission charges, the receipts could be passed on to another party.

Incentive base
A number of variables may serve as an incentive base. The two extremes are either actual emissions or an efficiency parameter:
- Actual emissions on the last trip.
- An emission performance index, such as the IMO CO_2 index.

The first incentive base would constitute an incentive to reduce emissions on the last trip to a EU port. It would target emissions most directly. However, this incentive base may be hard to incorporate in the existing tariff structure of infrastructure charges. These are not based on variable parameters such as speed or fuel use, but on fixed properties of a ship, such as its length, draught, et cetera, and on the number of days it stays at berth and the services it requires.

The second incentive base would encourage ship-owners to use fuel-efficient ships when visiting EU ports. If the incentive is strong enough (which depends on the level of the incentive), it would encourage ship-owners to improve the fuel efficiency of their fleet, either by changing operational procedures, training their staff to sail fuel-efficiently, or by scrapping inefficient ships and replacing them by fuel-efficient ships. This incentive base would be better compatible with current tariff structures for port charges.

We propose to include only the second incentive base in the first concept of this idea, because this is best compatible with current practice and because the difference with inclusion of shipping in ETS would be highlighted best.

Incentive level
The incentive level should be sufficient to encourage ship operators to take measures to decrease emissions in maritime transport. At the same time, one would not want to provide such strong incentives that similar environmental effects could be reached in other sectors at much lower costs.

5.2.3 Technical standards or performance standards and maritime transport

Ships entering EU ports could be required to meet certain technical standards (e.g. fuel efficiency of the engines) or performance standards (e.g. a maximum fuel consumption per unit of transport). Most experts on maritime law agree on this, but the issue may not be undisputed. Currently, most standards and requirements deal with safety issues and social aspects of shipping. It would in theory be possible to add standards on emissions or performance standards[50].

[50] Note that we discuss a regional scheme here. IMO standards are aimed at the global industry and have to be enforced by al the states that have ratified MARPOL.

The first question when elaborating this idea would be: are technical standards or performance standards more suited to abate emissions cost-efficiently? Marintek (2000) indicate that more emissions can be reduced by operational measures than by technical measures. Also, preliminary results of experiments with the CO_2 index show that even similar ships can have highly divergent fuel efficiencies, because of the way the ship is operated. This means that performance standards (emissions or fuel consumption per unit of transport) will be environmentally more effective than technical standards. The administrative burden of performance standards is also larger, since ships have to register cargo and fuel consumption per trip, instead of registering their engines emission factors.

A disadvantage of performance standards would be that the metrics are still under development. The most likely candidate for a metric would be the IMO CO_2 index, which is currently under development. However, it may take several years before enough experience has been gained with the index, so that its reliability can be properly assessed.

5.3 Selection of first concepts

Concept E: Aviation
The choice for a first concept has in fact been made for aviation: include the sector in ETS. Compared to other first concepts, many more definite choices have been made with respect to the design of a regional approach for aviation, due to the starting point of working out the current system under development. We therefore propose to work out further two different methods for expansion.

Concept F: Shipping
For shipping, there are three viable first concepts: inclusion in ETS, charges (either differentiated existing charges or new charges), and performance standards. Neither of these three has clear advantages over the other two. Inclusion in ETS could builds on existing measures, but it may be hard to measure shipping emissions accurately. This same difficulty affects the feasibility of charges. Performance standards would have the advantage that standards are common in shipping and that the sector can deal with them, but the metric is still very much in an experimental stage.

5.4 Further development of the concepts

This section takes the two concepts above and develops them further into full concepts for a regional start to address the climate impacts of aviation and maritime transport. Other concepts are dealt with in chapters 3 (allocation to countries) and 4 (sectoral commitments).

5.4.1 Kind and level of commitment

In a regional start, the kind of commitment is determined by the policy measure that is used to mitigate climate impacts. In the case of inclusion in ETS, aviation (and possibly maritime transport) are included in an emission cap for the system. One could argue that the commitment is absolute in this case. In the case of either differentiated existing charges or new emission charges, emissions are not capped. Rather, operators are encouraged to improve the efficiency of their vessels. Furthermore, if some of the costs are passed on to the consumer, the demand for transport is likely to fall relative to a no-policy scenario. One could argue that the sector is given a relative commitment in this case. The same holds for technical standards and performance standards.

A regional start may distort competition, limit economic growth and be contested by other countries. Therefore, the level of the commitment is restricted to what is acceptable both internally and internationally. In the end, this is a political decision which has to balance the environmental benefits against the possible economic losses and international political problems.

5.4.2 Roles of organisations and parties

In these concepts, aviation and maritime transport would not be included in a global climate policy regime. Therefore, a formal role for the UNFCCC would not be reasonable. IMO and ICAO could be invited to issue guidance on the actual policy measures proposed in order to ensure compatibility with other international policies. When this form of co-operation with the international bodies could be achieved, this would also facilitate the gradual expansion of the policy measures to other countries or regions.

5.4.3 Coverage of climate impacts

The concept for the inclusion of aviation and/or maritime transport in ETS could only be achieved when there would be a common metric for both emissions of international transport and emissions from ground based sources. In section 3.5.3 it has been argued that in that case, only emissions of greenhouse gases can be included in the climate policy regime. There are three main reasons for this:

- There is currently no metric that allows for treatment of short lived phenomena such as contrails and greenhouse gas emissions on an equal basis.
- Indirect effects of emissions can hardly be attributed to individual flights or voyages, which makes allocation of these impacts to aircraft operators or ship operators problematic.
- Negative climate impacts (cooling), which are indirect effects of emissions, are hard to incorporate, because they would create perverse incentives.

So in the concept of inclusion of both sectors in ETS, only CO_2 emissions can be included. The same argument applies for differentiated charges for maritime transport.

Regional policy measures aimed at reducing the climate impact of maritime transport by implementing performance standards could in principle also address other climate impacts. The only prerequisite would be that a adequate performance standard can be designed. However, the climate impacts of NO_x

emissions have almost no net effect. Furthermore, most other emissions have negative climate effects, which are hard to incorporate because they would create perverse incentives. So overall, a performance standard would best be aimed at CO_2 and possibly soot.

5.5 Conclusion: concepts for a regional start for the inclusion of international transport

This chapter has developed concepts for the inclusion of aviation and maritime transport in a regional climate policy regime. For aviation, this chapter builds on current developments in the EU, viz. inclusion of aviation in ETS. For maritime transport, there is currently not a favoured policy option. The analysis of this report shows that three possible policies could be envisaged, but each has disadvantages and neither stands out.

Concept E: A regional start for aviation: inclusion in the ETS
Emissions from aviation are included in the EU ETS. This could hold for all flights departing from EU airports, or to an alternative geographical scope. Potentially, non-CO_2 climate impacts could be incorporated by means of a multiplier. Aircraft operators are made responsible for emissions and can purchase additional allowances on the EU ETS market as necessary. In the event of the scheme being extended to other countries / routes, there could be differentiation between routes.

Concept F: A regional start for maritime transport
Emissions of maritime transport could be included in the EU ETS, or covered by emission charges. Alternatively, ships in EU jurisdictions could be required to meet certain performance standards.

Table 18 Concepts for the regional start

Concept	E Aviation	F Maritime
Allocation	No allocation	No allocation
Sector	Aviation	Maritime
Responsibility for the emissions	Aircraft operators	Ship operators
Kind and height of commitment	Absolute target (cap)	Absolute target (cap) (ETS); Relative target (performance standard); Neither relative nor absolute (differentiated charges)
Kinds of policy measures	Emission trading	Emission trading; differentiated charges or performance standard
Coverage of the measures	CO_2 only; flanking instruments for other impacts	CO_2 only (ETS and differentiated charges); All impacts (performance standard)
Roles of Parties, Groups of Parties, UNFCCC, ICAO and IMO	No roles for parties outside the EU, unless ICAO develops guidance before the adoption of the legislative proposal	No roles for parties outside the EU, unless IMO develops guidance before the adoption of a legislative proposal (ETS and differentiated charges) IMO develops performance standard (performance standard)
Geographical scope	Intra-EU, all departures from EU airports or all arrivals at and departures from EU airports	All voyages arriving in EU harbours

6 Assessment of the concepts

This chapter assesses the six policy options that have been developed in this report on four groups of criteria: environmental, political, economic and practical criteria.

6.1 Environmental assessment

The environmental assessment is based on three criteria:

- Coverage of climate impacts: which share of the climate impacts of aviation and maritime shipping are included in commitments and targets? The share is estimated comparatively.
- Scope for evasion: can industry actors (airlines, passengers, ship operators, cargo owners et cetera) evade the system?
- Incentives for action: are countries that have no commitment encouraged to take action to mitigate the climate impacts?

6.1.1 Coverage of climate impacts

In principle, the technology based sectoral approach covers all climate impacts. Other concepts cover only CO_2 emissions of a limited number of countries. In case of allocation and in case of the sectoral approach with an emission cap, CO_2 emissions of flights between the least developed countries are not covered by the policy. In case of a regional start, the inclusion of aviation in ETS covers only CO_2 emissions of flights to and possibly from the EU. In case of a regional start for maritime transport, either voyages to the EU are included, or ships that visit EU harbours.

Although the technology based sectoral approach covers all climate impacts, it is unlikely to reduce climate impacts as much as most other concepts. Because it relies solely on supply side measures (improvements in efficiency of transport), it cannot effectively limit the growth of the climate impacts, as most other concepts can.

Table 19 Assessment: coverage of climate impacts

	Allocation		Sectoral approach		Regional start	
	A Route vessel or aircraft	B Route passenger or cargo	C Emission cap	D Technology based	E Aviation	F Maritime
Coverage	+	+	+	-	±	±

6.1.2 Scope for evasion

All the concepts that differentiate commitments between routes are vulnerable to a border effect: passengers change their route in order to avoid the costs associated with the commitments. Likewise, cargo can be transported first to a country with no commitment, and from there to a country with a commitment in order to limit the costs to the last part of the route.

The size of the border effect depends on geography: when harbours or major airports in countries with different commitments are close to each other, the border effect is likely to be larger than when ports are far apart.

The size also depends on the geographical scope: when there is an abrupt discontinuity in policy stringency, such as in the regional start, the border effect is likely to be larger than when there is a gradual decline in stringency.

The concept based on allocation of emissions to the country of origin and/or destination of cargo or passengers leaves less room for this kind of evasion, since passengers and cargo have to move from their point of origin to their destination.

Since none of the concepts is based on fuel taxes or charges, evasion by tankering in countries with no commitments does not occur in any of these concepts.

Table 20 Assessment: scope for evasion

	Allocation		Sectoral approach		Regional start	
	A Route vessel or aircraft	B Route passenger or cargo	C Emission cap	D Technology based	E Aviation	F Maritime
Evasion	-	+	-	+	-	-

Note: a large scope for evasion is negative (-).

6.1.3 Incentives for action

In all concepts that employ emission trading as a policy instrument, countries with no commitments can engage in CDM or sectoral CDM. In some variants of the regional start for shipping, maritime transport does not engage in emission trading. In these variants, there is no incentive for countries with no commitments to engage in climate policy. In the technology based sectoral approach all countries have to take action, so this criterion becomes irrelevant.

Table 21 Assessment: incentives for action

	Allocation		Sectoral approach		Regional start	
	A Route vessel or aircraft	B Route passenger or cargo	C Emission cap	D Technology based	E Aviation	F Maritime
Incentives	+	+	+	n.a.	+	+/-

Note: N.a. not applicable.

6.2 Political assessment

The political assessment is based on two criteria:

- Equity. Is the burden of the policy measures distributed over countries in an equitable way, i.e. taking into account the capability to act and the responsibility for climate change, as well as the equal rights of humans to develop?
- Coherency with EU policy: is the concept in line with the general policy aims of the EU on transport and environment? The general policy aims on transport are laid down in the White Paper, currently under review (EC, 2001). The current Transport Commissioner has argued more than once that transport is a key driver to growth and should therefore not be limited. It is likely that the White Paper, once reviewed, will reflect this view. And the final guiding principles taken into account here are the Precautionary Principle and the Polluter Pays Principle, enshrined in the Maastricht Treaty of 1992 (article 130r, section 2[51]).

