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To shift or not to shift, that's the question

The environmental performance of the principal modes of freight and passenger transport in the policy-making context

Report

Delft, March 2003

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Publication Data

Bibliographical data:
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Transport / Policy / Environment / Effects / Comparative study / Emissions / Energy use / Investments / Price fixing / Competition (economical) / Capacity / Logistics

VT: Modal-shift

Publication number: 03.4360.09

Commissioned by: RIVM (Dutch National Institute of Public Health and the Environment)
Further information on this study can be obtained from Huib van Essen.

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Summary

Introduction and aim

The environmental performance of different modes of transport – whether perceived or real – plays a major role in transport policy decision making. For example, priorities in infrastructure investments and pricing strategies are partly driven by (perceptions of) environmentally 'good' and 'bad' modes, with cars and aircraft generally figuring as 'bad' and rail and water transport as 'good'. Indeed, if we calculate current average emissions of these four modes, such conclusions are easily drawn.

It can be queried, however, whether this observation still holds upon closer examination. In practice, mopeds do not compete with aircraft. More generally, environmental comparisons between transport modes only make sense for well-defined, homogeneous and competing markets and for complete transport chains. If sound transport policy conclusions are to be drawn, moreover, analysis must move beyond the present to include the anticipated *future* environmental performance of the various modes of interest.

Besides presenting a state-of-the-art review of the environmental performance of the main competing transport modes, this report has the additional aim of clarifying how the figures found in this study can be used in everyday transport (policy) decision making. This goal was added because experience has shown that environmental performance figures are all too easily put to generalised use[1].

Methodological conclusions

In this report we make a clear distinction between 'raw', unprocessed data and application of those data. Raw data relate to:

- the environmental impacts of moving vehicles: energy use and emission factors per vehicle kilometre;
- the environmental impacts of refineries and electrical power plants: energy use and emission factors per kWh or GJ;
- the logistical characteristics of transport modes (e.g. vehicle capacities and load factors);
- vehicle usage elasticities as a function of transport demand, used to calculate *marginal* energy use and emissions. Marginal values relate to the effects of one hypothetical extra passenger, *average* values to the average emissions of all passengers. This distinction is particularly interesting in the case of public transport, as demonstrated in footnote 1.

To permit comparison of specific transport situations, for each transport mode several sub-categories are distinguished, including size classes, fuel types, peak or off-peak hours, urban and extra-urban, and, in the case of freight transport, 'bulk' versus 'non-bulk' transport.

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1 Consider the example of a trip taken by off-peak and thus relatively empty train rather than by car. The rail operator will not respond to this increase in off-peak demand by laying on more off-peak trains, but first reap the benefits of increased load factors on existing trains. For this kind of off-peak transport decision by consumers, then, the so-called **marginal** environmental performance of public transport will always be superior to that of private transport. However, this implies in absolutely no way that constructing a new rail link will lead to lower emissions.

To ensure correct processing of these raw data we developed a seven-step approach which was applied in this study and which we also recommend for further analysis of this topic:

1 Define competing transport market sub-*segments*, for example bulk freight transport over medium distances.
2 Define a complete transport *chain* from origin to destination, including transport to and from loading point. If the transport mode to and from loading points is unknown, this report provides default emission estimates.
3 Decide whether comparison is to be based on an average passenger or tonne (*average* emissions) or a hypothetical extra passenger or tonne in a given situation (*marginal* emissions). Marginal emissions are of interest in the evaluation of measures that primarily affect the demand side, like individual travel advice or lowering of road fuel prices. Average emissions should be used for evaluation of measures that primarily affect the supply side, like train schedules or new infrastructure. If the marginal approach is adopted, average emissions should be multiplied by vehicle usage elasticities.[2] The report provides elasticities for peak and off-peak public transport.
4 Decide on *logistical* parameters like load factors, percentage of so-called 'non-productive rides' and detour factors. Default values are provided.
5 Decide on the year in which modes are to be compared.
6 Decide whether newly marketed vehicles in that year are to be compared or 'fleet-average' vehicles.
7 Decide on the environmental impacts to be compared. The most relevant emissions are usually CO_2, PM_{10} and NO_x. Noise nuisance and safety impacts may also often have to be compared.

Comparing the overall environmental impact of particular policy alternatives only makes sense if all potential factors of influence, direct or indirect, are duly accounted for, in particular:

- **environmental efficiency effects** (effects on environmental characteristics);
- **transport efficiency effects** (effects on logistical characteristics);
- **substitution effects** (modal shift, due to competitive characteristics);
- **volume effects** (effects on total transport volume).

The environmental impact of the last two of these effects can be calculated from the emissions per passenger kilometre or tonne kilometre of the respective transport modes. The first two effects cause direct changes in emissions per passenger kilometre or tonne kilometre. All policy measures have different types of effect, often working in opposing directions. The overall impact of a given policy measure depends on all the direct and indirect effects on the mode to which the policy measure specifically applies, and on the response of all other modes.

Conclusions on environmental performance of transport modes

This study presents and compares the quantitative emissions per passenger kilometre or tonne kilometre of CO_2, NO_x and PM_{10} for several well-defined, homogeneous transport market segments. The main conclusions of these comparisons are as follows:

- from an environmental perspective it makes no sense to speak of 'clean' or 'dirty' modes of transport. Environmental performance generally de-

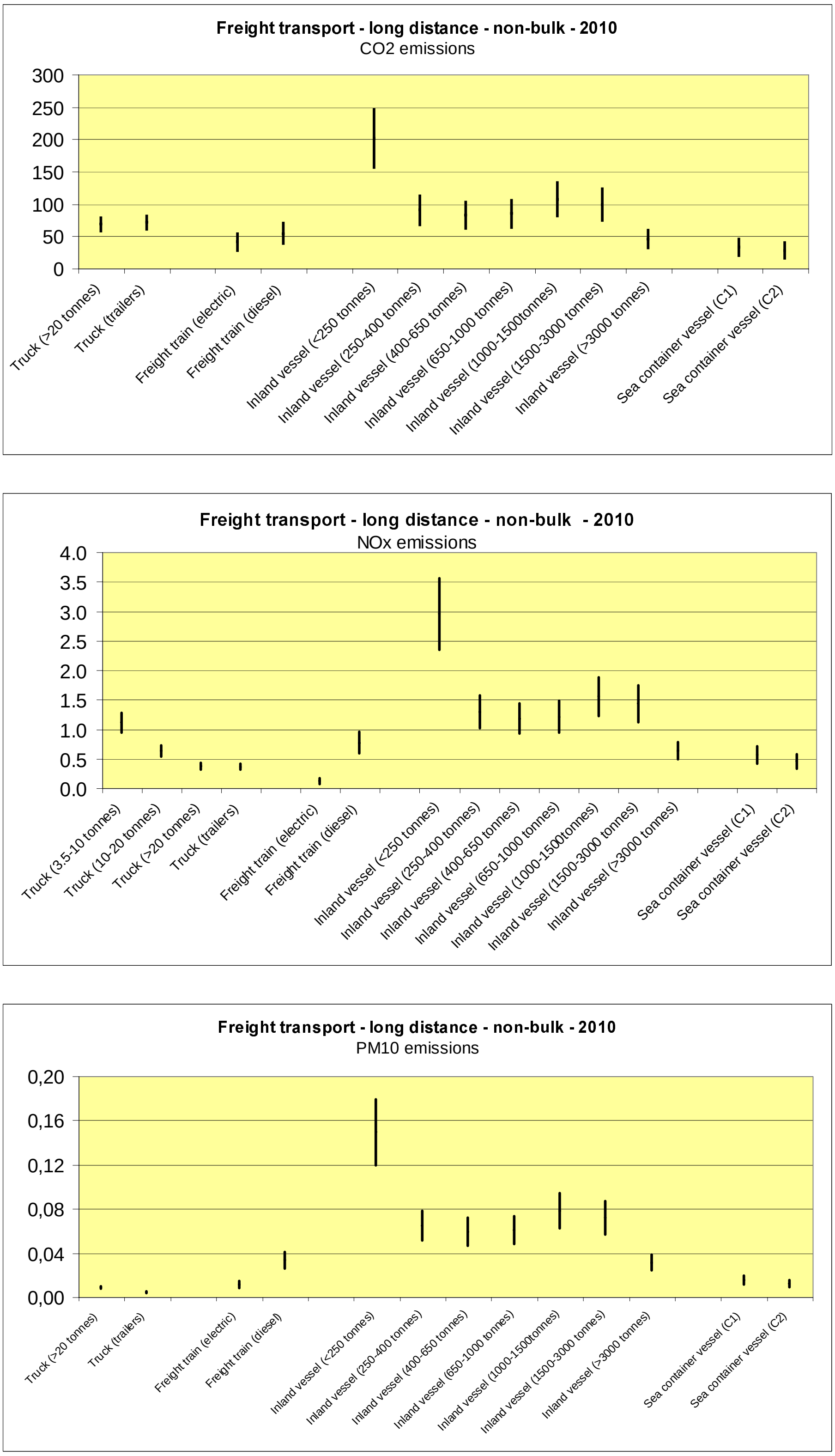
[2] When the number of hypothetical passengers becomes large, marginal emissions come to approximate average emissions.

pends more on installed technology and logistical characteristics than on mode *per se*;
- the results of any environmental comparison depend on the policy question for which an answer is sought. If, on a particular route, rail transport has lower emissions per tonne kilometre than road transport, say, this does not imply that building a new rail link will reduce the environmental burden.

