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Environmental data and policy on non-road transport modes

Working paper for the European Environment Agency

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Contents

Summary

In transport and environment policy the prime focus is on road transport. However, as environmental legislation is taking effect, the share of road transport in pollutant emissions is declining (with CO_2 emissions as an important exception). For non-road modes developments in emissions policy are generally lagging behind and data are relatively scarce (especially on shipping). In this context, EEA has asked CE Delft to write this report on the environmental performance, policy and challenges of the main non-road transport modes: aviation, shipping (both sea and inland) and rail.

Road transport is dominant in passenger and intra-European freight transport and related emissions. Emissions from non-road modes are significant, however, and growing. The share of non-road modes in greenhouse gas emissions is about 39% of total transport emissions in the EU-15, when non-CO_2 effects of aviation are included. The particularly quickly growing climate impacts from international aviation alone will, unless abated, use up almost 40% of the EU-25 CO_2 budget in 2050 if the current ambition of a 60% reduction in 2050 is adhered to. Non-road modes contribute about 36% of total transport NO_x emissions in the EEA-25. This is ten percent more than a decade ago and the share is still growing, although in absolute terms emissions are decreasing. International maritime shipping is the largest non-road emitter of NO_x.

Note that these should be considered rough estimates since it is not yet possible to draft consistent, comparable and reliable emission inventories for any non-road mode:

- For *aviation*, data for both bottom-up and top-down inventories are recorded (although they are not reported). For greenhouse gas emissions, several inventories of good quality have been drafted. The main obstacle for national emission inventories for aviation is the different possible allocation options.
- For the *rail* sector, there are currently no emission inventories available. For electric trains, data from the power sector could be used (although double counting should be avoided). For diesel trains, activity data and emission factors are available and of reasonable quality.
- For the *marine* sector, the main obstacle is the lack of agreement on national allocation of emissions. Furthermore, data availability is relatively low. Recently, emission inventories of maritime shipping were calculated for the EU using a bottom up model, for a number of allocation options.
- For *inland navigation*, some countries have reasonable emission inventories, but it will take a long time before comparable inventories can be drafted.

Emission and fuel standards in non-road modes have gradually been introduced in non-road modes since about 2000. It will take relatively long, however, before the effect of emission standards can be seen in total emissions data, since the average lifetime of locomotives and ships is much longer than that of trucks or cars. Environmental improvements in the short term can thus be achieved with

policies aimed at fuels, or with additional policy measures aimed at retrofitting or accelerated fleet renewal. Sulphur content in the fuels used by non-road modes may vary significantly. For 2009, for road transport the standard will be 10 ppm, which is a factor 100 or more below that currently foreseen for other modes, with maritime shipping lagging farthest behind. The environmental performance of rail depends a lot on the ratio of diesel versus electric transport. The evidence suggests that the share of electric in total rail transport is increasing, resulting in a probably improved environmental performance of rail.

For the greenhouse impacts of transport, CO_2 is not the only emission of concern. To compare modes properly, direct and indirect climate impact of non-CO_2 emissions should also be taken into account. The climate impact of non-CO_2 emissions makes the climate impact of aviation larger than could be expected from merely the CO_2 emissions. For maritime shipping the contrary might be true: non-CO_2 engine emissions might, at least in the short term, partly compensate the greenhouse effect of CO_2 emissions. Refrigeration equipment used in maritime vessels is, however, sources of fluorinated gas emissions, which are strong greenhouse gases. Average leakage rates are relatively high in maritime refrigeration equipment, compared to similar emissions from other transport modes or stationary sources. These emissions are currently not monitored or regulated.

An important element in the environmental policy of the European Commission is the attempts to shift the balance from road to rail, as described in the White paper on the Commission Transport Policy (CTP). Specific measures aimed at modal shift such as building new rail infrastructure, carry the risk of increasing the transport volume of rail or water transport without necessarily decreasing road transport volumes. Because of these types of unintended side-effects, the net effect on environmental impact of measures aimed at modal shift should always be carefully considered. This is particularly important because environmental performance generally depends more on installed technology and logistical characteristics than on mode per se, particularly in freight transport.

In the rail sector, there is a trend towards high-speed rail passenger transport over intermediate distances. Although energy use for high-speed trains is very variable, it is generally higher than of conventional trains. It should be kept in mind that high-speed trains compete on other markets than conventional trains. Differentiation of rail infrastructure user charges by environmental performance offers opportunities for emission reduction. Fuel excise duties already exist in most countries, but are strongly variable. Introducing or increasing these duties across the EU would provide an incentive to improve efficiency.

There is no policy to reduce greenhouse emissions from inland navigation. It also lacks excise duty for fuel for inland vessels and any other economic instrument, except from relatively low harbour dues. For introduction of an excise duty or other economic measures, legal obstacles like the Mannheim Convention need to be tackled first.

For international aviation and maritime shipping, the responsibility for the greenhouse gas emissions has not been assigned to individual parties. This is an obstacle for climate policy. The European Commission regards the inclusion of aviation in the EU Emission Trading System (ETS) as the most promising way forward. A working group will be set up, to consider ways of including aviation in the EU ETS. The Commission aims to put forward a legislative proposal by 2006.

For maritime shipping, fuel efficiency is relatively good compared to other modes. However, since bunker fuels are relatively cheap and not taxed, there is much less incentive to reduce fuel consumption than in road transport, for example. Both the EU and the IMO are working on the development of greenhouse gas policies, but no agreement has yet been reached.

1 Introduction

1.1 Background

In transport and environment policies the prime focus is on road transport. Emission inventories, test cycles, emission standards and other environmental policy for road transport have been highly developed over the years and are still further improved. The fact that road transport has the highest share in both the intra-European transport volume and the emissions of transport justifies this top priority.

However, environmental legislation is taking effect and thus the share in environmental impacts of non-road modes are increasing. The share of road transport in pollutant emissions is declining (with CO_2 emissions as an important exception). For non-road transport modes environmental legislation is generally lagging behind and it is expected that their share in pollutant emissions will rise. Examples are aviation, diesel locomotives and maritime shipping.

With respect to greenhouse gas emissions, both international aviation and international maritime shipping are not included in the Kyoto-agreement since emissions of these modalities are hard to allocate and statistics of emissions less well developed. Developments in emission ceilings policy for these modes are slow because the responsibility for setting limits is not assigned to a single party. In addition data and information on these modalities (especially on shipping) are relatively scarce.

International aviation and maritime shipping in the Kyoto-protocol
At the Third Conference of Parties to the Framework Convention on Climate Change in 1997, at which the Kyoto-protocol was drawn up, agreement could not be reached on how emissions from international aviation and shipping should be allocated among countries. The national inventories of annual national greenhouse gas emissions reported by Parties to the UNFCCC include only emissions from *domestic* air and marine transport. Emissions associated with fuel used for international transport activities are to be reported separately. As a result, emissions from international aviation and maritime shipping are not included in the emission targets for the period 2008-2012 set under the Kyoto-protocol.

Article 2.2 of the Kyoto-protocol states that '*Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from international aviation and marine bunker fuels, working through the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) respectively*' (UNFCCC, 1997).

At the moment, environmental impacts of aviation and maritime shipping have the attention of the European Commission (DG ENV), where climate policies have top priority, in particular for aviation. Recently, the Commission has initiated a study for emission trading in aviation (being carried out by CE Delft and partners). For maritime shipping a similar situation exists as a large study regarding greenhouse gas and pollutant emissions for the EC has been commissioned. Nevertheless there remain barriers that prevent a steady improvement of the environmental performance of the non-road modes. These barriers can be, among others, in knowledge.

1.2 Objective

The objective of this report is to provide a thorough overview of the issues related to emissions from non-road transport modes. This overview focuses on:

1. Current and expected emissions of non-road transport modes and the policies to improve this performance.
2. Barriers that prevent a steady reduction of the emissions of these non-road modes.
3. Gaps in data and knowledge, particularly with respect to emission inventories.

Chapter 2 through 6 treat aviation, rail, maritime shipping and inland navigation, respectively. Conclusions and recommendations are given in chapter 7.

The ultimate objective of this study is to contribute to the discussions and actions by the European Commission and EU member states to improve the environmental performance of non-road modes and the type of instruments that could be deployed to achieve this. An earlier version of this report was used as an input document for the workshop held in Brussels on June 29 2005. Decisions made at this workshop and comments from the participants have been incorporated in this final version.

1.3 Scope: environmental effects

Not all environmental effects will be discussed in this report. The focus is on the main emissions related to the use of fuels: CO_2, NO_X and particulate matter (PM). For modes that use fuels with a high sulphur content, navigation, SO_2 is also relevant. Other effects, such as noise, are often taken into account in general external cost studies. These studies will not be extensively mentioned in this report, as the scope is limited to the emissions data and policy.

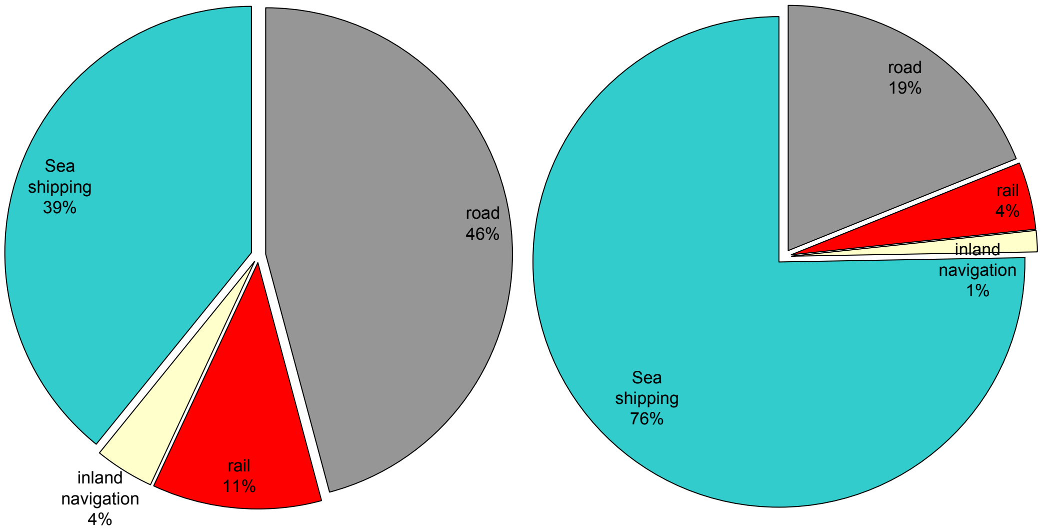
Special attention is paid to non-CO_2 climate effects that may be important for some modes, primarily aviation and maritime shipping. These effects are discussed in 2.6.

1.4 Importance of non-road modes: some key figures

This section provides some key figures to illustrate the importance of non-road transport in the EU concerning transport volumes and emissions.

With regard to freight transport volumes, non-road modes contribute more than half, with the largest share for maritime shipping (see Figure 1). Freight transport by air is, compared to the other modes, insignificant.

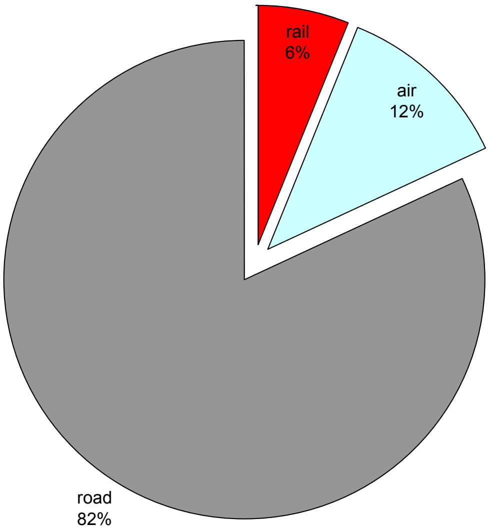
Figure 1 Current shares of freight transport volume (tonne-km), by mode, EU-25
a) Excluding extra-EU maritime shipping **b)** Including extra-EU maritime shipping



Note: Maritime shipping includes domestic and intra-EU shipping in the pie to the left (2001 data), and in the pie to the right (2003 data) also includes transport between EU and outside countries, with half of these tkm allocated to EU. All maritime shipping data are likely to be inaccurate. Data tables and meta data can be found in Annex A.1.

For passenger transport, air transport is the largest non-road mode, followed by rail. Passenger transport by ship is negligible (see Figure 2).

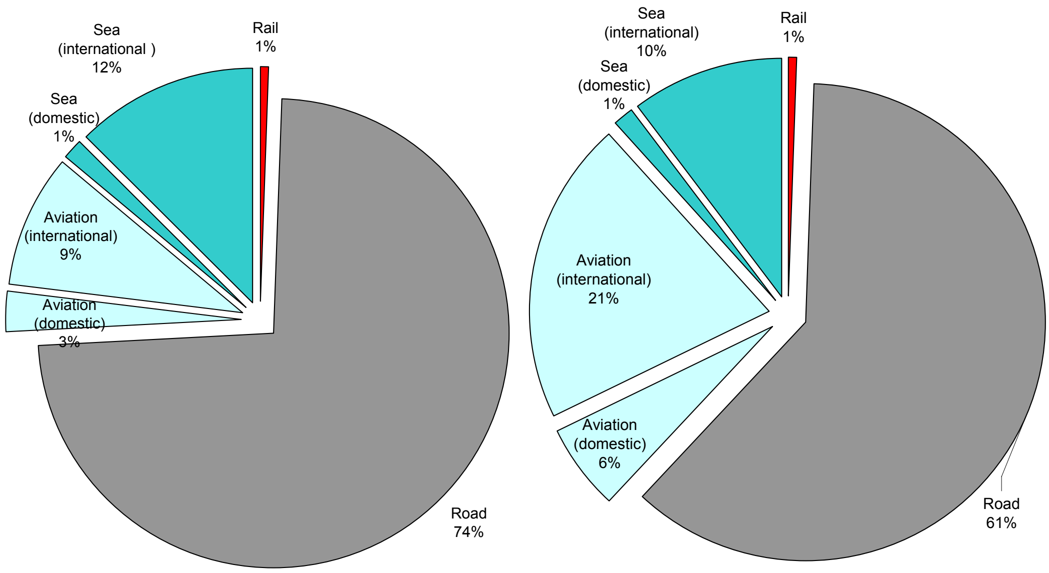
Figure 2 2001 shares of passenger transport volume (passenger-km), by mode, EEA-23



Note:EEA-23 refers to the old 15 EU member states, 5 new member states (Czech Republic, Slovakia, Slovenia, Poland and Hungary) plus Norway, Iceland and Turkey. Transport of passengers by sea is not included, but is very small. 'Air' includes all transport by European carriers in the EEA-23. Information is not available on transport by non-European air carriers. All passenger-km performed on international flights with origin or destination in an EEA-23 country are included. This is not fully consistent with the allocation of intercontinental maritime freight transport (Figure 1) but currently, data are lacking to apply the same allocation to passenger air transport. Data tables and meta data can be found in Annex A.2.

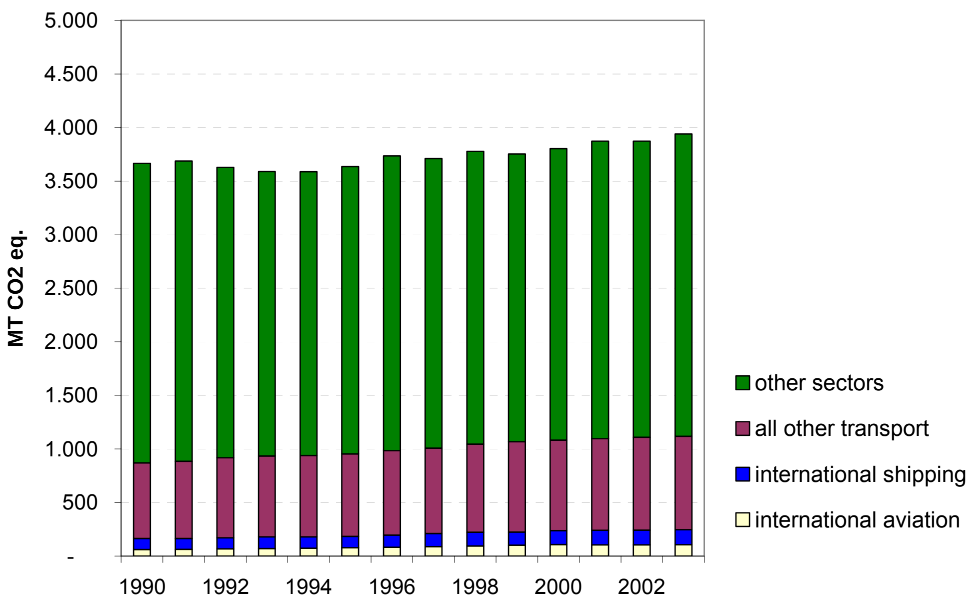
When CO_2 emissions are considered, the shares of maritime shipping and aviation are comparable (Figure 3, left), but if the climate effects of non-CO_2 emissions are taken into account (Figure 3, right) the share of aviation is much greater, and has increased significantly in recent years (Figure 4 and Figure 5). For maritime shipping non-CO_2 emissions could also play an important role, but have a reverse effect compared to aviation. The non-CO_2 emissions of maritime shipping may decrease the climate effects considerably, though the exact impact on the long term is currently unclear. Inland navigation is not reported separately, but is included under the maritime transport categories in the IPCC reporting used here.

Figure 3 2001 shares of Greenhouse gas emissions by mode, EU-15. Left: CO_2, right: taking into account the aviation climate impacts of contrails and NO_x emissions at high altitudes



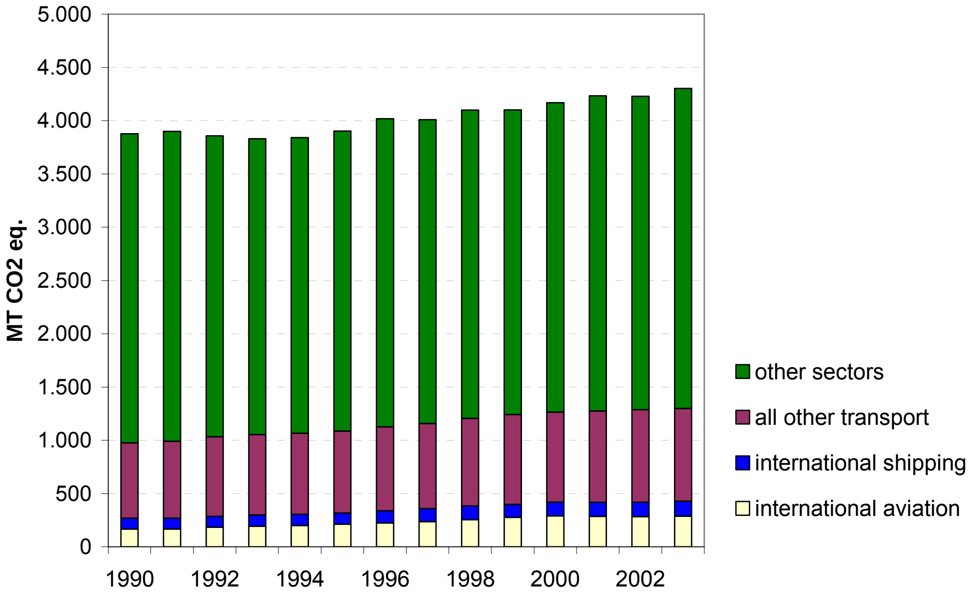
Note: Data are from EU-15, but indicative for all of Europe. Figure b estimates the shares taking into account the greater impact of aviation on climate change through aviation contrail NO_x emissions at high altitudes. The most likely value of a factor of 2.7 greater impact than that from the greenhouse gas emissions alone has been used here (see section 2.6). A similar approach could result in a substantial revision of the climate impact of maritime transport as well. Shares are calculated based on IPCC submissions which again are based on fuel sales. Emissions from inland navigation are partly included under the maritime transport categories. Data tables and meta data can be found in Annex A.4.

Figure 4 Trends in Greenhouse gas emissions in the EU-15, by sector



Note: Data are from EU-15, but indicative for all of Europe. Shares are calculated based on IPCC submissions which again are based on fuel sales. Emissions from inland navigation are partly included under the maritime transport categories.. Figures are in million tonnes of CO_2 equivalent, a measure including emissions of non-CO_2 greenhouse gases converted to CO_2 equivalent impact. 'Other sectors' refer to industry, households, etc, and excludes any impacts from land-use change.
Source: TERM 2005 02 EEA32 - Greenhouse gas emissions.

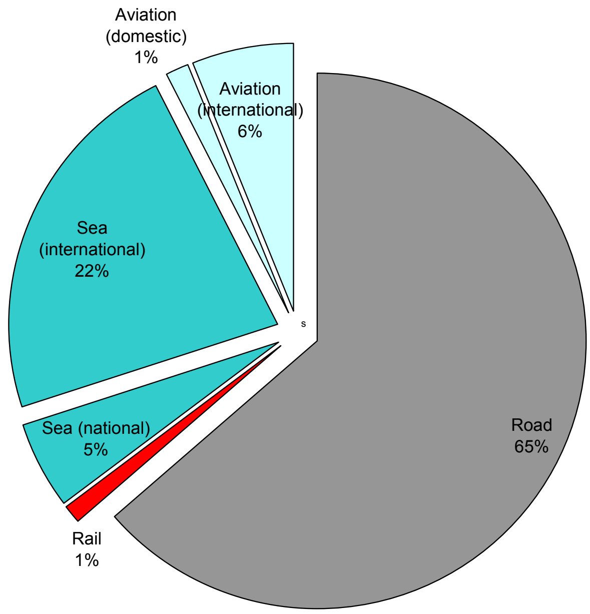
Figure 5 Trends in Greenhouse gas emissions in the EU-15, by sector adjusted for higher impact of aviation



The chart is similar to the one in the previous figure, except that for international aviation the CO_2 equivalent emissions are multiplied by a factor of 2.7 to account for the greater climate effect of aviation than that arising from the standard greenhouse gases (see text for discussion).
Source: TERM 2005 02 EEA32 - Greenhouse gas emissions.

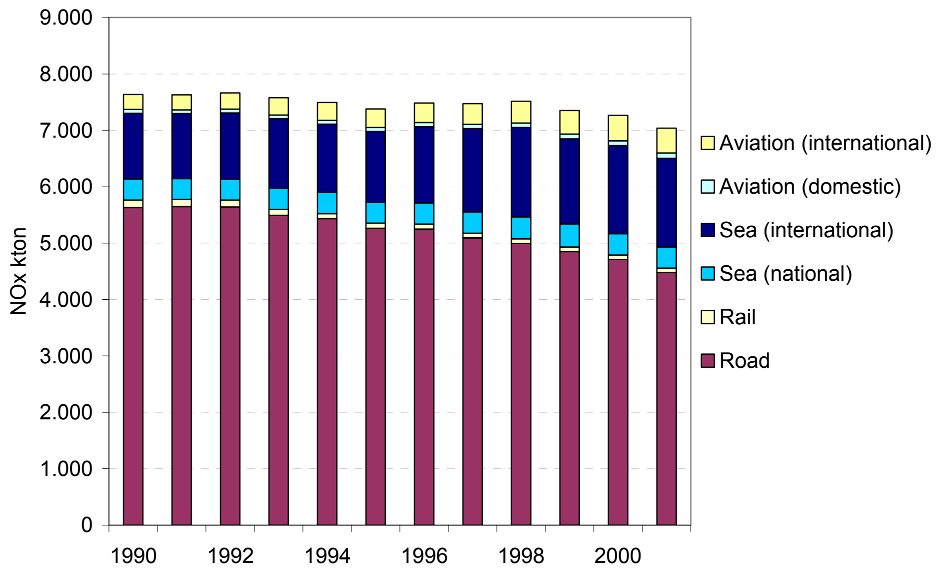
With NO_x emissions, maritime shipping has the largest share, followed by aviation and rail (see Figure 6), and the share of non-road modes in all transport NOx emissions is growing fast (Figure 7). It should be noted that for those emissions (air pollution) the location of emissions determines to a large extent the actual harmful impacts and should also be considered.

Figure 6 2001 shares of NO_X emissions by mode, EEA-25



Note: EEA-25 counts 25 European countries and is quite representative for Europe as a whole. Shares are calculated based on IPCC submissions which again are based on fuel sales. As a result, these emissions need not be confined to geographical Europe. Note that location of emissions also determines impacts on air quality See text for discussion. Emissions from inland navigation are partly included under the maritime transport categories. Data tables and meta data can be found in Annex A.

Figure 7 Trends in NO_x emissions in the EEA-25



Note: EEA-25 counts 25 European countries and is quite representative for Europe as a whole. Shares are calculated based on IPCC submissions which again are based on fuel sales. As a result, these emissions need not be confined to geographical Europe. Location of emissions also determines impacts on air quality -see text for discussion. Emissions from inland navigation are partly included under the maritime transport categories. Data tables and meta data can be found in Annex A.

2 Transport emissions policy and data

In European transport policy, focus is increasingly on non-road modes and modal shares. In this chapter, the Common Transport Policy is discussed (2.1), as well as existing methods for comparing transport modes (2.2) and assessing the effects of a modal shift (2.3). Also, currently set emission and fuel standards are shown for the different modes (2.4).

Next, the TRENDS results, that give a model for future modal shares and environmental impacts, are discussed (2.5).

In assessments of the environmental effects of transport, it is becoming increasingly clear that non-CO_2 climate effects may be very important, most notably for aviation and maritime shipping. An overview of these effects is given in paragraph 2.5.

This chapter concludes with a description of how to build emission inventories for transport in general (2.7) and a discussion of allocation principles for international modes (aviation, maritime shipping; 2.8).

In chapters 3 through 6, mode-specific issues will be discussed in detail.

2.1 Common Transport Policy

In 2001, the European Commission published the White paper on the Common Transport Policy (CTP): ‘European Transport Policy for 2010: Time to Decide’.

The White Paper signals some problem areas that should be solved by a common transport policy:
- Unequal growth in transport modes.
- Congestion on main roads, rail routes and airports.
- Harmful effects on environment and human health.

Together with the dependence on oil, these observations lead to a desire to decouple the effects of transport from economic growth, which is one of the pillars of the CTP. A better balance between modes is a central element, following the Gothenburg European Council.

With an integrated approach varying from pricing to revitalising alternative modes, the Commission attempts to shift the balance from road to rail and increase the market share of rail transport. The current share – and speed – of rail freight services is viewed as marginalization of this mode. The situation in the USA, a modern economy with a rail freight share of 40%, is referred to.

The CTP aims at a series of measures to solve existing problems, of which a few are listed here:

- Revitalising railways.
- Promoting transport by sea and inland waterways.
- Balancing growth in air transport and environment.
- Turning 'intermodality' into reality.
- Building Trans-European transport Network (TEN).
- Effective charging ('pricing') for transport.
- Research for clean, efficient transport.

The effective charging is targeting the internalization of external costs, such as the effects of emissions (fuel related) and the costs of infrastructure construction and maintenance. The White Paper expects that with proper pricing, rail will become more economically viable relative to road than is the case now. The growth in road transport so far would be partly enabled by the fact that the sector is not currently paying for the external costs incurred. An assessment of the White Paper by the Dutch environmental assessment agency (MNP, 2005) shows that this is not necessarily the case: in the Dutch situation, marginal cost charging for all modes would result in a modal shift toward road transport.

Focus of the effort to make transport cleaner and more efficient is specifically on road, maritime and air transport. Effective 'intermodality' is also viewed as one of the keys to make road freight transport less attractive. Joining up maritime, inland waterway and rail transport modes and increasing interoperability should receive attention according to the White Paper.

CTP Railway Packages
The first railway package allowed the regulated opening up of international goods transport, by separation of ownership and exploitation of tracks and third party access. It has applied since 15 March 2003. The measures of the second railway package that are approved by the Council of Ministers in 2004 improves safety and allows greater interoperability, as a result of a number of specific Directives and the setting up of the European Agency for Rail Safety and Interoperability. In the third railway package, the Commission is proposing to continue the reform of the railway sector by opening up international passenger services to competition within the European Union. It thus seeks to complete the integration of the European railway area and stimulate the rail mode. The Commission is also proposing to improve the rights of passengers using international services, establish a certification system for locomotive drivers and step up the quality of freight services.

Despite all efforts, there are no signs that the goal of the CTP of changing the modal split in favour of rail and water transport at the cost of road transport is being achieved. The modal shares of road transport are either constant (passenger transport) or growing (freight transport) (EEA, 2004).

2.2 Comparing transport modes

An important issue in transport policy is the comparison of emissions from different transport modes, particularly in relation to modal shift. In this section we discuss methods for comparing transport modes. This report does not include a comparison of emissions from different transport modes. For a direct comparison of modes different data would be necessary.

Many studies have been carried out to compare emissions of different transport modes. The first studies on this subject compared emissions of transport modes by top-down calculations, based on the total emissions and total transport volumes of whole transport modes. The next generation studies had a more sophisticated approach. By incorporating technical and logistical characteristics, differences within each transport mode were revealed.

The latest studies go even a step further and distinguish various market segments. Comparing modes in a specific segment of the transport market can be very different from comparisons in other market segments. For instance, under the umbrella of road transport we can find many types of transport, varying from small vans for urban deliveries with very low load factors, to trailer combinations up to 40 tons crossing the continent. Obviously, these different types of road transport compete on different markets, have different competitors, different load factors and different environmental performances. Therefore, a comparison of transport modes only makes sense for well-defined homogeneous market segments.

Another issue is the functional unit to refer emissions to. Such a unit is needed to relate the emissions to the performance or value of the transport achieved. The most commonly used unit is transport performance (tonne-km or person-km). Other options could be considered as well, such as the added value, but are more complicated and therefore have not been used yet. For passenger transport, the emissions per unit of travel time could also be a useful unit for comparing transport modes, since the total time budget of people is regarded relatively constant (commonly known as the *BREVER law*). However, no comparison based in this unit has been made until now.

Comparing the environmental impact of various transport modes, the entire effect of door-to-door delivery should be taken into account, and not merely the main transport mode. In many cases, such as a trip by aircraft or a container transport by rail or inland navigation, additional transport (often by lorry) will be necessary. Also the effect of detours may affect the results of a comparison. If the travel distance from A to B by one mode is much smaller than for another, the emissions to carry a certain load from A to B may be smaller although the emissions per tonne-kilometre are larger. Both additional transport at the ends of the transport chain and detours can result in additional emissions which should be included in the comparison.

Also, it is important which technology standard is used for the comparison. Is it best available technology, expected technology, current average mix? The

Ecotransit tool that is available on the web (www.ecotransit.org) gives energy use and emissions for a variety of freight transport modes. The user enters distance and weight and the results are calculated. The technologies that are used in the calculation should be taken into account when interpreting the results.

When the aim is to compare environmental effects, it is also important to take into account life-cycle effects in a similar fashion for all systems compared. This means, if electricity generation is included for electric trains, so should fossil fuel pre-combustion (such as refining) for cars. Also, one might want to distinguish where (and when) the emissions occur, as the resulting impacts may be different.

In any case, proper care should be taken in the interpretation of such comparisons. Several issues should be considered:
- Compare only modes that are actually competing and use characteristics for each mode that apply to the specific market which is investigated.
- Include all effects of a ‘door-to-door’ delivery (detours and additional transport steps at both ends of the chain).
- For any study, assumptions have to be made about the load factors of the various modes and this may influence the results significantly.
- Emissions of electricity generation vary significantly across countries and this may have an effect on the life cycles of all modes of transport.
- Include emissions from electricity production as well as refining in the case of fossil fuels; including the life-cycle emissions only for electricity would result in an unbalanced comparison.

2.3 Modal shift

Modal shift is not feasible in all cases. The different transport modes each have their own characteristics:
- Road is small-scale (30 tonne max.), fast and flexible.
- Air is small-scale (150 tonne max.), fast but less flexible.
- Rail and sea-shipping are large-scale (1,700 tonne max. for rail), long distance, slow and relatively inflexible.

Therefore, the goods that have a high value and that are perishable are commonly transported by air and road. Products that have lower values are transported by rail and ships. An ECMT analysis shows that the value of the goods that are transported varies greatly between the modes. An average road cargo is valued at 1,674 €/ton, compared with 924 €/ton for rail transport and 86 €/ton for inland waterway transport (ECMT, 2003). The prices reflect the different types of goods. Shipping and rail have a strong position in the bulk goods and container market, while air and road have a stronger position in end-products and high value products.