6.2.1 Equity

The two concepts that are based on allocation of emissions to countries score best on equity, since they incorporate climate impacts of international transport in multi staged targets, which are especially design to reflect the equity principles enshrined in the UNFCCC (Den Elzen, 2006).

The sectoral approach with an emission cap also distinguishes between regions capable of taking action and regions not capable. Depending on how this differentiation of commitments is implemented, this concept is also equitable. In contrast, the technology based sectoral approach gives equal responsibilities to all nations and thus ignores principles of equity.

The regional start is equitable in the sense that policies and measures are introduced first in countries most responsible for climate change and most capable to act. However, not all responsible and capable countries are required to implement policies.

[51] "Community policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Community. It shall be based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay. Environmental protection requirements must be integrated into the definition and implementation of other Community policies".

Table 22 Assessment: equity

	Allocation		Sectoral approach		Regional start	
	A Route vessel or aircraft	B Route passenger or cargo	C Emission cap	D Technology based	E Aviation	F Maritime
Equity	+	+	+	-	±	±

6.2.2 Coherency with EU policy

All policies that include aviation and maritime transport in industrialised countries in emission trading schemes allow for growth of transport. After all, innovation can reduce the emissions per amount of transport provided, and emission allowances can be bought from other sectors. Both measures would allow transport to grow. However, this growth will likely be less than business as usual since the costs for compliance will likely be passed on to consumers (partly or fully) and thereby reduce demand for international transport. The concept with the least stringent commitments, the technology based sectoral approach, will limit transport growth the least. In case of a regional start for maritime transport, the extent to which the transport growth will be limited depends on the actual policy implemented.

None of the concepts introduced in this report is fully compatible with the polluter pays principle, which would require a full internalisation of external costs. The only exception might be a emission charge for maritime transport in a regional start. However, by internalising costs of mitigation, a large share of external costs is likely to be internalised. Again, the concept with the least stringent commitments, the technology based sectoral approach, will internalise only a small part of external costs and therefore be out of line with the polluter pays principle.

Table 23 Assessment: coherency with EU policy

	Allocation		Sectoral approach		Regional start	
	A Route vessel or aircraft	B Route passenger or cargo	C Emission cap	D Technology based	E Aviation	F Maritime
Growth	+	+	+	+	+	+
Polluter pays	+	+	+	±	+	+

6.3 Economic assessment

The economic assessment is based on two criteria:

- Efficiency: does the concept create incentives to reduce climate impacts at the lowest cost, and, if the concept includes a market based approach, will it ensure that the market creates incentives that are in line with the overarching policy goal, which is to reduce climate impacts?

- Market distortions: is the concept likely to distort markets for international transport or related market, such as the market for transport fuels?

6.3.1 Efficiency

All concepts that use market based policies and measures to reduce climate impacts create incentives to take the cheapest measures first, and to use the innovative power of the industry to create more cheap measures. Concepts based on emission trading score better in this respect than concepts (partially) based on taxes and charges. Concepts based on performance standards also create these incentives, although the absence of trading limits the possibilities to search for cheap measures. Furthermore, these concepts will create an incentive to lower the costs of compliance by innovation (Popp, 2001). Concepts that use technical standards as the main instrument, by their nature, do not create incentives to take the cheapest options first.

Table 24 Assessment: efficiency

	Allocation		Sectoral approach		Regional start	
	A Route vessel or aircraft	B Route passenger or cargo	C Emission cap	D Technology based	E Aviation	F Maritime
Efficiency	+	+	+	-	+	+/±

6.3.2 Market distortions

When assessing whether concepts are likely to introduce market distortions, the relevant market has to be defined first. In passenger transport, passengers have a demand to travel from their point of departure to their point of destination. Likewise, cargo has to be moved from A to B. Passengers may opt for a direct flight, or may opt for a detour, but they are limited with respect to changing either their point of departure of their destination. The same holds for cargo. Consequently, the relevant market is a route. And as long as all operators on the same route are treated equally, the concept will not introduce distortions.

All the concepts introduced in the previous chapters either have no differentiation or a route based differentiation. Consequently, they are all unlikely to introduce market distortions.

Table 25 Assessment: market distortions

	Allocation		Sectoral approach		Regional start	
	A Route vessel or aircraft	B Route passenger or cargo	C Emission cap	D Technology based	E Aviation	F Maritime
Market distortions	+	+	+	+	+	+

6.4 Technical feasibility

6.4.1 Data availability

The concepts that use emission trading or –charges of vessels or aircraft as a main policy instrument all have good data availability, since emissions can be calculated from fuel use. The option based on allocation according to origin or destination of passengers or cargo suffers from the fact that data from different sources will have to be combined.

Table 26 Assessment: data availability

	Allocation		Sectoral approach		Regional start	
	A Route vessel or aircraft	B Route passenger or cargo	C Emission cap	D Technology based	E Aviation	F Maritime
Data availability	+	-	+	n.a.	+	+

6.4.2 Enforceability

Complex data situations may hamper enforcement. This is the case in the allocation based on routes of passengers or cargo, where data from different sources needs to be combined before compliance can be enforced. In all other cases, enforceability is generally good.

Table 27 Assessment: enforceability

	Allocation		Sectoral approach		Regional start	
	A Route vessel or aircraft	B Route passenger or cargo	C Emission cap	D Technology based	E Aviation	F Maritime
Enforce ability	+	-	+	+	+	+

6.5 Conclusion

Three options score best on the criteria used in the assessment: allocation based on the route of a vessel or aircraft, a sectoral approach within the UNFCCC, and a regional start for aviation.

Table 28 Assessment: conclusion

	Allocation		Sectoral approach		Regional start	
	A Route vessel or aircraft	B Route passenger or cargo	C Emission cap	D Technology based	E Aviation	F Maritime
Environmental criteria						
Coverage	+	+	+	-	±	±
Evasion	-	+	-	+	-	-
Incentives	+	+	+	+	+	+/-
Political criteria						
Equity	+	+	+	-	±	±
Transport growth	+	+	+	+	+	+
Polluter pays	+	+	+	±	+	+
Economic criteria						
Efficiency	+	+	+	-	+	+/±
Market distortions	+	+	+	+	+	+
Practical criteria						
Data availability	+	-	+	n.a.	+	+
Enforce ability	+	-	+	+	+	+

Note: n.a.: not applicable.

7 References

Bodansky, 2003
D. Bodansky
Climate commitments: assessing the options
In : J.E. Aldy, J. Ashton, R. Baron, et al.
Beyond Kyoto: advancing the international effort against climate change
Arlington : Pew Center on Global Climate Change, 2003

Berntsen, 2004
T. Berntsen
Impacts of aviation and other transport modes on the atmosphere: A European perspective.
London : Presentation at NERC/NCAS Town Meeting, Aviation Impacts on the Atmosphere, Birkbeck College, 11th – 12th November 2004

Capaldo, 1999
K. Capaldo, J.J. Corbett, P. Kasibhatla, P. Fischbeck, S.N. Pandis
Effect of ship emissions on sulphur cycling and radiative climate forcing over the ocean. *Nature* **400**, 743 – 746, 1999

CE Delft, 2004
R.C.N. Wit, B.E. Kampman, B.H Boon (CE Delft), in co-operation with: P.F.J. van Velthoven, E.W. Meijer (KNMI, Royal Netherlands Meteorological Institute), J.G.J. Olivier (RIVM-MNP), D.S. Lee (Manchester Metropolitan University)
Climate impacts from international aviation and shipping
State-of-the-art on climatic impacts, allocation and mitigation policies
Delft : CE, 2004

CE Delft, 2005
R.C.N. Wit, B.H. Boon, A. van Velzen (CE Delft), M. Cames and O. Deuber (Oeko-Institut), D.S. Lee (Manchester Metropolitan University)
Giving wings to emission trading
Inclusion of aviation under the European Emission Trading System (ETS): Design and impacts
Delft : CE, July 2005

CE Delft, 2005
R.C.N. Wit, B.H. Boon, A.M. van Velzen, O. Deuber, D.S. Lee
Giving wings to emission trading. Inclusion of aviation under the European emission trading system (ETS): design and impacts.
Delft : CE-Delft, No. ENC.C.2/ETU/2004/0074r, the Netherlands, 2005

COM(2005) 459 final
Communication from the Commission, the European Parliament, the European Economic and Social Committee and the Committee of the Regions: Reducing the Climate Change Impact of Aviation
Brussels : 27.9.2005

Criqui, 2003
P. Criqui, A. Kitous, M. Berk, et al.
Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025: Technical Report
Study Contract: B4-3040/2001/325703/MAR/E.1 for DG Environment

Den Elzen and Berk, 2004
M.G.J. den Elzen, M.M. Berk
Bottom up approaches for defining future climate mitigation commitments. RIVM report no. 728001029, National Institute for Public
Bilthoven : Health and the Environment, the Netherlands

Den Elzen, 2006
M.G.J. den Elzen, M. Berk, P. Lucas, P. Criqui, A. Kitous
Multi-Stage: A Rule-Based Evolution of Future Commitments Under the Climate Change Convention
In : *International Environmental Agreements* 6, 1-28, 2006

Den Elzen, 2007
M.G.J. den Elzen, M.M. Berk, J.G.J. Olivier
Analysis of some options for including international aviation and marine emissions in a post-2012 climate mitigation regime
MNP Report 500114007/2007

Ecofys, 2005
K. Blok, N. Höhne, A. Torvanger, R. Janzic
Towards a Post-2012 Climate Change Regime
Brussels : Ecofys, June 2005

Endresen, 2003
Ø.Endresen, E. Sørgård, J.K. Sundet, S.B. Dalsøren, I.S.A. Isaksen, T.F. Berglen, G. Gravir
Emission from international sea transportation and environmental impact. *Journal of Geophysical Research* **108**, doi: 10.1029/2002JD0029898, 2003

Figueres, 2006
C. Figueres
Sectoral CDM: Opening the CDM to the Yet Unrealized Goal of Sustainable Development
In: *International Journal of Sustainable Development Law and Policy* **2**, 2006

Gauss, 2006
M. Gauss, I.S.A. Isaksen, D.S. Lee, O.A. Søvde
Impact of aircraft NO_x emissions on the atmosphere, tradeoffs to reduce the impact – a 3D CTM study
In : *Atmospheric Chemistry and Physics* **6**, 1529 – 1548, 2006

Greener by design, 2005
Greener by Design Science & Technology Sub-Group
Air Travel – Greener by Design: Mitigating the Environmental Impact of Aviation: Opportunities and Priorities
London : Royal Aeronautical Society, July 2005

Heller and Shukla, 2003
T.C. Heller, P.R. Shukla
Development and Climate: Engaging Developing Countries
In: J.E. Aldy, J. Ashton, R. Baron, et al.
Beyond Kyoto: advancing the international effort against climate change
Arlington : Pew Center on Global Climate Change, 2003

IPCC, 1999
J.E. Penner, D.H. Lister, D.J. Griggs, D.J. Dokken and M. McFarland (eds)
Aviation and the Global Atmosphere. A special report of IPCC working groups I and III. Special Report of the Intergovernmental Panel on Climate Change
Cambridge : Cambridge University Press, 1999

IPCC, 2001
J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K Maskell and C.A. Johnson (eds)
Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.
Cambridge : Cambridge University Press, UK, 2001

Lee, 2003
D.S. Lee
Aviation—atmospheric issues and research programmes.
In : EC-NEPAIR, Work Package 1, Aircraft engine emissions certification – a review of the development of ICAO Annex 16 Volume II, Appendix IV, D.H. Lister and P.D. Norman (eds) pp 199 – 211, QinetiQ/FST/CR030440, **QinetiQ,** Farnborough, 2003

Sausen, 2005
R. Sausen, I.S.A. Isaksen, V. Grewe, et al.
Aviation radiative forcing in 2000: and update on IPCC (1999)
In : Meteorologische Zeitschrift **114**, 555 – 561, 2005