*Medium and long distance **freight** transport*
We start with an in-depth discussion on road and inter-modal transport of non-bulk goods (such as maritime containers) for the year 2010 over distances of over 100 km. This specific freight transport sub-segment represents the main market opportunity for rail and water transport. As such, it is essential in achieving the EU's policy target of stabilising the 1998 market share of rail and water transport. See 1 for a graphic picture.

The main conclusions of this specific comparison and for freight in general are:
- In **2010**, long-distance road transport will outperform **non-bulk intermodal** water and diesel-powered rail transport with respect to air pollution. Differences in CO_2-emissions between modes are relatively small in this segment. Which mode scores best depends on the specific case. Road transport generally scores several dozen per cent worse than rail and sea, but a little better than inland shipping.
- The picture is more favourable for rail and water transport when **bulk** transport and/or the year **2000** are considered. Crucial factors for rail and water appear to be type of traction (electrical power is far 'cleaner' than diesel), environmental performance of diesel engines (currently lagging behind road transport), logistical efficiency and vessel size.
- More generally, the differences in environmental performance between transport modes *in homogeneous and **competing** freight markets* are smaller than the differences between the *average emissions* of the modes in question. This is because the relatively cleanest sub-segment of road transport – long-distance transport with relatively new, well-filled and large trucks – is precisely the segment that competes with rail and water transport.
- The CO_2-emissions per tonne kilometre of freighter **aircraft** are extremely high compared with all other modes: from over *ten times higher* than the worst of all other non-bulk freight modes, up to *sixty times higher* than the best of these modes.

Figure 1 CO_2, PM_{10} and NO_X-emissions per tonne kilometre of inter-modal non-bulk freight transport by road, rail and water



Emissions of electric modes based on electricity production in Europe excluding nuclear power. Electricity production in the Netherlands has 38% lower NO_x and 65% lower PM_{10}-emissions.

*Short and medium distance **passenger** transport (in 2000)*[3]

- In these markets, passenger cars have by far the highest CO_2-emissions of all modes (thus contributing significantly to climate change). Car emissions of air pollutants are also higher than for most other modes, though much lower than for diesel stop trains (medium distance) and local buses (short distance).
- Electric modes (tramway, subway and inter-city trains) show by far the lowest *average* emissions per passenger kilometre. For medium distance, coaches, electric local trains and high-speed trains have low emissions per passenger kilometre compared with other modes. Local buses (short distance) and diesel local trains and regional buses (medium distance) have much higher air pollutant emissions per passenger kilometre than most other modes.
- If *marginal* emissions are the yardstick, the figures for off-peak public transport become much more favourable, with those for public transport in the peak probably somewhat less favourable.
- For the year 2010, differences between modes become substantially smaller, as most modes, particularly cars and buses, will become cleaner. Diesel-powered trains are probably an exception to this rule.

*Long distance **passenger** transport (in 2000)*

- The load factor and the transport to and from loading points (mode, distance, load factor) are decisive in determining which modes have the lowest emissions in this market.
- The climate impact of passenger transport by air is much higher than that of all other modes, particularly because this impact is not limited to CO_2-emissions alone. Coaches and inter-city trains show the lowest CO_2-emissions. High-speed trains score considerably worse.
- The CO_2 emissions of passenger cars on long distance trips are far lower than over short and medium distances, mainly because of the usually higher load factors achieved. In some cases the CO_2-emissions of passenger cars are among the ‘best in the class’.

[3] The results of short and medium distance passenger transport are fairly similar and are therefore taken together here.

1 Introduction

1.1 Comparison of modes: a foundation for transport decisions

Transport has a large share in the total emissions and energy use in Europe. In 1998, transport was responsible for 20% of all CO_2-emissions in Europe and for 63% of all NO_x-emissions [TERM 2001]. This is why the emissions of transport are an important issue for environmental policy.

For many transport decisions, it is assumed that one transport mode is more polluting than another. Both governmental policy decisions and individual transport decisions of companies or private people are based on comparisons of the environmental effects of different modes.

In governmental transport policies, the environmental effects of different transport modes are essential information for decisions on modal shift, pricing and infrastructure. In its White Paper "European transport policy for 2010: time to decide", the European Commission proposes modal shift as one of its policy targets [EC, 2001].

Comparing transport modes on their environmental burden, is not merely a subject for governmental policy makers. Also a 'responsible' company that wants to transport its goods, has to know the environmental effects of different modes to be able to make a well-founded decision. A family who plans to make an environmental-friendly European journey needs to know the environmental effects of different options.

But do all these decisions, based on existing comparisons of environmental effects, ultimately contribute to a decrease of the total emissions? The answer to this question depends on the data that are used and the way they are processed. A good comparison of modes requires data that make it possible to *predict* the effects of different transport decisions rather than data that merely *describe* the current situation.

1.2 A new approach to an old subject

Many studies have been carried out to compare emissions of different transport modes[4]. 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.

In this study we go a step further by looking at the question that needs to be answered. Predicting the effect of a new railway link to a seaport may require different data than needed for predicting the effect of lower prices of public transport or for giving a consumer advise on the environmental impact of individual transport decisions. In addition to that, comparing modes in a specific segment of the transport market can be very different from comparisons in other market segments.

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4 Like [TRD, 1979], [Danielis, 1995], [Banistar, 1995], [Scholl, 1996], [TUD, 1996], [CE, 1997a], [CE, 1997c], [RIVM, 1997], [WWF/DB, 1999], [CE/RIVM/TNO, 2000] and [SNM, 2001].

In 1997 RIVM has carried out a study on the energy use and emissions of several transport modes [RIVM, 1997]. This is an important and often used report with a thorough overview of emissions and energy use of many modes.

The aim of this study is to improve and update this report. The most important reasons for this are:

- there is a need for guidelines and cases that explain how to use the data, depending on the question and the transport market;
- there are new data available (emission factors, load factors, etc.);
- there is a need to add more transport modes;
- this new study is written in English to make it easier to use the results on a European scale.

This report has primarily been written for policy makers who want to compare the environmental impacts of their policy measures.

1.3 Required data and appropriate method depend on the question and the market segment

Different modes are often compared on the average emissions per passenger kilometre or tonne kilometre of each mode. However, in specific market segments and for the whole transport chain from origin to destination, differences in environmental impact between modes can be very different from these average values. This is why comparison of modes based on average load factors and average environmental performances, often leads to misleading conclusions. A comparison of transport modes only makes sense for well-defined homogeneous market segments and when the whole transport chain is considered.

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.

This is why in this study we make a clear distinction between the unprocessed data and the application of these data. The unprocessed data are the 'raw' data about the emissions per vehicle and about several characteristics like seat or load capacity and load factors. In these unprocessed data we distinguish per mode several categories like size classes, fuel types, peak or off-peak hours and the difference between 'bulk' and 'non-bulk' for freight transport. These unprocessed data for different categories give the possibility to calculate the emissions per passenger or tonne kilometre in any specific situation. This can result in a more reliable comparison of the environmental effects of modes than that is possible with average values.

1.4 Aims of this study

The aims of this study are:

1 To give an overview of the data required for the calculation of environmental impacts.
2 To present the emissions per passenger-kilometre or ton-kilometre of different modes in some well-defined homogeneous market segments and considering the whole transport chain.