The modal shift targets of the CTP find their major argument in the difference in average environmental performance between different modes of transport. Rail transport and navigation are often regarded as more environmentally friendly than road transport. However, the environmental performance generally depends more on installed technology and logistical characteristics than on mode per se, particularly in freight transport (CE Delft, 2003a). Therefore, a shift from road to rail or water does not in all cases decrease the total environmental impact of transport.

To be able to predict the total environmental impact of a policy measure, it is insufficient to merely compare average emissions of transport modes. All types of effects that can occur and that directly or indirectly effect the environmental impact should be looked at:
- *Environmental efficiency effects* (such a changes in emission factors).
- *Logistical effects* (such a changes in load factors or detours).
- *Substitution effects* (modal shift, caused by changes in competitiveness).
- *Volume effects* (effects on the total transport volume).

Policy measures have different types of effects that can often be opposite. The total effect of a policy measure depends on all direct and indirect effects on the mode for which the policy measure applies, and on all other modes.
Specific measures aimed at modal shift, like building new rail infrastructure, may boost the transport volume of rail without much decreasing road transport volumes. In those cases, the net effect is higher transport volumes and higher total emissions (CE, 2003a). Because of these types of unintended side-effects, the net environmental impact of measures aimed at modal shift should always be monitored carefully.

2.4 Emission- and fuel standards

Since the eighties, emission standards have been set for road transport, mostly in EU legislation. In this decade, emission standards are being introduced for non-road modes. Also, the sulphur content of fuels is increasingly subject to standards. Reducing the sulphur content of fuels will have a large impact on exhaust emissions as it will enable the introduction of more sophisticated after-treatment systems. Exhaust of sulphur compounds furthermore contribute to acidification of the environments as well as the formation of particles.

In the non-road mobile machinery (NNRM) directive (2004/26/EC), emission standards (HC, CO, NO_x and PM_{10}) and deadlines are set for rail and inland navigation, distinguishing between e.g. types and engine sizes. The directive introduces progressively lower emission standards until 2015. For rail and inland navigation, the first standards are introduced in 2006 (stage IIIA). The NNRM standards apply to ‘non-road steady cycle’ measurements (rail) and ISO 8178-4:2002 [E] test cycle (inland navigation), respectively.

Earlier standards for rail (diesel engines) were set by the UIC (Table 9). These standards applied to the ISO 8178/F test cycle. For inland navigation, the Central Commission for Navigation on the Rhine (CCNR) earlier set standards starting from 2002.

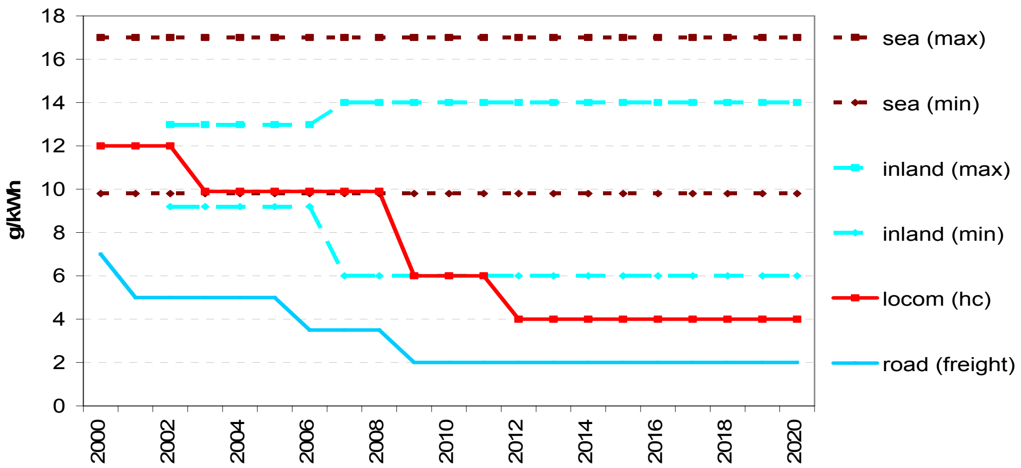
For maritime transport, an emission standard for NO_x is set (varying with engine speed in rpm) in the MARPOL convention (IMO). Although the emission standard was ratified only in 2005, it applies to all engines constructed after 2000. Engine emissions are tested on various ISO 8178 cycles (exact cycle depending on engine type). Engines are tested with distillate diesel fuels.

All in all, this means that emission standards do not offer a direct comparison of modes in terms of environmental effect. First, the specific test cycle is of influence. Second, the standards are typically given per unit of energy consumed, in which case the efficiency of the mode is not taken into account. Third, the same standard may be very strict for one mode but easy to achieve for another mode, due to technological differences.

Therefore, we limit the discussion here to diesel engines and freight transport, with standards roughly comparable as they are all given in g/kWh. In Figure 8 (NO_x) and Figure 9 (PM), an overview is presented of the emissions standards coming into force until 2015. For comparison, the standards for road freight transport (since 2000) are shown as well. The standards are given in gram per kWh (mechanical energy delivered by the engine).

For NO_x, the standards for maritime transport are clearly higher than for other modes of transport. Standards for road transport will remain stricter than the other modes for quite some time to come.

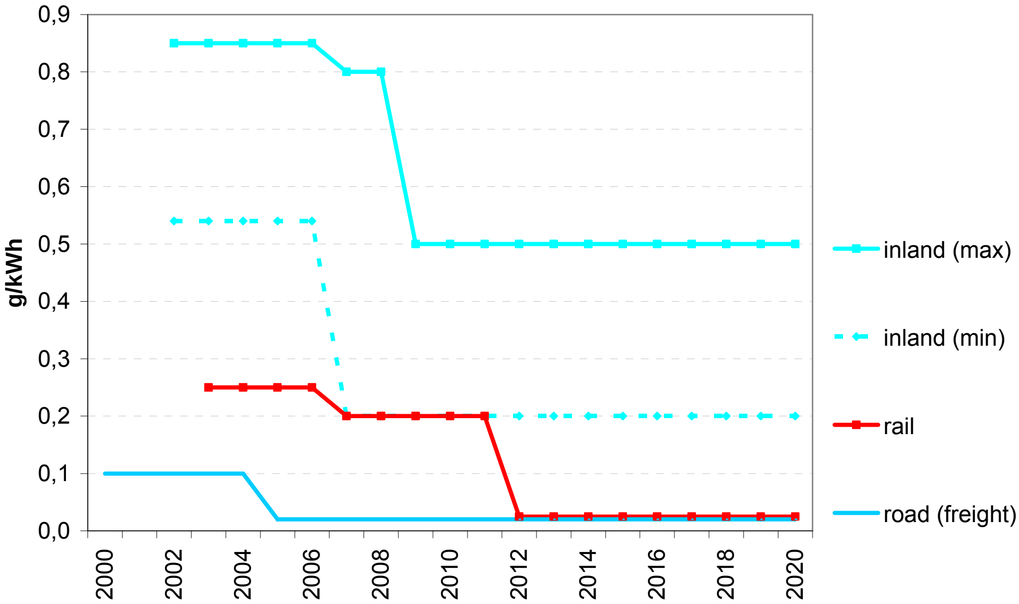
Figure 8 Standards for NO_x emissions for diesel vehicles ("hc" indicates combined standard for hc+NO_x emissions). For each mode, both the highest and lowest standards are shown. In practice, those different standards apply to e.g. different power classes for the same mode.



Standards data are taken from 2004/26/EC, Marpol Annex VI, CCNR.

For particulate emissions, no standards exists for sea-going engines. For rail, the standard for PM coincides with that for road freight from 2012. Standards for inland navigation vessels are considerably higher.

Figure 9 Standards for PM emissions for diesel vehicles. For each mode, both the highest and lowest standards are shown. In practice, those different standards apply to e.g. different power classes for the same mode.



Standards data are taken from 2004/26/EC, Marpol Annex VI, CCNR.

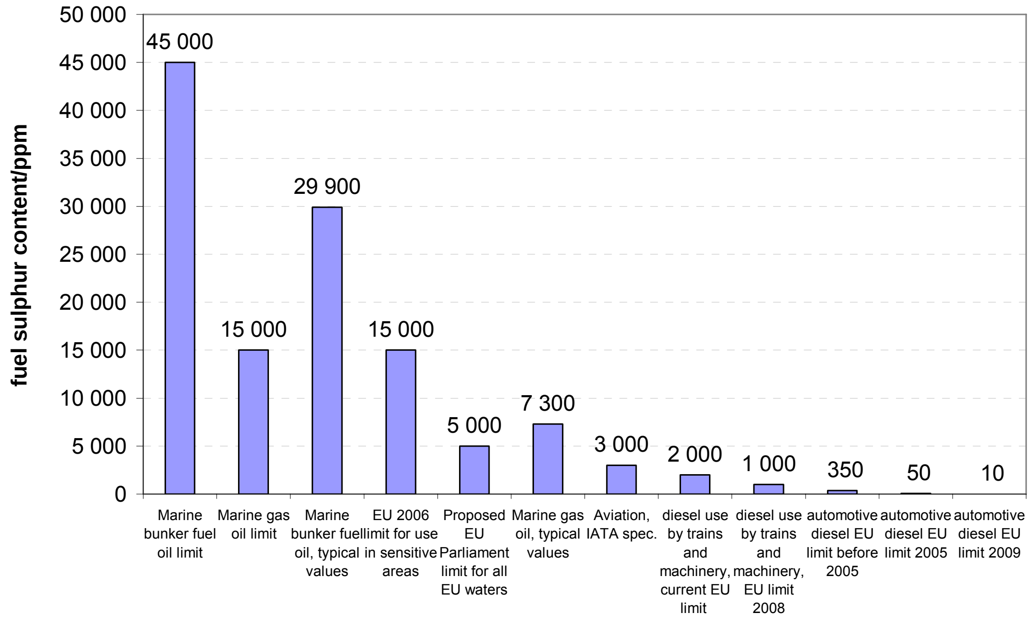
More details on the standards per transport mode are given in the respective chapters. It should be noted that these emission standards are set per kWh. This cannot be directly translated to the actual effects of the sector and its efficiency, in terms of, for instance, tonne-km. It is fair to say, however, that for non-road modes standards have been set much later than for road transport. Also, standards generally take longer to show actual effects on fleet emissions: non-road modes typically deal with smaller markets and fewer vehicles with a much slower turn-over over the fleet than road does. Additional policy is necessary to achieve environmental improvement in the short term.

Reduction of emissions of sulphur dioxide is achieved through reducing the sulphur content of fuels rather than setting emission standards. As mentioned before, reducing the sulphur content of fuels has additional benefits (apart from reducing SO_2 emissions) as it enables more sophisticated after-treatment systems and influences the formation of particles.

Table 1 Fuel sulphur content standards

Ocean-going ships	4.5%	MARPOL annex VI
	1.5% or 6 g/kWh	MARPOL (emission control areas)
	0.5%	Proposed EU parliament (EU waters)
	0.1%	EU 2010 (ships at berth in ports, 2005/33/EC)
Inland vessels	0.1%	EU 2010 (2005/33/EC)
	0.5%	EU 2010 (sea-going vessels on heavy fuel oil, 2005/33/EC)
Airplanes	0.3%	IATA specification
Trains	0.2%	Current EU
	0.1%	EU 2006
Automotive	50 ppm (0,005%)	Current EU
	10 ppm (0,001%)	EU 2009

Figure 10 Fuel sulphur content for different applications and sectors



Sources: Maximum permitted sulphur content for marine fuels are from IMO (1997). Typical values for marine fuels are from EMEP/CORINAIR (1996). Proposed maritime sulphur limits are from ENDS Daily (2005). Current and future EU limits are from EU Directives 99/32/EC, 98/70/EC and European Commission, 2005.

It is clear that there is a huge range in sulphur content in fuels. For 2009, for road transport the standard will be 10 ppm, a factor 100 or more lower than currently foreseen for the other modes.

2.5 Forecasts modal shares

For policy development, not only current modal shares and environmental effects are of interest, but also (model) forecasts of shares and emissions. Expected trends in market demand could lead to changes in environmental performance of the transport sector as a whole.
The TRENDS project, funded by the European Commission (DG TREN) and managed by Eurostat, was aimed at producing environmental pressure indicators of transport (main report dates from 2002). The data cover 1970 to 2020, where the data after 1995 (2001 for aviation) represent model forecasts. Air freight is not included.

The projected trends are based on available knowledge in approximately 2001. That means that trends in demand, engine efficiency and emissions standards are included only in as far as known in 2001 and that several emissions standards for the next decade (see 2.4) could not be taken into account.

Table 2 shows the TRENDS forecast of emissions and transport volumes for the different modes. Table 3 shows the shares in volume and emissions. In passenger transport, the share of air is clearly increasing, while the share of road decreases. All modes grow in absolute terms, but air grows most significantly. The expected growth for the different emissions is indicative of expected improvements in energy efficiency and/or reductions in polluting emissions.

Table 2 **Growth** in demand (pkm / tkm) and emissions from TRENDS (2003a) (EU15)

		Demand	CO_2	NO_x	PM
Passengers	Air	105.0%	39.7%	44.8%	n/a
	Sea	38.3%	28.8%	28.8%	28.7%
	Rail	25.5%	29.3%	14.9%	21.4%
	Road	23.5%	23.1%	-71.8%	-50.4%
	Total	*43.2%*	*27.9%*	*-40.6%*	*-38.8%*
Freight	Inland	15.0%	15.0%	15.0%	15.0%
	Sea	41.7%	44.8%	44.8%	44.9%
	Rail	8.2%	5.9%	-3.3%	-1.9%
	Road	48.2%	47.1%	-54.0%	-68.6%
	Total	*42.2%*	*45.7%*	*4.9%*	*2.0%*

Inland navigation, for example, is assumed not to improve its performance at all, as all growth rates are 15%. Also, for maritime transport, emission factors are not assumed to change, although curiously the average CO_2 emissions per unit of transport volume is improving for passenger transport and getting slightly lower for freight transport. The CO_2 emissions from rail passenger grow faster than the transport volume, in this forecast, probably because TRENDS calculates with an increasing share of high speed trains.

Table 3 **Share** in demand (pkm / tkm) and emissions from TRENDS (2003a) (EU15)

		Demand 2000	Demand 2020	CO_2 2000	NO_x 2000	PM 2000
Passengers	Air	23.8%	34.1%	28.0%	21.9%	
	Sea	1.3%	1.2%	0.5%	2.7%	7.2%
	Rail	5.5%	4.8%	2.1%	3.5%	8.2%
	Road	69.4%	59.9%	69.5%	71.9%	84.6%
Freight	Inland	0.8%	0.7%	0.8%	1.1%	0.8%
	Sea	79.1%	78.8%	32.4%	58.6%	61.4%
	Rail	1.6%	1.2%	1.1%	0.6%	0.5%
	Road	18.5%	19.3%	65.7%	39.7%	37.4%

The results of the TRENDS project give rise to a lot of discussion, with various stakeholders questioning the trends both in volume and in emission factors. The share of aviation for 2000, for instance, is much higher than the share presented for 2002 in the TERM fact sheets (**Fout! Verwijzingsbron niet gevonden.**). As was explained before, some of the assumptions on those trends are not up-to-date.

The underlying methodology appears to have inconsistencies, with e.g. emission factors for electric trains calculated over the full life-cycle of electricity generation but factors for diesel including only combustion. Also, it seems that electric trains are assumed to use the national electricity mix (of the country of origin?) which is not necessarily realistic (see further discussion in Chapter 4).

It should be noted that the original aim of the project was not to make forecasts, but to provide information about potential environmental consequences of modal shifts.

2.6 Non-CO_2 climate effects

It is becoming increasingly clear that in terms of greenhouse impacts of transport, CO_2 is not the only emission of concern. To compare modes properly, direct and indirect climate impact of non-CO_2 emissions should also be taken into account. In this, the following main mechanisms have been identified. They are still subject to large uncertainties when it comes to quantifying the effects.

Climate effects of emissions of NO_x

At low altitudes, up to the lower stratosphere (intercontinental subsonic aviation) NO_x contributes to climate change in two ways. One is through a complex process leading to the formation of ozone, which has positive radiative forcing, especially at the higher altitudes. The other is through its role in removal of CH_4, which results in a negative climate forcing. In the higher stratosphere, only important for supersonic air traffic, NO_x causes ozone depletion, with resulting negative radiative forcing.

These effects are mainly important for maritime shipping, inland navigation and aviation.

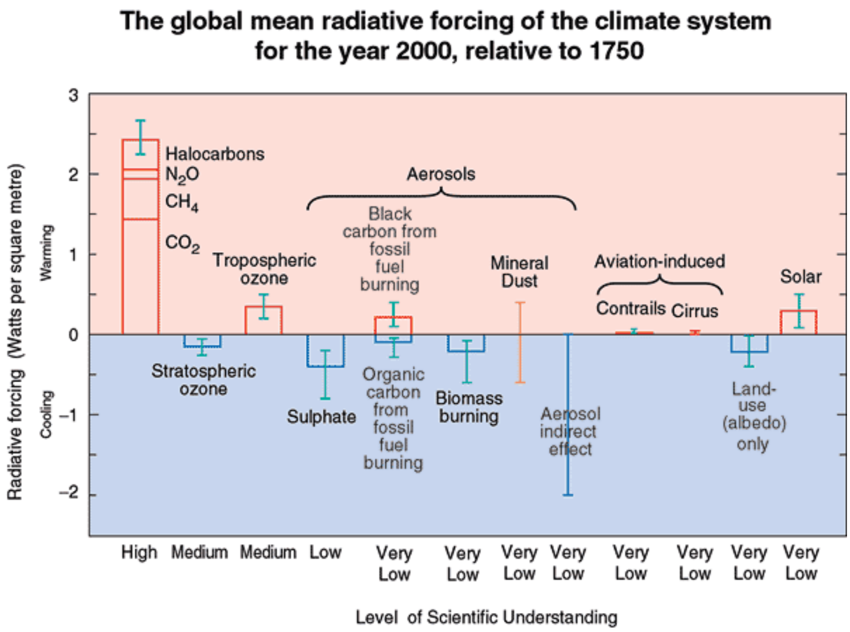
Climate effects of emissions of SO_2, soot and H_2O
The emission of SO_2 leads to the formation of sulphate aerosols in the atmosphere. These aerosols have negative (direct) radiative forcing (Figure 8). Moreover, all aerosols are thought to have negative (indirect) radiative forcing due to their role in cloud formation, but this is uncertain. This potential negative (indirect) effect also holds for soot as an aerosol, but the direct radiative forcing of soot is positive.

At higher altitudes, i.e. aviation, the emission of sulphur oxides may cause ozone depletion and thus also result in negative forcing. Besides, the emission of H_2O at high altitudes may cause ozone depletion. High-altitude emissions of H_2O by aircraft also have an important positive forcing effect, as the dwelling time of H_2O in the atmosphere is much longer in stratospheric layers than at lower altitudes.

The effects of SO_2 are important for shipping, with relatively high sulphur levels in fuel. The other effects are most important at high altitudes and thus for aviation.

For maritime shipping, there is also a greenhouse effect from non-engine emissions of refrigerant gases. These are discussed in 5.3.3 in the chapter on sea transport.

Figure 11 IPCC estimates for factors contributing to change in radiative forcing since 1750



Source: (IPCC, 2001).

Aviation-specific effects
The formation of contrails by jet engines takes place when ambient humidity is high. The sulphur content of the fuel can influence the process, however, as does the water in the exhaust fumes. Contrails may evolve into persistent cirrus, with additional climate effect. Contrails and cirrus are considered to have positive

radiative forcing (IPPC, 1999), although indirect or total effects might be negative, as is currently noted in the discussion about global dimming[1] (see also effects aerosols, Figure 11).

The effects are very uncertain in a quantitative sense. In all, the IPPC recommends a possible use of a factor of 2.7 with respect to the CO_2 emissions to account for all climate effects of aviation. However, cirrus formation is not included in this factor, since the climate impact of cirrus formation is still very uncertain. The factor 2.7 is a rough estimate and could be anywhere between 1 and 10 or an even wider range (IPPC, 1999).

2.7 Building an emission inventory

For several areas of policy making and monitoring, good insight into total emissions of economic sectors is needed. This holds for traffic and transport as well. This sector is complex when it comes to determining total emissions, though, primarily because activities are spread out and mobile, as opposed to large industrial sectors, where activity is limited to a number of large, stationary sources. An additional complicating factor of that mobile nature is that allocation is not straightforward for international transport; this is discussed in 2.8.

In this paragraph, we discuss the process of building an emission inventory for transport modes in a general sense. There are two main purposes of emission inventories:
1 General monitoring of emissions, for instance per mode or at even lower aggregation, to support policy development.
2 Application in specific policy instruments, such as emission trading (currently for CO_2).

Important in both cases is that the method applied is able to reflect the actual changes – effectiveness of measures – in what is chosen to be the relevant indicator (fuel consumption, emissions, etc.).

To construct an emission inventory for a particular mode, two extreme approaches may be distinguished, with actual methods often somewhere in the middle:
- ‘Top down’ (simple or fuel based) where energy consumption is used as a starting point and an average emission factor (in gram per MJ) applied.
- “Bottom up” (detailed or traffic (performance) based) where actual movements are monitored for each engine / fuel type, et cetera, with many different specific emission factors.

The preferred approach depends on the type of emission. Emissions of substances that result directly from the combustion of fuels can be estimated directly using a top-down approach. These substances (CO_2 and SO_2) depend

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[1] Global dimming is a name used for the phenomenon that air pollution causes global cooling by blocking some of the incoming sunlight. As air pollution is currently decreasing, this may actually speed up global warming.

directly on the type of fuel consumed and the amount of fuel consumed. For these emissions, bottom-up calculations should only be used when reliable statistics of fuel consumption are not available. This may for example be the case in marine shipping.
Other emitted substances are not a direct result of the combustion of fuels, but are formed in the combustion process. Incomplete oxidation may result in emissions of CO and PM. High temperatures and pressures in the combustion chamber may enhance the formation of NO and NO_2 (collectively known as NO_x). For these emissions, a top-down approach will not yield reliable inventories. Rather, a bottom up approach should be used.

In the bottom up approach, the average emission factors for fuels, in terms of gram per MJ, some details about actual technology, load factors and other factors influencing the emissions should ideally be taken into account. This means that data on the average fuel mix and technology mix have to be known. To calculate these averages properly, the actual transport volume for which each fuel and engine type is used has to be known. In the extreme case where all details are actually known, the 'top down' is the same as the 'bottom up' approach. In practice, the fuel mix may be known, but the technology mix (i.e. weighted by transport volume) is unlikely to be known.

A last factor influencing the emission factor is the way they have been derived: either from test cycles or from emission measurements on real life vehicle usage. The second method is preferable since real emissions can be very different from real life emissions.

2.8 Allocation of emissions of international transport

Emission inventories of international transport cannot be made unless the emissions are unequivocally allocated to states or regions. For example, consider a SAS plane that flies from Copenhagen to Madrid, crossing the airspace of Germany, the Netherlands, the UK, and France underway. It has taken in fuel in Copenhagen. Its passengers are from several Nordic countries and from Spain, several of whom will continue their journey towards Latin America. The plane carries cargo from the Far East. To which country should the emissions be allocated? To the countries that participate in SAS? To the country of departure, the country where the fuel is sold, the countries where the substances are actually emitted? To the country of destination of the plane, or of the passengers and cargo?

Currently, most countries use the (revised) 1996 IPCC guidelines to separate domestic/international emissions and these emissions are generally disaggregated before the calculation is made. For some Member States, the geographical area assumed for domestic emissions include islands, overseas territories or national territories outside boundaries of the main territory and geographical areas included can be different under different reporting regimes.

There is a considerable body of literature on allocation options, their advantages and disadvantages and their effects on emission inventories (UNFCCC, 1997; Owen and Lee, 2005a and b; Lee, 2005; Entec, 2005). Below, we will show the most prominent options studies and briefly outline the direction of the international debate on allocation.

Most studies either focus on air transport or on maritime shipping. The analyses for air transport predominantly start from the eight possible options that the ICAO considered in 1996 to allocate emissions of greenhouse gasses to states. These are:

- Option 1—No allocation.
- Option 2—Allocation of global bunker sales and associated emissions to parties in proportion to their national emissions.
- Option 3—Allocation according to the country where the bunker fuel is sold.
- Option 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.
- Option 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.
- Option 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.
- Option 7—Allocation according to the country of origin of passengers or owner of cargo.
- Option 8—Allocation to a party of all emissions generated in its national space.

In reviewing the options listed above, SBSTA (a subsidiary body of the UNFCCC) recommended that 1, 3, 4, 5 and 6 should form the basis of further work (UNFCCC, 1997). The other options were considered unfair or unviable for the allocation of greenhouse gas emissions to states. Of the recommended options, option 1 will not result in the inclusion of international transport in national emission inventories. Recent work on the inclusion of aviation in the EU Emission Trading System (ETS) has concluded that option 5 (allocation to the countries of departure and arrival) shows the best possibilities for emission trading (CE, OEKO INSTITUT, CATE, 2005).

The analyses for maritime shipping use slightly different allocation options, such as the options studies by Entec (2005). These are:

a Assignment according to Location of Emissions.
b Assignment according to Flag of Ship.
c Assignment according to Industry Fuel Sales Estimates.
d Assignment according to Reported Fuel Consumption.
e Assignment according to Freight Tonnes Loaded.
f Assignment in proportion to National Emissions; and
g Assignment according to Country of Departure/Destination.

The choice for allocation has a major impact on emission inventories for countries. Based on a multi criteria assessment, Entec (2005) concludes that option A is most fair and viable, but recommends studying all the other options further, except for B and F. Option B is open for evasion, while option F suffers from the fact that countries will be assigned with emissions which they cannot control in any way (for example, in this option, also land-locked countries would be assigned emissions from sea shipping).

It is beyond the scope of this report to analyse the consequences of the different allocation options in detail.

3 Aviation

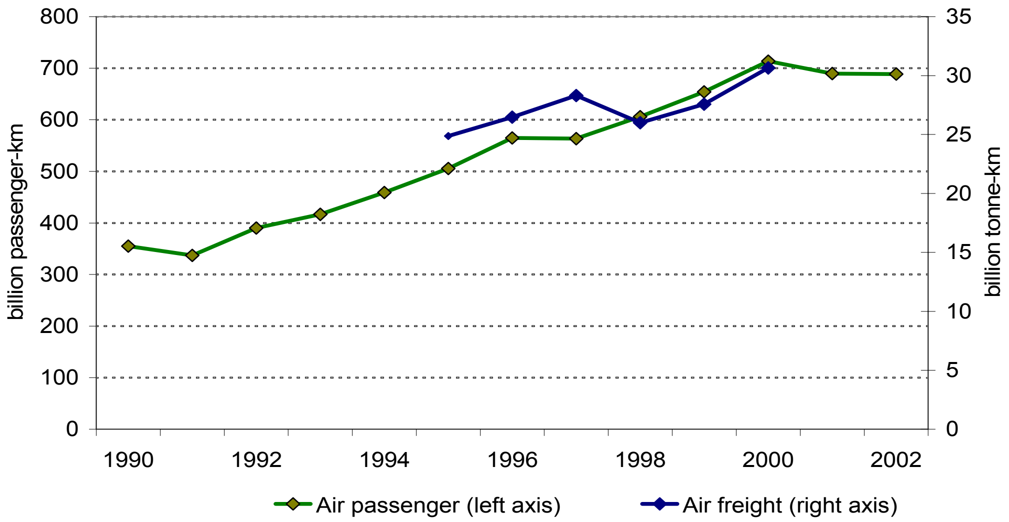
3.1 Introduction

Aviation enables us to travel long distances and cross geographical barriers with relative ease and speed. With the introduction of low cost carriers, this mode is becoming more and more popular to travel to holiday destinations. In freight traffic, the share of aviation is relatively low, because the speed advantage only balances the relatively high prices for transport in specific cases, such as transport of perishable goods (e.g. flowers) over long distances. This chapter gives an overview of the key figures on transport volumes and prices of aviation (section 3.2), the environmental performance (3.3 and 3.4) and the developments in emission reduction measures and policies (section 3.5 and 3.6). Section 3.7 provides an overview of emission inventories, which are essential for some of the emission reduction policies.

3.2 Key figures

The transport volume of aviation has increased substantially since the beginning of the nineties. Commercial air transport markets were significantly impacted by the events of September 11, 2001 and subsequent recovery has been slowed by ongoing security issues resulting from the wars in Afghanistan and Iraq and by SARS in Asia (see also Figure 12). It is expected that the impact from these developments will only be temporary. Growth is now beginning to return globally and in 2004 overall passenger traffic levels were only marginally below the levels experienced in 2000. Global passenger air travel is projected to grow by about 4-5% per year in the coming two decades (ICAO, 2004a). For Europe, (Eurocontrol, 2004) forecasts an annual growth in Europe of 3% in number of flights in the business as usual scenario. The growth in passenger-km will be different from this figure, as distance travelled also tends to grow.

Figure 12 Trends in air transport volumes in EEA-23



Note: Includes all transport by European carriers in the EEA-23 (a group including most European countries). Information for non-European air carriers is not available. All passenger-km performed on international flights with origin or destination in an EEA-23 country are included. Data tables and meta data can be found in Annex A.2.

Source: TERM 12 - passenger transport demand (forthcoming in 2005).

As was shown in section 1.4 aviation is the largest non-road passenger mode. Its share in greenhouse gas emissions is relatively large. Table 4 gives a summary of these figures. Account should also be taken of the non-CO_2 climate impact of aviation, due to NO_x emissions and contrail formation (see 2.6). The total climate impact of aviation were estimated by IPPC (1999) to be 2 to 4 times the effect of CO_2 emissions alone. Using the point estimate of 2.7, the total climate impact of aviation is then estimated at being comparable to the impact of 32% of total GHG emissions.

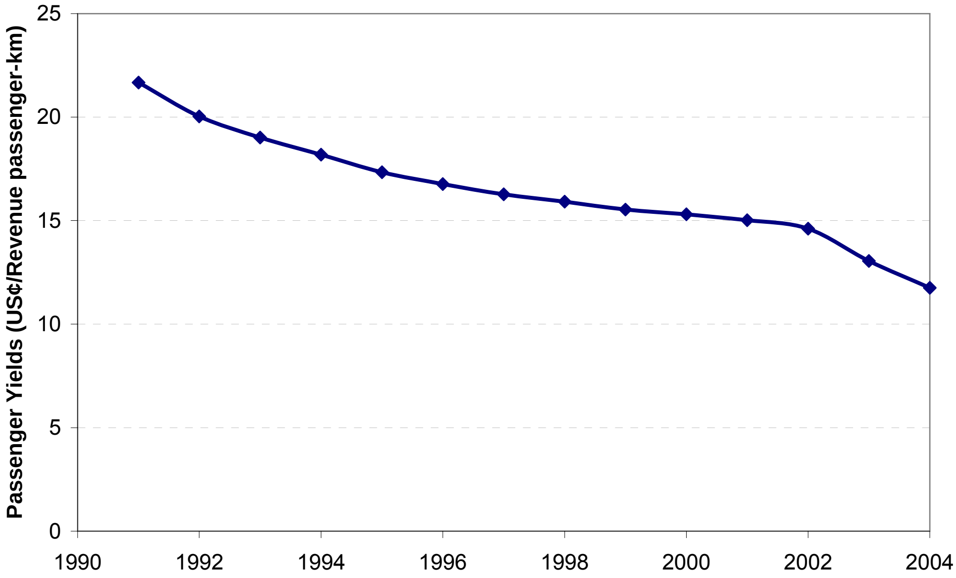
Table 4 Shares of aviation in transport volumes and transport emissions in the EU

Passenger transport volume (pass.-km)	Freight transport volume (tonne-km)	Greenhouse gas emissions	NO_X emissions
11.8%	< 1%	12%	8%

Shares are relative to the whole transport sector (including international aviation and shipping). Coverage varies but is representative of Europe as a whole - see data annex A for explanation on methodology.

One of the factors that has stimulated the rapid growth of air transport is the steady reduction in ticket prices. In particular in the second half of the nineties, and more pronouncedly after 11 September 2001, competition between airlines has intensified. An important factor in this is the rise of low cost carriers that offer basic services -mostly from regional airports- at a relatively low price. The declining trend in ticket prices is reflected in the yields of European air carriers (Figure 13).

Figure 13 Trend in yields for European air carriers



Note: Yields are revenues per passenger-km and the yields give an indication of how much prices of air travel have declined. In spite of this, the price for a specific ticket has often not declined, as Eurostat's price indexes reveal. These indexes do not take account of the shift in the travel market towards low cost carriers and further destinations. Figures are 'real' prices, thus adjusted for inflation and exchange rate fluctuations. Coverage: all European carriers for all destinations.