Stordal, 2005
F. Stordal, G. Myhre, E.J.G. Stordal, W.B. Rossow, D.S. Lee, D.W. Arlander, T. Svenby
Is there a trend in cirrus cloud cover due to aircraft traffic?
In : Atmospheric Chemistry and Physics **5**, 2155 – 2162, 2005

Stuber, 2006
N. Stuber, P. Forster, G. Rädel, K. Shine
The importance of the diurnal and annual cycle of air traffic for contrail radiative forcing
Nature 441 (15 June 2006) 864-867

Zerefos, 2003
C.S. Zerefos, K. Eleftheratos, D.S. Balis, P. Zanis, G. Tselioudis, C. Meleti
Evidence of impact of aviation on cirrus cloud formation
In : Atmospheric Chemistry and Physics 3, 1633 – 1644, 2003

CE Delft
Solutions for environment, economy and technology

Oude Delft 180
2611 HH Delft
The Netherlands
tel: +31 15 2 150 150
fax: +31 15 2 150 151
e-mail: ce@ce.nl
website: www.ce.nl
KvK 27251086

Aviation and maritime transport in a post 2012 climate policy regime

Annexes

Report

Delft, December, 2006

Author(s): Jasper Faber (CE)
Bart Boon (CE)
Marcel Berk (MNP)
Michel den Elzen (MNP)
Jos Olivier (MNP)
David Lee (MMU)

A MNP Report 500114007/2007

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

M.G.J. den Elzen
J.G.J. Olivier
M.M. Berk

MNP Report 500114/2007

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

M.G.J. den Elzen, J.G.J. Olivier, M.M. Berk

Contact:
Michel den Elzen
Global Sustainability and Climate (KMD)
Michel.den.Elzen@mnp.nl

This research was performed as part of the study “Aviation and maritime transport in a post-2012 climate policy regime” directed by CE Delft, which was conducted within the framework of the Netherlands Scientific Assessment and Policy Analysis (WAB) Climate Change Programme

Netherlands Environmental Assessment Agency (MNP), P.O. Box 303, 3720 AH Bilthoven, the Netherlands;

Tel: +31-30-274 274 5; Fax: +31-30-274 4479; www.mnp.nl/en

© MNP 2006
Parts of this publication may be reproduced, on condition of acknowledgement: 'Netherlands Environmental Assessment Agency, the title of the publication and year of publication.'

Acknowledgements

This study was performed as part of a study led by CE Delft, entitled “Aviation and maritime transport in a post-2012 climate policy regime”, conducted within the framework of the Netherlands Scientific Assessment and Policy Analysis (WAB) Climate Change Programme. We would like to thank Jasper Faber (CE Delft) and David Lee (Manchester Metropolitan University) for their comments and contributions. Special thanks are due to the advisory committee, consisting of members of the different ministries, who have provided us with critical and useful comments.

Abstract

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

The study reported here explores a number of options for including international bunker emissions in future climate mitigation regime and assesses the implications of their inclusion on regional emission allocations and mitigation efforts for a scenario that aims at a long-term stabilisation of greenhouse gases at 450 ppm CO_2-equivalent. Particular attention is given to two allocation options that appear to be the most practical from a policy perspective: allocation according to nationality/registration and allocation according to destination. The implications of allocating bunker emissions under a post-2012 regime are evaluated using a *Multi-Stage approach* where the number of parties taking on mitigation commitments and the level of commitments gradually increases over time in accordance with participation and differentiation rules. We also present a baseline scenario for future international bunker emissions up to 2050 and a CO_2 mitigation scenario based on enhanced energy efficiency improvement and the use of biofuels.

The regional responsibilities under various regional allocation options are analysed and the implications for mitigation targets in the other sectors when international bunkers emissions are being abated or left unabated are explored, as well as various options for regulating bunker emissions on the basis of sector-specific policies are evaluated. 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 also addressed.

One of the main findings of this analysis is that, in comparison to developing sector-based policies, the inclusion of bunker emissions in an international emissions trading scheme seems to be a more effective and cost-effective way, as 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.

Key words: marine emissions, aviation emissions, CO_2, international bunker emissions, climate policy, mitigation scenario

Rapport in het kort

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

In het kader van het EU-klimaatbeleid is het de bedoeling om de broeikasgasemissies van lucht- en scheepvaart onder te brengen in het Europese Emissiehandelsysteem. Deze studie verkent een aantal opties voor het opnemen van internationale bunkeremissies in een toekomstig klimaatregime en analyseert de implicaties voor de regionale emissieallocaties en reductiedoelstellingen voor een scenario dat zich richt op een stabilisatie van de broeikasgassen op 450 ppm CO_2-equivalent. Er is specifiek gekeken naar twee allocatie-opties voor de bunkeremissies die vanuit het klimaatbeleid het meest efficiënt lijken: allocatie volgens de nationaliteit/registratie en allocatie volgens bestemming. De implicaties van deze allocatie-opties worden geëvalueerd onder een post-2012 klimaatmitigatieregime gebaseerd op een Multi-Stadium-benadering. Deze benadering resulteert in een geleidelijke uitbreiding van het aantal landen met kwantitatieve doelstellingen evenals van de stringentheid van hun doelstellingen. We presenteren een baseline-scenario voor de internationale bunkeremissies tot 2050 en een reductiescenario voor CO_2 gebaseerd op een verhoogde energie-efficiency-verbetering en het gebruik van biobrandstoffen.

De regionale allocaties onder verschillende allocatieopties worden geanalyseerd en voor een goede beoordeling van de merites van de opties zijn de implicaties voor reductiedoelstellingen in de andere sectoren verkend, als wordt verondersteld dat internationale bunkeremissies worden beperkt of onbeperkt mogen doorgroeien. Verder worden er verschillende opties voor de regulering van de bunkeremissies op de basis van sectorspecifiek beleid geëvalueerd. Ten slotte worden de gevolgen van de relatieve hoge impact van niet-CO_2 emissies van luchtvaart op de stralingshuishouding geanalyseerd.

Een belangrijke conclusie van dit rapport is dat, in vergelijking met de ontwikkeling van sectorspecifiek beleid, het meenemen van bunkeremissies in een internationaal emissiehandelschema het meest efficiënt en kosteneffectief is. Het geeft de internationale transportsector de mogelijkheid om de toename in emissies van de sector te compenseren door het inkopen van emissiereducties bij andere sectoren, in plaats van zelf hun emissies te moeten reduceren. De mogelijkheden voor substantiële reducties in de lucht- en scheepvaart zijn slechts beperkt of zeer kostbaar. Voor het behalen van lage emissieniveaus is een portfolio van reductieopties in vele sectoren nodig; het uitsluiten van bepaalde activiteiten om aan emissiereductie bij te dragen maakt het moeilijker om sterke emissiereducties te behalen.

Key words: scheepvaart, luchtvaart, emissies, CO_2, internationale bunkers, klimaatbeleid, reductiescenario

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.

In our analyses we have focussed 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 we chose here the *Multi-Stage approach*. 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 globalization and technology development.

We present a baseline scenario for future international bunker emissions up to 2050 and regional responsibilities under various regional allocation options. Next, we analyse various scenarios for dealing with the international bunker emissions in future international climate policy. Here we will look 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.

Contents

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. These options were:

1. No allocation;
2. Allocation of global bunker sales and associated emissions to parties in proportion to their national emissions;
3. Allocation according to the country where the bunker fuel is sold;
4. Allocation according to the nationality of the transporting company, or to the country where an aircraft of ship is registered, or to the country of the operator;
5. Allocation according to the country of departure or destination of an aircraft or vessel; alternatively, emissions related to the journey of an aircraft or vessel shared by the country of departure and the country of arrival;
6. Allocation according to the country of departure or destination of passengers or cargo; alternatively, emissions related to the journey of passengers or cargo shared by the country of departure and the country of arrival;
7. Allocation according to the country of origin of passengers or owner of cargo;
8. Allocation to a party of all emissions generated in its national space.

In our analyses we have 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) and allocation according to destination (SBSTA Option 6). The first option was selected for analysis as it fits in with the present regulatory regimes for international aviation

[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).

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, route-related 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.

To explore the implications of allocating bunker emissions under a post-2012 regime for future commitments we chose the *Multi-Stage approach*, 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). We used the FAIR 2.1 model 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]. 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).

[2] FAIR 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 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).

The material presented in this report is structured as follows. In Section 2 we present a baseline scenario for future international bunker emissions up to 2050 and regional responsibilities under various regional allocation options. In Section 3 we analyse various scenarios for dealing with the international bunker emissions in future international climate policy. Within this context, we explore various options for regulating bunker emissions, 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, we 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. 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.

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. Historical CO_2 emissions from international shipping and aviation are surrounded by large uncertainties. For this reason, we 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, etc.) 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 are 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 Köhling (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 we assume 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 (2005) when we assume 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 1, 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 1. 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 (2006)) 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 our baseline (‘Business-As-Usual’) scenario. However, our 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).

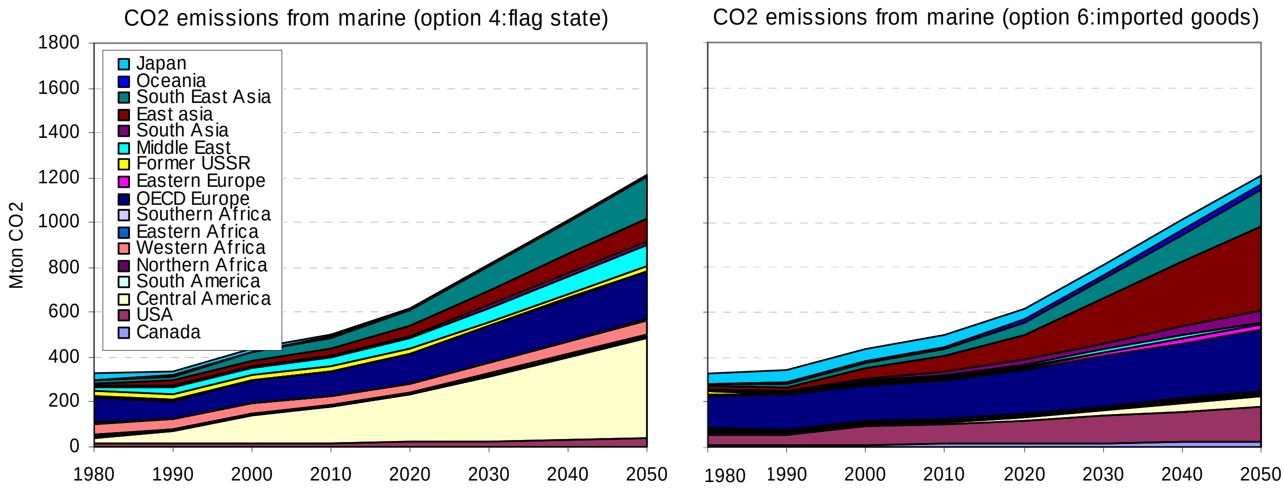


Figure 1. Baseline (trend) scenario for regional CO_2 emissions from marine transport using Option 4 (flag state) (left) or Option 6 (imported goods) (right). Source: this study.

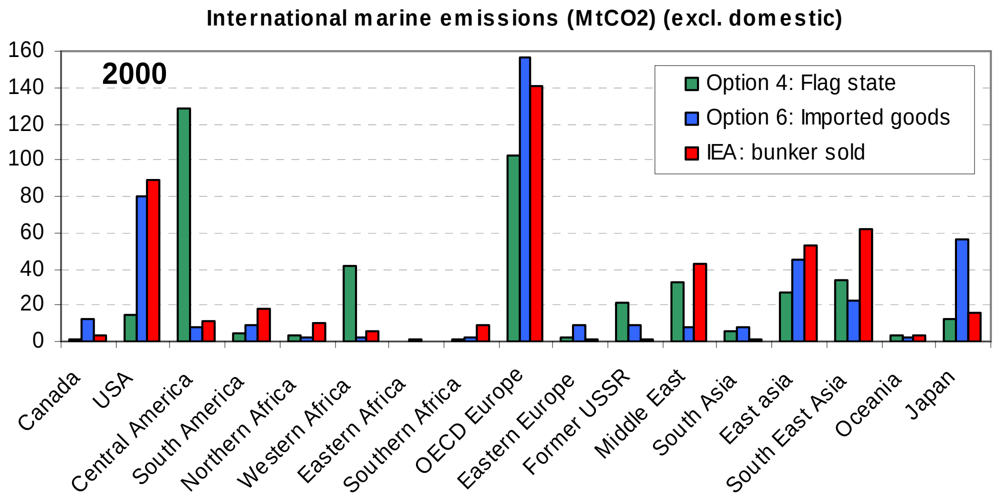


Figure 2. The effect of different allocation options – Option 3 (bunker sold), Option 4 (flag state) or Option 6 (imported goods) – on international marine emissions based on data from UNCTAD (2006). The IEA bunker sales data are also depicted here for comparison purposes. Source: this study.