3 To provide guidelines for the application of the data for policies that influence modal split.

In this report we make a clear distinction between 'raw', unprocessed data and application of those data. With the unprocessed data one should be able to calculate the environmental performance of transport modes in different situations and for different applications (e.g. for consumers, policy makers). Raw data relate to:

- the environmental impacts of moving vehicles: energy use and emission factors per vehicle kilometre;
- the environmental impacts of refineries and electrical power plants: energy use and emission factors per MJ fuel or electricity;
- the logistical characteristics of transport modes (e.g. vehicle capacities and load factors);
- vehicle usage elasticities as a function of transport demand, used to calculate *marginal* energy use and emissions.

For some modes (particularly public transport) the energy use and emissions of a *marginal* passenger are different from the *average* values. With the fourth data item mentioned above, these marginal values can be calculated.

The *marginal* values indicate the effects of one hypothetical extra passenger, while the average values indicate the average emissions of all passengers. A typical situation when one should use marginal emission values is when predicting the environmental effects of lower prices for public transport or changes in fuel tax. Calculating the effects of new train infrastructure, average emission values should be the basis. The difference between marginal values and average values will be further discussed in section 2.5.

1.5 Demarcation

1.5.1 Transport modes

This study is limited to those motorised transport modes and fuels that have a non-negligible share in the current transport market. For passenger transport this study covers the following modes:

- passenger cars (gasoline, diesel and LPG);
- motorcycles and mopeds;
- buses (diesel);
- tram and subway;
- passenger trains (diesel and electric);
- ferries;
- passenger aircraft.

For freight transport the following modes are covered:

- vans (diesel)[5];
- truck (diesel);
- freight trains (diesel and electric);
- inland shipping;
- sea shipping;
- freight aircraft.

[5] In this study vans are treated as freight transport: no work is done on the use of vans for passenger transport.

Modes or engines that are not yet mature or that serve only a small niche market are not included, like:

- electric and hybrid cars;
- buses or vans with other fuels than diesel;
- bio-fuels.

1.5.2 Emissions

Transport modes can be compared on several environmental aspects. Pollution, which is caused by the emission of several substances, and the greenhouse gas effect, which has a tight relation with the energy use, are two major effects. Other important environmental effects of transport are noise nuisance and habitat fragmentation. However, these effects are more difficult to quantify.

In this study we only look at the energy use and the most important emissions. If not indicated differently, all energies mentioned in this report are the *primary* energy use. The emissions that are covered in this study are:

- CO_2;
- NO_x;
- PM_{10};
- SO_2;
- CO;
- VOC.

1.6 How to use this report?

Chapter 2 deals with the methodology. In this chapter we present and explain the unprocessed data. The data itself can be found in annex A, the acknowledgement of the data in annex B.

The environmental effects of different modes can be compared by the emissions per ton-kilometre or passenger-kilometre. Chapter 3 provides guidelines that explain how the unprocessed data can be used to calculate these emissions of transport modes. Using these guidelines and the unprocessed data, the emissions per tonne kilometre or passenger kilometre of transport modes can be calculated for any specific situation.

In the next two chapters, using these guidelines, the results for passenger transport (chapter 4) and freight transport (chapter 5) are presented. We compare the emissions per passenger-kilometre or ton-kilometre of different modes in some well-defined homogeneous market segments and considering the whole transport chain. The data and background of all results can be found in annex B.

In chapter 6 we explain how the results of this study can be used to predict the environmental effects of different policy options. We make use of a conceptual model to explain the different mechanisms that determine the ultimate effect of a policy measure. We illustrate this model with a few cases that show how the data can be used for different types of policy issues. The cases in this chapter are for the larger part qualitative.

Chapter 7 presents the major conclusions and recommendations of this study.

2 Methodology and data

In this chapter we present the principles that are used for this study. Section 2.1 presents the general principles that have been used for the unprocessed data. In the next sections we go further into the different kinds of unprocessed data: vehicle emissions (section 2.2), refinery and electricity production emissions (section 2.3) and logistical characteristics (section 2.4). Section 2.5 explains the difference between average and marginal emissions.

An overview of all unprocessed data can be found in annex A. Acknowledgement of the unprocessed data with reference to the used sources can be found in annex B.

2.1 General principles

In this section, we describe the most important principles that apply to all unprocessed data in this study:
- bottom-up or top-down approach;
- years for which they apply;
- regions for which they apply;
- types of data.

In the next sections we go further into the assumptions that are specific for each type of data.

2.1.1 Mostly bottom-up, sometimes top-down

Most data are obtained with a bottom-up approach. This means that emission factors and energy use are calculated from the properties of vehicles. With a top-down approach the emission factors and energy use would be derived from statistical data on the total number of vehicle kilometres and the total fuel consumption of each transport mode.

Though the basic approach is bottom-up, some of the unprocessed data used in this study are from sources that obtained their data with a top-down approach. This is particularly the case with load factors that sometimes are obtained by using the average vehicle capacity, the total transport volume and the total number of vehicle kilometres.

In some cases there are remarkable differences between the results of a bottom-up and those of a top-down approach. Particularly the utilisation of trains, when derived from the total transport volume and total number of train kilometres turns out to be much lower than when derived from a bottom-up approach. The reason for this is that in a bottom-up approach, data about shunting and non-productive rides are often not available, underestimated or incomplete. The load factors and percentages of non-productive rides of trains that are used in this study have been checked with the most recent top-down values that are available. This has improved the reliability of these figures.

2.1.2 Years: 2000, 2010 and 2020

The data have been collected for the most recent year for which most data are available (2000). To be able to incorporate the effects of current and planned policies, emission standards and other developments, also data for future years are included in this study (2010 and 2020).

For 2010 and 2020 we assume that only emission rates change; other figures like load factors and occupancy rates are assumed to be the same as in 2000. For 2020, we distinguish two scenarios: the EC-scenario with no additional emission policy (“EC”) and the EC-scenario with additional policy (“EC-plus”), based on scenarios provided by the Dutch Ministry of Environment. The assumptions of the scenarios can be found in Annex B.

2.1.3 Regions: the Netherlands and Europe

The collected data are about the situation in the Netherlands, but most data are also representative for the EU. Because of the large differences within Europe, we include for the electricity production also the EU averages.

The *energy consumption* and *emission values* of vehicles are almost the same in the different EU countries. For passenger cars and trucks, small differences might appear, particularly in the energy consumption and CO_2-emissions, because of differences in the average vehicle size and age. However, in most cases these differences will be negligible. Also for other modes, the average EU values can be slightly different from the presented values, but will generally be almost the same.

The differences between the average *load factors* of the different EU countries can be larger. The average number of passengers per passenger cars, for instance, varies from 1.4 in Finland to 2.4 in Portugal [TERM 2001]. Also for freight transport, load factors and percentages non-productive rides can be rather different for other EU countries.

We conclude that the results of this study can be applied to other EU countries, as long as corrected for local differences, particularly of logistical characteristics.

2.1.4 Energy use, emission factors, logistical characteristics and elasticity factors

This study starts from a well-to-wheel approach. This means that both the energy use and emissions from vehicles and from the electricity plants and refineries are included. The unprocessed data of this study consist of data on:
- environmental effects of vehicles: energy use and emission factors;
- environmental effects of refineries and electricity plants: energy use and emission factors;
- logistical characteristics of transport modes (like the capacity of vehicles and load factors);
- data to calculate marginal energy use and emissions (elasticity factors).

In the next sections, we describe the principles that are specific for these different types of unprocessed data.

2.2 Energy use and emission factors of vehicles

The energy use and emissions values of vehicles depend on a large number of parameters and can be determined in several ways. The most important principles with respect to the energy use and emissions values of vehicles are described below.

2.2.1 Combustion engines and electric engines

The energy use and emission factors of vehicles are based on vehicle characteristics like size, vehicle capacity and fuel type. For all modes and all their subcategories, we give a vehicle specific energy use and for modes with a combustion engine, also the emission factors.

For modes with an electric engine, the vehicles itself have no emissions, except copper emissions due to wear of overhead lines. Obviously, the contribution of electricity plants and refineries should also be taken into account. These emissions are calculated with the vehicle energy consumption and the emission factors of the electricity plants. The energy values mentioned for electric modes are the *primary* electric energy consumption, so including the energy losses of the electricity production and distribution. The emissions of electricity production are discussed in section 2.3.