Source: AEA, 2004 (published annually, coverage varies from year to year).

3.3 Environmental performance of the aviation sector

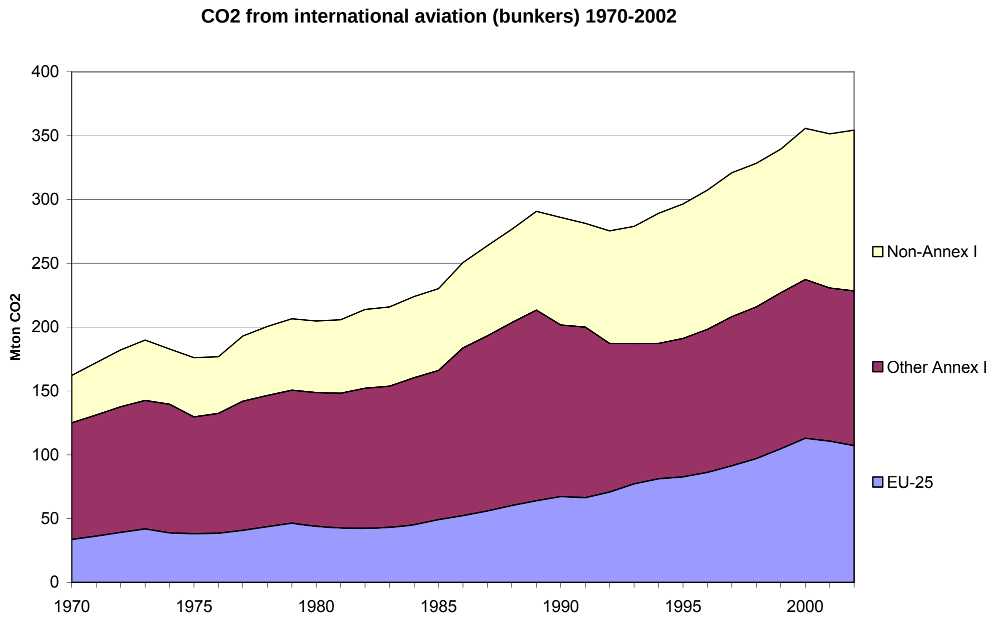
This section gives an overview of the CO_2 emissions from air traffic (3.3.1) and of the emissions of pollutants and noise (both in 3.3.2).

A particularity of aviation is that a substantial part of the movements take place in international airspace. This has been an important impediment for allocation of the associated emissions to specific nations. As most emission inventories (see also 3.7) and policies are nation based, this means that a large fraction of the environmental impacts may "escape" attention. It is therefore important to address also emissions from international aviation, apart from the emissions of domestic aviation that in fact are being allocated to the nation concerned.

3.3.1 CO_2 emissions

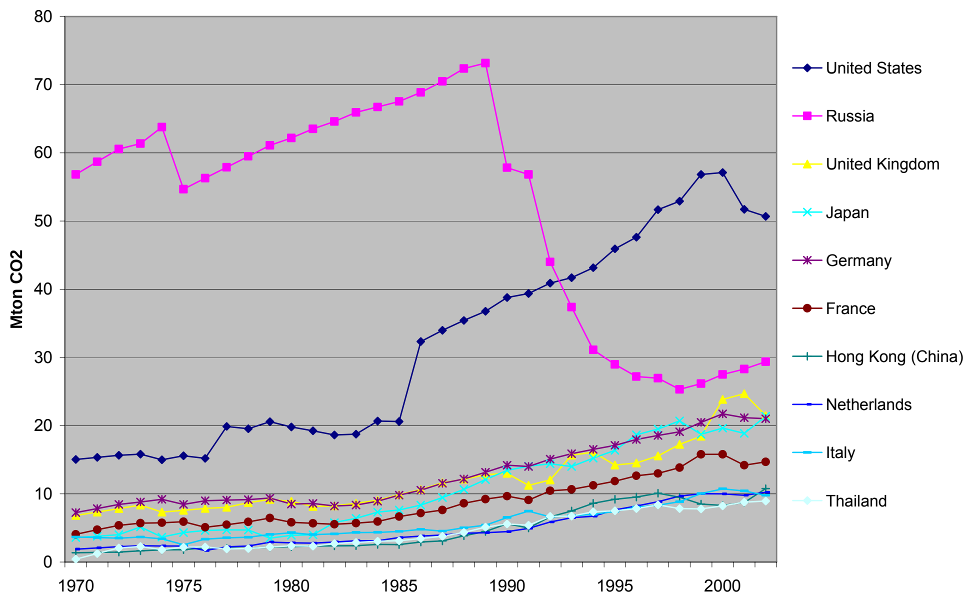
In the past decades total aviation emissions have increased, because increased demand for air transport has outpaced the reductions in specific emissions from the improvements in engine and aircraft technology and in the air traffic control system. Figure 14 summarizes this for global CO_2 emissions, based on the sales of bunker fuels.

Figure 14 Trends in global CO_2 emissions from international aviation, 1970-2002



Figures are based on bunker fuel sales and calculated according to the 1996 IPCC guidelines and provide a reliable rough estimate. Broadly, Annex I includes the 'industrialized countries' and economies in transition.
Source: IEA, 2004a.

Figure 15 Trends in international aviation CO_2 emissions of Top-10 countries, 1990-2002



Figures are based on bunker fuel sales and calculated according to the 1996 IPCC guidelines and provide a reliable rough estimate.
Source: IEA, 2004a.

Since 1990 the amount of international aviation fuel sold by Annex I countries[2] has increased by about 17%. The USA, the world's number 1 with a share of about 14% of global fuel consumption (2002, international traffic only 30% including domestic??), shows an increase of about 30%, but the amount sold by Russia, the world's number 2 with an 8% share in 2002, has decreased by one third since 1991. Overall, the group of EU-25 countries shows an increase of about 60% since 1990. Moreover, in the period 1990-2002, sales by non-Annex-I countries increased by about 40%. Sales by Hong Kong, Thailand[3], Singapore, Mexico and the mainland of the People's Republic of China in 2002 were double or triple the 1990 level (Figure 15).

Table 5 reviews CO_2 emissions from international bunker fuels for the 25 EU Member States.

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2 Annex I countries as listed in UNFCCC (broadly: 'industrialized countries' plus Turkey) include OECD-24 and EIT (Economies In Transition, which are the former USSR countries and Eastern European countries).

3 The importance in bunker fuel sales of countries such as Thailand is mainly due to transport of foreign visitors and transit passengers.

Table 5 CO_2 emissions from bunker fuels sales to international aviation in EU Member States (EU-25)

	CO_2 emissions from international aviation	International share in national total aviation emissions	Difference, 1990-2002, in CO_2 emissions from international aviation	Total national CO_2 emissions[4]	Importance of international aviation compared to total national CO_2 emissions
	Sales 2002	Sales 2002			
	[Mt]	[%]	[%]	[Mt]	[%]
Austria	1.5	93%	80%	66.0	2.3%
Belgium	3.8	99%	30%	134.4	2.8%
Cyprus	1.0	100%	28%	6.8	14.0%
Czech Republic	0.5	82%	-23%	114.9	0.5%
Germany	21.0	98%	48%	844.6	2.5%
Denmark	2.1	95%	17%	54.0	3.9%
Estonia	0.1	100%		14.7	0.4%
Spain	8.2	62%	137%	320.2	2.6%
Finland	1.1	70%	6%	65.1	1.7%
France	14.7	73%	52%	380.0	3.9%
United Kingdom	21.5	67%	65%	526.3	4.1%
Greece	2.3	66%	-4%	99.1	2.4%
Hungary	0.6	100%	26%	55.5	1.2%
Ireland	2.3	95%	113%	42.8	5.3%
Italy	9.8	97%	50%	442.4	2.2%
Lithuania	0.1	87%		12.4	0.7%
Luxembourg	1.2	100%	185%	9.3	12.4%
Latvia	0.1	100%		7.7	1.1%
Malta	0.2	100%	10%	2.6	9.3%
Netherlands	10.2	98%	130%	223.7	4.6%
Poland	1.3	100%	109%	283.8	0.5%
Portugal	1.8	80%	19%	64.1	2.9%
Sweden	1.8	72%	60%	53.3	3.3%
Slovenia	0.1	97%	4%	15.2	0.6%
Slovak Republic	0.1	100%		37.9	0.4%
EU total	*107.4*	*81%*	59%	*3876.3*	*2.8%*

Source: RIVM, 2004 data based on IEA (2004a).

In 2002 CO_2 emissions from international aviation were as high as 2.8% of the total national CO_2 emissions of the EU-25[5]. With the exceptions of Cyprus, Malta and Luxembourg, the associated emissions from bunker fuels sold were below 5% of total national CO_2 emissions for most EU Member States. A second point to be noted from the table is that CO_2 emissions from international aviation have increased by over 100% since 1990 for 5 EU countries (Spain, Poland, Ireland, Luxembourg, the Netherlands), while other countries show much more modest growth rates or even a decrease.

4 Excluding international aviation and maritime transport (i.e. cf. UNFCCC national total).

5 Taking account of the non-CO_2 impacts of aviation, the climate impact of international aviation is roughly comparable to the impact of 7.5% of the total national CO_2 emissions of the EU-25.

In addition to CO_2 also emissions of NO_x, soot, water vapour and the resulting contrails and cirrus clouds affect global warming (see 2.6). However, as the IPCC report on aviation and the global atmosphere (IPCC, 1999) indicates, the effects and mechanisms are currently not fully understood. Although progress in scientific understanding has been achieved since then, still not all effects are fully understood. Addressing the non-CO_2 impacts in mitigation policies is not straightforward for all impacts (see also section 3.5.1).

Without policy intervention it is expected that the unsustainable trend in aviation emissions will continue in the coming decades. Based on projections of demand growth, despite expected improvement in fuel efficiency of 1-2% per year, CO_2 emissions from global civil aviation are still expected to increase by 109% in the period 2002-2025 (AERO2K, 2004).

This growth is incompatible with strict long-term climate emission reduction targets. For 2050, a reduction of EU-25 greenhouse gas emissions by 60 % is a commonly stated ambition that is believed to be necessary to avoid serious climate change. Unabated growth of the aviation sector will in that case result in aviation accounting for 39 % of the total EU25 carbon budget. When taking into account the factor of 2.7 (see 2.6), aviation alone will cause a much larger greenhouse impact still (Tyndall, 2005).

3.3.2 Pollutant emissions and noise

Apart from the global climate impacts of aviation, air transport also poses local problems. The most important of these are exposure to noise and air pollution, especially in the vicinity of airports.

Being directly observable, noise nuisance has been recognized as a problem for some time now, and hence abatement measures are relatively well developed. The most important ones are:
- Noise standards by ICAO that led to improvements to the airframe/engine. These standards also formed the basis for the phasing out of so-called chapter 2 aircraft.
- Regulations for flights (e.g. quotas) and flight procedures (e.g. the continuous descent approach) during night time.
- Noise-based (sur)charges at airports that give an incentive to use quiet aircraft. At many airports the revenues of this charge are used to finance noise insulation and relocation programmes for houses in the vicinity of airports.

Polluting emissions at airports are increasingly in the spot lights, in part due to the EU air quality directive. In many cases airport operations or future developments (such as at Heathrow) are bound by air quality limits. At many airports this has led to emissions reduction programmes. In most cases these programs focus on the fixed installations or on the vehicles used for ground support. In some case however, incentives are also provided for ‘cleaner’ aircraft. In 1994 Zurich airport was the first in the world to introduce emission-based landing (sur)charges. After that Geneva, Bern, Basel, the major Swedish airports and London Heathrow and Gatwick have followed suit.

Both for noise (see e.g. (Anotec, 2003)) and local air quality the increase in aircraft movements (number of Landing and Take Off-cycles at airport) outweighs the improvements in environmental performance per aircraft. The total environmental impact of aircraft is increasing.

3.4 Environmental performance of aircraft

Improvements in aircraft fuel efficiency have been achieved since the dawn of the jet age in commercial aviation. Historically, these improvements have averaged 1-2% per year for new production aircraft (IPCC, 1999). These advances have been achieved through incorporation of new engine and airframe technology. Changes have included incremental and large-scale improvements.
Comparable developments in fuel efficiency are expected up to 2050. Based on improvement records to date, an airframe production average fuel-efficiency improvement of 10% is expected by 2015. Similarly, a 10% propulsion production average fuel-efficiency improvement is considered feasible in this time frame. In the longer term (2050) compared to 1997, a total aircraft production average fuel-efficiency improvement of 40-50% is considered feasible (IPCC, 1999).

With regard to the emissions of noise and pollutants, the rate of improvement at aircraft level is similar to that for CO_2. As indicted above, the increase in air transport operations (number of LTO-cycles at airport) outweigh these improvements.

3.5 Instruments and measures to reduce emissions

Until now the International Civil Aviation Organization (ICAO) has not been able to agree on any action to ensure effective implementation of mitigation policies aiming at reducing greenhouse gas emissions from international aviation. However, ICAO continues to study policy options to limit or reduce the environmental impact of aircraft engine emissions and develop concrete proposals and will provide advice as soon as possible to the Conference of the Parties of the UNFCCC, placing special emphasis on the use of technical solutions while continuing its consideration of market-based measures. The ICAO Assembly adopted at its 35th Session in October 2004 the following substantive revisions with regard to market-based measures to address aircraft engine emissions:

1 Voluntary measures: States are encouraged to limit international aviation emissions, in particular through voluntary measures and by making use of guidelines provided by ICAO.
2 Emission-related levies: States are urged to refrain from unilateral implementation of greenhouse gas emission charges prior to the next regular session of the Assembly in 2007. In addition, studies on such charges should continue, with the aim of completion by the next regular session of the Assembly in 2007.

3 Emissions trading: Further development of an open emissions trading system[6] for international aviation should be continued. This work should focus on two approaches:
   a ICAO would support the development of a voluntary trading system that interested Contracting States and international organizations might propose.
   b ICAO would provide guidance for use by Contracting States, as appropriate, to incorporate emissions from international aviation into Contracting States' emissions trading schemes consistent with the UNFCCC process.

Earlier, in 2004, it was already agreed by members of ICAO not to set up an aviation specific emission trading system based on a new legal instrument under ICAO auspices. Initiatives to implement any policy measure to mitigate international aviation emissions are therefore left to the individual Parties. ICAO would only provide guidance.

IPCC (1999), ICAO/FESG (2004b), CE Delft (1998) and (2002) and others have examined potential economic instruments for mitigating climate effects from aviation. Kerosene taxes and en-route emission charges are discussed below.

Kerosene taxes
At the global level no support exists for the introduction of kerosene taxes. The ICAO policy on exemption of aviation fuel from taxation has been called into question in only some, mainly European, states which impose taxes on fuel used by other transport modes and other sources of greenhouse gases. In fact, in 2005 a tax on kerosene used for domestic flights was introduced in the Netherlands. Studies (Resource Analysis, 1999) and (CE Delft, 2002) show that introducing a charge or tax on aviation fuel at a *regional* level would give rise to considerable distortions in competition and may need amendment of bilateral air service agreements. In addition, the effectiveness of kerosene tax imposed on a regional scale would be reduced as, for short and medium distance flights, airlines could take 'untaxed' fuel onboard into the taxed area (so-called fuel bunkering).

En-route emission charges
A study by CE Delft (CE Delft, 2002) analyzed the economic and environmental impacts of En-route emission charges for all flights in European Airspace. Using a scenario-based approach and an assumed charge level of € 30 per tonne of CO_2 and € 3.6 per kg of NO_X emitted, the study found a cut in forecast aviation CO_2 emissions in EU airspace of about 10 Megatonnes (9%) in 2010. This result would accrue partly (50%) from technical and operational measures by airlines the other half from reduced air transport demand, due to increased ticket prices resulting from airlines passing on the cost of the charge. The study also came to the conclusion that an en-route emission charge in European airspace designed

[6] 'Open' emissions trading means that participants in an international aviation trading scheme must be able to buy and/or sell emission allowances outside the aviation sector.

in a non-discriminative manner, would have no significant impact on competition between European and non-European carriers.

In its report to CAEP/6, the Forecasting and Economic Analysis Support Group (ICAO/FESG, 2004b) considered the potential economic and environmental impacts of various charges and emission trading schemes. For the period 1998-2010, the effects of a global CO_2 charge with a levy level equivalent to 0.02 $/kg to 50 $/kg jet fuel show a large range of effect on CO_2 reduction from 1% to 18% respectively. This effect is mainly caused by demand effects (75%). The analysis was carried out by the AERO modelling system.

3.5.1 Full climate impact of aviation

A major difficulty in developing a mitigation policy for the climate impacts of aviation is how to cover non-CO_2 impacts. Although knowledge of these effects is still relatively limited (see section 2.6), IPCC (1999) estimated that the total impact from aviation, excluding potential impact of cirrus cloud formation, may be in the order of 2 to 4 times the impact of CO_2 emissions alone. Aiming to reduce CO_2 emissions alone, may lead to adverse effects to other effects of aviation, such as NO_x emissions (see also (CE Delft, 2005)). This means that the environmental integrity of any mitigation policy depends on the extent to which these effects are also taken into account.

Three approaches can be distinguished with regard to non-CO_2 effects of aviation:

1 *No policy in the short and medium term*. As scientific understanding of some of the non-CO_2 climate impacts of aviation is still poor, consideration might be given to limiting initial mitigation policies such as emissions trading to CO_2 and waiting for additional evidence on non-CO_2 impacts before including them in the scheme. In terms of climate impacts, however, open emissions trading involving the aviation sector on the basis of CO_2 emissions alone would undermine the environmental integrity of the entire scheme. Furthermore, focusing solely on CO_2 might provide incentives for airlines to take measures that, while reducing their CO_2 emissions, may well have the negative trade-off of increasing NO_x emissions and thus increasing atmospheric ozone concentrations.

2 *Flanking instruments.* In this option, other policy measures would be relied on to ensure the environmental integrity of mitigation policies directed at CO_2 emissions, such as a CO_2 (or GHG) emission trading system. Basically, the main question to be investigated here is whether flanking instruments would be able to mitigate the non-CO_2 impacts of aviation effectively. Potential flanking instruments include:
   a Regulations on alternative flight altitudes (Fichter, 2004) to prevent contrail formation, based on Eurocontrol guidance, for example.
   b Continued NO_x LTO stringency through ICAO.
   c A NO_x cruise certification regime.
   d NO_x charges.
   e Other.

3 *Climate currency.* A methodology that addresses the full climate impact of aviation. Two methods that can be distinguished are:

   a *Multiplier approach.* Aviation reports on CO_2 emissions and a multiplier is applied to take account of the radiative forcing due to non-CO_2 impacts, for example based on the 2.7 point estimate cited in IPCC (1999) for the year 1992. CO_2 emission could be based on actual fuel use. Incorporation of the multiplier could be justified on a precautionary principle. When more scientific knowledge becomes available, the multiplier factor could be adjusted accordingly.

   b *Equivalent approach.* Aviation reports on CO_2 and NO_x and the conditions for formation of contrails and cirrus clouds are taken into account. The climate change impact is calculated from actual emissions in conjunction with data on temperature and humidity on the flight route. Each of the impacts is expressed in equivalent CO_2 tonnes to calculate the full climate impact of a flight.

It should be emphasized that the equivalent approach requires further development, being fairly theoretical at present. The feasibility of arriving at operational methodologies for addressing the full climate impact of aviation depends not only on improving scientific understanding of non-CO_2 impacts, but also on the potential for measuring or calculating these impacts on individual flights.

3.5.2 Measures induced by economic incentives

There is a wide range of measures that may be taken by the aviation industry in reaction to economic incentives to reduce emissions. The extent to which these actions are indeed taken clearly depends on the size of the incentive. Possible actions include, based on (CE Delft, 2002):

- *Accelerated fleet renewal.* If aircraft emission profiles play a greater role in airline economics, replacement of old aircraft will be brought forward in time.
- *Existing technical measures to current aircraft*, like wingtip devices, riblets or re-engining (see text box).
- *Technical measures to new aircraft on a medium/long term* (see text box).
- *Operational measures at aircraft level*: flight speed and altitude adaptations.
- *Operational measures at network level*: frequency and load factor measures.

For examples of how noise and polluting emissions at airports can be reduced, please see section 3.3.2.

In the report ‘ESCAPE; Economic Screening of Aircraft Preventing emissions' (CE Delft, 2000) the attractiveness of new technologies and new aircraft concepts were assessed. It was found that financial incentives related to environmental goals could significantly increase the economic attractiveness of such technologies and designs. However, quantification of the long-term impacts of such incentives in this respect was found to be unfeasible.

Technical measures to reduce aircraft emissions
There are various existing technical options that can be applied to aircraft in order to reduce fuel burn and emissions:

- *Wingtip devices*. The aerodynamic design of wings has an important effect on the total drag during cruise and therefore on an aircraft's emissions, but also on performance characteristics like payload-range capability, take-off and climb-out behaviour and thus noise. As wing design is always the result of a compromise between construction and maintenance costs, weight and future fuel costs, CO_2-emission incentives could have an effect on optimal wing design.
- *Riblets,* small grooves made on the surface of an aircraft in the direction of flow, reduce skin friction. Measured drag reductions - for an aircraft covered 100% with riblets, which is not practical - are in the range of 5-11%, most of the values converging to 8%. The ultimate drag reduction attainable on a real aircraft will be about 2-3%.
- *Re-engining*. In the 80s and 90s, with prospects of high fuel prices and increasingly severe noise restrictions, re-engining aircraft was a control option regularly considered and sometimes executed. In general however, re-engining has environmental potential, but it is extremely costly and the incentives are probably not sufficient to trigger such costly measures.

Besides these existing measures, on a longer term also the following measures might become feasible for new aircraft:

- *Accelerated development and introduction of ultra-high bypass engines*. It is well known that aircraft engines face a trade-off between CO_2 and NO_x emissions. As a general rule, the higher the pressure ratio in engines, the better the fuel efficiency but the higher the NO_x emission index (EI) per kg of fuel burnt. Therefore, only including CO_2 in the incentive could lead to engines that are too optimised towards high pressure ratios.
- *A renewed interest in turboprop engines*. Turboprop-equipped aircraft fly slower but about 30% more efficiently than turbojet-equipped aircraft. In the longer term, greater focus on environmental efficiency could improve the outlook for this type of engine, which today is often regarded as obsolete.
- *Increased wing aspect ratios*.
- *Increased application of light-weight materials* such as GLARE.

An argument that is sometimes brought forward, is that competition in aviation is fierce and that fuel costs are the most important element for airlines. Therefore very little is said to be potentially gained by charges. It is true that airlines and the aviation industry are forced by competition to save costs where they can. Therefore they will only implement measures that are cost effective under current charging regimes (sometimes based on extensive cost models). Higher charges will make some measures, that were too expensive before, profitable. The question is for how many measures this is true and how much effect may be achieved in total by imposing charges @@. An overview of supply side options for fuel reduction in aviation can be found in CE Delft (2002).

3.6 Policy context and developments

At the moment, major current and future environmental challenges for European policy makers are the reduction targets under the Kyoto-agreement for GHG emissions and the national caps under the NEC-directive. However, emissions from international aviation are not included in either of these (see also 2.8).

3.6.1 Global: ICAO

Until now, the International Civil Aviation Organization (ICAO) has not been able to agree on any action to ensure effective implementation of mitigation policies to reduce greenhouse gas emissions from international aviation bunker fuels, other than agreeing on best practice in terms of air traffic management. At the end of 2004, the 35th Assembly of ICAO decided not to set up an emission trading system for international aviation under their own auspices (ICAO, 2004a). Any initiative to implement new policy measures will be left to the states. This implies that Parties to the UNFCCC or regional organizations (e.g. European Union) have to take the initiative. ICAO agreed that it would only provide guidance for use by states, as appropriate, to incorporate emissions from international civil aviation in States' emission trading schemes with the UNFCCC process or a voluntary trading system that they might propose.

An important reason for the slow development of mitigation policies, both at global and regional level, is that international aviation (and marine) emissions are not included in the national inventories and hence excluded from the agreed-on targets under the Kyoto-protocol. Parties to the UNFCCC therefore do not feel an incentive to develop or actually implement policy measures to mitigate bunker fuel emissions. Moreover, this lack of incentive for action may continue as long as Parties to the UNFCCC will not be able to agree on the assignment of the responsibility for emissions from international bunker fuels.

3.6.2 Current EU position: keep all options open

In its 1999 communication, intended to steer its work on aviation and its environmental impacts in the following years, the European Commission (European Commission, 1999) addressed three market-based options:
- Kerosene taxation.
- Environmental levies.
- Open emissions trading.

Since the Commission's Communication on Air transport and the Environment in 1999, recognition of the need for action at EU level has been consistently underscored by Council conclusions and European Parliamentary resolutions on the Communication itself, on the taxation of aircraft fuel, on the Commission's Transport White Paper, on the European Climate Change Programme, and on the Integration of Environment and Sustainable Development into Transport Policy[7]. Most recently, when preparing for the Tenth Meeting of the Conference

[7] Communication Air Transport & the Environment, 1 December 1999 - COM (1999) 640. European Parliament Resolution on COM (1999) 640, 7 September 2000 - A5-0187/2000. Council Conclusions on COM (1999) 640, 28 March 2001 - Adopted 2252nd Council meeting - TRANSPORT - Brussels. European Parliament Resolution on taxation of aircraft fuel, 14 December 2000 - A5-0334/2000 Council Conclusions on Taxation of aircraft fuel, 29 June 2000 - Adopted 2281st Council meeting - HEALTH - Luxembourg. Commission White Paper European transport policy for 2010: time to decide - COM (2001) 370 European Parliament Resolution on COM (2001) 370, 12 February 2003 - PT-TA (2003) 054. Council Conclusions on European Climate Change Programme, 12 December 2001 - Adopted 2399th Council meeting - ENVIRONMENT - Brussels. Council Conclusions on 2nd review of its strategy on integrating environment and sustainable development into transport policy, 13 December 2002 - TRANSPORT - Brussels.

of the Parties to the UN Framework Convention on Climate Change, the Council of Ministers concluded (Council, 2004):

'RECALLS the need for urgent action to reduce greenhouse gas emissions related to the use of the international bunker fuels, taking into account the agreement in the Sixth Environment Action Programme that the European Community has approved, from which specific action to reduce greenhouse gas emissions from aviation and marine transportation should have been identified within ICAO by 2002 and within IMO by 2003; REITERATES its invitation to the Commission of December 2001, October 2002 and December 2003 to consider in a timely fashion such action and to make proposals in 2005; without precluding any market-based options, LOOKS FORWARD to the study by the Commission on addressing the climate change impacts of aviation through the EU emissions trading scheme'

This very recent Council conclusion shows that the EU needs a policy framework that allows action to deal with emissions from international aviation, without precluding at this stage any market based measures - taxes, charges or emissions trading. The precise choice as to which of these different market-based options should be implemented is a matter for further consideration. The effect on competition is a particular concern of the industry. In principle, if aircraft operators are required to make a contribution, all operators should do so, irrespective of their state of registration. Not only will this avoid unfair competition, it will also reduce the risk of undermining the environmental integrity of the measure. Regardless of which measures are eventually applied, it is important that the full climate change impact is addressed. The IPCC Special Report (IPCC, 1999) highlighted that, in contrast to many other sources, the total radiative forcing and thus the contribution to global warming from aviation is substantially higher than the effect of CO_2 emissions alone.

In 2005 a European Commission policy paper started the discussion with other European institutions on internalising the environmental costs of aviation. The Commission regards the inclusion of aviation in the EU Emission Trading System (ETS) as the most promising way forward. A working group will be set up, to consider ways of including aviation in the EU ETS to feed further discussions. The Commission aims to put forward a legislative proposal by the end of 2006.

A study published by the Commission (CE Delft, 2005) shows that the impact of inclusion of international aviation in the EU ETS depends, apart from the number of allowances distributed, on the flights to be included, the treatment of the climate impact of non-CO_2 effects and the way allowances are distributed. Emission reductions may foremost take place in other sectors, due to the higher marginal abatement costs in the aviation sector. This as will the overall impact, depends clearly on the emissions cap set. The study concludes that the impacts on ticket prices in 2012 of a cap set at 2008 emission level would be modest.

3.7 Emission inventory for aviation

As for other modes, emission inventories for aviation can serve general monitoring of aviation emissions to support policy development or being aimed at a specific instrument (see 2.7). Inclusion of aviation under the European CO_2 emissions trading system would require an accurate emission inventory. Several options have been investigated within the recent study on emissions trading for aviation commissioned by the Commission (CE Delft, 2005).[8] The results of this study are used here and give insight in options for accurate CO_2 monitoring. For pollutant emissions, additional data are necessary (see 2.7).

General allocation options are discussed in section 2.8. They will not be elaborated upon here. However, it is worth emphasizing that the methods to allocate emissions to regions or states could differ per type of emissions. There are good reasons to treat emissions of air pollutants differently from emissions of greenhouse gasses. Different allocation options result in different data requirements.

3.7.1 Current reporting by Member States based on fuel sales

Annual NO_x and GHG emissions of aviation are calculated by individual countries and submitted to IPCC. Data often lags two or more years behind and is not available for all EEA member states. About half of the EU Member States calculate emissions from aviation on bunker fuel statistics (IPCC Tier 1 methodology). The other half of Member States use a combination of fuel sales and Landing Take-Off (LTO) cycles (IPCC Tier 2 methodology) (European Commission, 2004b).

These emissions data for aviation based on bunker fuel sales have some limitations. They cannot make an accurate split between international and domestic flights. The majority of Member States also cannot separate intra-EU emissions from aviation from other international emissions from aviation.

In addition, the amount of bunker fuels sold is often not equal to fuel consumption used by flights from and to a country. Aircraft operators may take more fuel on board at airports where fuel is cheaper or because of operational reasons. The extra fuel taken on board can then be used for the next flight. This phenomenon is called ‘fuel tankering’.

8 In this study several options for emissions monitoring have been elaborated. This has been used as a major source for the paragraph on emission inventory for aviation in this report .

3.7.2 Overview of options

To establish more accurate monitoring and reporting protocols, emission inventory activities could rely either on self-reporting by participants or on third parties. For this purpose, data sources could thus include:

- ‘Self-reported’ data by airlines: under current legislation, trip fuel must be recorded for each flight (section 3.7.3).
- Data from air traffic management authorities, who keep track of all flights undertaken in their airspace. For example, EUROCONTROL currently keeps track of distances, aircraft types, environmental data and origin-destination pairs for every flight handled (section 3.7.4).
- Data from current operations of bunker fuel suppliers: these suppliers are currently under no obligation to report to authorities. Therefore, this option is not elaborated here.

If a monitoring system for CO_2 emissions would be set up because of the introduction of an emission trading system for aviation, these data could be used for more general monitoring purposes as well. However, since such an emission trading system would not cover pollutants, an additional monitoring method should then be set up to build an emission inventory for pollutants as well.

3.7.3 Trip fuel by aircraft operators

Every civil transport aircraft has to comply with airworthiness requirements and operational rules. These regulations set out that operators have an obligation to prepare flight documentation relating to each flight and keep it filed for a certain period, generally 3 months. These flight documents can serve as a basis for monitoring and reporting of trip fuel by aircraft operators.

The weight and balance documentation to be filled in by the aircraft operator after each flight includes information on the mass of fuel at take-off and the mass of trip fuel. Over and above the requirements of minimum data storage time, many operators collect information from these documents, including trip fuel data, and store it electronically in databases as part of company fuel management systems. Such systems enable detailed analysis of fuel consumption data, including disaggregation of the data according to whatever geographical or operational scope is necessary.

Based on the total trip fuel used by an aircraft operator within the boundaries of the geographical scope of the emission trading system, CO_2 emissions can be calculated by using an emission factor for the aviation fuel concerned (3.154 kg CO_2 per kg fuel burned).

Within the context of a CO_2 emission trading system, the Association of European Airlines (AEA) and a number of its members have expressed their preference for a monitoring and reporting method that is based on the actual trip fuel reported by aircraft operators[9]. They regard this as feasible and fairly straightforward to implement.

In order to estimate the emissions of pollutants, additional emission factors are needed. Emissions of pollutants per unit of fuel burned, vary across aircraft and engines used and flight patterns. A good estimate could be derived from average emission factors per unit of fuel burned. A more accurate calculation of pollutant emissions needs fuel data disaggregated per type of aircraft and engine type.