We note 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 we have 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 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 we assume 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 2 shows that the differences between both methods are substantial.

Table 2. 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).

We used the allocation of Owen and Lee's Option 5 as proxy for our 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, we scaled these emissions 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.

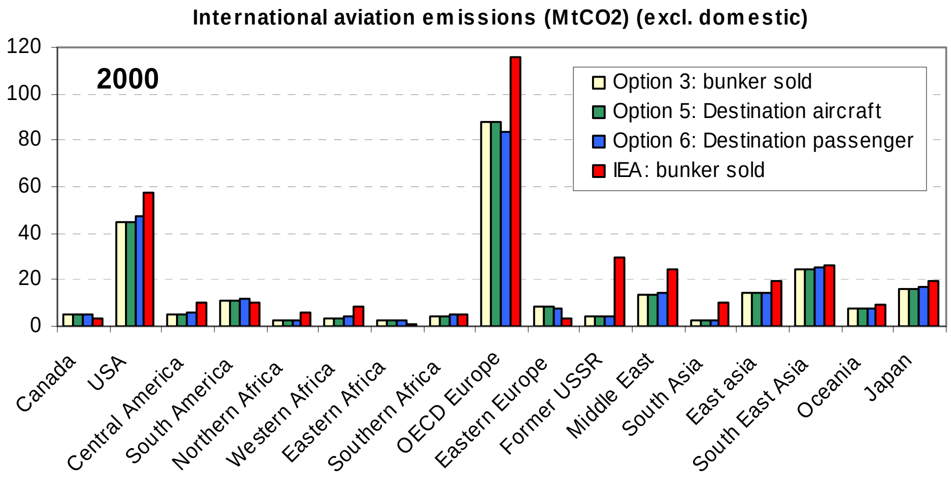


Figure 3. The effect of three different allocation options on international aviation emissions: Option 3 (bunker sold), Option 4 (flag state) or Option 6 (imported goods). Emissions are based on data of Owen and Lee (2005). For comparison, IEA data are also depicted.

We will 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

[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).

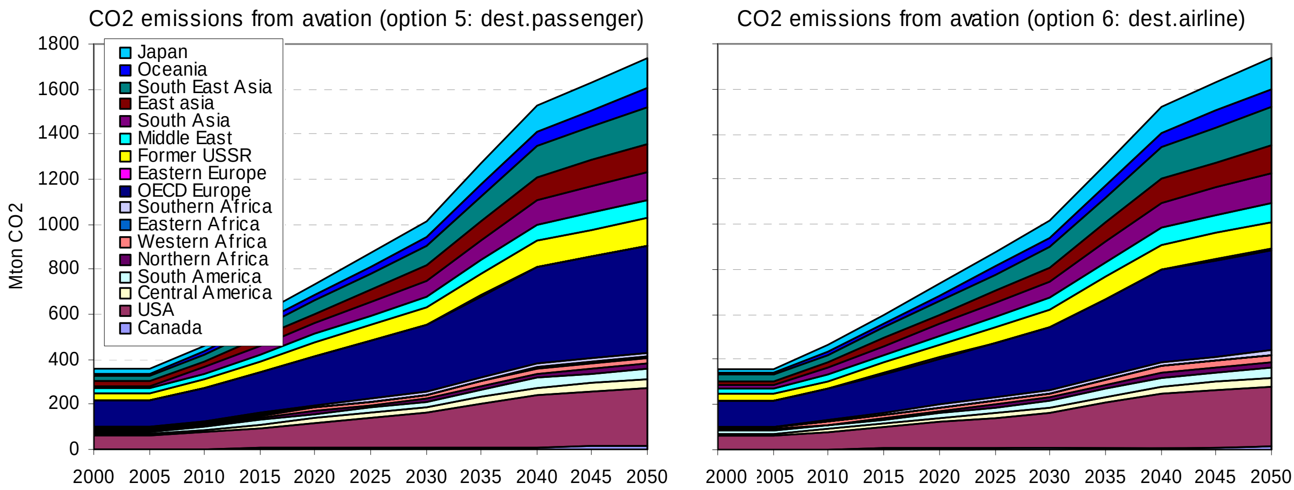


Figure 4. Baseline B2 (trend) CO_2 emissions scenario for international aviation allocated using Option 5 (destination/departure of passengers/cargo; used in analysis as proxy for Option 4) (left) or Option 6 (destination/departure of aircraft) (right) Source: historical data from IEA and scenario from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

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 2). 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 cannot 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.

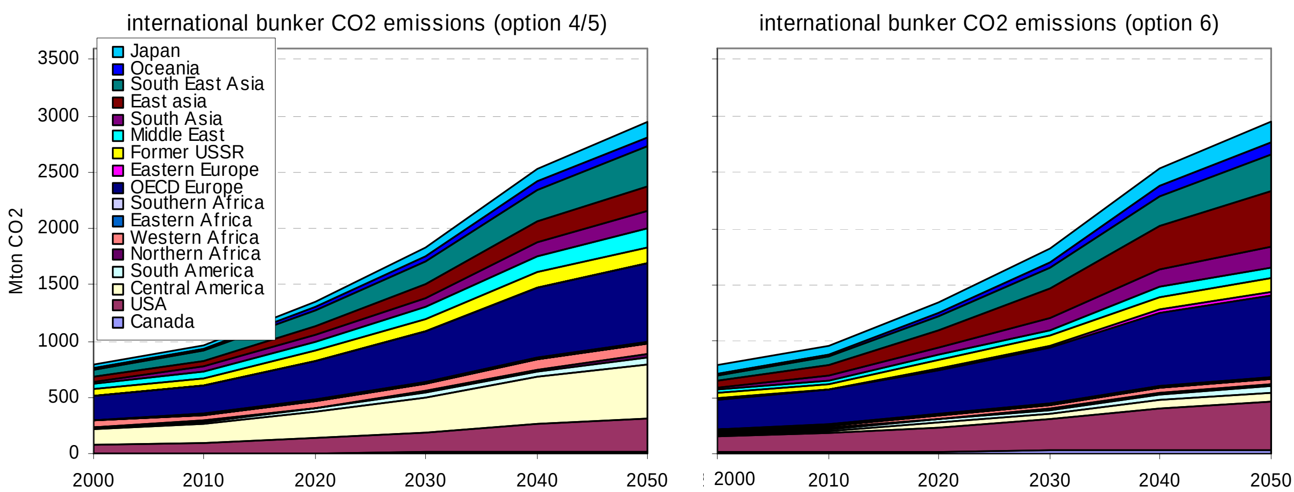


Figure 5. The international bunker emissions for the IPCC SRES baseline B2 scenario as constructed for this study for Option 4/5 [i.e. Option 4 for marine (flag state) and Option 5 for aviation (destination aircraft)] (left) and Option 6 marine and aviation (destination passenger/cargo) (right). Source: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

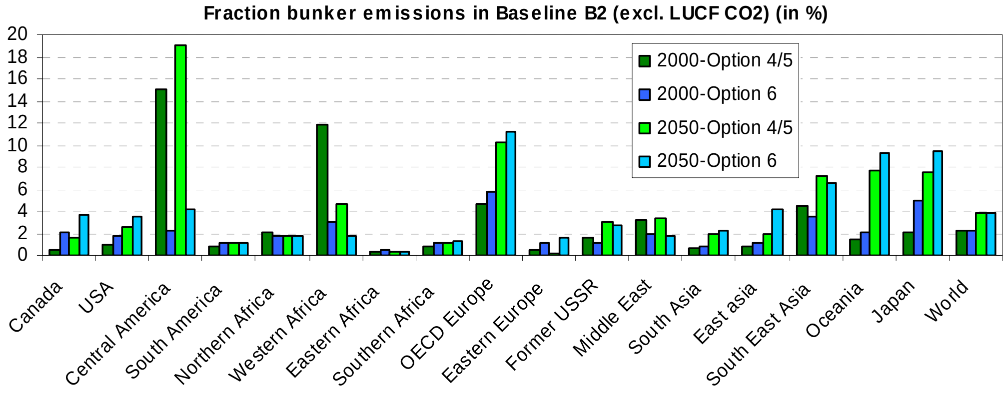


Figure 6. Fraction of the bunker emissions in the overall regional and global anthropogenic CO_2-equivalent emissions for the B2 baseline scenario in 2000 (green) and 2050 (blue) for Option 4/5 (i.e. Option 4 for marine and Option 5 for aviation) and Option 6 marine and aviation). Source: MNP-FAIR model.

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, Southeast 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 we use a quantitative approach to evaluate a number of scenarios in terms of how they deal with future bunker emissions. Our 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.). We 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). In Section 3.3, we evaluate 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. In Section 3.4, we examine 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, we assess the level of reductions in projected future bunker emissions 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 3 provides an overview of all cases.

In all of the cases assessed here we have used the medium growth baseline scenario – baseline B2 – as background for the analyses. The trend-based projections for the international shipping sector fit in well with this scenario. In addition,, for the policy cases, we have used 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, we only report the results for ten 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 3. 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%).

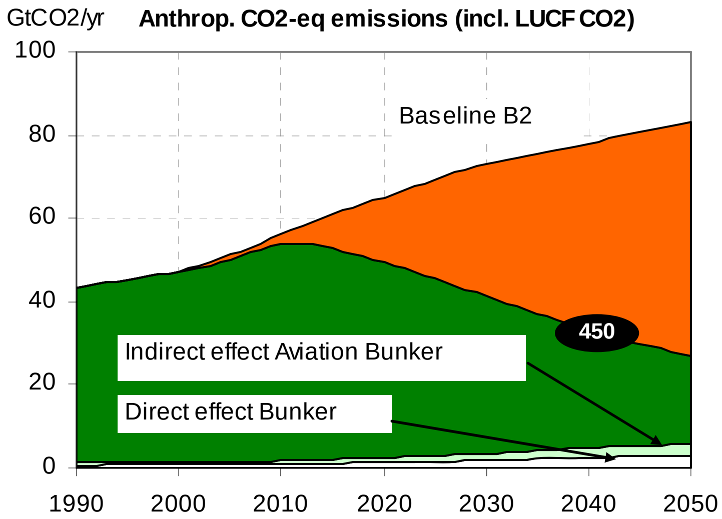


Figure 7. The share of (unabated) international bunker emissions(only the direct effects, used in the default calculations) (white area) in the B2 scenario (red area) compared to allowable emission levels for the stabilisation at 450 ppm CO_2-equivalent concentrations (hereafter S450e emissions pathway) (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 describe in den Elzen et al. (2006c)), as all countries need to compensate the increasing global bunker emissions. If we include the additional impact of non-CO_2 emissions from aviation to radiative forcing, 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 our 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 we add the unabated bunker emissions 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).