For all modes with combustion engines, the emissions of refining are calculated by using the vehicle energy consumption and the refinery emission factors. To obtain the total emissions of vehicles with combustion engines, the refinery emissions need to be added to the emissions of the combustion engines.

2.2.2 Influence of vehicle size and actual load

For some modes, the size of the vehicle is fixed and for all vehicles more or less the same. For other modes, like trains, trucks or vessels, the vehicle size varies a lot and has a large influence on the energy use. For this second category, we make use of size classes. For some of these modes we use the energy use and emissions per unit of load capacity kilometre (in seats kilometres or tonne kilometres) as unprocessed data.

For passenger transport, the energy use and emissions are almost independent of the actual load. However, for some freight transport modes, both quantities strongly depend on the actual load. For trucks and trains we give the energy use and emissions for empty vehicles and for vehicles with full load. For aircraft, inland shipping and sea shipping the energy use and emissions are only given for vehicles with an average load. For these vehicles the differences between the energy use and emissions of vehicles with empty load and full load are expected to be smaller than for transport modes over land.

2.2.3 Both fleet averages and new vehicles - no test cycle values

For some modes, emission standards have enforced a large decrease of the emissions. For these modes, it is important to distinguish the fleet average emission factors and the emission factors of new vehicles. This is the case for passenger cars and trucks.

The emission factors used are based on practical research. This means that we do not use values from test cycles. We made this choice because test cycles are based on a rather simplified usage pattern. In practice, emission factors are often higher than the values obtained from test cycles because in real life driving behaviour, temperature (cold starts), maintenance and wear are different from an ideal test cycle situation.

2.2.4 Specific assumptions for aircraft

For aircraft, the emission factors and energy use (per km) depend on the distance, because the energy use for take-off is very high. The longer the flight, the lower is the effect of the take-off in the average energy consumption of the whole flight. For this reason, we distinguish three distance classes for both passenger and freight air transport. For all other modes the emission factors and energy use (per km) are assumed to be independent of the distance. However, for some modes, the emission factors are given for different road types.

A large part of the emissions of aircraft is emitted in the high atmosphere. This part of the emissions of NO_X, PM_{10}, VOC, CO and SO_2 therefore has no significant effect on the local or regional air quality. For a fair comparison with other modes, we give the total LTO[6] emissions of NO_X, PM_{10}, VOC, CO and SO_2, including taxiing. The LTO emissions are the total emissions that are emitted close to the airports were the aircraft takes off and lands.

For interregional air-quality problems like acidification, ozone and small particles (PM_{10} and smaller) also the emissions in the higher atmospheres can give a significant contribution, as long as emitted in the same continent. Therefore, we also give in the unprocessed data the *total* emissions (per seat kilometre) of NO_X, PM_{10}, VOC, CO and SO_2, just like we do for other modes. The total emissions are the sum of the LTO emissions and the emissions of the cruise flight.

For aircraft, the contribution to the greenhouse effect is much larger than caused by the CO_2-emissions only. Particularly contrails and NO_x emissions give a large contribution to the greenhouse gas effect. The size of these effects depends on many parameters like altitude and weather conditions. A good estimation of the total greenhouse gas effect of aircraft can be calculated by using the IPCC factor. This is a multiplier for the CO_2-emissions, resulting in the total contribution to the greenhouse gas effect in CO_2 equivalents. In this study we used an IPCC factor of 2.7.

2.2.5 No analysis of traffic jams and vehicle life cycles

The following effects are not included in the emissions factors:

- indirect emissions and energy use caused by production, maintenance and dissembling of vehicles and infrastructure;
- traffic jams, because their effect on the total emissions of road transport is very limited. Consequently, emissions and energy use are assumed to be the same in peak and off-peak hours;
- except for the IPCC factor for aircraft, no other contributions to the greenhouse gas effect than CO_2-emissions are included. For cars particularly evaporation and leaking from air-conditioning systems can give a significant contribution to the greenhouse gas effect. Also methane

[6] LTO: landing and take off.

emissions can be relevant because of the high greenhouse gas effect of this gas. However, to limit the number of gases and because many required data are not available, all these effects are not included in this study.

The environmental effects of traffic jams, vehicle production and infrastructure

The environmental effects of *traffic jams* depend on two effects:

1 The driving pattern caused by the traffic jam affects the emissions and energy use for the vehicles involved. The effect depends on the driving pattern and on type of emission.
2 Traffic jams influence the traffic volume of road transport and of other modes by discouraging people to use their cars.

Traffic jams can have a substantial effect on the emissions of the cars involved, for the kilometres driven in the traffic jam. Studies on this subject conclude that in general the exhaust emissions of vehicles increase when the congestion increases. However, the effect on the average emissions per kilometre is rather small, because traffic jams have only a small share in the total number of vehicle kilometres [TNO, 2001].

Fighting traffic jams generally have a positive effect on the average emissions of the cars on the road, but these effects will often be compensated by an increase of the traffic volume. To predict the overall environmental effects of (fighting) traffic jams is rather complex and beyond the scope of this report.

Also the *building and production, maintenance and dissembling of vehicles and infrastructure* causes emissions. There have been several studies on this subject. According to a study of the Royal University of Groningen, driving is responsible for 85% of the total life cycle energy use of a passenger car [RUG, 1996]. The other 15% are mainly caused by the car production.

2.3 Energy use and emission factors of electricity plants and refineries

Besides the energy use and emissions of vehicles also the contribution of refineries and electricity plants have been investigated.

The emissions of electricity production are very different in the various EU countries, because of the different shares of coal, natural gas, hydropower and nuclear power. For this reason we present the emission factors of electricity production both for the Netherlands and for the whole EU.

The CO_2-emission of nuclear power is much lower than of power that has been produced by fossil fuels[7]. However, to the opinion of a substantial part of the population, nuclear power is no alternative mainly because of the safety and waste aspects. The comparison of transport modes powered by electric engines with modes that are powered by combustion engines can be rather different if nuclear power is excluded. For this reason we present the

7 The CO_2-emission of a nuclear power plant itself is zero. Therefore, the CO_2-emission of nuclear power is only determined by the energy use of refining, enrichment and by the processing of waste.

EU emission factors of electricity plants both with and without the share of nuclear power. In the Netherlands the share of nuclear power is very low and does barely effect the figures.

2.4 Logistical characteristics

To be able to judge the environmental effects of transport modes, besides the emission factors and energy use, also data that characterise the transport modes are needed. In this study we consider the following logistical characteristics:

- load factor (average load per vehicle for productive rides, expressed in % of total vehicle capacity or in number of passengers or tons per vehicle);
- productive rides or non-productive rides (in %);
- utilisation factor (this is the product of the load factor and the percentage productive rides;
- freight factor (only for passenger aircraft, indicating which percentage of the emissions and energy use of passenger aircraft is assumed to be for freight transport);
- detour factor;
- transport to and/or from loading point in the case of inter-modal transport.

Within (a subdivision of) a transport mode, we assume all load factors to be independent of the *type of fuel* and the *travelled distance*. For passenger cars, motorcycles and mopeds, we assume that there are no non-productive rides.

For passenger cars, the load factors are given *per transport motive* and for *peak* and *off-peak* hours. For all public transport modes, the load factors are given for peak, off-peak and total.

Detour factors and the emissions and energy use of *transport to and from loading points* depends very much on the specific transport situation. All detour factors on these subjects are best guesses of the project team, based on the values used in other studies. For transport to and from loading points no 'raw' data are presented. In the next chapter we describe how the effects of transport to and from loading points can be calculated. For the comparisons of modes in chapter 4 and 5, we included the effects of transport to and from loading points. The assumptions that we made for this will be explained in these chapters.

2.5 New approach: marginal values for individual transport decisions

It is important to distinguish the energy use and emission factors of an *average* passenger or tonne and those of *a hypothetical extra passenger or tonne in a given situation.* The second are called marginal values and can be very different from the average values.

For individual transport decisions, marginal values are the most relevant, because the consumer or consignor wants to know the environmental effects of his or her own transport decision.

For non-public transport the marginal values are easy to calculate because one knows exactly the effects of an individual transport decision on the number of vehicle kilometres.