3.7.4 Calculated emissions by EUROCONTROL

EUROCONTROL has extensive data on flight movement data for all flights within the European airspace. Furthermore, EUROCONTROL has developed in-house modelling capabilities in order to calculate estimates of aviation fuel use and related emissions. EUROCONTROL might therefore play a role in emissions monitoring. Emission data based on traffic data is probably more accurate than many existing emission data based on bunker fuel sales, but at least for CO_2 emissions, less accurate than emission data based on trip fuel by aircraft operators.

EUROCONTROL is currently working on an movements database and emission inventory database in the project GAES (Global Aviation Emission Studies). GAES builds further on the Aero2k[10] work and tries to establish an annual updated inventory. In the USA, the SAGE inventory is similar global emissions database. ICAO is aiming at one unique movement database and emission inventory. It is not yet clear whether this will be based on GAES or SAGE.

Flight movement data
EUROCONTROL data is gathered from archived flight plans, corrected by the actual route flown. The distance traveled is within 1% of the actual distance flown by the aircraft (the accuracy in emissions is much lower, see below). The flight plans are based on city pairs, split into domestic and international flights. The database includes all Instrument Flight Rules (IFR) flights from 33 countries since 1 September 1995.

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9 See Working Paper on technical/legal issues for the inclusion in an emission trading scheme (ETS) (AEA, 7 March 2005) and a unanimous standpoint presented by seven European airlines during an AEA meeting on March 30, 2005 in Brussels, Belgium.

10 The Aero2K project, which has been an EC Fifth Framework Programme project, has developed a global inventory of emissions and fuel usage from aviation for the year 2001/02, based on EUROCONTROL flight movement data.

In its PRISME data warehouse, EUROCONTROL currently stores the following data on each flight handled by the CFMU:

- Information from the (last) filed flight plan.
- Aircraft type.
- Airport of departure/airport of destination (city pair).
- The ICAO designator for the aircraft operating agency (see ICAO Doc. 8585) followed by the flight identification; *or* the registration marking of the aircraft; *or* the call sign determined by the military authorities if this is used to identify the aircraft during flight.

Emission models

The PRISME data warehouse contains flight movement data. To calculate the CO_2 and NO_x emissions associated with flight movements in the PRISME database requires additional industry data or publicly available data (e.g. fuel use data per aircraft/engine combination).

EUROCONTROL has developed a system to do so containing two operational models that can be used to calculate CO_2 and NO_x emissions (see text box):

- ANCAT3, and
- The Advanced Emission Model (AEM).

ANCAT3 is based on the EMEP/Corinair methodology and has been officially adopted by ECAC. In calculating fuel consumption and emissions in *LTO* and *cruise*, actual aircraft are modelled through 'conversion' to 19 generic aircraft representing the world's passenger jet fleet. This implies that all flight movements registered in the PRISME data warehouse will be linked to one of these 19 generic aircraft types of the ANCAT3 method.

The second model for emission calculation is the Advanced Emission Model (AEM). AEM has been developed by EUROCONTROL as a means to assess the environmental impact of future airspace and route network planning scenarios. In AEM the fuel burn and emission calculation for the Landing and Take-Off Cycle below 3,000 ft (LTO) is based on the ICAO Engine Exhaust Emissions Data Bank, which includes fuel flow data and emission indices for a large number of aircraft engines[11]. AEM links each aircraft appearing in the input traffic files to one of the engines in the ICAO Engine Exhaust Emissions Data Bank.

Above 3,000 ft, the fuel burn calculation is based on the ‘Base of Aircraft Data’ (BADA)[12] developed and maintained by EUROCONTROL itself. BADA specifies aircraft performance and operating procedure parameters for 267 different types of aircraft.

[11] For the LTO cycle, four modes are distinguished: i) take-off; ii) climb-out; iii) approach; and iv) idle (taxi). In the ICAO Engine Exhaust Emissions Data Bank the fuel flow and emission characteristics vary per mode. Furthermore, there are standard times per mode per aircraft type for the LTO. However, the idle time in particular can vary significantly per flight / airport. EUROCONTROL has no information on actual times spent in flight modes and therefore uses the standard mode times for emission calculations in AEM. At some airports information is available, e.g. taxi times at each airport.

[12] For more information on BADA see: www.EUROCONTROL.int/eec/public/standard_page/ACE_bada.html.

In the AEM validation report it is stated that AEM fuel burn calculation results are close to actual trip fuel data (EUROCONTROL, 2004). It is also concluded that, at the level of individual flights executed by a specific aircraft-engine combination, the AEM modelling data match actual trip fuel data much closer than the ANCAT3 computational results. The AEM model is therefore to be deemed the more suitable existing emission model available to EUROCONTROL for use in monitoring emissions[13].

Monitoring of contrails
At present, the only contribution of aviation to the GHG effect, that may potentially be monitored are CO_2 and NO_x emissions. As indicated in paragraph 2.6, current state-of-the-art models are not able to robustly assess the contribution of individual flights to the formation of contrails and cirrus clouds. In this respect it is noted, however, that EUROCONTROL is participating in a research project to analyse the probability and magnitude of aircraft contrail formation. The research model used in this project to predict contrail formation is currently only in an experimental phase and it is uncertain how long it will be before it is fully operational and accepted.

Application of EUROCONTROL data for emission inventory
The emission inventory of EUROCONTROL is not publicly available. The detailed data behind EUROCONTROL calculations are confidential. Therefore data must be aggregated to an appropriate level to ensure that each flight cannot be traced back to an airline. However, in December 2005, Member States will get the ability to view the emissions data of their own territories. This makes it possible to use these data as a verification for fuel based emissions data or to use them directly for monitoring and reporting.

The EUROCONTROL emissions data can be aggregated or disaggregated to various levels. A split between domestic, intra-European and other international flights and allocation to countries or airlines among others is possible.

The EUROCONTROL data is not validated by external party, but is validated from an operational point of view: the flight has been operated and charged for the use of the airspace. The main data gaps in the emission data from EUROCONTROL are the coverage of flights which are fully VFR (Visual Flight Rules, which is without using radar) or subject to military air traffic control rules and procedures only.

The emission inventory that EUROCONTROL already uses for its own activities could be developed further in collaboration with stakeholders like civil aviation authorities, airlines, the European Commission and its Agencies. Such a broader use of EUROCONTROL emissions data requires rules on the accessibility and use of these data by the various stakeholders.

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[13] For a detailed description see EUROCONTROL (2004), Advanced Emission Model (AEM3) v1.5. Validation report. EEC Report EC/SEE/2004/004.

3.7.5 Conclusion

The most accurate monitoring option for CO_2 is for aircraft operators to measure the actual fuel used on each trip flown per geographical zone. CO_2 emissions can then be calculated from the carbon content of that fuel. Under current international regulations, the amount of fuel used on each flight must already be registered by airlines. The European airline industry and their association have expressed their preference for a monitoring and reporting method based on actual trip fuel, reported by aircraft operators. They regard this as feasible and fairly straightforward to implement. If this method would be elaborated as a part of the implementation of aviation emission trading, general emission monitoring for policy makers could benefit from this.

Methodologies based solely on flight movement data have been developed by EUROCONTROL but data are not publicly available. For CO_2 emissions, an inventory based on actual fuel used is more accurate. However, for emissions of pollutants emission, an inventory based on flight movement data may be a good alternative. Moreover, it offers possibilities to compare and verify emissions calculated by two independent methods (based on fuel consumption and flight movement data).

4 Rail

4.1 Introduction

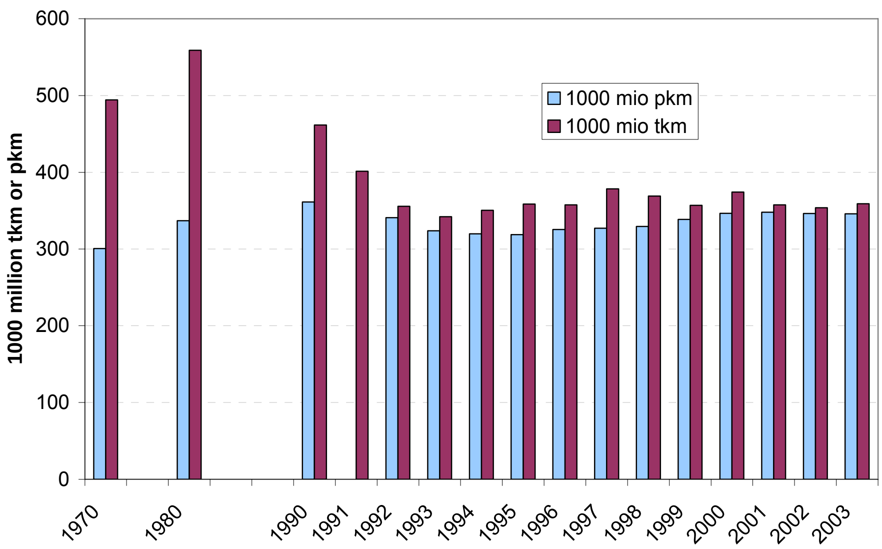
Rail transport has long been considered a relatively clean transport mode. With the success of strong reduction policies for polluting emissions in road transport, the focus is shifting towards these emissions in rail transport as well. This chapter provides an overview of environmental performance and policies in the rail sector. It includes some key figures, policy context, environmental performance, and conclude with bottlenecks and instruments for further improvement of the environmental performance.

4.2 Key figures

4.2.1 Share of rail transport declining

Rail transport is the oldest motorised transport mode and had a very high share in transport in the past. Over the last decades, the share of rail has continuously declined. While total transport volumes have grown by more than a factor 2 since the 1970's, the absolute volume of rail transport has remained fairly stable or has even declined somewhat since the 1980's (Figure 16).

Figure 16 Trends in transport performance by trains (EU-25)

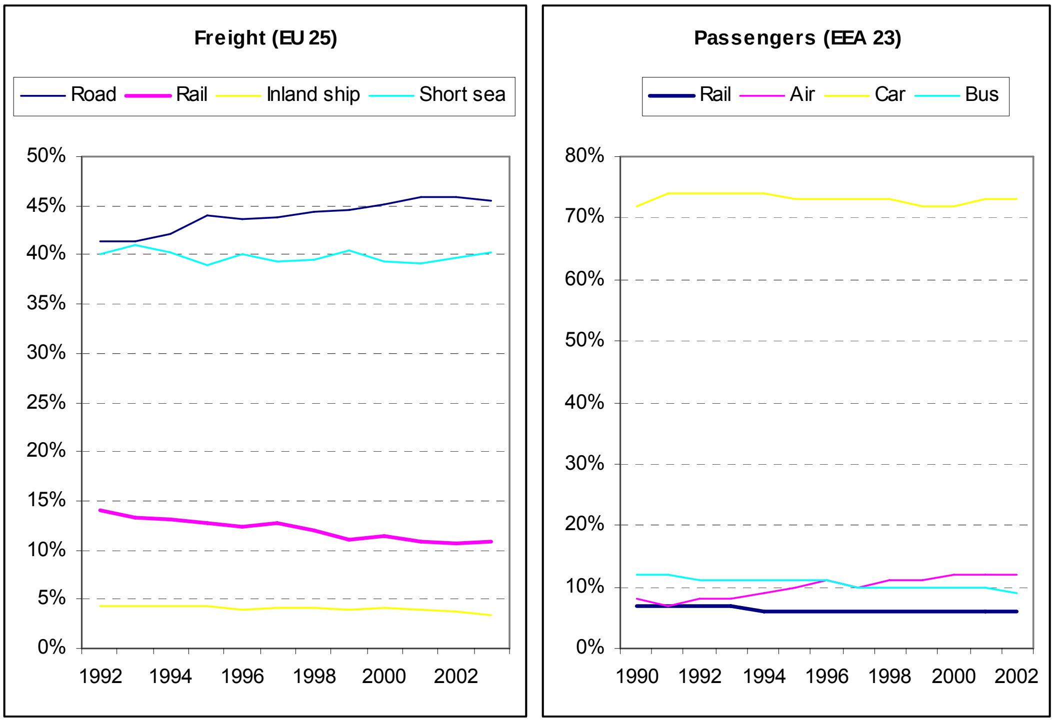


Data are collected annually by Eurostat. Passenger-km data are not harmonised and may not be accurate. See Annex A for more information. Transport by tram and metro is not included. For comparison, rail and metro produced 48 billion pkm in 2001 in EU-15, corresponding to about 1/6 of the volume of train transport.
Source: DG TREN, 2004.

In terms of share, rail transport has decreased even over the last decade, while the absolute performance is fairly constant since the early 1990's. Figure 17 shows the share of rail for both freight and passenger transport.

Because of its relative inflexibility, rail transport is losing ground to the lorry. For passenger transport, competition is mostly with intermediate-distance air travel.

Figure 17 Modal shares of rail in freight (EU 25) and passenger (EEA-23)[14]



Source: (TERM 12a/b, 2004) Passenger transport demand; (TERM 13a/b, 2004) Freight transport demand. For background data see Annexes A.1 and A.2. Short sea is an estimate of all intra-EU (domestic maritime) shipping.

Table 6 summarises the share of rail in the transport of passengers and freight, as well as in emissions.

Table 6 Shares of rail in transport volumes and transport emissions in the EU25 (2003, freight) and EEA23 (2002, passengers). Emissions (upstream) of electric rail transport are not included.

Passenger transport volume (pass.-km)	Freight transport volume (tonne-km)	Greenhouse gas Emissions (diesel)	NO_X emissions (diesel)
6.1%	11%	0.6%	1%

Emissions arising from the use of electric trains are not included. CE Delft estimates NO_x emissions from electric trains to be of similar size, but CO_2 emissions to be roughly four times bigger (see 4.3). Shares are relative to the whole transport sector. Coverage varies but is representative of Europe as a whole - see Annex A for methodology.

[14] EEA-23 refers to the old 15 EU member states, 5 new member states (Czech Republic, Slovakia, Slovenia, Poland and Hungary) plus Norway, Iceland and Turkey.

4.2.2 The freight market: the position of rail

Looking at the NST/R[15] chapters (classes of transport goods), the role of rail transport is dominant in some specific market segments: ore and waste of ore and steel (chapter 4), coal and other solid mineral fuels (chapter 2) and metal products (chapter 5) (Table 7). However, the biggest share in the total performance of rail is that of chapter 9 – machinery, manufactured articles and miscellaneous – constitutes about a third of total rail transport. Road is prominently there in all segments, since road has a strong position in domestic transport.

The shares of rail in groups 5 and 9 have increased substantially during the nineties (Figure 18). This is mainly due to the increase in containerised goods that are not specifically identified, but reported as miscellaneous.

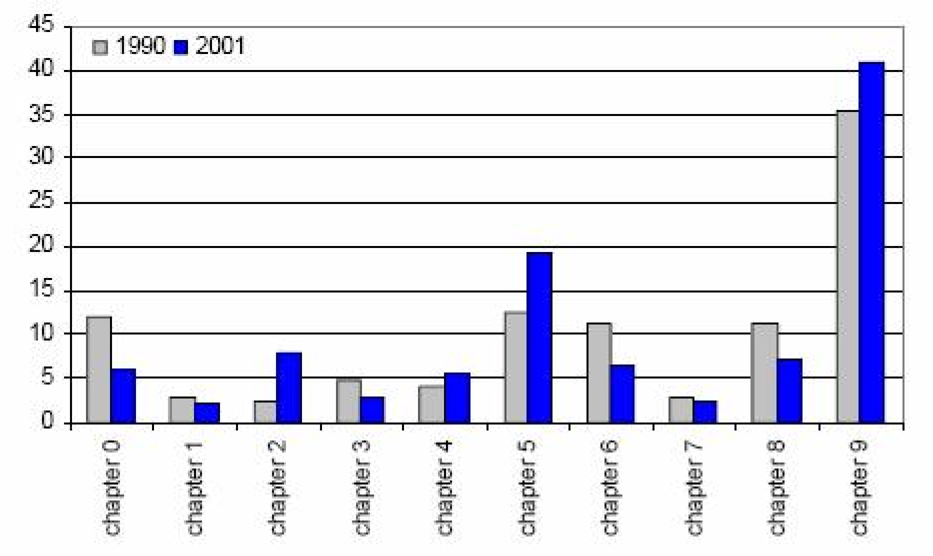
Table 7 Modal shares of goods for EU-15 (tkm and% of tkm for 2001)

Type of goods	Road	Rail	Other	Total	*Share rail in "chapter"*
Agricultural products (0,1)	388 (21.6%)	22 (1.2%)	13 (0.7%)	423 (23.5%)	*5%*
Coal, other solid mineral fuels (2)	13 (0.7%)	18 (1%)	23 (1.3%)	54 (3%)	*33%*
Petroleum and petroleum products (3)	54 (3%)	14 (0.8%)	113 (6.3%)	182 (10.1%)	*8%*
Ore and waste of ore and steel (4)	13 (0.7%)	20 (1.1%)	7 (0.4%)	40 (2.2%)	*50%*
Metal products (5)	81 (4.5%)	38 (2.1%)	4 (0.2%)	122 (6.8%)	*31%*
Cement, building materials (6)	214 (11.9%)	22 (1.2%)	43 (2.4%)	279 (15.5%)	*8%*
Chemicals, fertilizers (7,8)	120 (6.7%)	25 (1.4%)	11 (0.6%)	156 (8.7%)	*16%*
Machinery, manufactured articles and miscellaneous (9)	455 (25.3%)	86 (4.8%)	2 (0.1%)	543 (30.2%)	*16%*
All goods	1343 (74.7%)	245 (13.6%)	216 (12.0%)	1798 100%)	

The category 'Other' refers to estimates of inland navigation and pipeline transport.
Source: Shares: (Eurostat, 2003). Total tkm: (DG TREN, 2004).

[15] Nomenclature uniforme des marchandises pour les Statistiques de Transport, Revisée (NSTR); the classification used for transport goods.

Figure 18 Share of NST/R goods chapters in international rail transport in 1990 compared to 2001 (%)



See Table 7 for information on each chapter. Shares are calculated on the basis of tkm for the following Member States: Belgium, Germany, Greece, France, Italy and Portugal. For national rail transport the distribution is roughly similar.
Source: (Eurostat, 2003).

4.3 Environmental performance of the rail sector

The environmental performance of rail transport is strongly dependent on the type of traction: electric or diesel-powered. In general, the environmental performance of electric trains is superior to diesel trains, because:

1 Electric trains do not emit pollutants in urban areas that deteriorate the local air quality, while diesel trains do.
2 Specific emissions per unit of energy (in particular pollutant emissions) of electricity plants are much lower than for diesel engines, although varying strongly with the type of energy source used for electricity generation.
3 The efficiency of an electric train is generally better than that of a diesel train (see Figure 23).

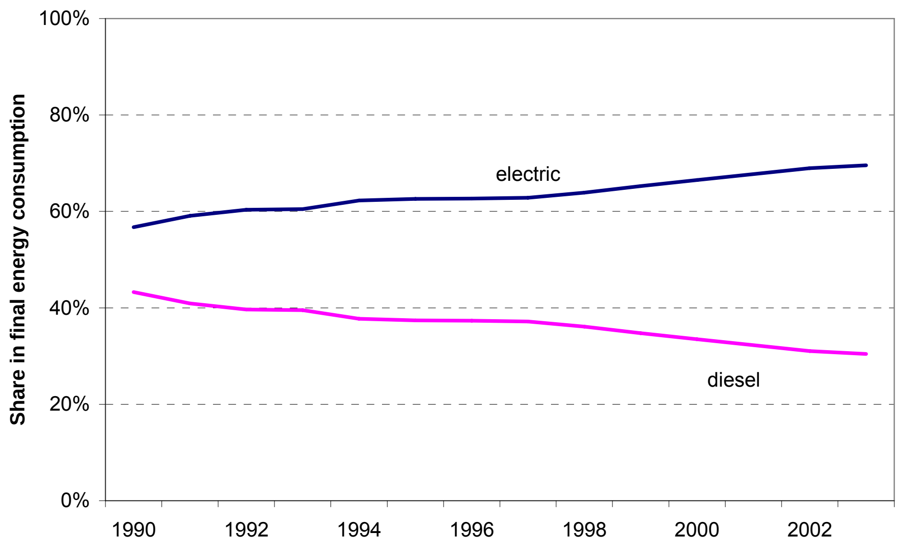
Emission data for rail generally do not include emissions from electric trains. Therefore, there are no time series available for the emissions of the rail sector as a whole. Data are available for final energy consumption, which is to some extent an indicator of the trends in CO_2 emissions. The relation between final energy consumption is different for electric and diesel trains, respectively. For electric trains, the emission factors from TRENDS range from 63 to 296 kg CO_2/GJ. For diesel, the direct emission factor is approximately 75 kg CO_2/GJ and indirect emissions (upstream) are approximately 10 kg CO_2/GJ (Wuppertal, 2003).

In Figure 19, the trends for energy consumption are shown. The share of electricity is increasing, while the total final energy consumption decreased by 4% over the same period of 1990 to 2002 (Eurostat data) for the EU25. Although the CO_2 emissions per unit of energy consumed may in some cases be higher for electricity than for diesel, emissions per unit of performance are lower on average

(Figure 23) due to the higher efficiency of electric trains. Energy efficiency has increased over the last decade, with a steady increase in passenger transport (Figure 16) and stable energy consumption.

All in all, it is hard to say whether the total CO_2 emissions of the rail sector, when taking into account full life-cycle emissions for both electricity and diesel, have increased or decreased over the last decade. A more detailed analysis could reveal this. An estimate of current CO_2 emissions from electric can be made using an emission factor for EU electricity production of 127 g/MJ electricity. This yields a total of 27 Mton, from total energy consumption of 5.2 MTOE (Eurostat), which is roughly four times as much as the emissions of CO_2 (equivalent) gases from diesel trains, which total 6.7 Mton (Annex A4).

Figure 19 Trends in final energy consumption in EU25 for diesel and electric trains



Source: (Eurostat, 2005a).

For other emissions, such as NO_x, the difference between electric and diesel are even more pronounced (Figure 24). It is to be expected that with an increasing share in the energy consumption of electric trains, total NO_x emissions have declined.

Compared to the total emissions of transport, the contribution of the rail sector is rather limited, as is shown in Table 8 for NO_x emissions and section 1.4 for other emissions as well.

Emissions from electric trains are not included in these sources, but a rough estimate can be constructed, using a NO_x emission factor of 0.33 g/MJ electricity (CE Delft, 2003a). This yields a total of about 82 kton NO_x, quite similar to the total for diesel trains, while the energy consumption by electric trains is more than twice as high. Also, for electricity generation, the NO_x is not emitted in densely populated areas, thus causing less harm per unit emitted.

Table 8 Emissions of rail transport and all transport

NO_x (EU25, kton)	1990	2001
All transport	7,633	7,039
Rail (diesel only)	132	78
Rail (electric, estimate)		82
Share of rail		2.3%
CO_2 (EU15, Mton)		
All transport	855	1047
Rail (diesel only)	9.8	6.7
Rail (electric, estimate)		27
Share of rail		3.2%

Data source: see Annex A.

Because of the large differences between the emissions of electric and diesel trains, it is important to distinguish the following developments:
- The environmental performance of trains (section 4.4).
- The share of electric and diesel trains (section 4.5).

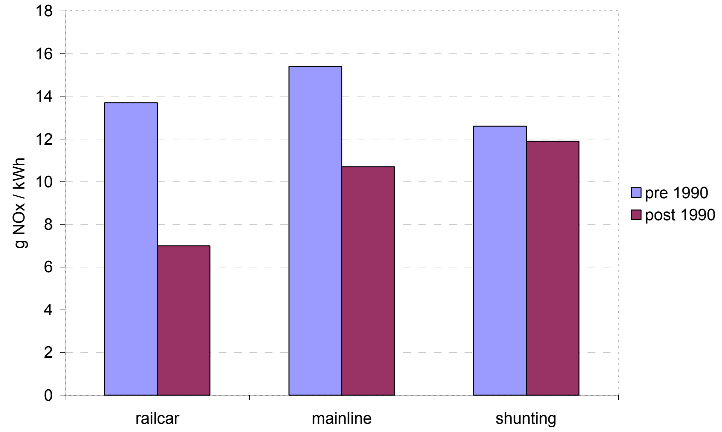
4.4 Environmental performance of trains

The environmental performance of trains is to a large extent determined by the type of traction: electric or diesel. Electric trains do not have any direct emissions of CO_2, NO_x, and particulate matter, but there are indirect emissions arising from production of the electricity for the traction. These emissions can be relatively easily calculated, but will vary widely from country to country. Electric trains have lower air polluting emissions since power generation is more efficient and consequently relatively clean. In countries where electricity generation is nearly emission free, such as in Sweden, transport with electric trains generates extremely low emissions. There are only few studies delving into the subject.

For diesel trains, there have been significant emission reductions since the 1990's due to UIC's emission standards (see Table 9), though progress is still lagging with respect to road transport vehicles. Emissions arising from diesel rail transport have received modest attention and rely on incidental studies such as (CE Delft 2003a) which examines the environmental impact of several transport modes.

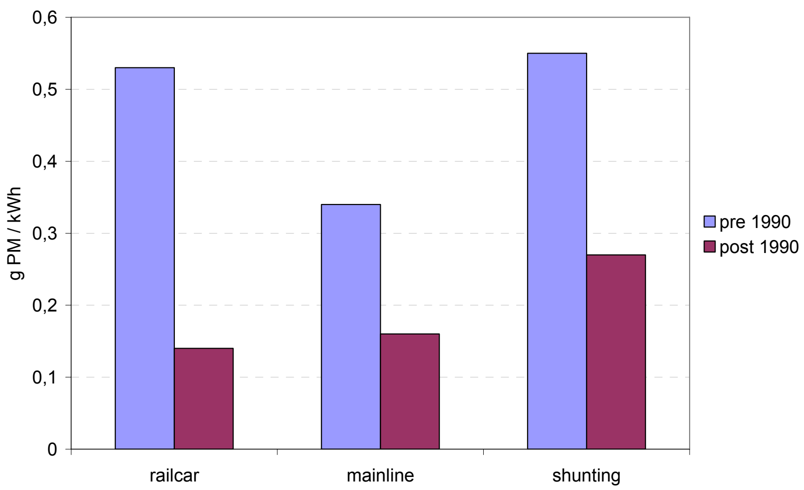
In the Rail Diesel Study (Halder & Lochter 2005) emission data are inventoried by questionnaire to operators. In the next two figures, current emission factors for diesel are given for NO_x and particulate matter (PM).

Figure 20 Current emission factors for NO_x for diesel engines, resulting from European questionnaire



Source: Rail Diesel Study (Halder & Lochter 2005). Mainline is separate engine car, while railcar indicates integrated engine. Shunting locomotives are only used for shunting.

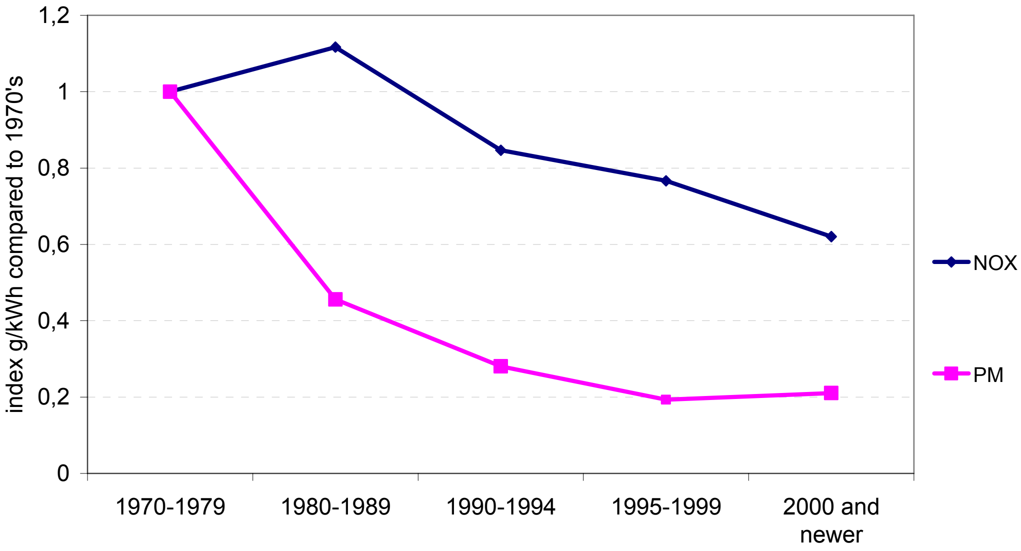
Figure 21 Current emission factors for PM for diesel engines, resulting from European questionnaire



Source: Rail Diesel Study (Halder & Lochter 2005).

For diesel railcars and mainline locomotives, large reductions in those emissions are seen between older and newer material. The trend is even more clearly demonstrated in Figure 22, although it should be noted that these data are only valid for Deutsche Bahn.

Figure 22 Long term trends in emission factors for diesel engines for Deutsche Bahn



Source: Rail Diesel Study (Halder & Lochter 2005).

For electric trains, such data are not readily available.

4.4.1 Passenger trains

It is hard to find data to allocate emissions or energy consumption to passenger transport specifically. Increasing electrification (Figure 19) has probably resulted in decreasing environmental pressures. There are developments that may increase the environmental pressure of passenger rail transport again, for instance a shift towards high-speed trains. Another possible issue is the supposed increasing 'dieselification' on local tracks; this is discussed in paragraph 4.5.

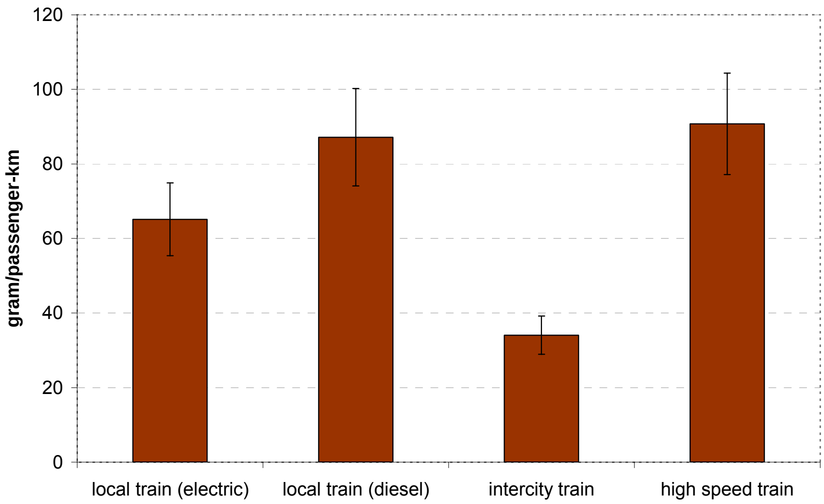
To compete with air transport on long distances and to meet consumer demands, high speed trains were introduced in Europe two decades ago. Most of the high speed links are in France (TGV), but the network is extending fast over Europe. Between 1991 and 2001, the total performance of high-speed rail passenger transport in Europe increased from 22 to 65 billion pkm[16].

High speed trains (HST) consume more energy than conventional electric trains, since the air resistance (drag) that needs to be overcome is very high. In TRENDS, electricity consumption of high-speed trains is said to range from 60 to 160 kJ/tkm (assuming electricity consumption from national grid). The efficiency factor is largely dependent on speed, with the range mentioned roughly equivalent to a range in speed of 100 to 250 km/h (TRENDS Railway module).

[16] High speed trains in Europe, 2002, CCFE/UIC/UNIFE.

In Figure 23, the CO_2 emissions per pkm of different train types are compared for data from CE Delft (2003a). On average, the energy consumption of high speed trains is higher than that of conventional electric intercity trains. Local (short distance) trains also have higher energy consumption, since they have a high stopping frequency.
Apart from higher CO_2 emissions, diesel powered trains also have considerably higher PM_{10} and NO_x emissions than electric trains, as suggested by Figure 24[17].

Figure 23 CO_2 emission of different passenger trains (note that the range on high-speed trains can be large and depends on actual speed, see text)



The variation displayed arises from typical ranges of load factors. ‘Intercity trains’ and ‘high speed trains’ are of electric traction and the CO_2 emissions are calculated from the average CO_2 emissions of power generation in EU. Figures are adapted from the source by excluding CO_2 contributions from car transport to the train stations.
Source: CE Delft, 2003a.

In this report, no focus is given to comparison of modes in terms of specific emissions. See Chapter 2 for a generic discussion on the comparison of different modes.