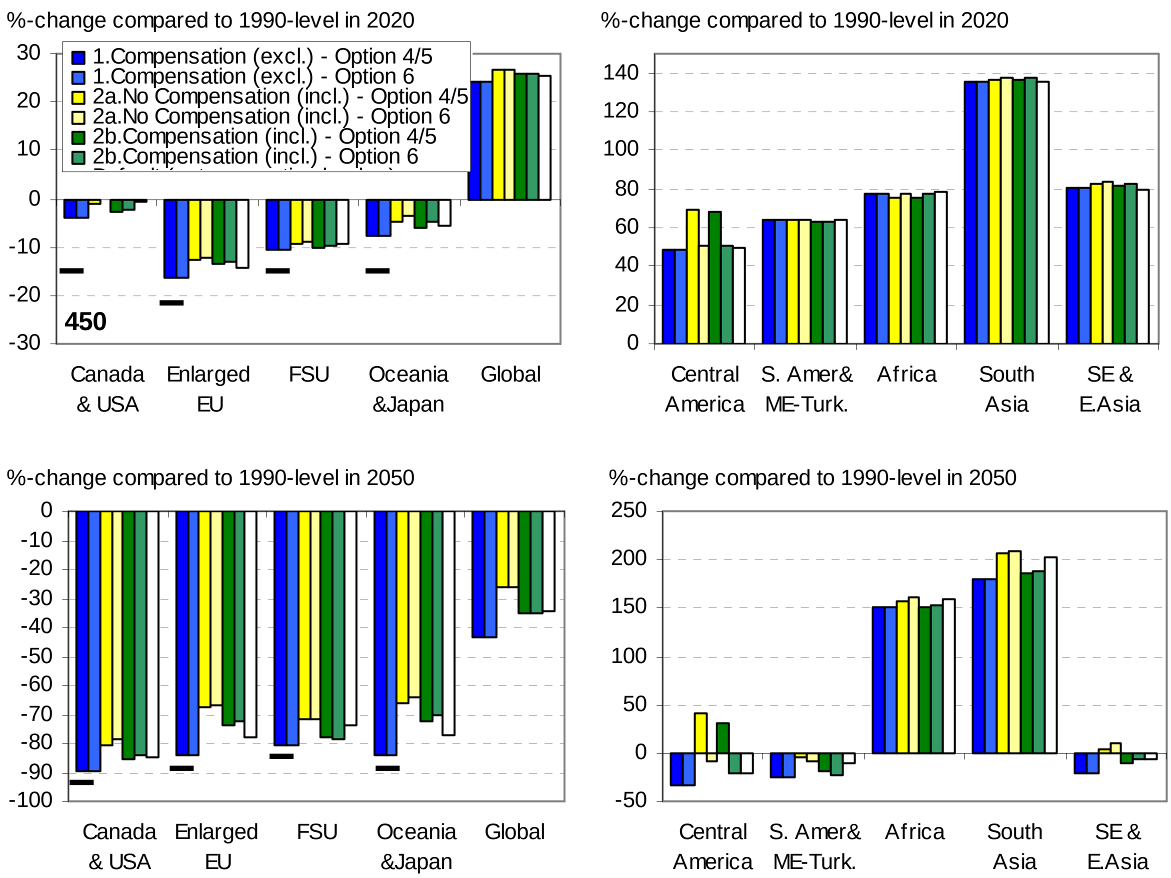


Figure 8. Percentage change in the CO_2-equivalent emission allowances relative to the 1990 emissions level for the *excluding* bunkers case in 2025 and 2050 for the S450e emissions pathway for Option 4/5 (i.e. Option 4 for marine and Option 5 for aviation) and Option 6 (marine and aviation). For comparison 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.

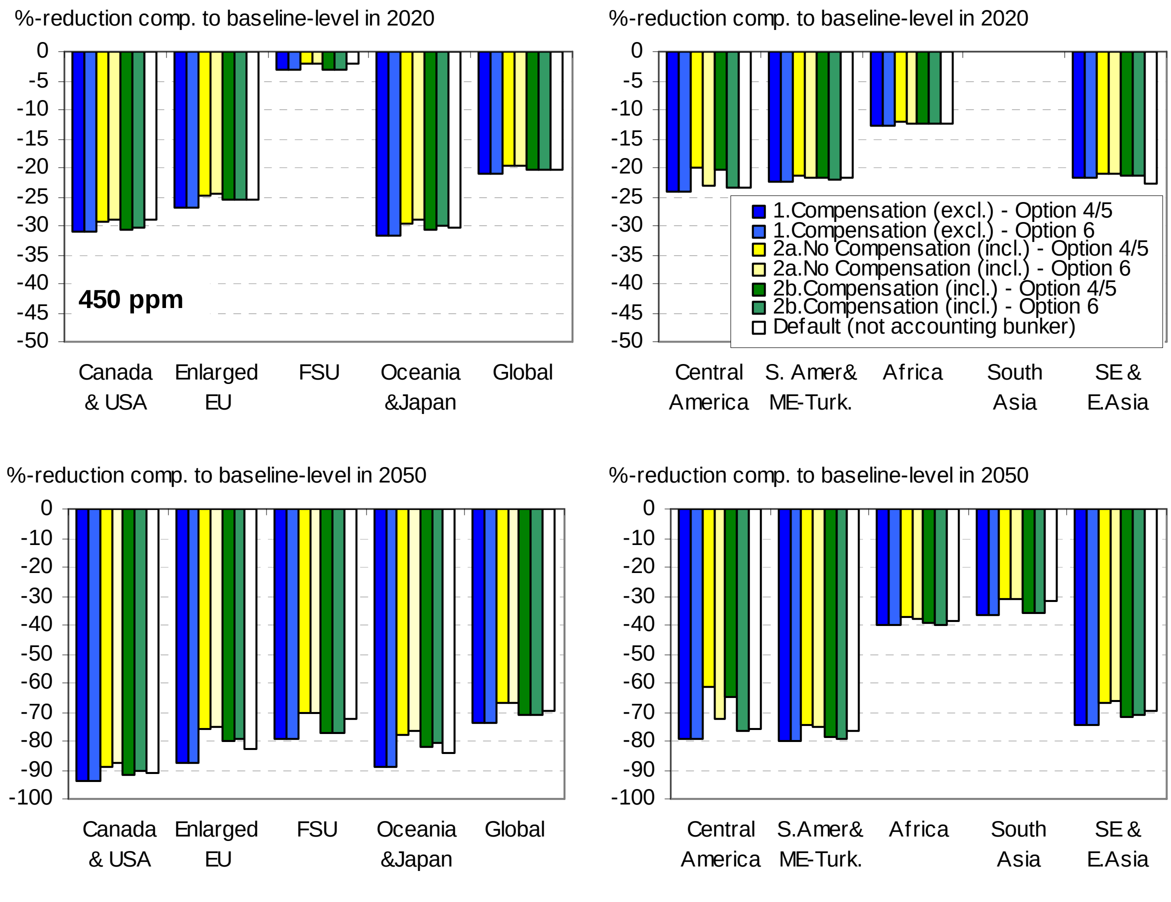


Figure 9. Percentage change in the CO_2-equivalent emission allowances relative to the B2 baseline scenario emissions level for the case of *excluding* bunkers in 2025 and 2050 for the S450e emissions pathway for Option 4/5 (i.e. Option 4 for marine and Option 5 for aviation) and Option 6 (marine and 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 4. 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 4): countries in Stage 2 have emission limitation targets (intensity targets), while countries in Stage 3 adopt absolute reduction targets. The

[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)].

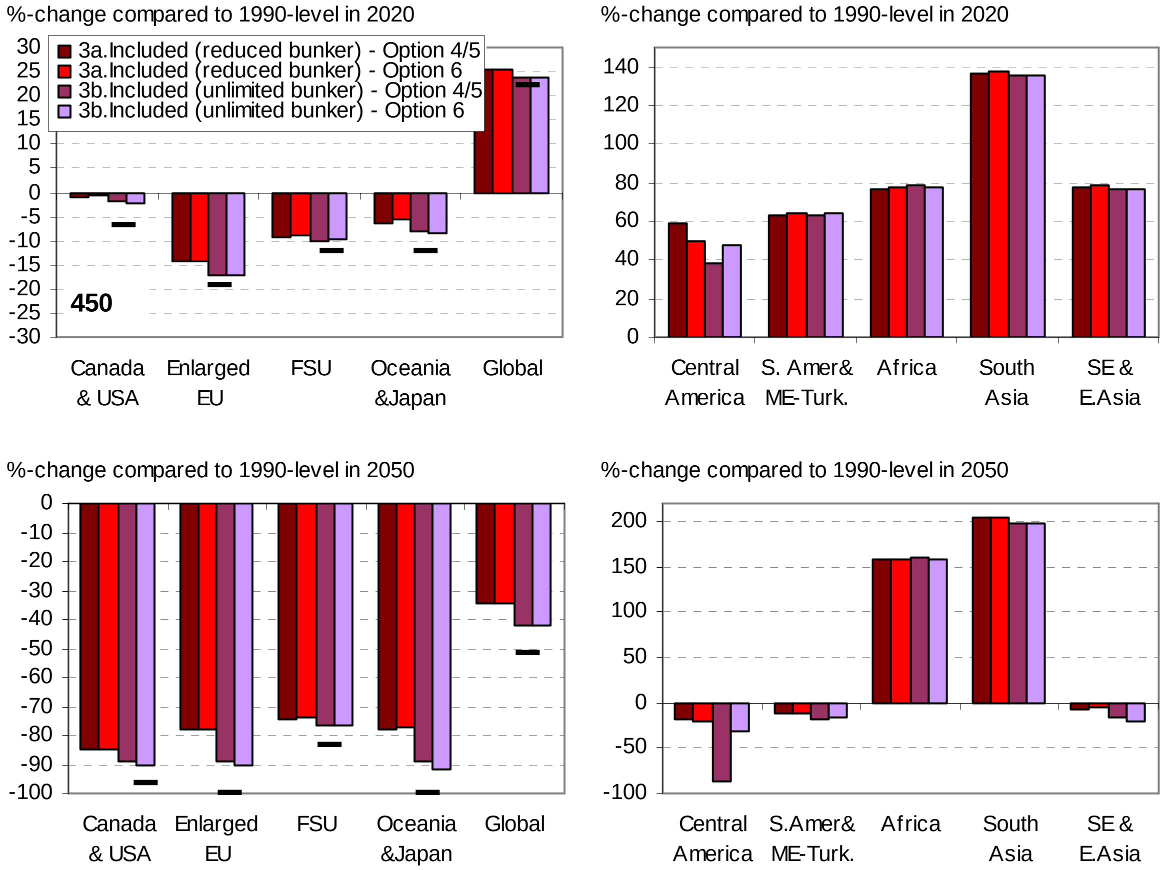


Figure 10. Percentage change in the CO_2-equivalent emission allowances relative to the 1990 emissions level for the *including* bunkers case in 2025 and 2050 for the S450e pathway for Option 4/5 (i.e. Option 4 for marine and Option 5 for aviation) and Option (6 marine and aviation). The lines included 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.