For public transport, this relation is more complex. What is the effect of a marginal passenger choosing the train during peak hour or during off-peak hour? Rietveld has made a detailed analysis of the capacity management of the Dutch Railways, 'NS' [Rietveld, 2002]. The main conclusion of his study is that the marginal environmental burden during the peak is much higher than usually thought, whereas it is almost zero at the off-peak period. The major reason for this is that railway companies determine the size and frequency of trains mainly on the number of passengers during off-peak hours. Most extra materials used during peak hours, remain in use during off-peak and continue to have its environmental impact. Consequently, the effect of one extra passenger during off-peak is almost zero, while one extra passenger in peak contributes to longer trains with a higher frequency during the whole day.

In this study we use elasticity values for the energy consumption for calculating the marginal emissions of public transport modes, based on the results of Rietveld's study. The elasticity multiplied with the average energy use and emission factors, yields the marginal values. The used elasticity values are shown in Table 1.

For all trains, the elasticity values for peak hours are the values of Rietveld. For off-peak we assume a near zero value: 0.1. These elasticity values are not equal to zero, because the frequency and length of trains is not completely independent of the marginal passengers. An elasticity of 0.1 means that one extra passenger will result in emissions equal to 10% of those of an average passenger. For long-distance trains, we make no difference between peak and off-peak, resulting in an elasticity of exactly one. This means that the emissions of an extra passenger are equal to those of an average passenger.

For all other public transport modes, the flexibility in vehicle-size will be lower than for trains, but the flexibility in frequency will be much higher. Therefore, we assume a lower elasticity value of 1.0. Because of the higher flexibility, the elasticity during off-peak will be higher than for trains. We assume a value of 0.3. This means that the emissions of an extra passenger are equal to 30% of those of an average passenger.

Like for all elasticities, these values are only valid when the changes in volume are small compared to the total volume. In case of a large modal shift, the elasticity values cannot be used.

Table 1 Elasticity values for peak and off-peak

Transport mode	***Elasticity peak***	***Elasticity off-peak***	***Elasticity long-distance***
Local train	1.21	0.1	
Inter-city train	1.21	0.1	1.0
HST	1.21	0.1	1.0
City bus	1.0	0.3	
Regional bus	1.0	0.3	
Tram	1.0	0.3	
Subway	1.0	0.3	

For freight transport, all marginal emissions are assumed to be equal to the average emissions. There is no evidence that a marginal tonne will cause different emissions than an average ton. The reason for this is that the freight transport system is an open market with commercial operators that will always try to improve their efficiency. Unlike the public transport systems, freight transport is demand driven. There are not many fixed schedules. And if they exist they will be killed if they are not profitable.

3 Guidelines for calculating the emissions per tonne kilometre for passenger transport modes

3.1 Introduction

The environmental effects of different modes can be compared by the emissions per tonne kilometre or passenger kilometre.[8] This chapter provides guidelines that explain how the unprocessed data can be used to calculate these emissions for different transport modes. Using these guidelines and the unprocessed data, the emissions per tonne kilometre or passenger kilometre can be calculated for any specific situation. In the next two chapters we will apply the guidelines that are presented in this chapter to compare different modes in different markets.

3.2 General guidelines for the comparison of modes

To ensure correct processing of the raw data we developed a seven-step approach, which we also recommend for further analysis of this topic:

1. Define competing transport market sub-*segments*, for example bulk freight transport over medium distances.
2. Define a complete transport *chain* from origin to destination, including transport to and from loading point. If the transport mode to and from loading points is unknown, this report provides default emission estimates.
3. Decide whether comparison is to be based on an average passenger or tonne (*average* emissions) or a hypothetical extra passenger or tonne in a given situation (*marginal* emissions). Marginal emissions are of interest in the evaluation of measures that primarily affect the demand side, like individual travel advice or lowering of road fuel prices. Average emissions should be used for evaluation of measures that primarily affect the supply side, like train schedules or new infrastructure. If the marginal approach is adopted, average emissions should be multiplied by vehicle usage elasticities[9].
4. Decide on *logistical* parameters like load factors, percentage of so-called 'non-productive rides' and detour factors. Default values are provided.
5. Decide on the year in which modes are to be compared. For long term policy decisions, emission factors for 2010 or 2020 will usually be more appropriate than those for 2000.
6. Decide whether newly marketed vehicles in that year are to be compared or 'fleet-average' vehicles.
7. Decide on the environmental impacts to be compared. The most relevant emissions are usually CO_2, PM_{10} and NO_x. Noise nuisance and safety impacts may also often have to be compared.

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[8] Comparing different modes on the emissions per vehicle kilometre makes no sense because of the large differences in vehicle size. Therefore, e choose to compare modes on their emissions per passenger kilometre or tonne kilometre.

[9] When the number of hypothetical passengers becomes large, marginal emissions come to approximate average emissions.

Comparing the overall environmental impact of particular policy alternatives only makes sense if all potential factors of influence, direct or indirect, are duly accounted for, in particular:

- **environmental efficiency effects** (effects on environmental characteristics);
- **transport efficiency effects** (effects on logistical characteristics);
- **substitution effects** (modal shift, due to competitive characteristics);
- **volume effects** (effects on total transport volume).

The environmental impact of the last two of these effects can be calculated from the emissions per passenger kilometre or tonne kilometre of the respective transport modes. The first two effects cause direct changes in emissions per passenger kilometre or tonne kilometre. All policy measures have different types of effect, often working in opposing directions. The overall impact of a given policy measure depends on all the direct and indirect effects on the mode to which the policy measure specifically applies, and on the response of all other modes. This is further discussed in chapter 6.

3.3 Calculating the emissions per passenger-kilometre for passenger transport modes

In this section we explain how the emissions per passenger kilometre can be calculated. The calculation consists of five steps, which are described in the next subsections:

1 Vehicle energy use.
2 Vehicle emissions.
3 Emissions of refining.
4 Emissions of electricity production.
5 Emissions of the transport to and from loading points.
6 Total emissions.

3.3.1 Vehicle energy use per passenger-kilometre

For all passenger modes, the first step is to calculate the energy use of the *vehicle* per passenger-kilometre.

If the energy use of the vehicle is given *per vehicle-kilometre*, the energy use of the vehicle can be calculated with the following formula:

$$E_{vehicle} = e_{vehicle} * (1+d) / (L*p)$$

$E_{vehicle}$	:	Energy use of the vehicle in MJ (primary) per passenger-km
$e_{vehicle}$	:	Energy use of the vehicle in MJ (primary) per vehicle-km
d	:	Detour factor in %
L	:	Load in passengers per vehicle
p	:	Percentage productive rides in %

For some public modes, the energy use is given in MJ per seat-kilometre instead of in MJ per passenger-km. For these modes the vehicle energy use per passenger can be calculated by using the load factor instead of the load:

$$E_{vehicle} = e_{seat} * (1+d) / (l*p)$$

e_{seat}	:	Energy use of the vehicle in MJ (primary) per seat-km
l	:	Load factor in %

3.3.2 Vehicle emissions per passenger-kilometre

For *non-electric modes*, the *vehicle emissions* per passenger-kilometre can be calculated in the same way as the *energy* per passenger-kilometre is calculated. Instead of the *energy use* per vehicle-kilometre, one needs to use the *emissions* per vehicle-kilometre:

$EM_{vehicle} = em_{vehicle} * (1+d) / (L*p)$

$EM_{vehicle}$:	Emission factor of the vehicle g per passenger-km
$em_{vehicle}$:	Emission factor of the vehicle g per vehicle-km

Like for the energy use, for some modes, the emission factors are given in MJ *per seat-kilometre*. For these modes the calculation of the emissions is also similar as of the energy use:

$EM_{vehicle} = em_{seat} * (1+d) / (L*p)$

em_{seat} :	Emission factor of the vehicle g per seat-km

For *aircraft*, this formula can only be used for the CO_2-emissions. The result needs to be multiplied by the IPCC-factor to obtain the CO_2-emissions of aircraft including all other greenhouse gas effects or aircraft. For the other aircraft emissions, it is better to use the *LTO emissions* in gram per passenger-kilometre, which are calculated as follows:

$EM_{aircraft\text{-}LTO} = em_{seat\text{-}LTO} * (1+d) * (1-f) / (l * TD)$

$EM_{aircraft\text{-}LTO}$	:	LTO emission factor of aircraft in g per passenger-km
$em_{seat\text{-}LTO}$	:	LTO-emission factor of aircraft in g per seat
f	:	Freight factor in %
l	:	Load factor in %
TD	:	Travel distance

For *electric modes* the vehicle emissions are zero.