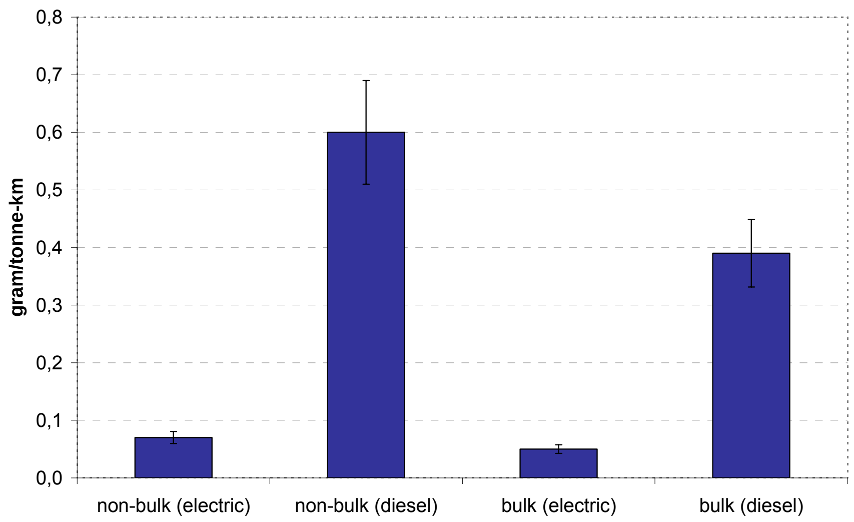
4.4.2 Freight trains

From an environmental point of view, two important market segments in rail freight transport are bulk and non-bulk transport:
- Bulk transports involve large quantity and weight.
- Non-bulk transports can be transports of container or cargo that have lower weights[18].

[17] This figure covers freight trains, but the ratios between the NO_x and PM_{10} emissions of electric and those of diesel trains are the same for passenger trains.
[18] The load capacity of a bulk train is around 1,700 tonnes, the load capacity of a non-bulk train is around 800 tonnes.

The load factor of the trains influences the environmental performance of trains. For NO_x emissions this is illustrated in Figure 24. For PM_{10} emissions the picture is very similar.

Figure 24 NO_x emissions of different freight trains



The variation displayed arises from ranges of assumptions of load factors. NO_x emissions from electric trains are calculated from the average NO_x emissions of power generation in EU. Figures are adapted from the source by excluding NO_x contributions from transport by lorry to and from loading points.
Source: CE Delft, 2003a.

4.5 Trends in diesel / electric ratio

The environmental performance of the rail sector depends on the ratio between electric and diesel transport. Due to the liberalisation and opening of the rail market, the number of rail transport companies has increased considerably. Many small companies emerged on the rail freight market. It has been tentatively observed that these companies may mainly choose for diesel traction (CE Delft, 2003b), for the following reasons:

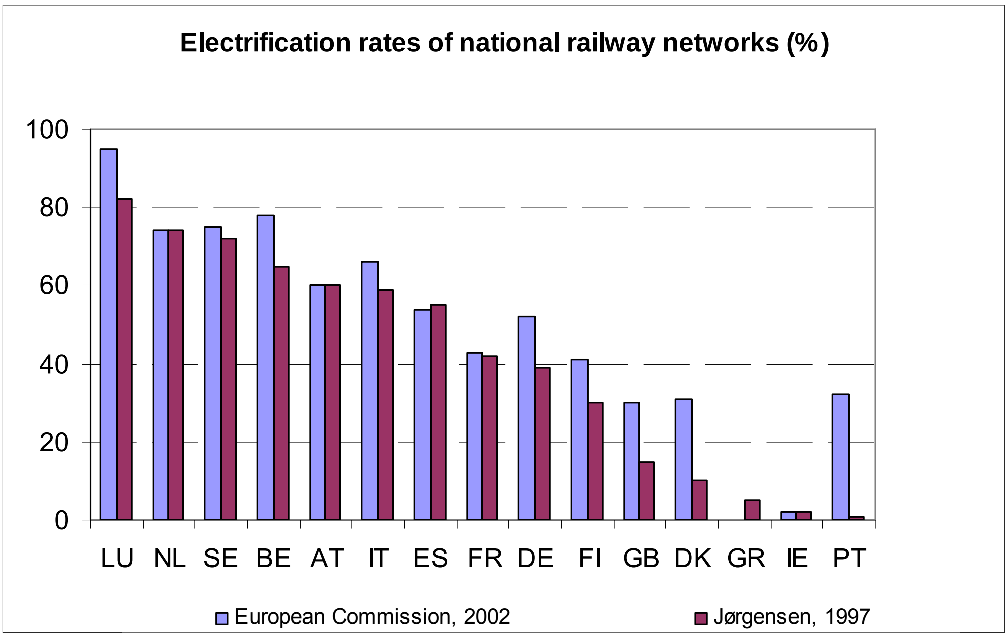
- Lack of electrification on parts of railways. Diesel traction gets you everywhere.
- Lower initial investments; a diesel locomotive is least expensive.
- Lack of interoperability across different EU countries due to different voltages.

The emergence of new rail transport companies may therefore result in an increase in the use of diesel traction. As may be seen in Figure 23 and Figure 24, this might put more pressure on the environment and especially on local air quality.

There are several approaches to define the ratio between electric and diesel transport: electrification rates of railway tracks, the share of electric trains in the fleet, the share in transport volumes and, finally, the share in the energy consumption. These indicators will be assessed in this section.

Electrification of tracks
The use of electric trains depends on the rate of electrification of the rail network. In general, the main tracks are equipped with overhead wires. Many regional tracks however are not equipped, because of the high investments needed. An overview of electrification rates is shown in Figure 25. It shows a tendency of increasing electrification. However, electrification does not exclude the use of diesel locomotives and moreover the rate is not a good indicator for the fraction of volume transported by electric trains, as will become clear in the following figures.

Figure 25 Electrification rates of railway tracks in EU countries

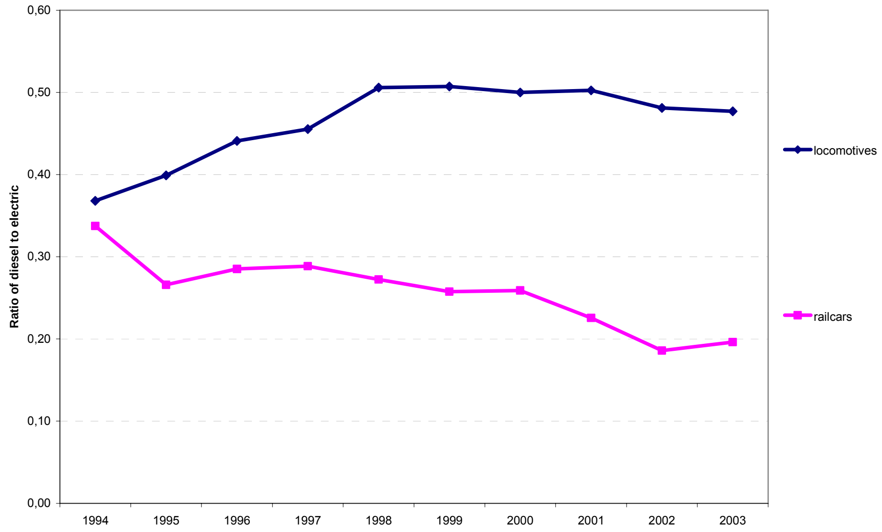


Source: (European Commission, 2002a; Jørgensen, 1997).

Composition of the fleet
In the Rail Diesel Study (Halder and Lochter, 2005) commissioned by the European Commission, rail operators have been asked about their expectations about the development of the diesel fleet. The large majority expects the diesel fleet to decrease or remain stable. Only 14% expects the fleet to increase. There is some distinction between mainline locomotives and diesel railcars, though, with 45% expecting the latter to increase.

More quantitative information on past or expected trends is hard to find. In Figure 26, data for Sweden show a relative increase in number of diesel locomotives, but a similar relative decrease in the number of diesel railcars. This seems to be in line with the idea that if 'dieselification' is happening, it would be for freight traffic, but the opposite trend would be happening for passenger transport. The net effect cannot be derived from these figures.

Figure 26 Trends in terms of numbers of engines, diesel and electric in Sweden

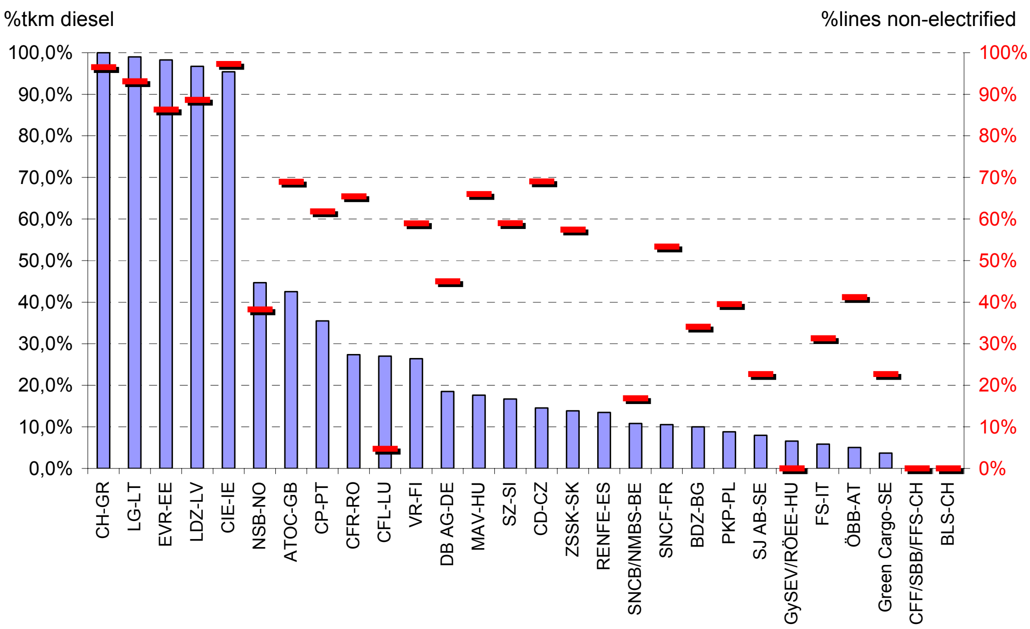


Source: Engstrom and Ahlander, 2005

Transport volumes

Figure 27 gives an overview of the share of diesel trains in the transport volume of the freight market. In this figure, also the shares of non-electrified lines are indicated. It is clearly seen that the percentage of non-electrified railway lines is not a good indicator of the percentage of diesel rail traffic, as non-electrified lines are typically used much less frequently than the electrified lines.

Figure 27 Percentage of diesel rail traffic (in gross-tkm for both freight and passengers) and non-electrified lines per country; second two-letter code in each combination is the country name, e.g. CH-GR indicates Greece

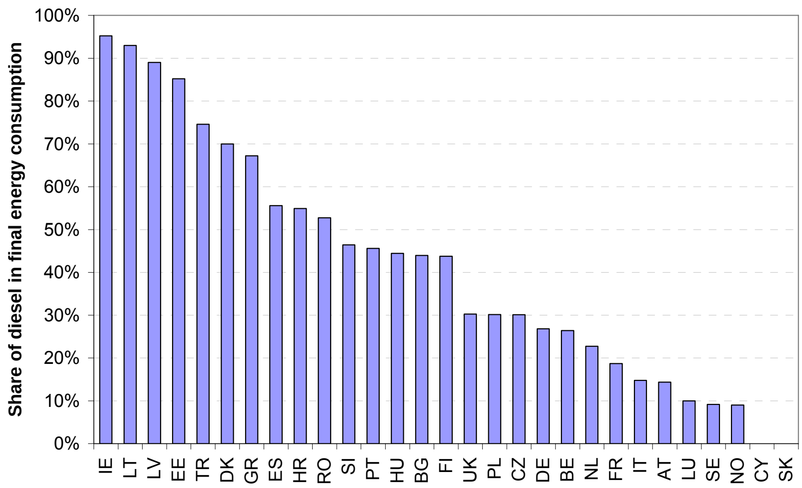


Source: Rail Diesel Study (Halder & Lochter 2005).

No data on trends in the share of diesel in total transport performance were available in this study, but such data are probably monitored by the UIC.

Energy consumption
Another possible indicator for the share of diesel is its share of the total final energy consumption. In Figure 28 this is shown for European countries. There are some discrepancies between Figure 27 and Figure 28, for instance for Greece, Norway and Slovakia. These are probably indicative of the variations between the several statistical databases, although there may be some differences in coverage (both time and operators).

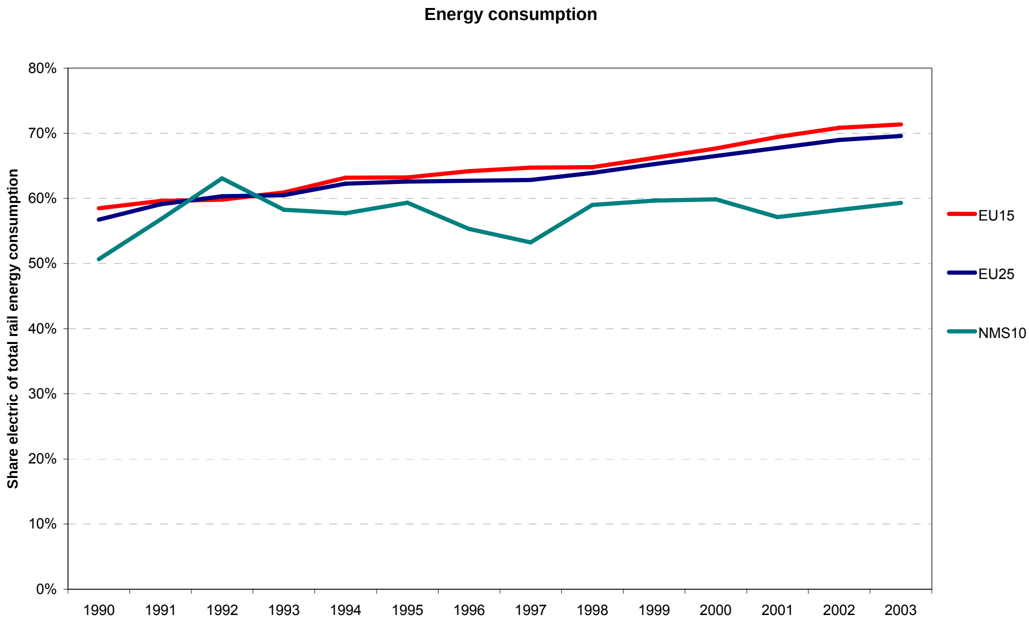
Figure 28 The share of diesel in the total final energy consumption by country



Source: (Eurostat, 2005a).

Looking at the trends in energy consumption for the EU25 as a whole, it is clear that the share of diesel has decreased continuously over the last decade or more (Figure 29).

Figure 29 Share of total final energy consumption of electric rail transport



Source: (Eurostat, 2005a). NMS10 stands for the 10 “new member states” in EU25

To conclude, there is no evidence of dieselification on a noticeable scale from any of the indicators assessed. It is conceivable that dieselification may be happening for rail freight in some countries, but overall, the share of electricity is seen to increase, at least until recently. A more detailed analysis of the share of diesel and electric in terms of performance (tkm and pkm) should reveal definite answers.

4.6 Technical and operational measures for reducing emissions

The primary types of instruments available to give incentives to improve the environmental performance of the rail sector are:

1 Regulation (e.g. emission and fuel quality standards).
2 Introduction (or increase) of an excise duty on diesel.
3 Differentiation of the user charge for railway infrastructure.

These instruments, which will be further discussed in section 4.7, can induce a range of technical measures:

– Non-engine based measures[19] to increase energy efficiency:
  - Optimizing physical parameters: mass reduction, improved aerodynamics and decreasing friction.
  - Regenerative braking with energy recovery.
  - Reducing the energy consumption for comfort functions, such as air conditioning and heating, by proper insulation and ventilation.
  - Energy efficient driving, to optimize speed at all times during the journey for instance reducing braking.

[19] CE, 2005; www.rail-energy.org.

- Increasing the load factor.

– In engine measures for diesel trains:
  - Injection timing; reduces formation of NO_X.
  - Air intake improvements; reduces formation of NO_X and PM_{10}.
  - Optimisation of the combustion system; reduces formation of PM and HC. Electronic engine control may further enhance exhaust emission control.
  - Exhaust gas re-circulation (EGR); reduces NO_X emission.

– Exhaust gas after-treatment measures for diesel trains:
  - Selective catalytic reduction (SCR); reduces NO_X in the exhaust gas.
  - NO_x absorber catalysts.
  - Particle filters; reduce the emissions of PM_{10} as well as HC and CO.

In-engine measures (injection retarding, electronic motor-management systems and turbo chargers) can achieve a reduction of NO_X emissions compared to the current fleet emissions of over 50%. Exhaust gas after treatment measures can achieve even larger emission reductions, but their feasibility and performance also depend on fuel quality (sulphur content). For the non-engine based measures, the increase in energy efficiency may be considerable (e.g. 10-20% for mass reduction (CE Delft, 2005).

4.7 Policy context and developments

Since rail transport and freight in particular lost ground in the '70's and '80's, the European Union has taken various measures to improve the competitiveness of rail. In its strategic papers, a number of objectives with regard to rail can be found:

– The objective of a modal shifting from road to rail was first formulated in the Sustainable Development Strategy in 2001 (European Commission, 2001a) This objective has been backed by the Gothenburg European Council that called for measures to shift the balance between the modes.
– The White paper on the Common Transport Policy 'European Transport Policy for 2010: Time to Decide' the shift of passenger flows towards alternative modes, in particular rail, is a central element (European Commission). With an integrated approach varying from pricing to revitalising alternative modes, the Commission attempts shift the balance from road to rail and increase the market share of rail transport.

Three main policy instruments are highlighted in the CTP:

1 Infrastructure investment policy geared to railway (TEN).
2 Road pricing, to make rail more attractive.
3 Three so-called 'railway packages' of which two have been adopted already to improve the competitiveness of rail and freight passenger transport.

In Chapter 2 a more elaborate discussion of the CTP is given.

4.7.1 Emission and fuel quality standards

With respect to the environmental performance of rail transport, the UIC exhaust emission limit values (Table 9) have been leading during the eighties and nineties for diesel trains. However these limit values are not mandatory.

Table 9 UIC exhaust emission limit values for diesel locomotives and railcars (g/kWh)

		HC	CO	NO_X	PM_{10}
Limit value applicable from 01/1993		1.6	4	16	1.6
Limit value applicable from 01/1997		0.8	3	12	0.8
Limit value applicable from 01/2003	P≤ 560 kW	0.6	2.5	6	0.25
	P> 560 kW	0.8	3	N >1,000 rpm: 9.5 N ≤ 1,000 rpm: 9.9	0.25
Target objective limit value applicable from 01/2008 on		0.4	2.0	6	0.20

The limits apply to the ISO 8178/F test cycle. Source: UIC.

A Community Directive (2004/26/EC)[20] on emission standards for mobile machinery was adopted in 2004, further formalizing and tightening the UIC emissions standards. This directive prescribes amongst others limit values for air pollutants from locomotives and railcars running on diesel, see Table 10.

Table 10 EU emission standards for diesel locomotives and railcars

<table>
<tr><th colspan="6">Locomotives</th></tr>
<tr><th>Class nom. power in kW</th><th>CO in g/kWh</th><th>HC in g/kWh</th><th>NO_X in g/kWh</th><th>PM_{10} in g/kWh</th><th>Date of market introduction for new or replaced engines</th></tr>
<tr><td>130 < P< 560 kW</td><td>3.5</td><td colspan="2">4.0</td><td>0,2</td><td>31-12-2006</td></tr>
<tr><td>560 kW < P</td><td>3.5</td><td>0,5</td><td>6,0</td><td>0,20</td><td>31-12-2008</td></tr>
<tr><td>2,000 kW < P and swept volume > 5 l/cylinder</td><td>3.5</td><td>0.4</td><td>7.4</td><td>0.27</td><td>31-12-2008</td></tr>
<tr><td>130 kW < P</td><td>3.5</td><td colspan="2">4.0</td><td>0,025</td><td>31-12-2011</td></tr>
<tr><th colspan="6">Railcars</th></tr>
<tr><td>130 kW < P</td><td>3.5</td><td colspan="2">4.0</td><td>0.2</td><td>31-12-2005</td></tr>
<tr><td>130 kW < P</td><td>3.5</td><td>0.19</td><td>2.0</td><td>0.025</td><td>31-12-2011</td></tr>
</table>

Source : directive 2004/26/EC.

These emission standards only have effect on new trains and trains that undergo a major overhaul. However, the life span of a train or locomotive is rather long, around 30 years. Therefore the penetration of clean trains is very slow.

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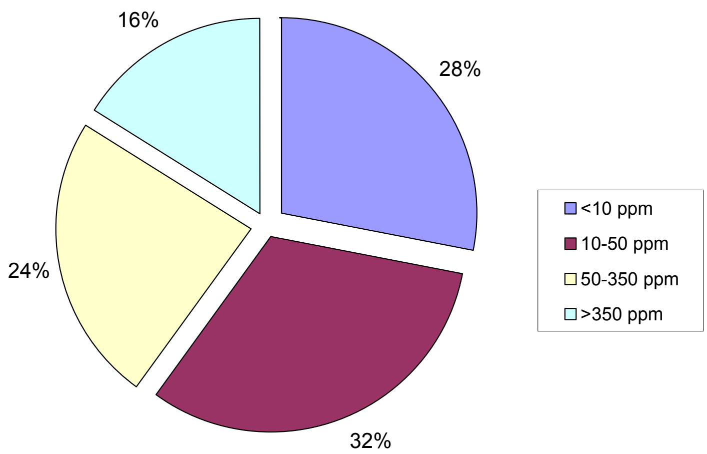
[20] Official Journal L 146, 30/04/2004 P. 0001 - 0110.

For electric trains the environmental performance depends on the emissions of power plants. The improvement of the environmental performance of power plants immediately results in cleaner rail transport.

The sulphur content of diesel fuel has influence on the engine emissions, together with other characteristics as cetane number, aromatics, density and distillation characteristics. The influence of the sulphur content is, however, the most significant.

In the figure below, an indication is given of the use of diesel with different sulphur content; however, as the fractions indicate companies and not actual traffic, the indication is fairly rough.

Figure 30 Percentages of companies operating in different diesel fuel sulphur-content classes



Source: European questionnaire in Railway Diesel Study.

A comparison of fuel sulphur for different applications is given in Figure 10 (section 2.4). The current EU-limit for non-road applications is a maximum of 2,000 ppm. From 2008 on this value will be 1,000 ppm (Directive 99/32/EC). The European parliament has been pushing for non-road diesel fuel specifications that meet road vehicle fuel standards (50 ppm from 2005 on and 10 ppm from 2009). However, in conciliation the Parliament failed in its bid to extent the current rules for road vehicles.

4.7.2 Introduction (or increase) of excise duty on diesel

At the moment, the fiscal treatment of diesel fuel for the carriage of goods by rail varies greatly among the EU-15 countries. For example, in Germany, the excise duty is 0.47 €/l, while in the Netherlands this level is about 0.05 €/l and in Belgium diesel fuel for rail applications is exempt from fuel taxes.
In general, the introduction of excise duty on diesel fuel for rail transport would have the following effects:

- An increase in efficiency of rail freight transport (where possible) by higher load factors, improved routing, and more efficient engines[21]. This reduces the environmental impact of rail transport on a per tonne-km basis.
- A shift towards electric locomotives, which reduces primarily NO_X and PM_{10}-emissions of rail transport.
- A reduction in demand for rail transport, leading to either a net loss of demand, or a shift towards road or waterway transport[22].

When considering the effectiveness of an excise duty on the reduction of emissions of NO_X and PM_{10}, one can show that the effectiveness of (an increase of) an excise duty is lower than setting emission standards and the differentiation of the user charge. While the latter two directly affect the actual emissions, an introduction of an excise duty only stimulates to avoid costs (fuel savings), not to reduce pollutant emissions. The introduction of an excise duty therefore is an effective means to reduce CO_2 emissions, since these are, unlike NO_X and PM_{10}, directly linked to fuel consumption. For the same reasons the cost-effectiveness of the introduction of an excise duty for the reduction of NO_X and PM_{10} is not high from a theoretical point of view.

4.7.3 Differentiation and increase of the user charge

The EU has set itself the objective to reach more sustainable transport by among others the introduction of fair and efficient pricing. Internalisation of external costs of all transport modes encourages the use of the most environmentally friendly means of transport. EU Directive 2001/14/EG provides the opportunity to take environmental performance into account when setting charges for infrastructure use.

An overview of current user charges in Europe is shown in Table 11. As can be seen from this table, these charges differ considerably over Europe.

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21 An overview of various options for increasing efficiency of rail transport can be found at: http://www.railway-energy.org/tfee/index.php.

22 In many cases both effects will occur, depending on the specific situation which effect dominates.

Table 11 User charges for freight trains in Europe in 2002

Country	Infrastructure charges in € per train km	
	Conventional trains	Heavy trains
Netherlands	0.22	0.22
Belgium	1.30	1.50
France	0.70	0.70
Germany	2.80	2.80
Switzerland	6.50	6.50
Italy	2.05	2.10
Austria	4.30	6.70
Poland	4.20	7.50
Czech Republic	0	0

Source: The Dutch Ministry of Transport, Public Works and Water Management.

When the environmental costs of train exploitation are internalised by differentiation of the user charge to emission performance, hauliers would be stimulated to operate low emission locomotives.

The differentiation of the user charge is considered to be the most effective means to reduce emissions, since it allows for measures to be taken over the whole chain of operational activities (also logistics, load factors) in response. In contrast, the setting of emission standards only stimulates to reduce the emission level of locomotive engines. For the same reasons the cost-effectiveness of a differentiation of the user charge is higher than the cost-effectiveness of setting emission standards.

4.8 Emission inventory

To construct an emission inventory for rail, we face slightly different issues than for the other modes of transport, due to use of electricity. This issue is not necessarily a complicating one. Typically, a national railway system will use one ‘type’ of electricity. This is often the national mix, in other words, the electricity from the standard grid. Other operators may have their own electricity mix. Once this mix is known, the emission factors per kWh are the same for all trains. This is contrary to the situation for diesel, where emission factors per kWh depend on the fuel specifications, the type of engine and driving conditions.

Therefore, the approach to an emission inventory for rail should distinguish between electricity and diesel. Electricity can be covered accurately by the top-down approach (see section 2.7), whereas diesel should ideally be covered by the bottom-up approach based on actual traffic or on a combined approach. For CO_2 emissions, however, the total derived from fuel sales can provide a good estimate.

Emission factors for electricity mixes are typically known, but a disadvantage is that they may be very variable. However, using the total final energy consumption by railway transport (available from Eurostat) and emission factors for the average national electricity mix could give a good first approximation to the total emissions.

For diesel, using only final energy consumption (available from Eurostat) and one average emission factor will result in a very crude estimate, although for CO_2 emissions this may well be an acceptable approach. The annual data that are submitted to IPCC by individual countries are derived this way.

Data on transport volumes for diesel (and electric) are available, per operator, in the UIC statistics. Further differentiation to engine type and journey conditions are desirable for air pollution, but currently probably not feasible. This approach is applied in country reporting to UNECE/CLRTAP/EMEP, a regularly updated source. These data are used in TERM fact sheets. NO_x and other emissions data rely on approximate emission factors. Data often lag two or more years behind and no data is available for some EEA member states, notably Turkey. Other supplementary data rely mainly on available ad hoc studies. Emissions data for (different types of) trains rely mainly on incidental studies such as (CE Delft, 2003a) which examines the environmental impact of several transport modes.

An important question is what the goal of the emission inventory is. For monitoring the contribution of rail to total emissions and also comparing diesel to electric, it could be important to include upstream emissions for both electric and diesel trains.

For a national emission inventory, however, these upstream emissions should not be included, however, as they are already covered by the inventory for the energy sector. Only direct diesel emissions need to be added to the total national emissions, but for monitoring the emissions due to rail transport, upstream emissions for both diesel and electric are best included.

Overall, it can be concluded that data sources are available and relatively reliable, though frequently incomplete (in terms of country or volume coverage). Emission factors for emissions other than CO_2 are probably crude.

5 Maritime shipping

5.1 Introduction

Shipping is the largest transport mode in the EU. The largest share of this is maritime shipping (on seas), inland navigation (on inland waterways) is a much smaller mode. This chapter gives an overview of maritime shipping; inland navigation is covered in chapter 6.

In maritime shipping there is goods transport (the main shipping sector) and passenger transport which is typically done by ferries and (to a lesser extend) cruise ships. When analyzing the environmental performance and policies of this sector, there are several important issues that play a role.

Concerning environmental performance, the main issues are:

- The fuel efficiency of sea vessels is generally considered to be relatively good, compared with other transport modes; however, it does not seem to improve.
- The emissions of air pollutants is relatively high, due to a high sulphur content of the fuels used and the lack of stringent engine emission standards.
- The air pollutants that are emitted close to shores or in harbours may contribute significantly to local air quality problems in inhabited regions.
- Tradeoffs may have to be made between climate benefits or pollution reduction, because non-CO_2 emissions of maritime shipping (particularly SO_2) may have a relative strong cooling impact (see section 5.3.1).

Regarding environmental policy, the maritime shipping sector is treated quite differently from the land based modes of transport. For example, the NEC-directive by the European Union includes emissions of maritime shipping that take place in the harbour areas of the various countries, but not those that take place elsewhere. In the Kyoto-agreement, international maritime shipping emissions are not included in the national emissions at all. In that respect, maritime shipping and aviation are quite comparable.

In the following, the environmental performance and policies in the maritime shipping sector are discussed in some more detail. Section 5.2 gives key figures for the scale of maritime shipping and its emission. Section 5.3 discusses the climate emissions including important non-CO_2 climate emissions, as well as pollutant emissions. Other environmental problems that shipping may cause, mainly regarding pollution of the marine environment, will not be addressed here, even though these problems can be very severe. Section 5.4 and 5.5 discuss ships speeds and the factors that determine emissions of individual ships, and finally sections 5.6 and 5.7 discuss emission inventories and how to reduce emissions

5.2 Key figures

Even though shipping is, in general, a much more energy-efficient mode of transport than road, rail or air transport (expressed in MJ/tonne-km), its contribution to global emissions is significant and growing. This is mainly caused by the continuous growth of maritime shipping, which is hardly compensated by specific emission reductions. Figure 31 illustrates the relevance of the sector in transport. Already, the share of maritime shipping in the total freight transport volume is large - 39% if only intra-European transport is included (see Table 12) and an estimated 77% if transport between EU and foreign countries is included.

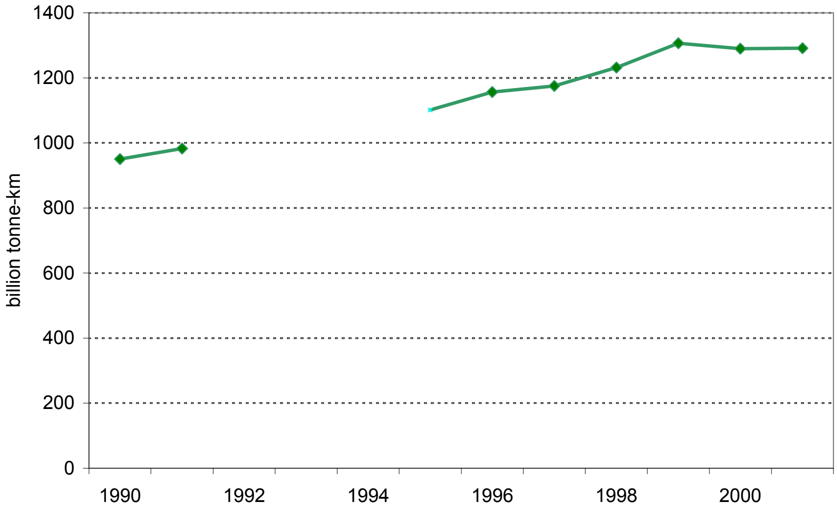
Almost 59% of the world's fleet consists of relatively small vessels with less than 5,000 dead weight tonnes (DWT). However, these vessels account for only 5% of the world's tonnage. At the other end of the scale the largest 3% of vessels by number, account for 36% of the world's tonnage. Tankers and dry bulk carriers make up 26% by number and 69% by DWT of the world cargo carrying fleet (Van der Most PFJ, 1990).