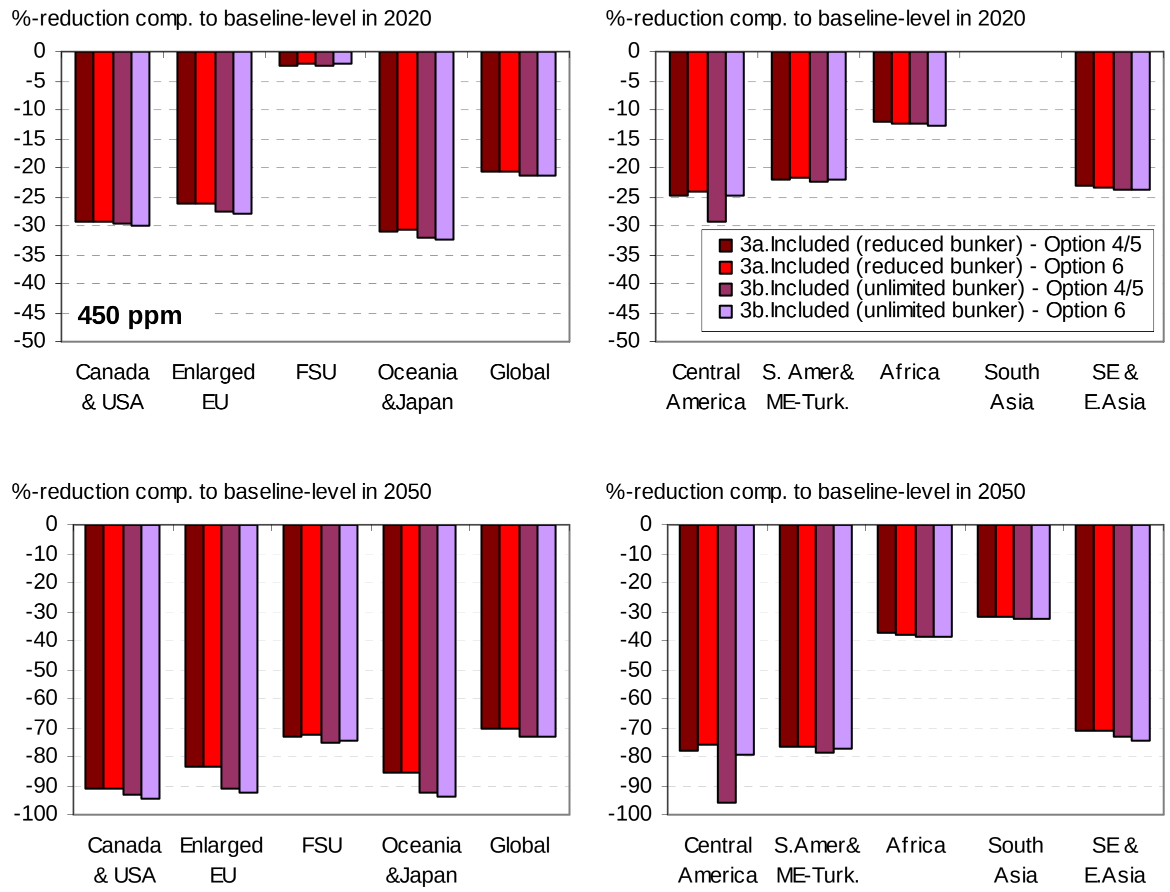


Figure 11. Percentage change in the CO_2-equivalent emission allowances relative to the B2 baseline emissions level for the *including* bunkers case in 2025 and 2050 for the S450e pathway for Option 4/5 (i.e. Option 4 for marine and Option 5 for aviation) and Ooption 6 (marine and aviation). Source: 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 and Oceania & 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 we include the additional impact of non-CO_2 emissions from aviation to radiative forcing, 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. In this section we 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, we develop a mitigation scenario for these sectors up to 2050.

3.4.1 High-Efficiency scenario for international marine transport

In our High-Efficiency scenario, we assume a limited energy improvement of 10% in 2020 and 25% in 2050. 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 our 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

In our High-Efficiency-Biofuels scenario, we assume 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, we assume that the overall improvement in fuel efficiency will 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 our 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.

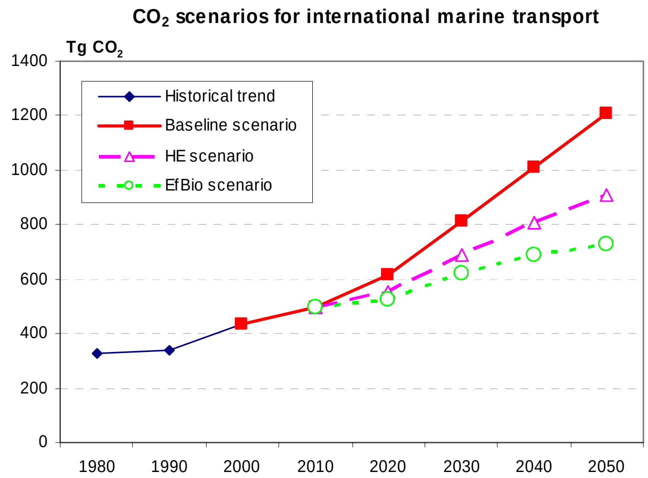


Figure 12. Comparison of scenarios for CO_2 emissions from international marine transport during the period 1980–2050: B2 baseline (trend) scenario, High-Efficiency scenario and High-Efficiency-Biofuels scenario.

3.4.4 High-Efficiency scenario for international aviation

In our High-Efficiency scenario, we assume 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 our 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) indicate 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, we have made a rather conservative estimate and assumed 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). In Figure 13 we show 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.

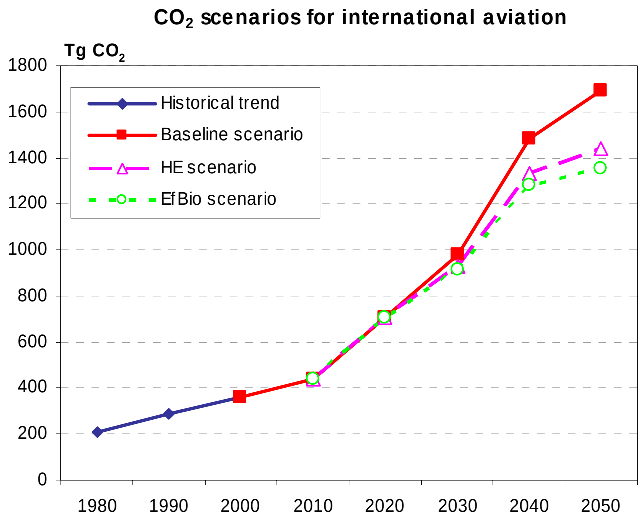


Figure 13. Comparison of scenarios for CO_2 emissions from international aviation for the period 1980–2050: B2 baseline (trend) scenario, High-Efficiency scenario and High-Efficiency-Biofuels scenario.

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).

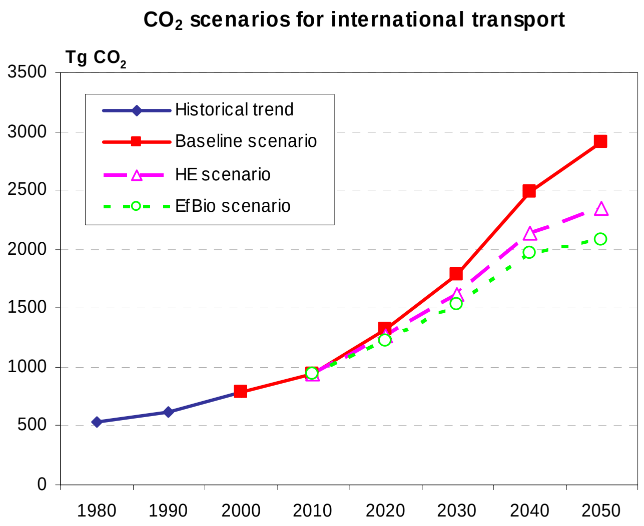


Figure 14. Comparison of scenarios for CO_2 emissions from international marine and air transport in the period 1980–2050: B2 baseline (trend) scenario, High-Efficiency scenario and High-Efficiency-Biofuels scenario.

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).

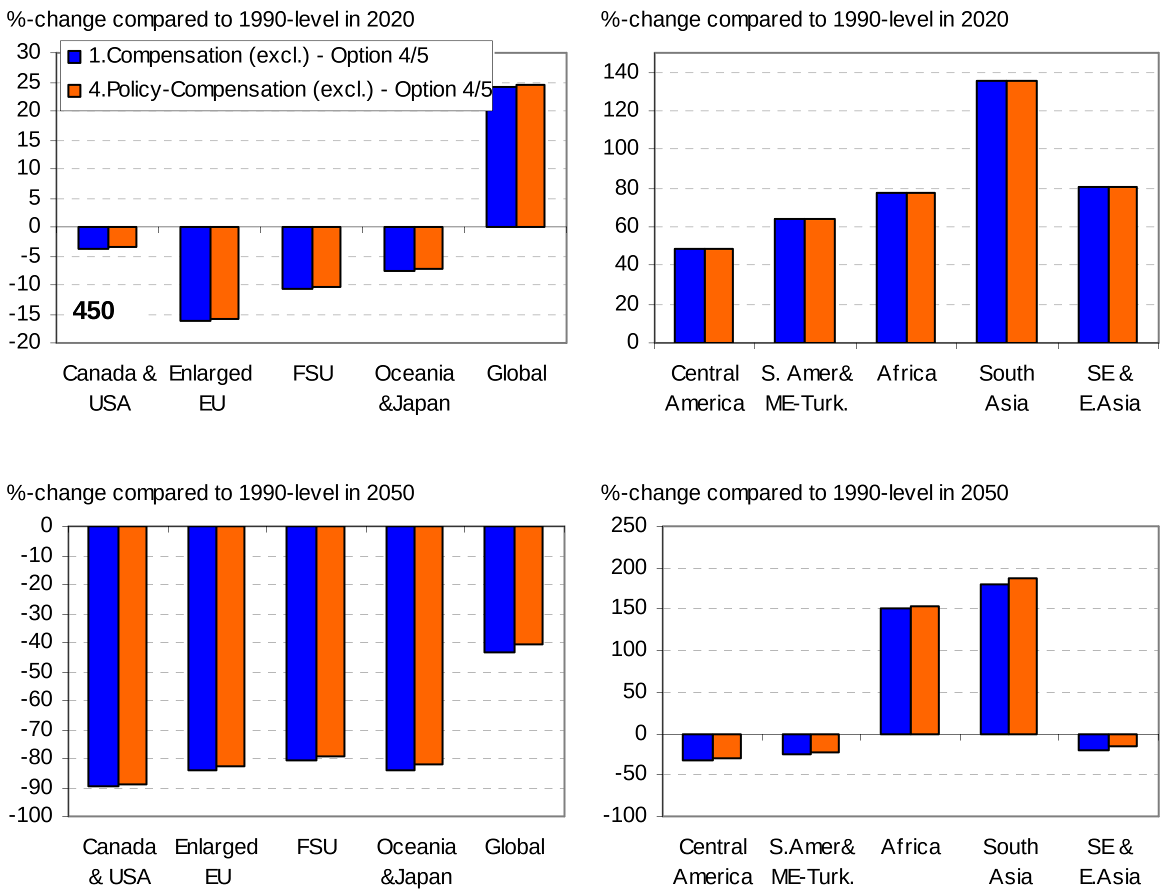


Figure 15. Percentage change in the regional CO_2-equivalent emission allowances relative to the 1990 emissions level for the sectors covered under the Multi-Stage approach with sector-based abatement of bunkers (policy-compensation) versus no abatement of bunker emissions (compensation) in 2025 and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

In our analyses we focussed 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 5. 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
	Gt CO_2	% of total	% of total	Gt CO_2	% of total	% of total	Gt CO_2	% of total	% of total
Shares (a)									
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 5):

- 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 bunkers 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 Southeast 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.

References

Anderson, K., Bows, A. and Upham, P., 2006. Growth scenarios for EU & UK aviation: contradictions with climate policy. Working Paper 84, Tyndall Centre for Climate Change Research, MACE/MBS, University of Manchester, Manchester, UK.

Berk, M.M. and den Elzen, M.G.J., 2001. Options for differentiation of future commitments in climate policy: how to realise timely participation to meet stringent climate goals? Climate Policy, 1(4): 465-480.

CEF, 2000. Scenarios for a Clean Energy Future. Interlaboratory Working Group (Oak Ridge, TN; Oak Ridge National Laboratory and Berkeley, CA; Lawrence Berkeley National Laboratory). report no. ORNL/CON-476 and LBNL-44029. On internet: http://www.ornl.gov/sci/eere/cef/.

Corbett, J. J., Fischbeck, P. S. and Pandis, S.N., 1999. Global nitrogen and sulfur inventories for oceangoing ships. Journal Geophysical Research, 4(3): 3457-3470.

Corbett, J. J. and Köhler, H.W., 2003. Updated emissions from ocean shipping. Journal Geophysical Research(108(D20), 4650, doi:10.1029/2003JD003751).