3.3.3 Emissions of refining per passenger-kilometre

For *all non-electric modes*, the emissions of refining the fuel is calculated using the energy use of the vehicle and the emission factors of refineries:

$EM_{refining} = em_{refining} * E_{vehicle}$

$EM_{refining}$:	Emission factor of refining in g per passenger-km
$em_{refining}$:	Emission factor of refining in g per MJ fuel

For *electric modes* the refining emissions are assumed to be zero.

3.3.4 Emissions of electricity production per passenger-kilometre

For *electric modes*, the emissions of electricity production is calculated by:

$EM_{electricity} = em_{energy} * r_{energy} * E_{vehicle}$

$EM_{electricity}$:	Emission factor of the electricity production in g per passenger-km
em_{energy} :	Emission factor of the electricity production in g per MJ *electric* energy
r_{energy} :	Energy return of electricity production and distribution in %

For all *non-electric modes* the emissions of electricity production are zero.

3.3.5 Transport to and from loading points

The transport to and from loading points is very dependent on the distance and the transport mode that is used for it. The contribution to the total emissions can be calculated by:

$EM_{tr.\ loading\ points} = EM_{mode} * t$

$EM_{tr.\ loading\ points}$:	Emission factor of the transport to/from loading points in g per passenger-km
EM_{mode} :	Emission factor of the mode used for transport to/from loading points in g per passenger-km
t :	Total travel distance to/from loading points compared to the travel distance between the loading points, in %

3.3.6 Total emissions

The total emission is the sum of all emissions of the vehicle, refining, electricity production and transport to/from loading points:

$EM_{total} = EM_{vehicle} + EM_{refining} + EM_{electricity} + EM_{tr.\ loading\ points}$

EM_{total} :	Total emission factor of the trip, including those of refining, electricity production and transport to/from loading points, in g per passenger-km

3.4 Calculating the emissions per ton-kilometre for freight transport modes

In this section we explain how the emissions per tonne can be calculated for different transport modes. The calculation consists of the same five steps as that of passenger transport, which are described in the next subsections:
1 Vehicle energy use.
2 Vehicle emissions.
3 Emissions of refining.
4 Emissions of electricity production.
5 Emissions of the transport to and from loading points.
6 Total emissions.

3.4.1 Vehicle energy use per ton-kilometre

For all freight modes, the first step is to calculate the energy use of the *vehicle* per ton-kilometre.

For *inland shipping and sea shipping*, this can be calculated in the same way as for most passenger modes:

$E_{vehicle} = e_{vehicle} * (1+d) / (L*p)$

$E_{vehicle}$	:	Energy use of the vehicle in MJ (primary) per ton-km
$e_{vehicle}$	:	Energy use of the vehicle in MJ (primary) per vehicle-km
d	:	Detourfactor in %
L	:	Load in tons per vehicle
p	:	Percentage productive rides in %

For non-bulk sea vessels, the load can be calculated by multiplying the number of TEU's by the average number of tons per TEU. In this report we calculate with 10 tons/TEU.

For *trucks and trains*, the unprocessed data give different values for the energy use of *empty vehicles* and for the energy use of *full vehicles*. A good estimation of the energy use of vehicles with any other load can be obtained by linear interpollation between these two values:

$e_{loaded} = l*(e_{full} - e_{empty}) + e_{empty}$

e_{loaded}	:	Energy use of a vehicle with load factor l, in MJ (primary) per vehicle-km
l	:	load factor in %
e_{full}	:	Energy use of a full vehicle, in MJ (primary) per vehicle-km
e_{empty}	:	Energy use of an empty vehicle, in MJ (primary) per vehicle-km

The average energy use per ton-kilometre of a truck or train can be calculated with:

$E_{vehicle} = [e_{loaded}*p + e_{empty}*(1-p)] / (L*p)$

For *aircraft* the energy use in the unprocessed data is already given in MJ per ton-km.

3.4.2 Vehicle emissions per ton-kilometre

For *trucks, diesel trains, inland vessels and sea vessels*, the emission factors are given in gram per MJ fuel. For these modes the *vehicle emissions* per ton-kilometre can be calculated from the *energy use* of the vehicle by:

$EM_{vehicle} = em_{MJ\text{-}fuel} * E_{vehicle}$

$EM_{vehicle}$:	Emission factor of the vehicle g per ton-km
$em_{MJ\text{-}fuel}$:	Emission factor of the vehicle g per MJ fuel

For *electric trains* the vehicle emissions are zero.

For *aircraft* all emissions per ton-kilometre are given in the unprocessed data. The value for the CO_2-emissions needs to be multiplied by the IPCC-factor to obtain the CO_2-emissions of aircraft including all other greenhouse gas effects or aircraft. For the other aircraft emissions, it is better to use the *LTO emissions* in gram per passenger-kilometre, which are calculated as follows:

$EM_{aircraft\text{-}LTO} = em_{ton\text{-}cap\text{-}LTO} * (1+d) / (l * TD)$

$EM_{aircraft\text{-}LTO}$	:	LTO emission factor of aircraft in g per ton-km
$em_{ton\text{-}cap\text{-}LTO}$	:	LTO-emission of aircraft in g per tonne load capacity
l	:	Load factor in %
TD	:	Travel distance

3.4.3 Emissions of refining per passenger-kilometre

For all *non-electric modes,* the emissions of refining the fuel is calculated using the energy use of the vehicle and the emission factors of refineries:

$EM_{refining} = em_{refining} * E_{vehicle}$

$EM_{refining}$:	Emission factor of refining in g per ton-km
$em_{refining}$:	Emission factor of refining in g per MJ fuel

For *electric modes* the refining emissions are zero.

3.4.4 Emissions of electricity production per passenger-kilometre

For *electric modes*, the emissions of electricity production is calculated by:

$EM_{electricity} = em_{energy} * r_{energy} * E_{vehicle}$

$EM_{electricity}$:	Emission factor of the electricity production in g per ton-km
em_{energy} :	Emission factor of the electricity production in g per MJ *electric* energy
r_{energy} :	Energy return of electricity production and distribution in %

For all *non-electric modes* the emissions of electricity production are zero.

3.4.5 Transport to and from loading points

The transport to and from loading points is very dependent on the distance and the transport mode that is used for it. The contribution to the total emissions can be calculated by:

$EM_{tr.\ loading\ points} = EM_{mode} * t$

$EM_{tr.\ loading\ points}$	:	Emission factor of the transport to/from loading points in g per ton-km
EM_{mode}	:	Emission factor of the mode used for transport to/from loading points in g per ton-km
t	:	Total travel distance to/from loading points compared to the travel distance between the loading points, in %

3.4.6 Total emissions

The total emission is the sum of all emissions of the vehicle, refining, electricity production and transport to/from loading points:

$$EM_{total} = EM_{vehicle} + EM_{refining} + EM_{electricity} + EM_{tr.\ loading\ points}$$

EM_{total}	:	Total emission factor of the trip, including those of refining, electricity production and transport to/from loading points, in g per ton-km

4 Results passenger transport

4.1 Introduction and assumptions

In this chapter we compare the emissions of several modes for passenger transport. We distinguish three distance categories:

- short (<10 km);
- medium (10-250 km);
- long (>250 km).

For each distance category we compare the modes that compete in that market segment. We use the data for 2000 and only fleet averages (thus not the data for new vehicles).

For short and medium distance, we distinguish average and marginal emissions. For the marginal emissions, we distinguish peak and off-peak. The marginal emissions of the public transport modes are calculated by using the elasticity values as discussed in section 2.5. For the other modes, we use no elasticity values, but only choose different occupancy rates for peak and off-peak.

For all cases we distinguish a *best case scenario* and a *worst case scenario*. We introduce this bandwidth to show the effect of transport to and from loading points, detours and of variations in load factors. We do not pretend to present the absolutely best and worst cases, because this would result in such a large variation in emissions (caused by some extreme assumptions that hardly occur) that the figures would practically give no information.

The used differences between the best case scenario and worse case scenario are:

1 For the best case scenario we assume no **transport to and from loading points**. For the worst case scenario, we use 0% to 15% for medium and long distance, depending on the mode. The exact percentages can be found in Annex B. For medium distance all transport to and from loading points is assumed to be by city bus, for long distance by passenger car (petrol). For short distance, we assume also for the worst case no transport to and from loading points.