Table 12 Key figures for maritime shipping and inland navigation

	Passenger transport volume (pkm)	Freight transport volume (tkm)	Greenhouse gas emissions	NO_x emissions
Share of maritime and inland navigation in volume / emissions	insignificant	39% (77%*)	14%	28%

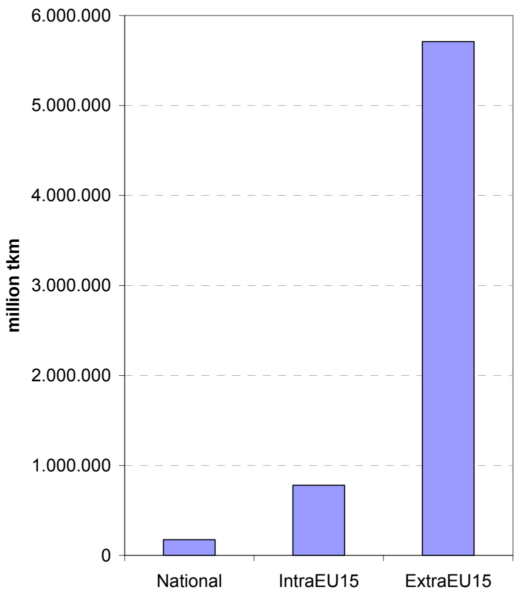
Note: Shares are relative to the whole transport sector. Coverage varies but is representative of Europe as a whole - see Annex A for details. *The share of freight transport volume including half of all transport with origin or destination outside Europe is 77% (see also Figure 32 below). The share of emissions is determined based upon fuel sales, and is not limited to emissions over European territory. The scope is therefore not quite similar to that for freight transport volumes due to different allocation methods, but as emissions from international shipping are included they are more comparable to the share of freight transport volume that includes transport between Europe and outside destinations.

Figure 31 Trends in maritime shipping transport volumes



Note: Estimate includes all domestic transport and intra-European transport. Transport with origin or destination outside of Europe (EEA-23) is not included. The volume would be much greater if that were to be included as well (see figure Figure 32 for an indication). It is interesting that growth apparently stopped after 1999 while at the same time fuel sales for the sector increased (see section 5.3.1). The reason for this is unclear. It could be a sign of inaccurate statistics. Another explanation could be that while intra-EU shipping has declined somewhat in the last years, shipping between EU and other destinations has increased, producing a net growth (as indicated by preliminary estimates from Eurostat).

Figure 32 The scale of maritime transport between EU and non-EU



Figures should not be seen as accurate but give a rough indication. ‘ExtraEU15’ includes transport between EU-15 and countries outside EU-15; half of the kilometres run are here allocated to EU-15. ‘IntraEU15’ includes transport between EU-15 countries. ‘National’ includes transport with origin and destination in the same country.
Source: TERM 13 2005 fact sheet, (Eurostat, 2005b).

5.3 Environmental performance of the marine sector

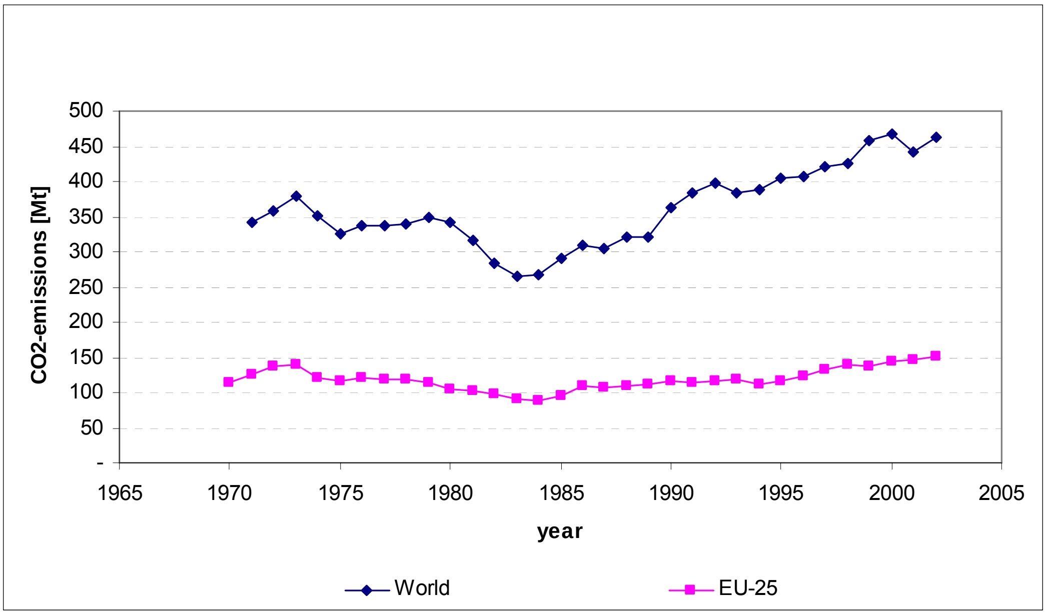
The following section discusses the environmental performance of the marine sector. Though emissions of greenhouse gases and polluting substances are treated separately, there are important overlaps as particularly SO_2 may have important climate and pollution impacts.

5.3.1 Climate impacts from CO_2 emissions

Shipping contributes to the global emissions of greenhouse gases from fossil fuels by about 2.5% in 2002 (approx. 460 Mton per year) (IEA, 2004b). This figure is based on recorded fuel sales. Since 1995, bunker fuel sales (and therefore CO_2 emissions from the marine sector) have grown almost continuously, as can be seen in Figure 33. Between 1990 and 2002, CO_2 emissions have grown with 28%, an average yearly growth of 2%. This is also fairly consistent with data from the TRENDS database (TRENDS, 2003). The decline that appears during the seventies and early eighties is inconsistent with TRENDS data that shows increase during the seventies and a decline only in 1980-1983. TRENDS calculates ship emissions based on ship traffic data instead of bunker fuel sales, what may explain the discrepancy[23]. In any case, the decline is linked to the oil crises and the increasing prices of fuel in that period. This in turn spurred development in engine design to improve the fuel efficiency that led to a 20% improvement (Figure 34).

[23] A greater preference by maritime shipping companies to buy bunker fuels outside of Europe during the 70's could produce such a discrepancy, however, we do not know if this is actually the case.

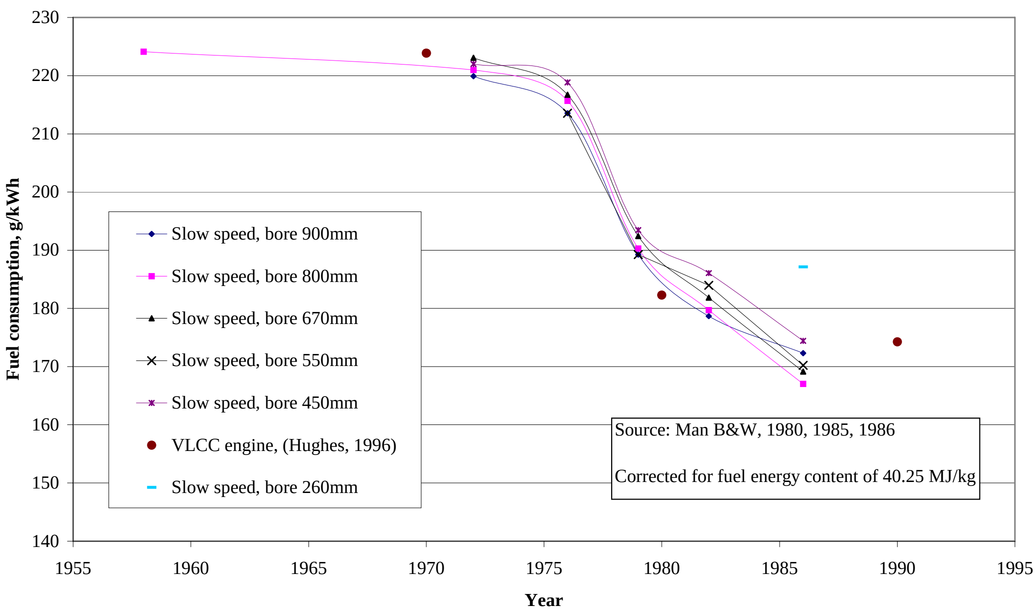
Figure 33 trends in global and EU-25 CO_2 emissions of maritime shipping, based on bunker fuels sales statistics



The decline during the 1970's and the early 1980's is probably not indicative for emissions from European transport. Eurostat data suggest that intra-EU short maritime shipping transport volumes grew by more than 5% a year, exceeding the growth during the 1980's and 1990's. While this excludes deep maritime shipping, estimates used in the TRENDS model does include this and indicate an increase of CO_2 emissions during this period.

Source: IEA, 2004a.

Figure 34 Fuel Economy Improvements of main types of Marine Diesel Engines



Source: TRENDS, 2002.

In Table 13, some details are given regarding the countries were these marine bunker fuels are sold. In 2002, 53% of the global bunker fuel was sold in Annex I countries. This percentage was fairly constant over the past years, with a modest increase of 8% increase from 1990. However, bunker fuel sales of the EU-25 increased overall by over 32% during that period. In 2002, almost one third of all marine bunkers were sold in the EU25. Non-Annex I sales increased by about 60% between 1990 and 2002.

Table 13 Trends in CO_2 emissions from bunker fuels sold to international shipping, 1990 to 2002, worldwide, in Annex I, Annex B and non-Annex I countries and in the EU-25

Country	1990	2002	Diff 02/90	Share in international shipping
	[Mt]	[Mt]	[%]	[%]
World	363	463	28%	100%
Annex I [1]	225	244	8%	53%
Annex B [2] - USA and Australia	131	166	26%	36%
EU 25	110	145	32%	31%
Non-Annex I	138	219	59%	47%

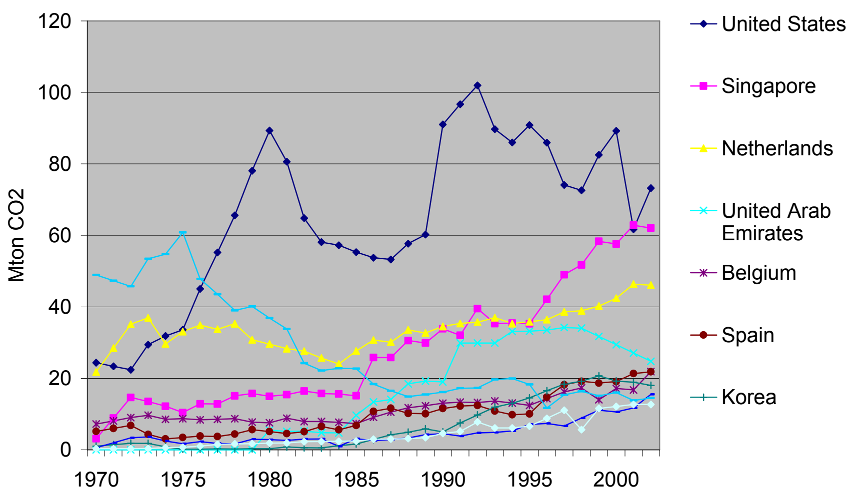
Source: RIVM, 2004, data based on IEA, 2004a.

1 Annex I countries in UNFCCC ('industrialized countries' plus Turkey): OECD-24 plus EIT (Economies In Transition (former USSR countries and Eastern European countries)).

2 Countries with an emission target under the Kyoto-protocol: Annex I countries excluding Turkey and Belarus. The USA and Australia have indicated that they will not ratify the Kyoto-protocol.

In Figure 35, the bunker fuels sales development (expressed as the CO_2 emissions that are caused by these fuels) is shown for the top-10 countries in the world. The USA is number 1 with a share of 16%, Singapore is number 2 with a 13% share in total global sales, (showing an increase by about 80% in the period 1990-2002), and the Netherlands (the port of Rotterdam) is number 3.

Figure 35 Trends in international marine CO_2 emissions from bunker fuel sales of Top-10 countries, 1990-2002



Source: (IEA, 2004a).

5.3.2 Climate impacts from non-CO_2 engine emissions

To date, most focus has been on the principle greenhouse gas, CO_2, as it is the single biggest cause of climate change. However, as discussed in section 2.6, other climate effects may be important. In the case of maritime transport this is the case due to the relatively large emissions of SO_2 and NO_x that both have climatic impacts.

The positive climate effect of NO_x emissions may be in the same range as effects from CO_2 ship emissions. However, this is probably partly offset by the negative effect of CH_4 depletion. In all, it is likely that ship NO_x emissions will produce a net warming effect, but this conclusion is highly uncertain and may change as scientific understanding improves.

Sulphur aerosols due to ship emissions have a cooling effect. Though poorly understood, this cooling effect may exceed the warming effect of CO_2 and NO_x emissions combined. A study of the IMO [IMO, 2000] states that in total, the current net radiative forcing from ships is probably small or negative (net cooling). Another study Endresen (2003) found similar magnitude forcings for NO_x, but a net small *positive* radiative forcing when all emissions were included but excluding indirect effects of sulphur emissions which were indicated to be uncertain but could be large (but negative, see Figure 11). It should be noted that the level of net forcing may change with time, as sulphate particles have much shorter atmospheric lifetimes than CO_2.

An important consequence of the cooling effect is that reducing maritime emissions (particularly SO_2) in order to combat air pollution, might have substantial climate effects. The non-CO_2 forcing effects are very complex and still poorly understood. Effects vary highly depending on location and season. A more reliable determination of these effects is necessary for designing effective climate policy for maritime shipping and for making a proper trade-off between climate policy and pollution control policy, where necessary.

5.3.3 Climate impacts from refrigerants

A third source that affects radiative forcing is emission of refrigerants. In maritime transport, refrigerants are used in several applications, such as:

- In ships with temperature controlled loading space (with onboard refrigeration systems).
- In refrigerated containers (with individual refrigeration units).
- In refrigeration systems on fishing vessels (used for both food processing and storage).
- In air conditioning for passenger or crew areas.

Share and impacts of refrigerants

In the past, the refrigerants used were detrimental to the ozone layer. The production and use of these substances were therefore controlled under the Montreal Protocol, and are subsequently being phased out. However, both the ozone-depleting substances and their substitutes are greenhouse gases which contribute to global warming. Some of the alternatives are therefore covered under the UNFCCC and in the Kyoto Protocol (namely HFCs, PFCs and SF_6) (IPCC, 2005).

The global warming potential (GWP) of these substances is significant: HFCs have GWPs typically between 1,000 and 3,000 times higher that that of CO_2 (MCG, 1998).

The UNFCCC concludes that these gases currently contribute to 2% of the total GHG emissions of Annex I countries (UNFCCC, 2003). However, their share is increasing as they are used to replace ozone depleting gases regulated by the Montreal Protocol: as total Annex I CO_2 emissions decreased by nearly 1% over the period 1990-2000, total emissions of HFCs, PFCs and SF_6 increased by 24%, mostly as a result of an increase of HFC emissions[24].

In the European Union, emissions of refrigerant (halocarbons and SF_6) account for 1.0% of total EU-15 GHG emissions in 2003 (EEA, 2005). HFC emissions in 2003 were found to be 74 times higher than in 1990, mainly due to the phase-out of ozone-depleting substances. ‘Refrigeration and air conditioning equipment’ is by far the largest sub-category accounting for 72% of HFC emissions. No separate data are provided for the marine shipping sector.

Refrigerant emissions in maritime shipping

The Technology and Economic Assessment Panel of the IPCC (IPCC/TEAP) has recently made an inventory of global emissions of refrigerant gases (IPCC, 2005). In their report, data and forecasts are provided about the total volume of refrigerants and refrigerant emissions in various subsectors of the refrigerant sector, including transport[25]. The results regarding the maritime shipping and fishing subsector are given in Table 14. The main results are that about 8.3 ktonne of refrigerants was used in maritime transport and fishing vessels (0.78% of the total), with an annual leakage rate estimated to be about 2.8 ktonne (1.1% of the total). Expressed in Mt CO_2 eq, total refrigerant emissions in the transport sector was about 22 Mtonne. No CO_2 eq emission figures are given for the maritime shipping and fishing subsector, however we would estimate these to be about 9.5 – 10.6 Mtonne CO_2 eq.

[24] NB. Refrigeration equipment also consumes energy, which also causes CO_2 emissions. These emissions are not included in these data.

[25] All data for Annex I countries only.

Table 14 Refrigerant volume and emissions from maritime transport and fishing vessels

	Refrigerant volume in use [ktonne]	% of total volume in use	Refrigerant emissions [ktonne]	% of total refrigerant emissions	Refrigerant emissions [Mt CO_2 eq]
Total refrigerants contained in refrigerant equipment	1,079		250		1,060
Refrigerants used in the transport sector	16	1.5%	6	2.4%	22 (2.1% of total)
Refrigerants used per transport subsector					
Maritime transport and fishing	8.3	0.8%	2.8	1.1%	
Road transport	4.3	0.4%	1.8	0.7%	
Rail transport	0.8	0.1%	0.4	0.1%	
Container transport	2.5	0.2%	1.1	0.4%	

Source: (IPCC, 2005).

Maritime transport and fishing is thus considered to be the major contributor to refrigerant emissions of the transport sector (IPCC, 2005). Annual refrigerant emissions of this subsector are estimated to be almost 35% on average. This is relatively high: total annual refrigerant emissions are estimated to be 23% of the volume in use.

Apart from this work by the IPCC, a number of member states have carried out studies in which refrigerant emissions from fishing vessels, refrigerated containers or ships were analysed. Especially the Netherlands have been active in this field, carrying out inspections on fishing and merchant vessels operating under the Dutch flag (Klingenberg, 2005). Inspections between 1996 and 2001 revealed that the refrigeration equipment on board both merchant vessels and trawlers showed an average annual refrigerant leakage of 50%. Among cutters, the figure was 80%. Only very few vessels could claim a refrigerant leakage of less than 10%. This clearly compares unfavourably to the performance of refrigeration equipment on land, where legislation, enforcement and industry efforts have resulted in a reduction of annual leakage from a double-figure percentage to approximately 4.5%. The result is that marine vessels operating under Dutch flag contain only 5% of refrigerants in use in the Netherlands, but contribute 35% of the total refrigerant emissions.
When analysing absolute figures (VROM, 2003), annual emissions from ships under Dutch flag are about 350 tonnes. Since the type of refrigerants emitted is not reported, we can only roughly estimate what this means in terms of CO_2 eq emissions: assuming the global warming potential of HFC-134a, 1300, this amounts to 450 ktonne CO_2 (for comparison: total GHG emissions of the Netherlands were 215 Mtonne in 2003 (EEA, 2005))

A German inventory of refrigerant emissions (UBA, 2005) estimated the emissions of refrigerated containers, ship air conditioning and fishing vessels. They estimated the total global emissions of refrigerated containers, and attributed 10% of these emissions to Germany – Germany's approximate share in world trade. Regarding emissions of ship air conditioning equipment, the emissions from ocean-going vessels sailing under German flag were attributed to Germany. This approach was partly based on practical considerations, as data on ships under foreign flag are scarcely available. Their emission estimates were partly based on ship and container data, partly on literature, and partly on interviews with experts. Their main conclusions regarding emissions are the following:

- Operational HFC emissions from refrigerated containers are estimated at 10% per year. This estimate is mainly based on expert opinion.
- Using the allocation method mentioned above, the German share of emissions of HFC-134a and HFC-404A from refrigerated containers is estimated to be 22 tonne per year and 1.7 tonne per year respectively. Expressed in CO_2 eq, this amounts to about 35 ktonne CO_2 eq per year. Emissions of other refrigerant gases were not calculated.
- For ships air conditioning systems, a leakage factor of 5% per year was assumed, based on expert estimations.
- Operating emissions from these systems, using the allocation method given above, was thus estimated to be 1.13 tonne HFC-134a per year, i.e. 1.7 ktonne CO_2 eq per year.

For comparison: total GHG emissions of Germany were 1,018 Mtonne in 2003 (EEA, 2005).

It should be noted that refrigerant emissions in shipping are currently not monitored. Sales figures, import and export of refrigerants are often being monitored, but no distinction is made between individual buyers, i.e. these data do not provide information on the sales to the shipping sector. Therefore, the data given above are based on estimates.

Furthermore, due to phase out of refrigerants controlled under the Montreal Protocol, the type of refrigerants used in marine vessels are changing over time. An overview of these developments can be found for example in (UNEP, 2002) and (IPCC, 2005).

Causes of high emissions and possible mitigation measures
The relatively high leakage rates of refrigeration equipment in marine vessels are partly attributed to the harsh environmental conditions at sea, such as the corrosive salt-laden and wet atmosphere, vibrations and torsion. Furthermore, poor maintenance, the failure to detect leaks, the age and complexity of equipment, the technology used and lack of enforcement also contribute to these high leak rates (Klinkenberg, 2005).

This list of causes also points at what measures could be taken to reduce emissions (Klinkenberg, 2005). These measures may relate to both operation and maintenance of the equipment. For example formal maintenance systems can be introduced, crew members can be trained and made aware of the problem, leak detection systems may be improved. Furthermore, newly constructed ships could be required to install indirect rather than direct refrigeration systems, to replace synthetic refrigerants with natural alternatives, and to apply the principles of Life Cycle Engineering within the design of refrigeration installations.

Recent policy developments

As mentioned earlier, refrigerants are included in and regulated by the Kyoto Protocol. To regulate the emissions of these gases, the EU is currently in the process of deciding on a regulation on stationary applications and a directive on vehicle air conditioning. These are expected to be agreed on by the European Commission by the end of 2005. The use of refrigerants in maritime shipping is not regulated in these proposals. However, the proposal does include the statement that the Commission shall publish a report by 2007 on, among other topics, refrigeration systems contained in transport modes other than motor vehicles.

5.3.4 Regional and local air pollution

Even though shipping is relatively fuel-efficient, its emissions of SO_2, NO_x and PM_{10} are high in comparison with other transport modes (when comparing engines, see section 2.4). This is due to the different kinds of fuel used by shipping, containing relatively large amounts of sulphur (see Figure 10) and to the lack of emission standards for engines, for years a very common policy in the realm of road transport.

In 2002, Entec published a study, performed for the European Commission, which quantified and analyzed the emissions of ships associated with movements in the EU area, using data from 2000 (Entec, 2002). This study yielded, among other things, a quantification of ship emissions of SO_2, NO_x, CO_2 and hydrocarbons in the North Sea, Irish Sea, English Channel, Baltic Sea and Mediterranean, as well as in-port emissions of these pollutants plus particulate matter. Also, detailed information was derived regarding ship emissions per vessel type and flag state, differentiating trips according to whether the starting port or destination port is inside or outside the European Community.

Some of the main conclusions were as follows:

- Total air pollutant emissions of maritime shipping (incl. ferries and fishing vessels) in the area under investigation were estimated to be approximately 3617 kton NO_x, 2,678 kton SO_2 and 134 kton HC. For PM_{10}, only the emissions in ports were estimated, approximately 21 kton (all figures for 2000).
- Approximately 4.5% and 6.2% of these NO_x and SO_2 emissions respectively, were emitted in-port. For HC, this value is higher, 13%. Of all European ports, Rotterdam was the one with the largest amount of emissions.
- Approximately 40% of pollutant emissions originate from vessel movements between ports within the EU-15, 14% from EU-15 to non-EU/non-accession countries (NON) and 12% from NON to EU-15 movements. The remaining 34% are due to other movements (from, to or between accession countries, between NON-countries).

- Approximately 49% of the emissions arise from NON-flagged vessels, 31% from EU-flagged vessels and 18% from accession country-flagged vessels.
- For particles emitted in ports, just over 50% arises from EU-15 to EU-15 vessel movements. The majority (40%) were contributed by NON-flagged vessels, followed by 36% from EU-flagged and 24% from accession country-flagged vessels.

Strikingly, though not surprisingly, most emissions were found to occur relatively close to shore, in the Baltic, in the North Sea, in the Mediterranean, along the coast of Portugal, etc. Approximately 30% of all emissions in the region under investigation were emitted in the North Sea and Baltic.

In 2000, the Norwegian Meteorological Institute (Jonson, 2000) analyzed the effects of international pollution levels. The results show that most of the nitrogen and sulphur emissions from shipping are deposited in the sea[26], close to the sources. The remaining pollutants are then dispersed through the atmosphere, with some fraction later being deposited on land, mainly in coastal regions. For many countries bordering the sea, sulphur emissions from shipping are among the largest contributors to this form of pollution: close to or over 10%. Marine shipping was found to contribute even more to NO_x emissions in various coastal countries (roughly between 10 and 20%, with Malta an exception at 38%), owing to the longer residence time of nitrogen compounds in the atmosphere. Evidently, all these percentages are higher along coasts, and lower further inland.

The study also looked at the effects of these depositions, by analysing to what extent shipping emissions contribute to exceedances of critical loads of acidity and nutrient nitrogen. The conclusion was that shipping contributes significantly to the exceedance of both. For acidity, shipping traffic was found to contribute over 50% to exceedances in most of the coastal areas along the English Channel and the North Sea, in the Baltic sea along the coast of Germany and Poland, and also in large parts of Sweden and Finland. For nitrogen, maritime shipping contributes to over 50% of exceedances along large parts of the Baltic coast and in Greece, Croatia, Italy and Spain.

A preliminary estimate of the influence of shipping emissions on atmospheric concentrations of particulate matter, again by the Norwegian Meteorological Institute (Fagerli, 2001), concludes that shipping traffic contributes between 10% and 30% to particulate emissions in most West European coastal areas. However, these calculations are only considered to be a first, rough estimate, based on a limited amount of data, so that further research on this topic was recommended.

[26] Note that this study and Fagerli, 2001 used 1990 emission data.

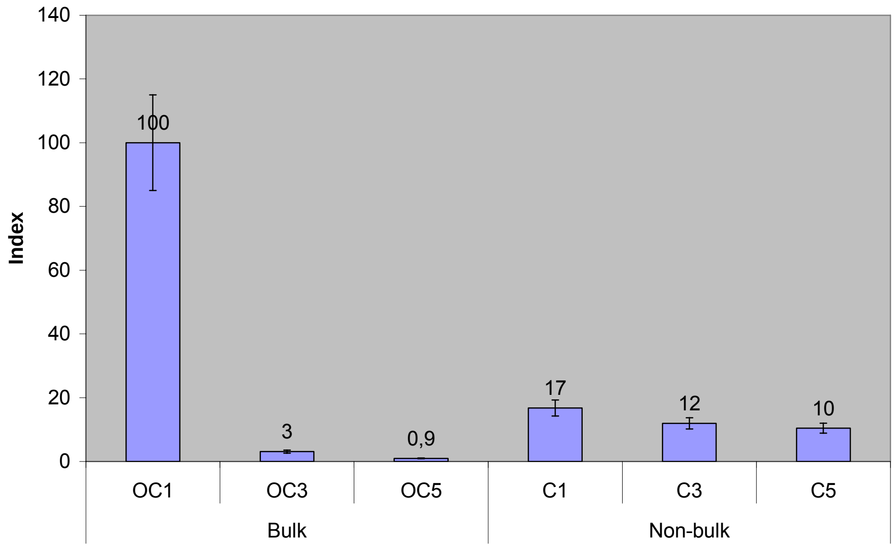
5.4 Environmental performance of ships

Large sea-going ships can provide a very energy-efficient means of freight transport, but emission control technology has developed much slower than for most other modes, resulting in much higher emissions of pollutants than energy consumption would lead to believe.

Ship emissions are subject to almost no regulation and have received modest attention. Regular statistical sources provide at best information for the total sectoral emissions, and insights into emissions from individual ships have to come from individual studies, like (CE Delft, 2003a). These suggest that individual ship emissions show enormous variation depending on ship size, engine technology, fuel, and other factors.

Figure 36 gives an indication of the range of environmental performance for several types of maritime ships. Due to advantages of scale, larger ships tend to have lower emissions per tonne-km. Due to the larger volumes carried by big bulk carriers, the figures for OC5 and OC3 are more likely to represent typical values.

Figure 36 Emissions per tonne-km of different types of maritime ships



OC1-OC5 denotes different size classes of sea bulk carriers ranging from 1,100 to 175,000 Gross register tonnage[27]. C1-C5 denotes different size classes of sea container vessels ranging from 350 to 4,000 TEU[28]. All figures are index figures, where 100 is equal to the emissions of the OC1 class ship. An index of 100 corresponds to 140 g CO_2/tonne-km, or 3.0 g NO_x/tonne-km, or 0.2 g PM_{10}/tonne-km as the case may be. These emissions take into account typical load factors. All values can be found in Annex A.5.
Source: (CE Delft, 2003a).

27 1 gross register ton = 100 cubic feet = 2.83 cubic metres.

28 A twenty-foot equivalent unit (6.1m). A standard unit for counting containers of various lengths and for describing container ship capacity. A standard 40' container equals 2 TEU's.

5.5 Trends in ship speeds

Ship emissions depend heavily on the sailing speed: higher speeds results in higher fuel consumption (all other factors assumed constant). Numerous publications state that ship speeds have increased and are continuing to increase. This notion is not supported by much empirical evidence, however. Furthermore, from the scarce empirical studies available, it seems that it is a matter of historical perspective whether ship speeds are increasing or decreasing.

In 1996, T&E published a study into air pollution from marine ships (Oftedal, 1996). One of the graphs shows the historical evolution of ship design speeds for three types of ships: ferries, container ships and oil tankers. Design speeds for all these ship started to decrease in the first half of the 1970s, following the first oil crisis. A lower design speed results in a lower fuel consumption, so by lowering the design speed, shipping companies were able to counter the rising cost of fuel. From the mid-1980s onward, ship speeds started to rise again. For ferries, they had surpassed their 1970 level by 1995, but for oil tankers they remained well below their pre-oil crisis level until at last 1995. The T&E graph has been checked by other authors, including Marintek (2000), who have confirmed the graph.

To conclude, the empirical evidence shows that ship design speeds are responsive to oil prices. The increase or decrease in ship speeds varies per type of ship.

It is possible that ship speeds have increased at the same time that fuel efficiency of engines has improved. In that way, it is possible that emissions have remained constant or have decreased, even though ship speeds have increased.

5.6 Instruments and measures to reduce emissions

Currently, the emissions that take place on open sea are not allocated to any of the EU countries or (in the case of greenhouse gases) Kyoto-members. This lack of responsibility, in combination with the very international (in many cases global) nature of shipping, makes it very difficult to implement any environmental policies in this sector.

The consequence is that even though the fuel consumption of ships is on average relatively low per tonne-kilometre, policies that are aimed at emission reductions are much less stringent in this sector than in for example road transport.

For CO_2 emissions, no policies are in place at all. Therefore, the contribution of shipping to the EU or world total emissions of both CO_2 and air pollution (acidification, eutrophication) is increasing with the increasing shipping volume.

5.6.1 Reduction potential of technical and operational measures

Due to the current lack of large scale, stringent environmental policies in this sector, there is still quite some potential to reduce emissions. For example:

- SO_2-emissions can be reduced by reducing the sulphur content of the bunker fuels, or by implementing desulphurisation equipment (scrubbing devices).
- NO_x and PM_{10}-emissions can be reduced by technical measures, such as:
  - Implementing NO_x abatement technologies: selective catalytic reduction (SCR), humid air motors (HAM), exhaust gas recirculation (EGR), water injection, internal engine measures.
  - Shore-side electricity in ports.
  - Exhaust gas cleaning (Ecosilencer sea water scrubber).
- Fuel consumption (and hence CO_2 and other emissions) can be reduced by either technological or operational means; for example (IMO, 2000).
  - Optimization of hull and propeller design.
  - Choice of fuel.
  - Fleet planning (incl. reducing speed).
  - Weather routing.
  - ‘Just in time’ routing.
  - Optimal cargo handling.

For fuel consumption, the technical measures alone can, using current technology, produce a 5-30% reduction in fuel consumption for new ships, and slightly less for existing ships (Table 15). Operational measures can add another estimated 1-40% (Table 16) saving.

For NO_x, the emissions can be reduced significantly, up to 95% using SCR. Other measures have less potential, albeit at lower cost.