Daggett, D., Hadaller, O., Hendricks, R. and Walther, R., 2006. Alternative Fuels and Their Potential Impact on Aviation, NASA, Cleveland, Ohio. Report no. NASA/TM-2006-214365, October 2006. Prepared for the 25th Congress of the Aaronautical Sciences (ICAS 2006), Hamburg, 3-8 September 2006. Available at http://gltrs.grc.nasa.gov.

den Elzen, M.G.J, Lucas, P. and van Vuuren, D.P., 2006a. Exploring regional abatement costs and options under allocation schemes for emission allowances. Climatic change, submitted.

den Elzen, M.G.J, Meinshausen, M. and van Vuuren, D.P., 2006b. Multi-gas emission envelopes to meet greenhouse gas concentration targets: costs versus certainty of limiting temperature increase. Global Environmental Change, in press.

den Elzen, M.G.J., 2002. Exploring climate regimes for differentiation of future commitments to stabilise greenhouse gas concentrations. Integrated Assessment, 3(4): 343-359.

den Elzen, M.G.J. and Berk, M.M., 2003. How can the Parties fairly and effectively establish future obligations under long-term objectives? In: D. Michel (Editor), Climate policy for the 21st century: meeting the long-term challenge of global warming. Center for Transatlantic Relations, Washington, D.C., pp. 79-112.

den Elzen, M.G.J., Berk, M.M., Lucas, P., Criqui, C. and Kitous, A., 2006c. Multi-Stage: a rule-based evolution of future commitments under the Climate Change Convention. International Environmental Agreements: Politics, Law and Economics, 6: 1-28.

den Elzen, M.G.J. and Lucas, P., 2005. The FAIR model: a tool to analyse environmental and costs implications of climate regimes. Environmental Modeling and Assessment, 10(2): 115-134.

den Elzen, M.G.J., Lucas, P. and van Vuuren, D.P., 2005. Abatement costs of post-Kyoto climate regimes. Energy Policy, 33(16): pp. 2138-2151.

Endresen, Ø., Sørgård, E., Sundet, J. K., Dalsøren, S. B., Isaksen, I. S. A., Berglen, T. F. and Gravir, G., 2003. Emission from international sea transportation and environmental impact. Journal Geophysical Research, 108(D17), 4560, doi:10.1029/2002JD002898.

Eyring, V., Kohler, H.W., Lauer, A. and Lemper, B., 2005a. Emissions from international shipping: 2. Impact of future technologies on scenarios until 2050. Journal of Geophsical research, 110: 18.

Eyring, V., Kohler, H.W., van Ardenne, J. and Lauer, A., 2005b. Emissions from international shipping: 1. The last 50 years. Journal of Geophsical research, 110: 12.

Gupta, J., 1998. Encouraging developing country participation in the climate change regime, Institute for Environmental Studies, Free University of Amsterdam, Amsterdam, the Netherlands.

Höhne, N., Phylipsen, D., Ullrich, S. and Blok, K., 2005. Options for the second commitment period of the Kyoto Protocol, research report for the German Federal Environmental Agency. Climate Change 02/05, ISSN 1611-8855, available at www.umweltbundesamt.de, ECOFYS Gmbh, Berlin.

Houghton, R.A., 2003. Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850–2000. Tellus, 55B: 378–390.

ICF, 2006. Including Aviation into the EU ETS: Impact on EU allowance prices. Final Report, 01 February 2006., Department for Environment, Food & Rural Affairs (DEFRA), London and Department forTransport (Dft), London, UK.

IEA, 2004. World Energy Outlook 2004. International Energy Agency, Paris.

IEA, 2005. CO2 emissions from fuel combustion 1971-2003, 2005 Edition. International Energy Agency, ISBN 9 92-64-10891-2 (paper) 92-64-10893-9 (CD ROM), Paris, France.

IMAGE-team, 2001. The IMAGE 2.2 implementation of the SRES scenarios. A comprehensive analysis of emissions, climate change and impacts in the 21st century. CD-ROM publication 481508018, Netherlands Environmental Assessment Agency (MNP), Bilthoven, the Netherlands.

IPCC, 1999. Aviation and the global atmosphere. Cambridge University Press, Cambridge, UK.

King, C., 2006. Framing the Issue – Shipping: Canadian Shipowners Association (CSA). Presented at: "Bunker Fuel: MARPOL Annex VI Consultation Meeting", Arlington, VA, February 23, 2006. Organised by the American Petroleum Institute (API). Proceedings on internet: http://api-ep.api.org/training/index.cfm?objectid=D5FC25A0-3462-4914-BF99F40976289B32.

OECD, 2006. Project on the impacts of globalisation on transport: managing the environmental effects in the context of the ESTIMATE strategy. Analysis of the Impacts of Globalisation on Transport and the Environment. Working Party on National Environmental Policy/ Working Party on Transport. OECD Headquarters, Paris, 24 January 2006. Report no. ENV/EPOC/WPNEP/T(2006)3.

Olivier, J.G.J., Van Aardenne, J.A., Dentener, F., Pagliari, V., Ganzeveld, L.N. and Peters, J.A.H.W., 2005. Recent trends in global greenhouse gas emissions: regional trends and spatial distribution of key sources. Environmental Sciences, 2(2-3): 81-100.

Owen, B. and Lee, D.S., 2005. International Aviation Emissions Allocation – Future Cases (Report 3 of 3) Data Appendix. CATE-2005-3(C)-3a, Manchester Metropolitan University.

RMI, 2004. Winning the Oil Endgame. On internet: http://www.oilendgame.com/index.html. Rocky Mountain Institute, Snowmass, CO, USA. ISBN 1-881071-10-3.

Sausen, R., Isaksen, I. Grewe1, V., Hauglustaine, D., Lee, D.S., Myhre, G., Köhler, M.O., Pitari, G., Schumann, U., Stordal, F. and Zerefos. C. (2005) Aviation radiative forcing in 2000: An update on IPCC (1999). Meteorologische Zeitschrift, Vol. 14, 555-561 (DOI: 10.1127/0941-2948/2005/0049)

Saynor, B., Bauen, A. and Leach, M., 2003. Matthew LeachThe Potential for Renewable Energy Sources in Aviation. Report 07 August 2003, Imperial College Centre for Energy Policy and Technology, Imperial College, London, UK.

Taylor, R.B., 2005. A report on the proceedings, "Charting the Course: Marine Fuel Efficiency and Emissions Conference", Toronto, January 18-19, 2005. Organised by Transport Canada. Proceedings on internet: http://www.tc.gc.ca/programs/environment/Freight/training/marine/menu.htm.

Tuinstra, W., Ridder, W de, Wesselink, L.G., Hoen, A., Bollen, J.C. and Borsboom, J.A.M., 2005. Aviation in the EU Emissions Trading Scheme. MNP report no. 500043001, Netherlands Environmental Assessment Agency (MNP), Bilthoven, the Netherlands.

UN, 2004. World Population Prospects: the 2004 revision, United Nations Department for Economic and Social Information and Policy Analysis, New York, NY.

UNCTAD, 2006a. Handbook of Statistics 2005. Data downloaded April 2006 from internet site: http://stats.unctad.org/Handbook/ReportFolders/ReportFolders.aspx.

UNCTAD, 2006b. Trade and Development Report 2006, http://www.unctad.org/en/docs/tdr2006_en.pdf. United Nations, New York and Geneva.

Van Aardenne, J.A., Dentener, F.J., Olivier, J.G.J., Klein Goldewijk, C.G.M. and Lelieveld, J., 2001. A 1 x 1 degree resolution dataset of historical anthropogenic trace gas emissions for the period 1890-1990. Global Biogeochemical Cycles, 15(4): 909-928.

van Vuuren, D.P., Cofala, J., Eerens, H.E., Oostenrijk, R., Heyes, C., Klimont, Z., den Elzen, M.G.J. and Amann, M., 2006a. Exploring the ancillary benefits of the Kyoto Protocol for air pollution in Europe. Energy Policy, 34: 444-460.

van Vuuren, D.P., den Elzen, M.G.J., Eickhout, B., Lucas, P.L., Strengers, B.J. and Ruijven, B., 2006b. Stabilising greenhouse gas concentrations. Assessment of different strategies and costs using an integrated assessment framework. Climatic Change, in press.

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), Southeast Asia (notably Singapore) and the USA also show significant growth rates (Figure A.1).

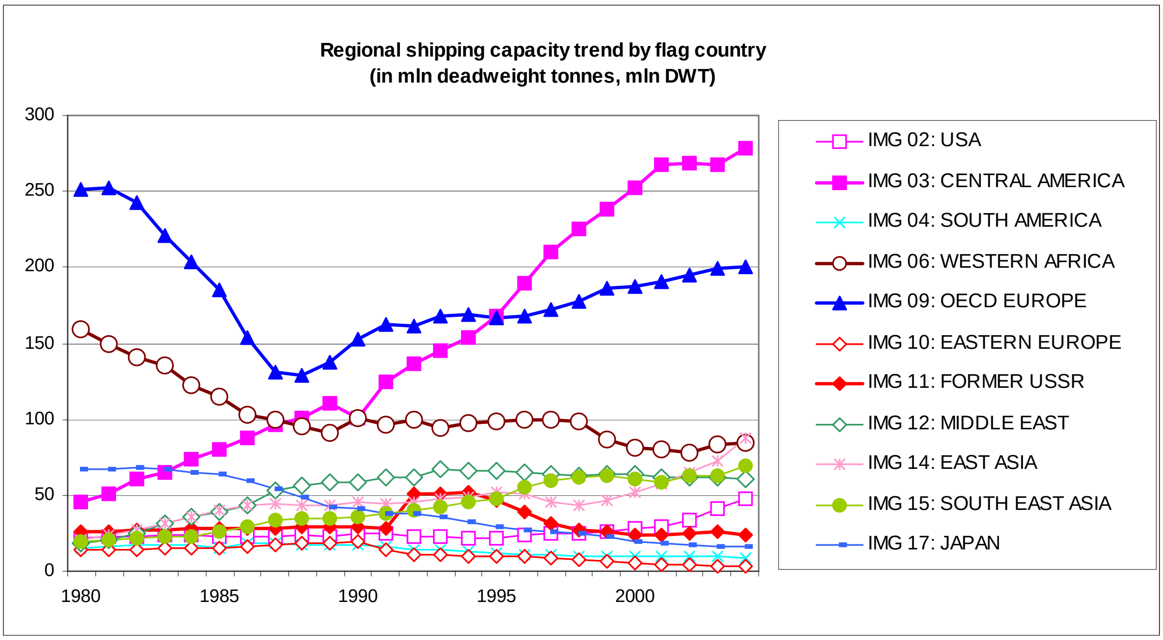


Figure A.1. Trends in regional shipping capacity in the period 1980–2004 (in million DWT). Source: UNCTAD (2006a).

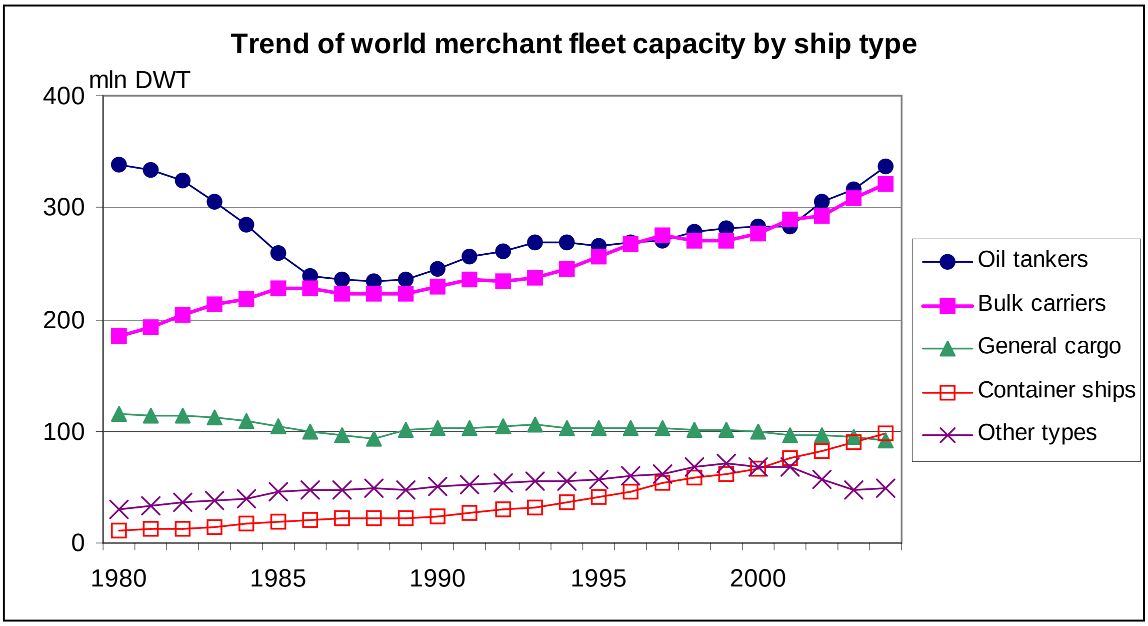


Figure A.2. Global trends in the shipping fleet by ship type (in million DWT). Source: UNCTAD (2006a).