2 For the best case scenario we assume no **detour factors**; for the worst case scenario, we assume a detour factor of 0% to 25%, depending on the mode. The exact percentages can be found in Annex B.

3 For the **utilisation factors** (the product of the load factor and percentage productive rides), we use **an uncertainty margin**. We chose a margin of 15% for the utilisation for cars, buses, trams, subways, trains and aircraft[10]. The best case scenario is the average load factor multiplied with 1.15; the worst case scenario is the average load factor multiplied with 0.85. The precise assumptions that have been used for each mode in the best case scenario and worst case scenario can be found in Annex B.

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[10] For motorcycles and mopes, we have no figures about average occupancy rates in peak and off-peak hours. Therefore, for the marginal emissions we calculate with 1 or 2 passengers per vehicle and do not use an uncertainty margin of 15%.

4.2 Short distance (in a city)

Short distance is here defined as 0 to 10 kilometres. Some typical motives for short distance passenger transport are commuting, shopping, visits, recreation and education.

Within a city there are usually many transport modes available for short distance transport, but outside cities, the number of options is often much lower. In this section, we compare the emissions of all possible transport modes within a city[11]:

- passenger car - per fuel;
- moped;
- city bus;
- tram;
- subway.

We compare these modes on:

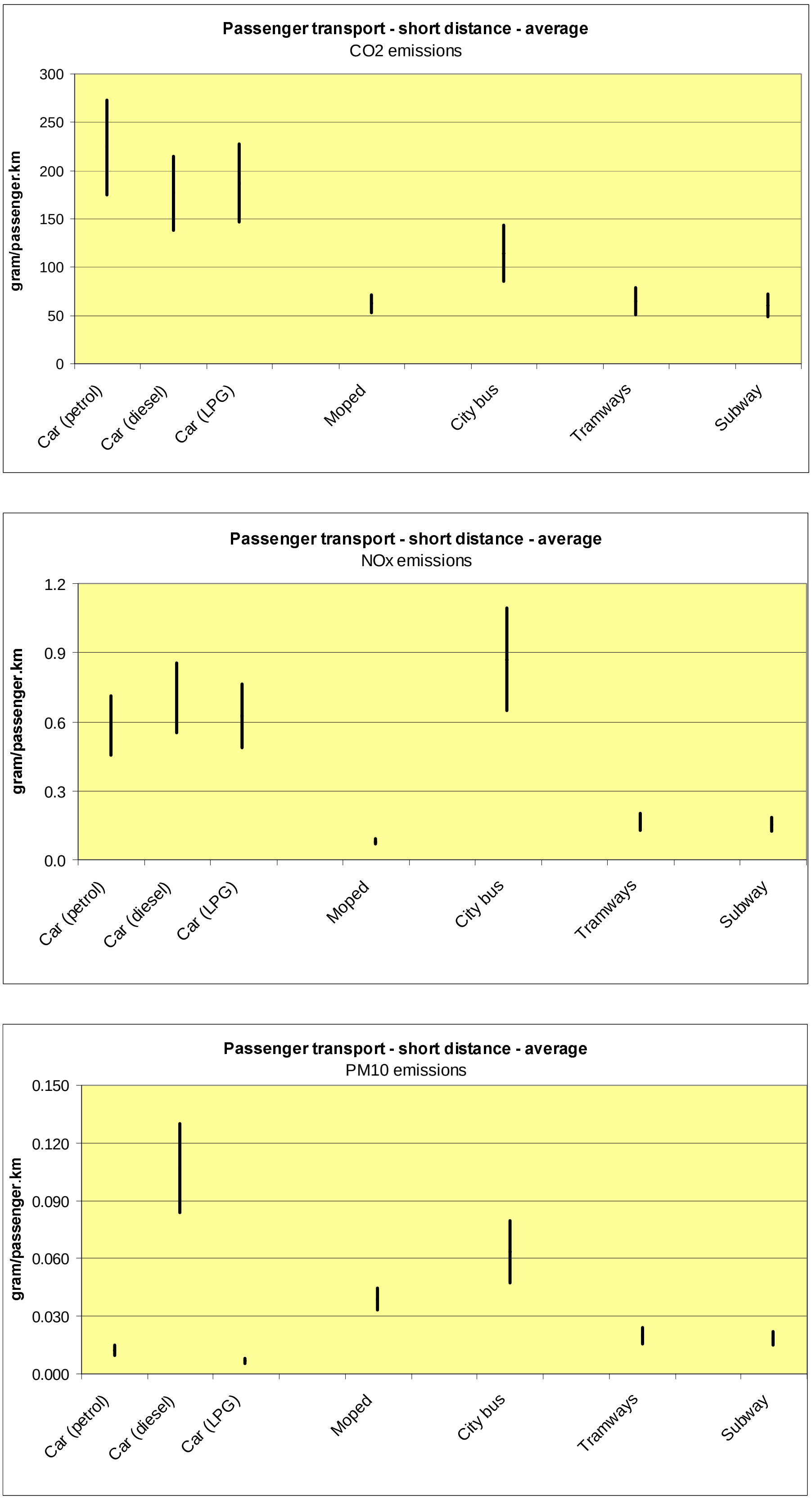
- average emissions (Figure 2);
- marginal emissions during peak (Figure 3);
- marginal emissions during off-peak (Figure 4).

We conclude that moped, tramway and subway show by far the lowest average emissions per passenger kilometre. Passenger cars show the highest average emissions per passenger kilometre, except from the relatively very low PM_{10}-emissions of petrol and LPG cars. The CO_2-emissions of city buses are much lower than those of passenger cars, but much higher than those of moped, tramway or subway. The city bus scores less good at PM_{10} and particularly NO_x, where it scores worst of all modes.

For the marginal emissions *during peak*, we can draw the same conclusions as above. For the marginal emissions per passenger kilometre *during off-peak*, the public transport modes are relatively more in favour. Particularly tramway and subway have very low marginal emissions per passenger kilometre in off-peak. These marginal emissions are only valid if the number of extra passengers in a given situation is small compared to the total number of passengers.

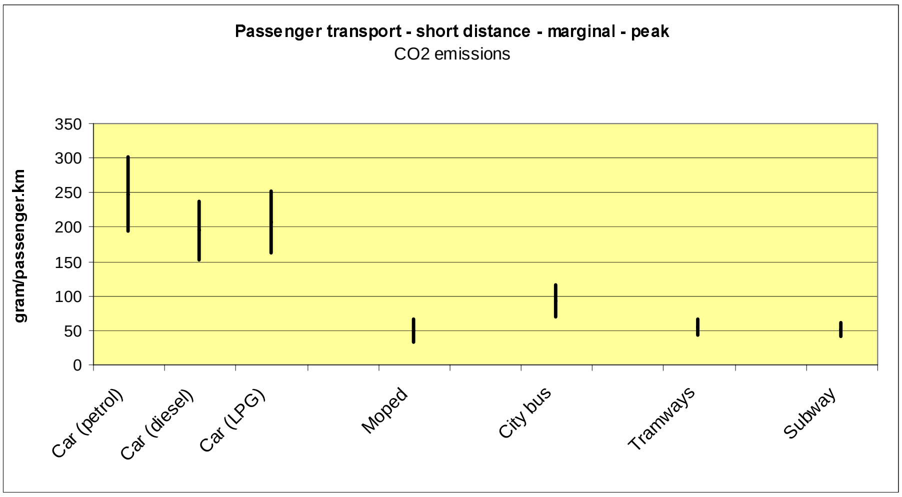
[11] For short distance passenger transport, walking and cycling are in many cases also an option (with zero emissions!), but in this report the scope is limited to motorised transport modes.