Table 15 Fuel saving potential by technical measures. Source: IMO, 2000

Measures, new ships	**Fuel/CO_2 saving potential**	**Combined[1)]**	**Total[1)]**
Optimised hull shape	5 – 20%	5 – 30%	5 – 30%
Choice of propeller	5 – 10%		
Efficiency optimised	10 – 12%[2)] 2 – 5%[3)]	14 – 17%[2)] 6 – 10%[3)]	
Fuel (HFO to MDO)	4 – 5%		
Plant concepts	4 – 6%	8 – 11%	
Fuel (HFO to MDO)	4 – 5%		
Machinery monitoring	0.5 – 1%		
Measure, existing ships	**Fuel/CO_2 saving potential**	**Combined[1)]**	**Total[1)]**
Optimal hull maintenance	3 – 5%	4 – 8%	1 – 40%
Propeller maintenance	1 – 3%		
Fuel injection	1 – 2%	5 – 7%	
Fuel (HFO to MDO)	4 – 5%		
Efficiency rating	3 – 5%	7 – 10%	
Fuel (HFO to MDO)	4 – 5%		
Eff. Rating + TC upgrade	5 – 7%	9 – 12%	
HFO to MDO	4 – 5%		

1 Where potential for reduction from individual measures are well documented by different sources, potential for combination of measures is based on estimates only.
2 State of art technique in new medium speed engines running on HFO.
3 Slow speed engines when trade-of with NO_x is accepted.

Table 16 Fuel saving potential of operational measures measures

Option	Fuel/CO_2 saving potential	Combined[1)]	Total[1)]
Operational planning/Speed selection		1 – 40%	1 – 40%
Fleet planning	5 – 40%		
'Just in time' routing	1 – 5%		
Weather routing	2 – 4%		
Miscellaneous measures		0 – 5%	
Constant RPM	0 – 2%		
Optimal trim	0 – 1%		
Minimum ballast	0 – 1%		
Optimal propeller pitch	0 – 2%		
Optimal rudder	0 – 0.3%		
Reduced time in port		1 – 7%	
Optimal cargo handling	1 – 5%		
Optimal berthing, mooring and anchoring	1 – 5%		

1 Where potential for reduction from individual measures are documented by different sources, potential for combination of measures is based on estimates only.

Source: (IMO, 2002).

5.6.2 Current measures

In maritime shipping, most environmental policies are implemented by the International Maritime Organization (IMO)[29]. In view of the very international scope of the sector, most measures require an international, preferably global approach. However, some regional or local measures have also been realized, also within the EU.

Emission policy in the maritime shipping sector has so far been driven mainly by air pollution[30]. The NO_x and SO_2 emissions of shipping vessels are relatively high compared with other modes, and contribute significantly to air pollution in certain coastal and harbour areas. The main policy initiative aimed at reducing these emissions is the addition of an Annex VI to the MARPOL agreement, that came into force in May 2005. This Annex VI:

- Restricts the maximum allowable fuel sulphur content to 4.5%[31].
- Designates Sulphur Oxide Emission Control Areas (SOxECAs) in which the sulphur content of the fuels used is limited to 1.5% (currently only the Baltic Sea areas, but agreement has been reached that the North Sea will follow).
- Establishes NO_x standards for new ship engines (including existing engines that undergo a major conversion).

Although this Annex was issued in 1997, it was not before May 18, 2004, that it was ratified by a sufficient number of IMO member states[32]. It came into force on

29 The IMO is a specialized agency of the United Nations responsible for measures to improve the safety and security of international shipping and to prevent marine pollution from ships. IMO's governing body is the Assembly, which is made up of all 164 Member States. The Council acts as governing body in between Assembly sessions. It prepares the budget and work programme for the Assembly. The main technical work with regard to mitigation of environmental impacts from international shipping is carried out by the Marine Environment Protection Committee (MEPC).

30 As mentioned before, this report is limited to air emissions only. However, in shipping, the environmental problems caused by pollution of the marine environment (due to both legal and illegal emissions to water and due to accidents) are probably even larger.

31 This is of limited consequence, as the typical sulphur content is substantially lower (see @@).

19 May, 2005. The NO_x standards for ship engines are generally considered not to be very stringent, since virtually all ship engine manufacturers already build engines that meet these standards for several years (Nera, 2004).

Also, Special Areas and Particularly Sensitive Sea Areas have been identified in which specific protection measures have been put in place.

In 2005, the European Parliament and Council amended Directive 1999/32/EC as regards the sulphur content of marine fuels. In the new Directive 2005/33, the EU SOxECA's are implemented, but in addition the sulphur content of marine fuels used by inland waterway vessels and vessels at berth in Community ports is limited to 0.1%, with effect from 1 January 2010 (European Commission, 2004a and 2005).

On a more local or regional level, as far as known by the authors of this report, there are currently only two cases of environmental policies that aim to restrict emissions to air:

- Environmentally differentiated fairway dues in Sweden.
- Environmental differentiation of tonnage tax in Norway.

None of these incentives are based on GHG emissions, but generally relate to fuel sulphur content, engine emissions (mainly NO_x), ship safety features and management quality. Elsewhere, seagoing ships are hardly taxed at all, paying only the cost of the services provided in ports (European Commission, 2002b).

So far, no policies are in place that are aimed at reducing greenhouse gas emissions from shipping. As in aviation, no taxes are levied on the bunker fuels used.

5.6.3 Developments

Air pollution

If shipping is to maintain its reputation as environmentally friendly transport mode, more efforts will be required to reduce emissions of SO_x and NO_x in the future. Now that the Marpol Annex VI will come into force soon, a major hurdle is taken on this issue. It provides IMO members with the opportunity to assign SO_x emission control areas, and to set up a system of monitoring and control. Efforts are made to include the North Sea area in that scheme. In view of the significant contribution of shipping to pollution along a number of coast lines in Europe, this measure might also be useful in other areas within the EU (e.g., the Mediterranean Sea).

Furthermore, it is a first measure regarding emission control of engines. However, it is still only a first step, since the standards are still very high, compared with emission standards in other transport modes and the potential of current technology.

[32] Note that only a few of the EU countries have as yet ratified the Annex.

In the EU, only the emissions of ships that are in ports are included in the NEC directive. Emissions of ships at sea are not allocated to the various countries, and are thus not included in emission totals. Besides the efforts that the various EU countries put into the IMO MEPC discussion, the EC is also investigating options to implement market-based instruments that provide incentives for emission reductions. The research that is being done on this topic is briefly described in section 5.6.4.

Greenhouse gases

At the international level, work on reducing the climatic impact of shipping has proceeded at the United Nations through the Framework Convention on Climate Change (UNFCCC) and the International Maritime Organization (IMO). The environmental activities of the IMO are undertaken largely MEPC.

International maritime transport has a number of distinct characteristics that complicate policymaking to reduce GHG emissions in this sector (IMO, 2000). For example, a significant portion of such transport and its emissions takes place in international waters, making it difficult to define the nation or territory where 'generation' of marine transport services takes place. Furthermore, it is often difficult to determine the country of ownership of a vessel, or the real owner responsible for its operation. Ships are often operated on a charter or lease basis, with various lease systems being used. The majority of the world's cargo-carrying capacity is registered in non-Annex I countries, however, the majority of the world's bulk shipments either starts or finishes their journey in an Annex I country. Furthermore, bunker fuels are commonly sold by dealers independent of the major oil companies, which makes administration of bunker fuels sold and bunker fuel taxes complex.

Apart from these political issues, there is a significant technical hurdle to take before GHG policies can be implemented: the actual fuel efficiency or fuel consumption of a ship is currently not monitored. When Marpol Annex VI comes into force, bunker fuel monitoring will be improved strongly (the volume and sulphur content will be registered each time a ship refuels), but fuel consumption per trip or per nautical mile is not yet monitored.

Since the GHG report was issued in 2000, the IMO Marine Environment Protection Committee (MEPC) has continued to work on this topic. Views differed on how IMO should formulate an overall policy on reduction of CO_2 emissions. However, discussions continued and resulted, among other things, in the conclusions that a voluntary environmental indexing scheme was found to be the most appropriate mechanism at this stage for reducing ships' emissions (see the text box below).

In 2003, the IMO Assembly adopted a resolution 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 (IMO Assembly Resolution A.963(23)).

In the following years, discussions about a possible approach to GHG emissions reduction policy continued in the MEPC, as well as the development of an operational-based index as a starting point for an IMO indexing scheme. At the MEPC meeting in July 2005, Interim Guidelines for Voluntary Ship CO_2 Emission Indexing were agreed upon, for use in trials (MEPC 53/WP.11). Industry and organizations are asked to use these Guidelines on a trial basis, and report their experiences and data to the MEPC, so that the Guidelines can be developed further.

CO_2 emission indexing

The IMO considers development of a CO_2 emission indexing scheme to be an appropriate starting point for reducing marine GHG emissions. In the past few years, the MEPC worked on the development of such a scheme, resulting in draft interim guidelines for a ship CO_2 emissions indexing scheme, for use in voluntary trials (MEPC 53/WP.11).

The basic idea behind a CO_2 emission index is that it describes the energy efficiency (i.e. the fuel efficiency) of a ship, i.e. the CO_2 emission per tonne cargo per nautical mile sailed. This index could, in the future, assess both the technical features (e.g. hull design) and operational features of the ship (e.g. speed). The current guidelines address the combination of both, since the index is determined using operational data on actual fuel consumption, distances sailed and load transported.

The CO_2 emission index is currently defined as:

*the mass of CO_2 emitted per (mass of cargo * transport distance).*

Its unit is g CO_2/(t cargo * nautical mile).

For passenger ships, ‘mass of cargo’ should be replaced by number of passengers carried, while for car ferries the number of cars could be used, and so on. One would generally first determine fuel consumption rather than the mass of CO_2 emitted, later converting these data to mass of CO_2.

The initial index of a ship should:

- Cover the fuel used by both the main and auxiliary engines.
- Be based on the average value of energy efficiency over a period of one year for existing ships, at least half a year for new ships.

Even though these guidelines show the main features and methodology that can be used for a CO_2 emissions index, there are still a fair number of hurdles to take before such a system could become operational as a basis for policy. The main bottleneck appears to be that there is major variation in the fuel efficiency of similar ships, which is not yet well understood (see for example IMO document MEPC 51/INF). There seems to be considerable scatter in the specific engine efficiency of ships investigated, which could not be properly explained by the deadweight of the ships, year of build, ship speed and several other ship design characteristics. Before this system can be used in an incentive scheme, the reasons for the data scatter need to be understood. This is a prerequisite for reliable prediction of the economic, competitive and environmental effects of any incentive based on this method. Only then can incentives involving this index be properly designed and optimized for achieving political and environmental objectives.

Apart from the IMO, the European Union is also putting effort into the development of policies to reduce GHG's in the maritime shipping sector. In 2002, the EU published a European Union strategy to reduce atmospheric emissions from seagoing ships (European Commission, 2002b). The background of this strategy is the 6th Environmental Action Programme (6EAP), which lays down targets for both air quality and greenhouse gas reduction and requests the Commission to identify and undertake specific actions to reduce GHG emissions from international marine shipping if no such actions are agreed within IMO by 2003.

In the EU strategy (European Commission, 2002b) a number of objectives are being proposed to guide EU and national policies. For GHG emissions the objective is to reduce ships' unitary emissions of CO_2, although no quantitative goal was proposed. The strategy concludes with a number of actions and recommendations related to GHG reduction, including the statement that international action through IMO is the best way to regulate the environmental performance of ships.

However, it also states that the Commission will consider taking action at EU level to reduce ships' unitary GHG emissions if IMO has not adopted a concrete, ambitious strategy by 2003. The European Parliament then adopted a motion in 2003 regarding this strategy, generally supporting the conclusions and calling on the Commission to come forward - before the end of 2004 - with proposals for EU-wide economic instruments aimed at reducing atmospheric emissions from ships.

Also at the end of 2003, the Council of the European Union reached conclusions regarding this strategy, supporting the development of an IMO Strategy to limit GHG emissions from shipping, and underlining the need to improve the methodologies for estimating and reporting emissions from ships. The Council also recognizes the need to investigate specific EU actions with respect to the reduction on GHG emissions by marine transportation, and invites the Commission to report on possible actions on ship GHG emissions in 2005.

5.6.4 EU research on market-based instruments in international shipping

In 2003 the European Commission commissioned NERA to investigate the feasibility of a broad range of market-based approaches to regulate atmospheric emissions from seagoing ship in EU sea areas. The study focused primarily on policies to reduce the air pollutants SO_2 and NO_x, but the approaches adopted were also deemed applicable to other emissions, including CO_2.

Six market-based programmes were analyzed, three trading and three charging schemes. Subsidies were also identified as a possible approach, but these were not studied further. The feasibility of these policy options was then assessed using various environmental, efficiency, distributional and institutional criteria.

The results of a follow-up study, again commissioned by the EC, were published recently. In scope it included both pollutant and GHG emissions. Regarding GHG emissions, the project consisted of two parts (Entec, 2005 and Nera, 2005[33]):

- Assigning ship emissions to European countries, according to seven different allocation approaches.
- Elaboration of practical details of four possible EU market-based instruments to reduce shipping emissions.

5.7 Emission inventory

Lack of data or poor data quality seems to be the norm for maritime shipping. Individual ship’s trip data registration does not provide sufficient information to accurately determine distance travelled, let alone emissions. Bunker fuel statistics are of limited use due to tankering. Little primary statistical information is publicly available. For example, an important source of data, the Lloyd's Register, can only be accessed by paying members, which further hampers research efforts. Nevertheless, research projects for the EC have resulted in estimates for the emissions of the sector in the EU, using shipping activity data and average emission factors.

In 2004, EEA organised a workshop on emissions of greenhouse gases from aviation and navigation. From the results of this workshop it can be concluded that almost all Member States base their calculations to estimate emissions from navigation on bunker fuel sales (EC, 2004b). Common problems include lack of data on inland waterways and fishing, no split or only a rough split between domestic and international emissions and a lack of clarity whether military emissions are included. The majority of Member States cannot separate intra-EU emissions of navigation from other international emissions of navigation.

In the following, current practices are described first, after which we describe in more detail the possibilities for emission inventories in maritime shipping.

5.7.1 Current practice

In this report the data on transport volumes (tonne-km) of maritime shipping are taken from Eurostat and is estimated annually for national and intra-EU15 shipping. These are rough estimates and will not improve until data registering is improved. For shipping between EU15 and other countries, very crude estimates exist but only for a few years and the methodology is not fully developed. These emission data is based on ship’s activity data, bunker fuel sales and emission factors. Unlike CO_2 emissions, which are directly related to fuel consumption, NO_x and other emissions data rely on approximate emission factors. The appropriateness of allocation of emissions based on fuel sales can be questioned, but alternative data sources are lacking. A more fundamental issue, however is that CO_2 or NO_x emissions don’t make good indicators of the

[33] There are also other reports published in the framework of this project, but these deal with NO_x and SO_x emissions only.

environmental pressures caused by maritime shipping - see earlier for discussion. Other supplementary data rely mainly on available ad hoc studies.

In 2002, a study commissioned by the EC was carried out by Entec in which shipping emissions in the EU were estimated (Entec, 2002)[34]. This study was based on ship activity data from Lloyds and ship characteristics data from Lloyds and IVL for the year 2000, combined with average emission factors for different ship types.

In 2005, Entec drafted emission inventories for SO_2, NO_x, VOC, PM and CO_2, using seven assignment methods. Even though the calculations are quite rough, based on generic assumptions regarding emission factors, types of fuel used, duration of in-port activities, etc., these calculations probably provide the most reliable inventory of shipping emissions in the EU currently available.

5.7.2 Building an emission inventory for maritime shipping

There are various different methods to make an emission inventory, as described in 2.7. Besides, an emission inventory can be based on actual (i.e. measured and reported) data or on model calculations. The first is the most accurate method, if measurements are accurate and reliable. Note that the second method also replies on actual data to feed into the model (e.g., ship activity data and emission factors).

General allocation options are discussed in section 2.8. They will not be elaborated upon here. However, it is worth emphasizing that the methods to allocate emissions to regions or states could differ per type of emissions. There are good reasons to treat emissions of air pollutants differently from emissions of greenhouse gasses. Furthermore, different policy objectives could need different assignment methods.

The data needed to calculate total emissions also differs per substance. For all emissions, data on actual emissions would be the best basis for calculations. However, these data are currently not available. Table 17 shows the alternative data requirements for five selected emissions in the second column.

- Emissions of *carbon dioxide* can be calculated most accurately from fuel type and fuel consumption. Alternatively, CO_2 emissions can be calculated from ship activity data and emission factors.
- Emissions of *sulphur dioxide* can be most accurately calculated from fuel consumption and sulphur content of the fuel (again assuming complete oxidation). In case a maritime ship has an exhaust gas cleaner that cleans the exhaust gas from sulphur dioxide, data on the performance of the cleaner would also be needed.

[34] In a subsequent study, the outcomes of this study were used to assign emissions to member states (Entec, 2005).

– Emissions of *nitrogen oxides* cannot be calculated from fuel consumption, as they differ between engine types and depend also on engine maintenance. In order to calculate these emissions accurately, data are needed of emission factors of maritime ships, preferably regular measurements of emissions of each individual ship. These emission factors need to be combined with activity data in order to obtain total emissions.
– The same holds for emissions of *particulate matter*.

Table 17 Data requirements and availability for emission inventories

Emissions	Basis for calculation	Data availability
CO_2	Fuel consumption or sales per fuel type Alternatively, ship activity data and emission factors	Activity data: Fair Emission factors: Fair Country and ship fuel sales data good from bunker delivery notes from 2005 onwards, but fuel consumption can not be assigned to trips. Bunker fuels sales data quality before 2005 is considered to be relatively poor.
SO_2	Fuel consumption or sales and sulphur content (possibly use of exhaust gas cleaners) Alternatively, ship activity data and emission factors	Activity data: Fair Emission factors: Fair Fuel consumption: Per ship or country: Good from bunker delivery notes, but fuel consumption can not be assigned to trips. Poor otherwise. Performance of exhaust gas cleaners: Fair
NO_x	Activity data and engine emission factors	Activity data: Fair Emission factors: Fair Fuel consumption and sales data: see above
PM_{10} or $PM_{2.5}$	Activity data and engine emission factors	Activity data: Fair Emission factors: Fair Fuel consumption and sales data: see above

In the third column, Table 17 also shows the data availability. Data availability differs per type of emission.
– If emission data of *carbon dioxide* and *sulphur dioxide* are needed per country, they could in principle be calculated from fuel sales data in a comparatively straightforward way. However, bunker fuel sales data quality is currently regarded to be relatively poor, due to issues such as unreported and unrecorded offshore bunkering. As of 2005, fuel suppliers in states that have ratified MARPOL 73/78 Annex VI are obliged to supply bunker delivery notes and fuel samples when they sell bunker fuel[35]. On the basis of these notes, it is possible to calculate total emissions of carbon dioxide and sulphur dioxide.

[35] As of October 2005, the following states have ratified MARPOL 73/78 Annex VI: Azerbaijan, Bahamas, Bangladesh, Barbados, Bulgaria, Croatia, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Japan, Liberia, Marshall Islands, Norway, Panama, Poland, Saint Kitts and Nevis, Samoa, Saudi Arabia, Singapore, Spain, Sweden, United Kingdom, and Vanuatu (www.imo.org). Several other states, including the Netherlands, are currently in the process of ratification (personal communication, Jaap Kolpa, Dutch Ministry of Transport).

These emissions then have to be assigned to trips in order to be able to allocate them in inventories. Such an assignment is not straightforward since fuel consumption data are not recorded, only fuel sales. Estimates may be derived on the basis of activity data. These data are available from commercial sources, such as Lloyd's Marine Intelligence Unit or AMVER (Automated Mutual-assistance Vessel Rescue system). Several studies have shown that these sources are useful in drafting emission inventories (Entec, 2002 and 2005; Eyring, 2005).

- Fuel suppliers in states that have not ratified MARPOL 73/78 Annex VI are not obliged to supply bunker delivery notes and fuel samples. They may do so voluntarily, but at this stage it is not clear whether bunker delivery notes will become standard practice. If that is the case, they can provide useful data regarding CO_2 and SO_2 emissions per ship and per country. If bunker delivery notes are not available, or are not available for every fuel intake of a ship, other data are needed to calculate emissions of carbon dioxide and sulphur dioxide. CO_2 emissions can still be calculated on the basis of fuel intake, of which most (if not all) vessels keep records. However, these records do not show the sulphur content and can therefore not be used to calculate SO_2 emissions. In the absence of bunker delivery notes, calculation of SO_2 emissions need to be based on assumptions of the sulphur content of fuel used. This is the method used by Entec (2002 and 2005), for example. However, these assumptions are quite arbitrary by nature and may result in errors in emission calculation.
- Emissions of NO_x and *particulate matter* depend strongly on specific engine characteristics, and cannot be calculated from data on fuel consumption. These emissions need to be calculated on the basis of emission factors and activity data, as has been done in Entec (2002 and 2005), for example. Entec uses average emission factors for different marine ship types from both public and commercial sources: IVL and Lloyd's register engineering services, distinguishing different emission factors for ships at sea, manoeuvring and at berth.

As mentioned before, the methods used by Entec (2005) are quite rough, aimed at providing preliminary data on different assignment methods. Nevertheless, it seems to provide the most accurate database for EU shipping emissions currently available. However, there is clearly room for improvement of the quality of the input parameters and assumptions used. For example, the data on emission factors could probably be improved considerably if more measurements were available. Also, an effort could be made to include ships smaller than 500 GT, not included in the current study. These are estimated to contribute to about 8% of total emissions. However, since these emissions occur relatively close to shore, their relevance to air quality may be more significant than that.

In Entec (2005), several technical developments are mentioned that will provide opportunities to improve the emission inventories in the future:

- On-board global positioning systems (GPS) are now standard on the commercial fleet and in combination with a data-logger would allow detailed historic time-location reconstruction of ship movements.

- Automatic Identification System (AIS) transponders will allow shore-based systems to identify and track vessels within VHF radio distance, about 40 nautical miles. These will mandatory by July 2008 to improve safety at sea.
- Continuous emission monitoring systems (CEMS) could provide highly accurate data on emissions from individual ships. They are technically feasible, but investment and operating costs are high.

Once a model such as the one constructed by Entec is built, updating it with new parameter values or input data is relatively cheap. In the case of the Entec model, updating the ship activity and characteristics databases requires the purchase of new data from Lloyds. Entec (2005) suggests that an update every 5 years would be sufficient to capture maritime shipping emission trends. A higher frequency only seems justified if drastic policy changes or other developments occur, or if more accurate input data are available.

6 Inland navigation

6.1 Introduction

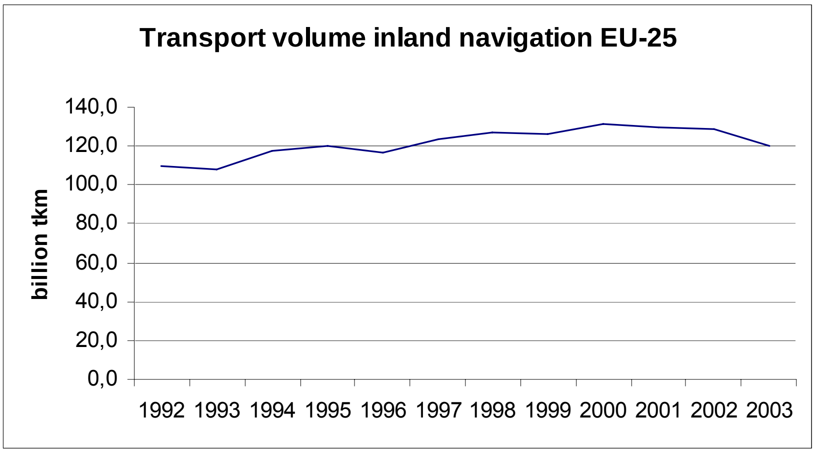
Inland navigation plays an important role for the transport of goods in Europe, particularly on the river Rhine and its tributaries. More than 35,000 kilometres of waterways connect hundreds of cities and industrial regions. Of all 25 Member States, 18 have inland waterways and 10 have an interconnected inland waterway network[36]. However, in only few countries inland navigation plays a substantial role in the freight transport market.

6.2 Key figures

The transport volume of inland navigation has remained more or less constant over the last decade. Where freight transport as a whole has grown by 35 % between 1992 and 2003 in the EEA countries, inland navigation has not got its share in this volume growth. Therefore the share in the total transport volume has declined from 4.7 % in 1992 to 3.4 % in 2003[37].

From 2000 to 2003, not only the share in total transport volume, but also the absolute transport volume of inland navigation has declined, with a notable 8 %. However, the low level of 2003 can be regarded as an incidental dip caused unfavourable water levels in the second half of the year (CCNR, 2004).

Figure 37 Development of transport volume of inland shipping in EU25



Source: EEA TERM 2005, fact sheet 13a.

The market share of inland navigation varies highly among Member States (Table 18). The total transport volume of inland navigation in the EEA region is for 98% shipped in Germany, the Netherlands, France and Belgium. Germany

[36] Source: website Directorate-General Energy and Transport: europa.eu.int/comm/transport/iw/index_en.htm

[37] If extra-European sea-shipping is excluded.

and the Netherlands alone account already for 84% of the total transport volume of inland navigation in all EEA member states. Note that the share in the EEA member states mentioned in Table 18 is higher than mentioned in the first paragraph of this section, because maritime shipping is not included here in the total transport volume.

Table 18 Countries with the highest shares of inland navigation in its total freight transport volume by road rail and inland waterways in 2003

Country	Share
Netherlands	29%
Germany	14%
Belgium	12%
Romania	7%
Hungary	5%
Bulgaria	4%
Austria	4%
France	3%
Luxembourg	3%
Slovak Republic	2%
Czech Republic	1%
Poland	1%
EEA-30	*5%*

Source: EEA TERM 2005, fact sheet 13a.
Note: Maritime shipping and aviation are not included in the total transport volumes used to calculate these shares. Countries with a share of less than 1% are not listed.

6.3 Environmental performance of the inland navigation sector

The statistics on emissions of inland navigation are poor. A major problem is that many countries do not distinguish between domestic short maritime shipping and navigation on inland waterways. In the emission inventories submitted to the IPCC, for example, emissions from inland waterway transport are included in two separate categories (national and international shipping) each of which also includes emissions from maritime shipping. Therefore, no solid data are available on the emissions of navigation on inland waterways.

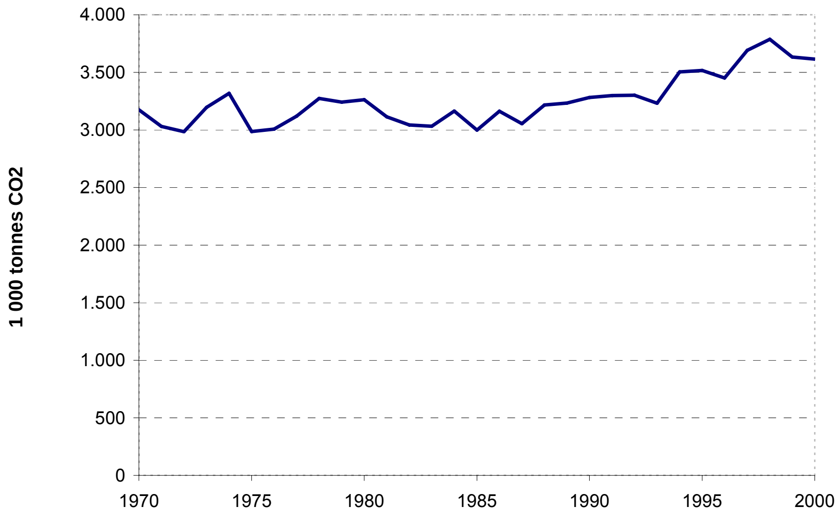
However, the TRENDS database has constructed some estimates. These estimates are based on Eurostat's data on transport volumes (tonne-km) for inland navigation and estimates of fuel consumption and emission factors given typical assumed operating conditions. The results for inland navigation is shown in Figure 38 and Figure 39.

6.3.1 Climate emissions

CO_2 emissions from Inland navigation in the 15 old EU member states for which estimates exist have remained nearly constant during the last 30 years, but increased in the 1990's due to growing transport volumes. No information is available for non-CO_2 emissions that may also be relevant for the climate impact.

As with maritime shipping, the lack of advanced emission control technology for inland vessels results in relatively high NO_x and SO_2 emissions which may have a significant climate impact (see also section 2.5).

Figure 38 CO_2 emissions from inland navigation in the EU-15

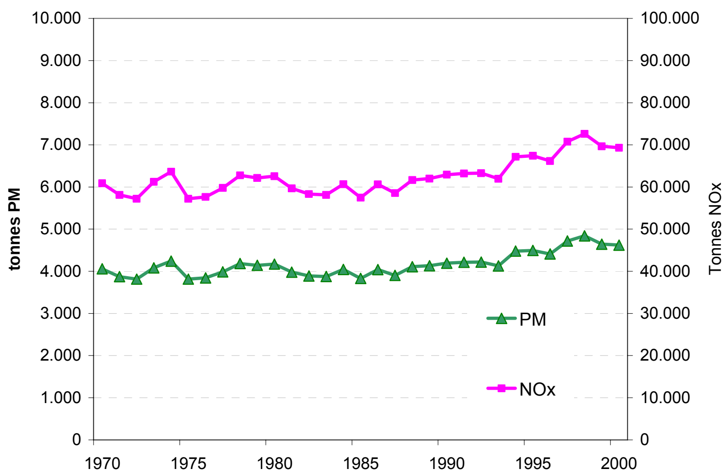


Source: (TRENDS, 2003).

6.3.2 Regional and local air pollution

As with CO_2, emissions of NO_x and particulates have remained roughly constant during the 1970's and 1980's and have increased somewhat during the 1990's as a result of growing transport volumes. These estimates assume there has been no change in emission factors for the pollutants in the given period.

Figure 39 NO_x and PM emissions from inland navigation transport in the EU-15

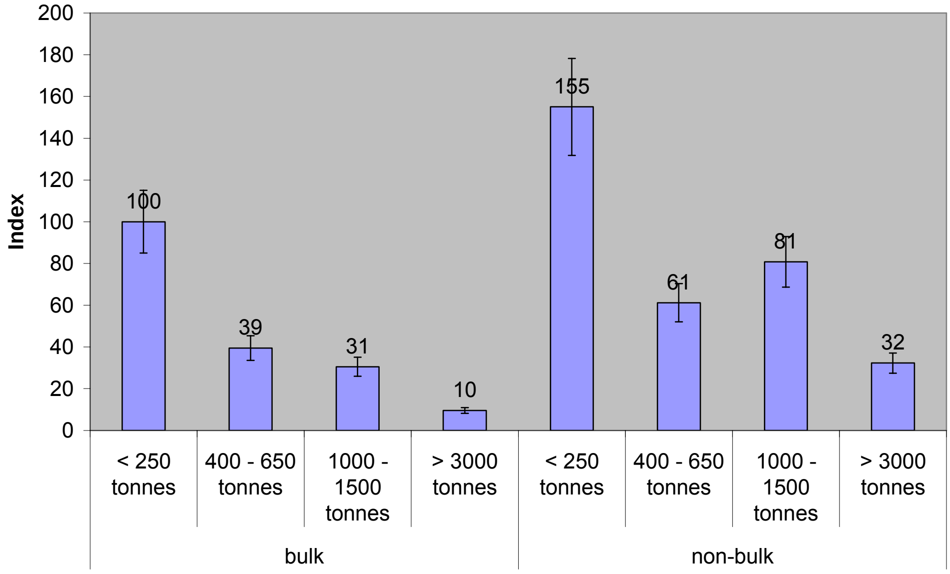


Source: (TRENDS, 2003).

6.4 Environmental performance of inland vessels

The environmental performance of inland vessels displays great variation depending on the size class of the vessel. In terms of emissions per tonne goods transported, large vessels outperform smaller ones by up to a factor of ten. As with maritime ships emissions from inland vessels also depend on engine technology, emission control technology, speed, and other factors.

Figure 40 Emissions per tonne-km of different types of inland vessels



The size ranges used reflect the whole spectrum of inland vessels used. The heavier categories of vessels account for most of the transport, while the smallest size category is rarely used. All figures are index figures, where 100 is equal to the emissions of the <250 tonne ship (bulk). An index of 100 corresponds to 121 g CO_2/tonne-km, or 1.9 g NO_x/tonne-km, or 0.1 g PM_{10}/tonne-km as the case may be. These emissions take into account typical load factors.
Source: (CE Delft, 2003a).

Until the middle of the seventies, engines for inland vessels were optimised on robustness and endurance. Later engine design focused on optimisation of combustion processes in order to increase engine power and fuel efficiency. Higher combustion temperatures and a higher air surplus resulted in a growth in NO_x emission factors (Germanischer Lloyd, 2000). Since 1990, NO_x emission factors of new engines started to decline.