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.

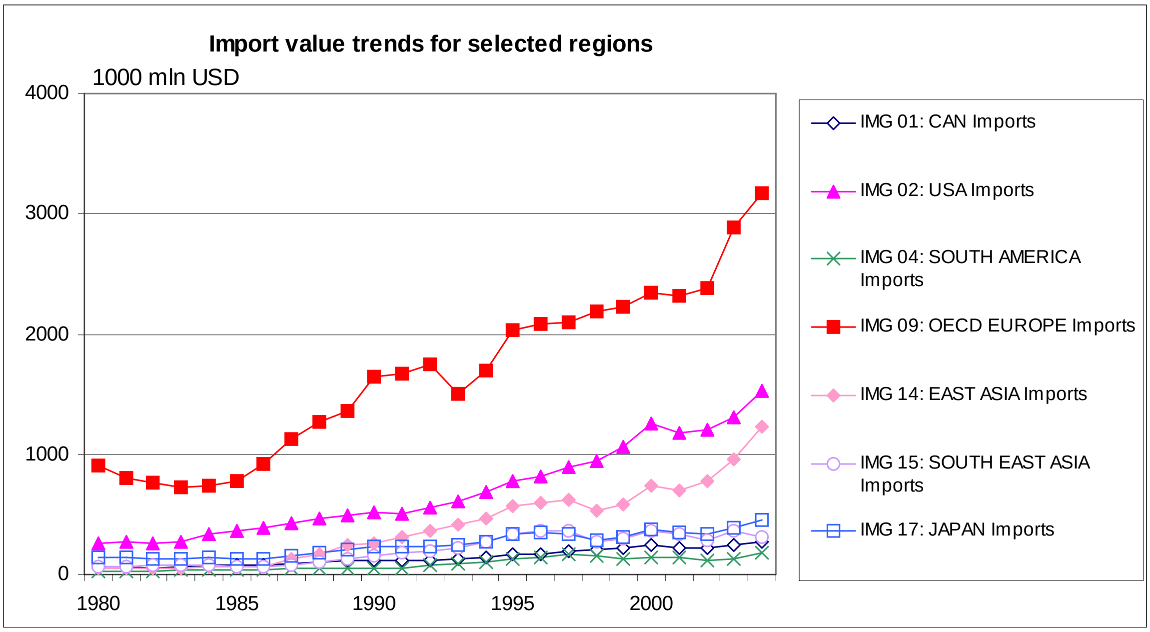


Figure A.3. Trend in regional imports for selected regions (including intraregional trade) (in million 1000 USD). Source: UNCTAD (2006a).

A.2 Trend CO_2 scenario for international shipping

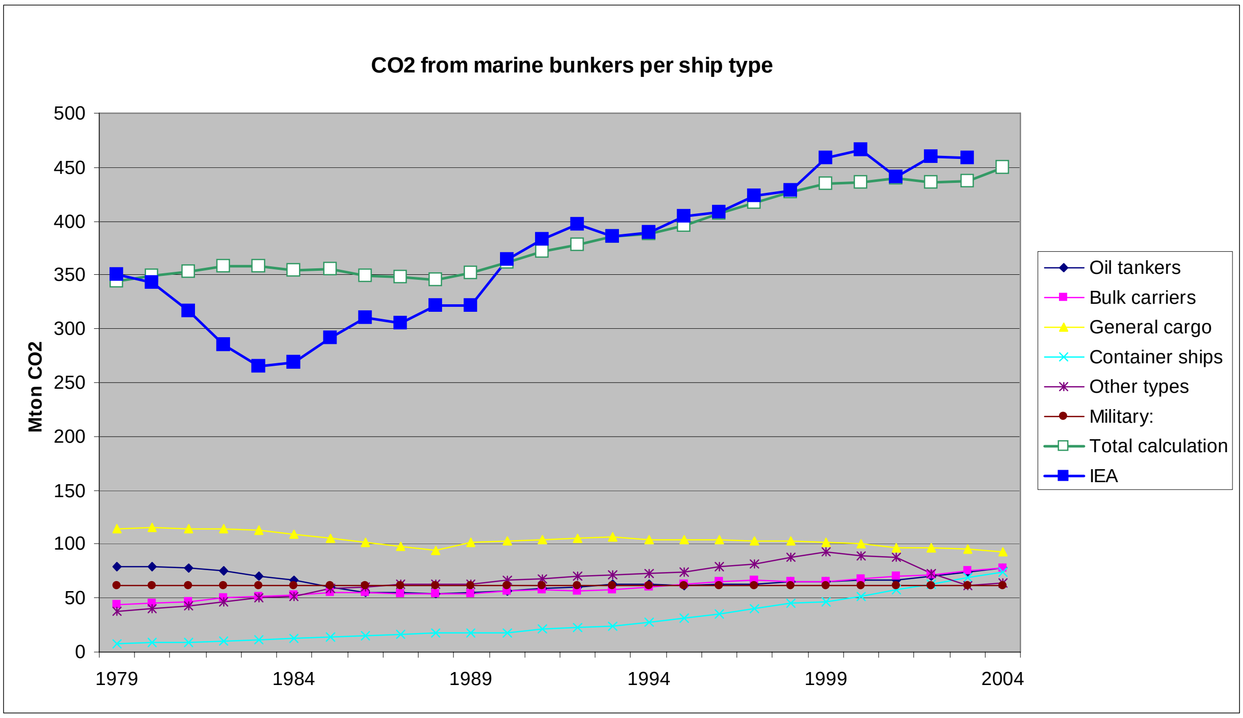
A baseline (trend) scenario was constructed based on historical data available on the shipping capacity per ship type [Dead Weight Tonnes (DWT) of tankers, bulk carriers, container ships, general cargo, among others] from UNCTAD (2006). The following assumptions are made:

- 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 we applied a linear extrapolation of the growth trend in 2020–2030 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.

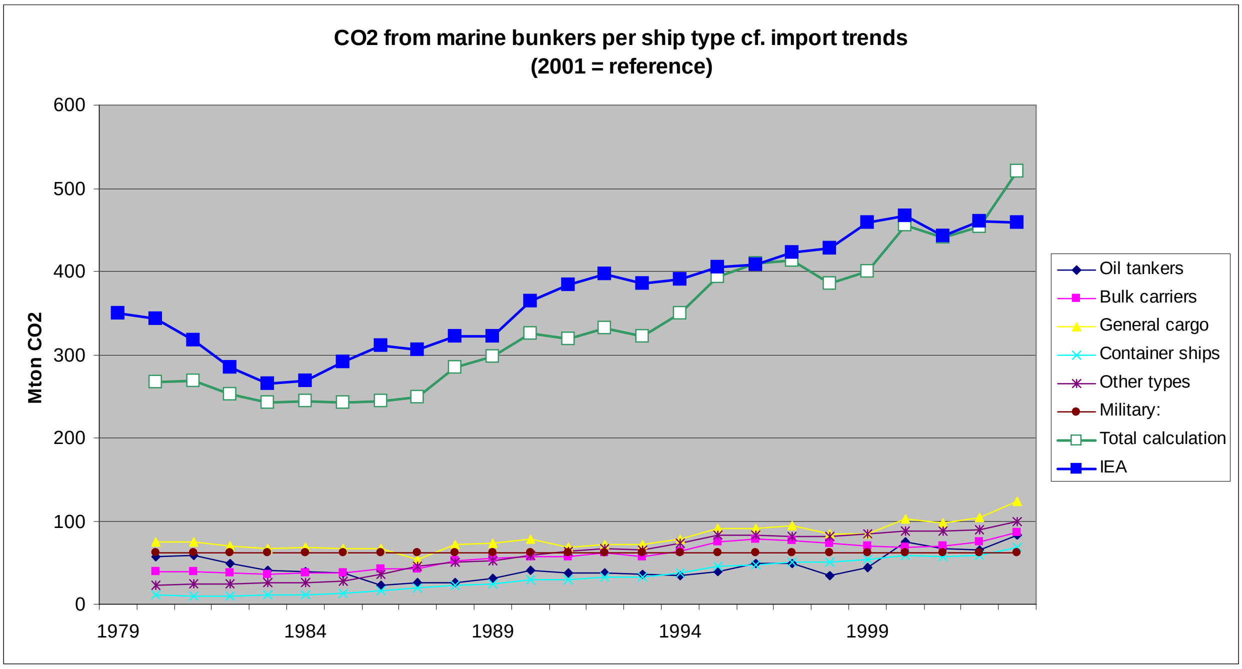


Figure A.5. Comparison of CO_2 emissions reported by IEA (2005) and calculated from import values per ship type (UNCTAD, 2006), assuming constant specific fuel consumption (GJ/US$, calculated for 2001).

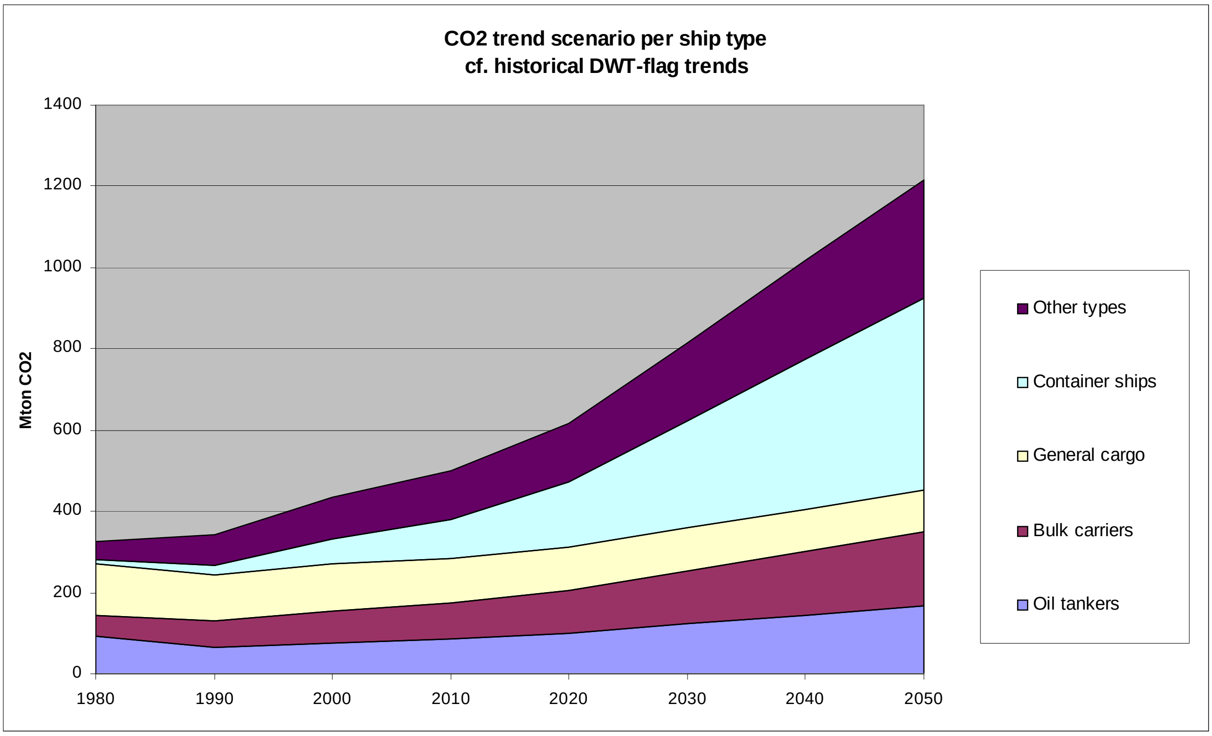


Figure A.6. Trend scenario for CO_2 emissions per ship type based on historical DWT trends per ship type.

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