Statistics from the Dutch emission inventory confirm this picture (Table 19). It also shows that the average fuel efficiency has increased steadily with about 15% between 1975 and 2002. Over the same period of time, the average PM_{10} emission factor has been halved.

Table 19 Trend in average emission factors an fuel efficiency of inland vessel engines on Dutch territory

	NO_x *g/kWh*	**PM_{10}** *g/kWh*	**Fuel** *kg/kWh*
<1974	10	0.6	235
1975-1979	13	0.6	230
1979-1984	15	0.6	225
1985-1989	16	0.5	220
1989-1994	14	0.4	210
1995-2001	11	0.3	205
>2002	8	0.3	200

Source: (AVV, 2003).

In 2002, the first stage of CCNR emission standards for new engines turned into force (see section 6.6), followed by the second stage in 2007. However, the average emission factors of new engines in 2002 are already below the levels of this second phase.

Average emissions factors of inland vessel engines are much higher than emissions factors of new engines. Vessel engines have a very long lifetime, varying from 10 to more than 30 years. Therefore the current emission standards, which only apply to new engines, give a relatively slow decline in average emission factors of the fleet. Without additional policy for the existing fleet, it will take several decades before the average emission factor of the fleet will be reduced substantially. This is illustrated by the share of different emission ranges in the fleet of German and Dutch vessels (Table 20).

Table 20 Shares engines with a certain emission factor in Germany and the Netherlands

NO_x emission range *g/kWh*	**Share in the fleet**	
	Germany (3,000 engines)	The Netherlands (5,000 engines)
<10	5.6%	48.9%
10-12	71.9%	36.8%
12-14	7.4%	5.0%
>14	15.1%	9.3%

Source: (Germanischer Lloyd, 2000).

6.5 Technical and operational measures for reducing emissions

The options for emission reduction for inland vessels are similar to those for maritime ships (see section 5.6.1). The main options are:

- SO_2-emissions can be reduced by reducing the sulphur content of the bunker fuels.
- NO_x and PM_{10}-emissions can be reduced by technical measures, such as:
  - Implementing NO_x abatement technologies: selective catalytic reduction (SCR), humid air motors (HAM), exhaust gas recirculation (EGR), water injection, internal engine measures like improved combustion control by adjustment of fuel injection.

- Particulate filters.
- Shore-side electricity in ports.

– Fuel consumption (and hence CO_2 and other emissions) can be reduced by either technological or operational means; for example (IMO, 2000).
  - Optimization of hull and propeller design.
  - Choice of fuel.
  - Fleet planning (incl. reducing speed).
  - Optimal cargo handling.
  - Economy-meter.

Technical measures alone can produce a 5-30% reduction in fuel consumption, using current technology (RIVM, 2002). NO_x emissions can be reduced significantly, up to 95% using SCR.

6.6 Policy context and developments

Emissions policy for inland navigation has been focused on pollutant emissions. The main instruments applied are emission standards (by CCNR and the Commission, 6.6.1) and fuel standards (6.6.2). Policy developments with respect to greenhouse gas emissions and other policy developments are listed in section 6.6.3 and 6.6.4 respectively.

6.6.1 Emission standards for pollutants

The CCNR has set the first emission standards for inland navigation a few years ago, before the Commission did. These CCNR Phase 1 standards became effective at January 2002. CCNR Phase 2 standards will become effective in 2007. The CCNR standards are currently applied to new engines only.

Table 21 shows the levels of the CCNR emission standards phase 1 and phase 2. The standards of phase 1 have limited effects on the emissions because they reflect more or less the current technology. In 2001, 70% of the German and 80% of the Dutch vessels already met the emission levels of phase 1 (CBRB, 2001)[38]. Average emissions of the Dutch fleet still exceed CCNR phase 1 standards because of the long life of old, dirty engines.

[38] CBRB, annual report 2001.

Table 21	Emission standard of CCNR phase 1 and phase 2

	Power (kW)	NO_x (g/kWh)	PM_{10} (g/kWh)
Phase 1	$37 \le P_N < 75$	9.2	0.85
	$75 \le P_N < 130$	9.2	0.70
	$P_N \ge 130$	$n \ge 2800$ rpm: 9.2 $500 \le n < 2800$ rpm: $45 * n^{(-0.2)}$	0.54
Phase 2	$18 \le P_N < 37$	8.0	0.80
	$37 \le P_N < 75$	7.0	0.40
	$75 \le P_N < 130$	6.0	0.30
	$130 \le P_N < 560$	6.0	0.20
	$P_N \ge 560$	$n \ge 3150$ rpm : 6.0 $343 \le n < 3150$: 45 * n(-0.2) – 3 $n < 343$ rpm : 11.0	0.20

Source: (CCNR, 2001).

Directive 2004/26/EC regulates gaseous and particle emissions from internal combustion engines to be installed in non-road mobile machinery[39]. In contrast to previous EU regulation, this includes engines in vessels for inland navigation. In 2005, small engines will have to comply with the emission standards. Larger engines will follow in 2006 and 2007. Just like the CCNR standards, EU standards are currently applied to new engines only. An overview of the EU standards for inland vessel engines is shown in Table 22 and Table 23.

EU emission standards are not exactly compatible with CCNR standards. The CCNR standards regulate NO_x emissions as such, while the EU standards regulate combined emissions of nitrogen oxides and hydrocarbons. The reason for this combination is that the Commission sought explicitly to introduce standards that were compatible with standards in other parts of the world, notably Japan and the USA[40].

Currently, the CCNR and EU are trying to harmonise their standards. Both organisations do not intend to develop a common standard, but they seek a pragmatic solution. The EU already recognises engines that comply with CCNR-1 standards. It appears that in practice, engine manufacturers and shippers may freely choose between engines that comply with either the EU or the CCNR standard.

A revision of the current Directive 2004/26 (including emissions standards for inland vessels) is expected at the end of 2007.

[39] Directive 2004/26/EC of the European Parliament and of the Council, 21 April 2004.

[40] COM(2002) 765 final, 27.12.2002.

Table 22 Limit values for new engines

Category: swept volume/net Power (SV/P) (litres per cylinder/kW)	Carbon monoxide (CO) (g/kWh)	Sum of hydrocarbons and oxides of nitrogen ($HC+NO_x$) (g/kWh)	Particulates (PT) (g/kWh)
V1:1 SV≤0.9 and P>37 kW	5.0	7.5	0.40
V1:2 0.9≤SV <1.2	5.0	7.2	0.30
V1:3 1.2≤SV <2.5	5.0	7.2	0.20
V1:4 2.5≤SV <5	5.0	7.2	0.20
V2:1 5≤SV <15	5.0	7.8	0.27
V2:2 15≤SV <20 and P ≤3300 kW	5.0	8.7	0.50
V2:3 15≤SV <20 and P>3300 kW	5.0	9.8	0.50
V2:4 20≤SV <25	5.0	9.8	0.50
V2:5 25≤SV <30	5.0	11.0	0.50

Table 23 Entry into force dates for emission limits for inland waterway vessels (placing on the market dates)

Category	Entry into force dates
V1:1	31 December 2005
V1:2	30 June 2005
V1:3	30 June 2005
V1:4	31 December 2006
V2	31 December 2007

6.6.2 Fuel standards

In 2005, the European Commission amended Directive 1999/32/EC as regards the sulphur content of marine fuels. In the new Directive 2005/33/EC, the sulphur content of marine fuels used by inland waterway vessels is limited to 0.1%, with effect from 1 January 2010 (European Commission, 2005). An exception is made for vessels using heavy fuel oil that go to sea. For this category a sulphur limit of 0.5% will apply.

6.6.3 Policy developments for greenhouse gas emissions

Inland navigation is included in and regulated by the Kyoto Protocol. However, until now there is no dedicated policy for reduction of greenhouse gas emissions from inland navigation.

Just as for maritime shipping, fuel for inland vessels is relatively cheap because of the lack of fuel charges. Introduction of a fuel charge for inland navigation could provide incentives to improve fuel efficiency of vessels and provide charges better aligning external cost.

However such a charge is not likely to be introduced in the near future, because of legal obstacles. In 1952, an additional protocol was added to the Mannheim Convention (see also text box) stating explicitly that fuels used in inland shipping shall be free of taxes, duties and levies. Any economic incentive based on fuels seems therefore not to be feasible under the current law.

> **The Central Commission for Navigation on the Rhine (CCNR) and Mannheim Convention**
>
> Besides national governments and the Commissions, the Central Commission for Navigation on the Rhine (CCNR) is a major policy making authority for inland navigation in Europe.
>
> The CCNR is based on the so-called Mannheim Act of 1868. The main tasks of the CCNR are to ensure the freedom of navigation on the Rhine and its tributaries, and to maintain a uniform legal regime governing navigation along the full length of the river. The river Rhine and its tributaries are by far the most important inland waterway in the EU, making that CCNR a major player in inland navigation policy.
>
> The CCNR has five member states being Netherlands, Belgium, Germany, France and Switzerland. Committee resolutions must be made unanimously. Thus, each member state has a veto right.

6.6.4 Other policy developments

Action programme by the European Commission

The European Commission intends to present a Communication on the promotion of Inland Waterway Transport by the end of 2005. The Communication will set out an integrated action programme, focusing on concrete actions to fully exploit the market potential of inland navigation and to make its use more attractive.

The consultation document for this Communication listed several proposed actions and measures. For emission policy the most relevant issues that were included are in the field of *Stimulate fleet modernisation and innovation*:
- Develop and facilitate use of innovative vessel concepts and technologies.
- Encourage use of eco-efficient engines and renewable energy sources.
- Develop refit concepts for existing vessels.

The main instruments that were listed are the following:
- State aid guidelines for support programmes.
- Support programme to facilitate efficiency, environment and safety-enhancing technologies (incl. research and fiscal incentives).
- EU RTD and support programmes (FP 7, lead projects for sector innovation).
- European inland navigation Innovation Fund.
- Funding Handbook for inland navigation.
- Reinforced environmental and safety legislation (incl. waste disposal, dangerous goods).

Subsidy program for emission reduction measures for inland vessels

An example of additional emission policy for inland navigation is a recent initiative in the Netherlands. The Dutch government will start a subsidy program for emission reduction measures for inland vessels. This program, which was approved by the European Commission at 5 July 2005, will grant a subsidy in the following cases[41]:

- Purchase of a low emission engine instead of a conventional engine (either for a new vessel or an existing vessel).
- Purchase of a low emission engine instead of revision of an conventional engine.
- Retrofit measures like installation of an SCR (either for a new vessel or an existing vessel).

Economic instruments

Economic instruments to reduce emissions from inland navigation have not got much attention. A reason behind this is the current lack of charges for inland navigation. Therefore, almost all new pricing instruments would increase the cost price of the sector, unless the revenues would be ploughed back in the sector (like with a combination of charges and subsidies for clean technology).

In most other transport modes pricing instruments are applied and further being developed. Rail operators pay infrastructure charges and often also fuel or energy charges, air companies pay airport taxes and noise charges, road hauliers pay fuel excise duty, road toll and other infrastructure charges. Inland navigation is an exception, because except from some harbour duties, this sector does not pay any charges.

In 2004, CE Delft carried a preliminary study for the Dutch Ministry of Housing, Spatial planning and Environment on pricing policy for inland navigation. It focused on economic incentives to reduce NO_x emissions.

Three types of economic incentives were investigated: a differentiated fuel charge, a differentiated waterway charge and differentiated harbour dues. All incentives act by charging vessels with low emissions less than vessels with high emissions.

A detailed calculation shows that an incentive level of € 2.5 per kg of NO_x emitted constitutes an adequate incentive that will induce vessels responsible for the majority of emissions to invest in emission reducing technology. The incentives studied differ in their effectiveness, their feasibility and in their possibilities to guarantee compliance.

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41 Source: http://informatie.binnenvaart.nl/binvrtmilieu.php.

This study also listed the following arguments that could be brought forward for investigating additional emission policies for inland navigation:

- Both the CCR and the EU standards only apply to *new* engines. Given the rather long lifetime of engines (up to several decades), it will take a long time before these standards translate into a significant reduction of emissions.
- Neither the EU nor the CCR standards are ambitious from an environmental point of view. Even with the existing technology, emissions can be reduced much more.
- Compliance with agreed National Emission Ceilings (NECs), might become more difficult without additional policies.
- Several studies show that costs of reducing NO_x in inland shipping are low compared to other sectors[42]. From a macro-economic point of view, it is therefore economically efficient to allocate a substantial part of the NO_x emission reductions that are needed for meeting the NECs in European Member States to the inland shipping sector. '
- It lacks policy measures to reduce greenhouse gas emissions from inland navigation.

6.7 Emission inventory

Emissions from inland navigation are monitored in various ways. In many countries, inland navigation is a very small sector, resulting in no or very little attention for monitoring it. In countries where inland navigation has a significant share in the total transport volume, emissions are generally monitored based on bunker fuel statistics. However, this makes it hard to allocate emissions to a flag or geographical area (see 2.8). Moreover, emissions the split between inland navigation and sea shipping is not always made in the same way.

Because of the Kyoto-protocol, reporting on emissions from inland navigation is required and thus also being improved in countries where inland navigation is a relatively important mode. Bottom-up methods (see 2.7) are developed for reporting to IPCC, to be able to distinguish national emissions from emissions on other territories.

In the Netherlands, a new methodology has been developed for monitoring CO_2, NOx, PM10, CO, HC and SO2 in 2003 (AVV, 2003). This method distinguishes between main engines and auxiliary engines. Both types of engines are included in the model. The emission calculations are based on energy use which is calculated using the following parameters:

- A list of 28 vessel types.
- Required engine power per vessels type, for each category of waterways.
- Routes and distances per vessels type, for each category of waterways.

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[42] Brink, R.M.M. van den, A. Hoen, B. Kampman, R. Kortmann and B.H. Boon, 2004: 'Optiedocument Verkeersemissies: effecten van maatregelen op verzuring en klimaatverandering', *RIVM Rapport* 773002026.

The model discriminates between:
- Loaded and unloaded navigation.
- Sail direction (with respect to the flow).

The emission factors for pollutants that are used in this model are the same as the ones listed in Table 19. The emission factors used are thus rather rough average values.

Belgium is currently developing a similar emission model. Also Germany has a similar model, but slightly less advanced. These types of movement-based national models could serve as a basis for a European model, though they seem hard to harmonize.

An alternative approach would be a fuel based approach. This approach could yield better results for CO_2 and SO_2, but not for NO_x CO, HC and PM, as these compounds are not formed directly from the combustion of fuel. A fuel based approach would require much better, completer and more detailed fuel data (at least differentiated to different vessel types) than are currently available.

7 Conclusions and recommendations

7.1 Non-road modes contribute significantly to transport volume and emissions

Non-road modes account for more than half of the freight transport volume in the EU-25 (measured in tonne-km). Of these modes, sea shipping has the largest share in this kind of transport (39% when extra-EU maritime shipping is excluded, 76% when included), followed by rail and inland navigation. Freight transport by air is, compared to the other modes, insignificant.

In passenger transport, non-road modes play a less significant role, only 18% of the passenger kilometres are travelled by modes other than road transport: 12% by air and 6% by rail.

Non-road modes have a smaller share in emissions than in transport volume, but emissions are significant and growing. When looking at greenhouse gas emissions, the share of non-road modes is about 26% of total transport emissions in the EU-15 if non-CO_2 effects of aviation are excluded, and 39% when they are included. The main contributors to greenhouse gas emissions are aviation and maritime shipping, the effects of rail and inland shipping are almost negligible. The particularly quickly growing climate impacts from international aviation alone will, unless abated, use up almost 40% of the EU-25 CO_2 budget in 2050 if the current ambition of a 60% reduction in 2050 is adhered to. Regarding NO_x emissions, non-road modes contribute about 36% of total transport emissions in the EEA-25, 10% more than a decade ago, and growing. International maritime shipping is the largest non-road emitter (27% of total transport emissions), followed by aviation (7% of the total).

It is becoming increasingly clear that in terms of greenhouse impacts of transport, CO_2 is not the only emission of concern. To compare modes properly, direct and indirect climate impact of non-CO_2 emissions should also be taken into account. The climate impact of non-CO_2 emissions makes the climate impact of aviation larger than could be expected on merely the CO_2 emissions. For maritime shipping the contrary might be true: non-CO_2 emissions might, at least at the short term, partly compensate the GHG effect of CO_2 emissions.

7.2 Modal shift and comparisons of transport modes

With an integrated approach varying from pricing to revitalising alternative modes, as described in the White paper on the Commission Transport Policy (CTP), the European Commission attempts to shift the balance from road to rail and increase the market share of rail transport.

However, there is always a risk that specific measures aimed at modal shift, like building new rail infrastructure, boost the transport volume of rail or water transport without much decreasing road transport volumes. Because of these types of unintended side-effects, the net environmental impact of measures aimed at modal shift should always be taken into account during the decision making process.

The following key issues should be paid attention to when comparing the environmental impacts of different transport modes:
- Compare only modes that are actually competing and use characteristics for each mode that apply to the specific market which is investigated.
- Include all effects of a "door-to-door" delivery (detours and additional transport steps at both ends of the chain).
- For any study, assumptions have to be made about the load factors of the various modes, these may influence the results significantly.
- Emissions of electricity generation vary significantly across countries and this may have an effect on the life cycles of all modes of transport, but obviously most significantly on electric rail.
- Emissions from electricity production should be included in case of electrical rail transport, emissions of oil production, transport and refining should be included when calculating the emissions of fossil fuels.

7.3 Emission and fuel standards

Emission and fuel standards in non-road modes lag behind, compared to road transport, but standards are now being introduced in non-road modes as well. It will take relatively long, however, before the effect of emission standards can be seen in total emissions data, since the average lifetime of locomotives, ships or airplanes is much longer than that of trucks or cars. Environmental improvements in the short term can thus be achieved with policies aimed at fuels, or with additional policy measures aimed at retrofit or accelerated fleet renewal.

There is a huge range in sulphur content in the fuels of non-road modes. For 2009, for road transport the standard will be 10 ppm, more than a factor 100 less than currently foreseen for the other modes, with maritime shipping lagging far behind.

7.4 Environmental measures and policy per mode

7.4.1 Aviation

The main conclusions with respect to aviation are:
- At the moment the responsibility for the greenhouse gas emissions of aviation has not been assigned to individual parties.
- Scientific insight into the magnitude and mechanisms of the non-CO_2 climate effects (NO_X, contrails, cirrus clouds, soot) is incomplete, let alone that it is clear how these can be made operational for policy instruments. Additionally, insight into the effects and feasibility of flanking instruments is lacking.
- In ICAO, the USA and Australia block any progress within the Annex-1 countries. Non-Annex-1 countries also cause delays.

- Aviation, other than the landing and take-off cycle, is not included in the NEC-directive that gives emission ceilings for CO_2 and pollutants (NO_X, PM).
- Local air quality in the vicinity of airports is becoming increasingly important and in many cases hinders the future development of airports. A few airports give incentives by means of emission-based landing charges to induce airlines to use cleaner aircraft.
- In 2005 a European Commission policy paper started the discussion with other European institutions on internalising the environmental costs of aviation. The Commission regards the inclusion of aviation in the EU Emission Trading System (ETS) as the most promising way forward. A working group will be set up, to consider ways of including aviation in the EU ETS to feed further discussions. The Commission aims to put forward a legislative proposal by the end of 2006.

7.4.2 Rail

Currently, emission standards for diesel-powered engines are set by the UIC. In 2006, the first EC emission standards will come into force. Because of slow fleet renewal, standards will still take long to have an actual effect on (total) emissions.

For rail, emissions of diesel-powered transport are in principle included in national inventories. The emissions of electric rail are included in the inventories for electricity production and CO_2 emissions are thus covered by the emission trading scheme. This does not provide direct incentive to the rail sector to reduce emissions, however. It also means that comparisons of total emissions for various transport modes are biased, as emissions of electric rail transport are not currently included. There is a trend towards toward high-speed rail passenger transport over intermediate distances. Although emission factors for high-speed trains are very variable and depend partly on speed, they are in general less efficient than conventional trains, but it should be kept in mind that high-speed trains compete on other markets than conventional trains.

Average emissions of the rail transport sector are influenced by the relative shares of diesel- and electric-powered trains. The overall trend seems to be toward an increasing share of electric rail transport, which could in principle result in lower average emissions. However, if this is partly due to the developments in high-speed rail, this may not be the case.

Differentiation of infrastructure user charges by environmental performance offers opportunities for emission reduction. Fuel excise duties already exist in most countries, but are strongly variable. Introducing or increasing these duties across the EU would provide an incentive to improve efficiency.

7.4.3 Maritime shipping

The main conclusions regarding maritime shipping policies are the following:

- The emissions that take place on open sea are currently not allocated to any of the EU countries or (in the case of greenhouse gases) Kyoto-members.
- Fuel efficiency is relatively good compared to other modes. However, since bunker fuels are relatively cheap and not taxed, there is much less incentive to reduce fuel consumption than in road transport, for example.
- Both the EU and the IMO are working on the development of greenhouse gas policies, but no agreement has yet been reached.
- Emissions of SO_2, NO_x and other substances may have significant short and medium term climate impacts. However, the science on this issue is currently insufficient to provide reliable answers and more research is needed.
- Annex VI of the IMO Marpol agreement contains the first engine standards (regulating NO_x emissions) and fuel sulphur limits in this sector. It came into force in 2005. This provides the opportunity to start discussions on tightening these standards[43] and designate more EU regions as SO_x Emission Control Areas. However, emissions policy development on a global level is found to be a difficult and long-term process.
- In 2005, an EU Directive was issued that regulates the sulphur content of marine fuels in EU waters. SO_x Control Areas are implemented, and the sulphur content of fuels used by inland waterway vessels and vessels at berth in ports was limited, with effect from 2010.
- Refrigeration equipment used in maritime vessels are sources of fluorinated gas emissions, strong greenhouse gases. Average leaking rates are relatively high in maritime refrigeration equipment, compared to emissions from other transport modes or stationary sources. These emissions are currently not monitored or regulated.

7.4.4 Inland navigation

Emission standards for inland navigation have come into force and will be tightened in 2006 and 2007. However, standards do not yet reflect the lowest levels that can be reached with current techniques. Moreover, it takes long until standards will become effective, since engines of inland vessel have a very long lifetime. Therefore further steps in emission standards are needed to further decrease emissions from inland shipping. Additional policies like subsidies on the installation of emission reducing techniques can speed up the process of emission reduction.

There is no policy to reduce greenhouse emissions from inland navigation. It also lacks excise duty for fuel for inland vessels and any other economic instrument, except from relatively low harbour dues. Introduction of an excise duty or other economic measures legal obstacles like the Mannheim Convention need to be tackled first.

[43] The NO_x standards for ship engines are generally considered not to be very stringent, since virtually all ship engine manufacturers already build engines that meet these standards for several years.

7.5 Emission inventories

In this report, emission inventories have been drafted for all non-road modes except for rail. However, currently it is not possible to draft consistent, comparable and reliable emission inventories for any non-road mode. The reason for this differs per mode:

- For aviation, the main obstacle is the different possible allocation options. Since a large part of aviation is international, allocation of emissions from these flights may have significant impacts on the countries for which inventories are calculated. In the aviation sector, data availability does not seem to pose large problems. Data for both bottom-up and top-down inventories are currently recorded (although they are not reported). For greenhouse gas emissions, several inventories of good quality have been drafted, demonstrating that this is indeed possible.
- For the rail sector, there are currently no emission inventories available. However, drafting an emission inventory does seem possible once some methodological issues have been dealt with. The obstacles encountered in other sectors are of minor importance to the rail sector. Allocation of international emissions is not so problematic and may prove to be insignificant for most countries. This is due to the fact that international rail transport is much smaller than national rail transport in most countries. Furthermore, data seems to be readily available. For electric trains, data from the power sector could be used (although double counting should be avoided). For diesel trains, activity data and emission factors are available and of reasonable quality.
- For the marine sector, the main obstacle is the lack of agreement on allocation of emissions. Furthermore, data availability is relatively poor. The inventories currently available rely heavily on data that is only commercially available, and on average emission factors for only a limited number of ship categories. Recently, emission inventories of maritime shipping were calculated for the EU using a bottom up model, for a number of allocation options.
- For inland navigation, some countries are much more advanced than others. This means that some countries have solved their data and methodological issues, while other countries still have a long way to go. This means that it will take a long time before comparable inventories can be drafted. Furthermore, the issue of allocation seems not to addressed currently, though this may have a significant impact on inland shipping in countries with international waterways, such as the Rhine and Danube countries.

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Environmental data and policy on non-road transport modes

Working paper for the European Environment Agency

FINAL

Annexes

Report

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A Data tables

A.1 Freight transport volume in billion tonne-km (EU-25)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Road			1,048	1,053	1,120	1,242	1,260	1,313	1,382	1,435	1,480	1,510	1,549	1,555
Rail			356	340	349	359	360	380	370	357	374	360	359	368
Inland navigation			110	108	117	120	116	124	127	126	132	130	129	114
Short Maritime shipping	950	983	1,013	1,043	1,073	1,101	1,157	1,175	1,232	1,307	1,290	1,291	1,346	1,375
Shares														
Road			41%	41%	42%	44%	44%	44%	44%	44%	45%	46%	46%	46%
Rail			14%	13%	13%	13%	12%	13%	12%	11,1%	11,4%	10,9%	10,6%	10,8%
Inland navigation			4,4%	4,3%	4,4%	4,2%	4,0%	4,1%	4,1%	3,9%	4,0%	3,9%	3,8%	3,3%
Short Maritime shipping			40%	41%	40%	39%	40%	39%	40%	41%	39%	39%	40%	40%

Coverage: EU-25. Volumes for maritime shipping have been estimated for all countries not belonging to the 15 old member states. The estimation is based on reported energy consumption by maritime shipping. The inclusion of these states adds only 2.9% to the total for EU-15. Short Maritime shipping includes domestic and intra-EU shipping. An estimate of the magnitude of transport volumes from shipping between EU and outside countries is given in annex A.6). Data for road, rail, and inland modes is collected annually in conformity with EU directives, and is quite reliable. These data are contained in Eurostat Structural Indicator data sets. Data for short maritime shipping comes from Eurostat estimates and is probably not very accurate. The latter data are available in ‘EU transport and energy in figures - statistical pocketbook 2004’. The data in this table is also used in TERM 13 2004 - freight transport demand.

A.2 Passenger transport volume in billion passenger-km (EEA-23)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Rail	338	340	331	326	321	324	325	330	335	345	358	361	357
Air	355	337	390	417	459	506	564	563	606	654	714	689	689
Car	3,294	3,482	3,625	3,683	3,740	3,801	3,876	3,951	4,048	4,133	4,208	4,259	4,339
Bus	567	555	556	549	534	551	563	567	574	571	573	565	555
Shares													
Rail	7%	7%	7%	7%	6%	6%	6%	6%	6%	6%	6%	6%	6%
Air	8%	7%	8%	8%	9%	10%	11%	10%	11%	11%	12%	12%	12%
Car	72%	74%	74%	74%	74%	73%	73%	73%	73%	72%	72%	73%	73%
Bus	12%	12%	11%	11%	11%	11%	11%	10%	10%	10%	10%	10%	9%

Note: EEA-23 includes 23 European countries: B; DK; D; EL; E; F; IRL; I; L; NL; A; P; FIN ; S ; UK; CZ; HU; PL; SK; SI; TR; IS; NO. Passenger-km (pkm) for air includes all transport by European carriers in the EEA-23. Information is not available on transport by non-European air carriers. All pkm performed on international flights with origin or destination in an EEA-23 country is included, so do not occur exclusively on European territory. Due to varying and somewhat inconsistent coverage, air pkm data should be interpreted with caution. Data for road and rail modes is collected annually by Eurostat, though not in a harmonised way, and data is less accurate than the freight volume data. These data are contained in Eurostat Structural Indicator data sets.

Source: TERM 12 - passenger transport demand (2005).

A.3 NO_x emissions in kilotonnes

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Road Transport	5,630	5,647	5,641	5,495	5,435	5,265	5,251	5,092	4,993	4,852	4,710	4,478
Railways (diesel)	132	129	121	107	91	89	87	83	82	83	82	78
Navigation (national)	374	371	368	371	375	369	375	379	392	405	376	377
Navigation (int. bunkers)	1,168	1,150	1,179	1,232	1,211	1,256	1,351	1,477	1,582	1,509	1,562	1,573
Civil Aviation (domestic)	69	67	69	68	66	70	75	76	81	86	87	95
Civil Aviation (int. bunkers)	260	263	284	306	318	329	347	367	386	416	449	439
Total transport	7,633	7,627	7,663	7,579	7,495	7,379	7,485	7,474	7,517	7,351	7,266	7,039

Note: Coverage is EEA-26, which includes Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, United Kingdom, Czech Republic, Estonia, Hungary, Latvia, Malta, Poland, Slovakia, Slovenia, Bulgaria, Romania, Iceland, and Norway. Data is based on fuel sales. Each country reports fuels sales and the shares of international and domestic transport. Emissions are calculated with the help of emission factors and in the case of air transport, the reported number of landings and take-offs. Emissions from electric trains is not included, but an estimate is provided in section 4.3. Emissions are not restricted to European territory.

Source: TERM 03 data sheet. Original source: Submissions to IPCC.

A.4 Greenhouse gas emissions in Mtonne CO_2 equivalent (EU-15)

Year	1990	2001
Rail (diesel)	9.8	6.7
Road	649.1	770.8
Domestic air	22.0	27.9
Domestic sea	16.9	15.0
International sea	100.2	130.6
International air	56.7	95.5

Note: Data covers EU-15, but these values are indicative of Europe in general, as EU-15 accounts for most of Europe's greenhouse gas emissions. Data includes annual emissions of CO_2, CH4, N_2O, HFCs, PFCs and SF6 in UNFCCC reporting format (in million tonnes) converted to their global warming potential where necessary (100-year time horizon) for addition and comparison with the Kyoto-protocol targets. Some data gaps have been filled, see source below for more details. Emissions from electric trains is not reported separately, but falls under emissions from electricity production. CE Delft roughly estimates CO_2 emissions alone to be roughly 27 Mton (see section 4.3). The 'sea' categories also include inland navigation, though its share is very small.

Source: TERM 02 data sheet. Original source: submissions to IPCC. While originally reported separately, international emissions are included in this table.

A.5 Specific emissions of NO_x, CO_2, and PM_{10}

Maritime shipping				
		CO_2	NO_x	PM_{10}
Bulk	OC1	141.33	2.95	0.20
	OC3	4.36	0.09	0.006
	OC5	1.33	0.03	0.002
Non-bulk	C1	23.67	0.49	0.03
	C3	16.85	0.35	0.02
	C5	14.75	0.31	0.02

Adapted from original data by omitting contribution by transport to and from loading points and detour factors. The resulting values do take into account typical loading factors that differ between bulk and non-bulk transports. The original study includes a 15% margin of variation in load factors, which is included in Figure 36.

OC1-OC5 denotes different size classes of sea bulk carriers ranging from 1,100 to 175,000 Gross register tonnage, the latter corresponding to a large oil tanker. C1-C5 denotes different size classes of sea container vessels ranging from 350 to 4 000 TEU.

Source: CE Delft, 2003a.

A.6 Maritime shipping transport volumes

Million tkm	National	IntraEU15	ExtraEU15	Total
BE	298	69.04	1,046,133	1,115,470
DK	2,265	25,516	144,756	172,537
DE	1,094	93,093	1,249,881	1,344,069
EL	8,403	55,722	173,362	237,488
ES	31,506	120,572	1,368,671	1,520,749
FR	34,117	86,056	1,290,012	1,410,185
IE	334	23,242	81.29	104,866
IT	45,481	114,299	1,399,665	1,559,445
NL	:	110,809	2,457,755	2,568,564
PT	3,998	28,988	181,306	214,292
FI	3,162	89,772	121,394	214,328
SE	7,539	64,605	212,404	284,548
UK	36,518	190,504	1,690,426	1,917,448
EU15	174,715	780,673	11,417,056	12,372,443

These are the preliminary estimates of Eurostat's Maritime transport working group and are for the year 2003. Data are very rough estimates based on incomplete data. Information on tonnage carried, origin/destination ports, and a port to marine coastal area (MCA) distance matrix has been used for the estimates. No long time series exist for these data. The ExtraEU-15 includes all tkm between EU15 and origins or destinations outside of EU-15. It is arguably more fair to allocate only half of the EXtraEU15 tkm to EU15. Note also the discrepancy between the national+intra-EU15 figures above and those reported for maritime shipping in Annex A.1.