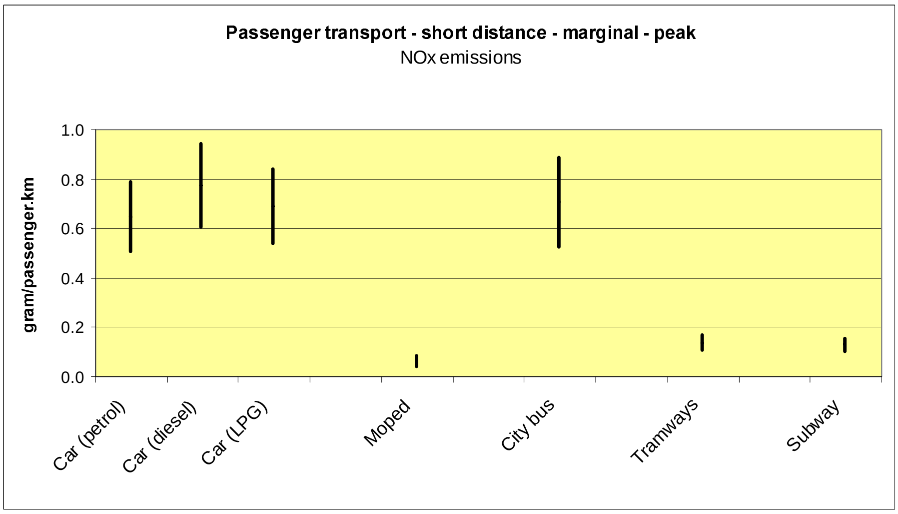
Figure 2 **Average** emissions per kilometre for **short distance** passenger in 2000

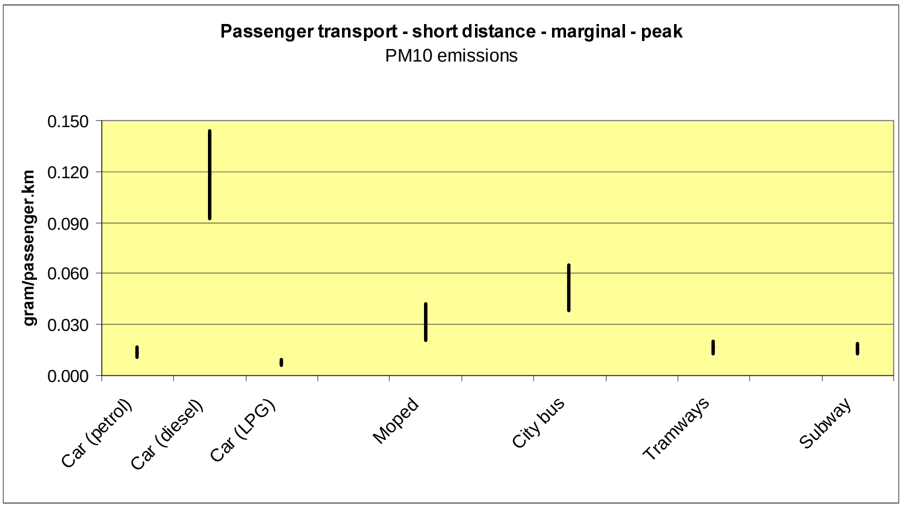


Emissions of electric modes based on electricity production in Europe excluding nuclear power. Electricity production in the Netherlands has 38% lower NO_x and 65% lower PM_{10}-emissions.

Figure 3 **Marginal** emissions per passenger-kilometre for **short distance** passenger transport in peak hours in 2000

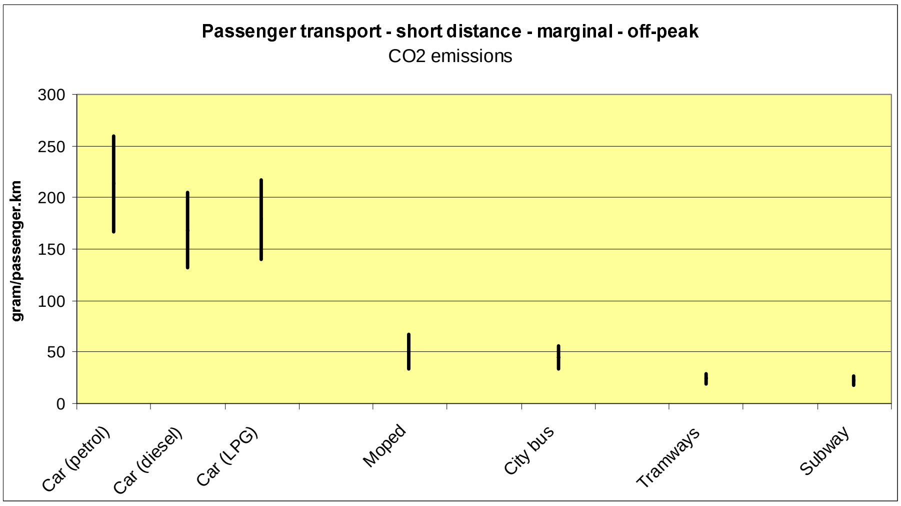


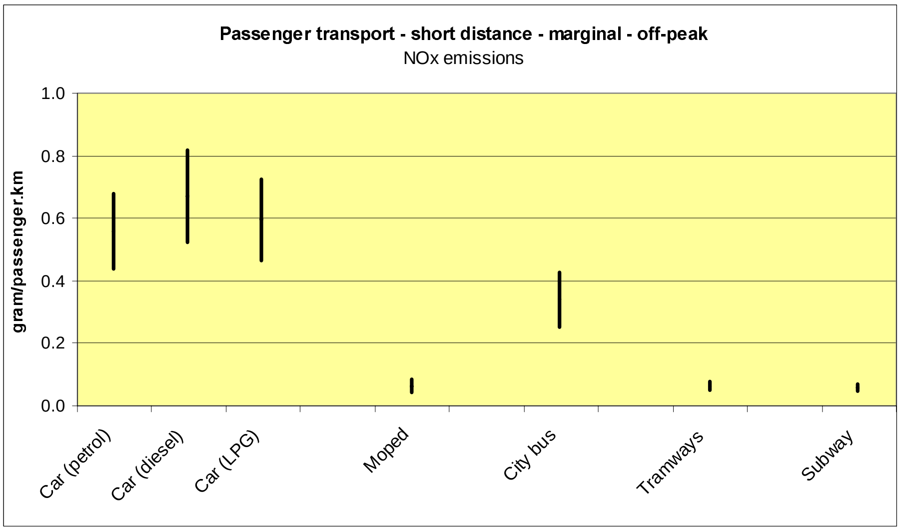


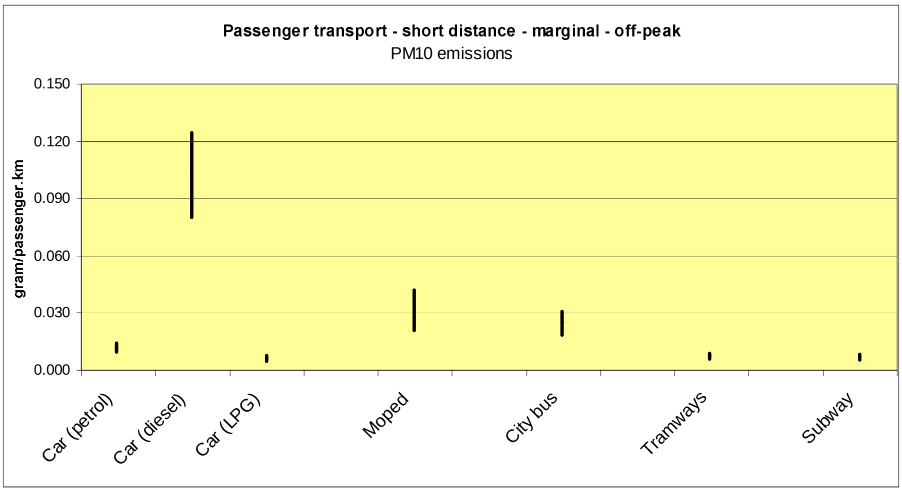


Emissions of electric modes based on electricity production in Europe excluding nuclear power. Electricity production in the Netherlands has 38% lower NO_x and 65% lower PM_{10}-emissions.

Figure 4 **Marginal** emissions per passenger-kilometre for **short distance** passenger transport in **off-peak** hours in 2000







Emissions of electric modes based on electricity production in Europe excluding nuclear power. Electricity production in the Netherlands has 38% lower NO_x and 65% lower PM_{10}-emissions.

4.3 Medium distance

Medium transport covers the whole range from 10 to 250 kilometres. Some typical motives for medium distance passenger transport are commuting, visits, education, business trips or recreation.

For medium distance, we compare the following modes:

- passenger car - per fuel;
- motorcycle;
- regional bus;
- coach;
- local train;
- inter-city train;
- high speed train.

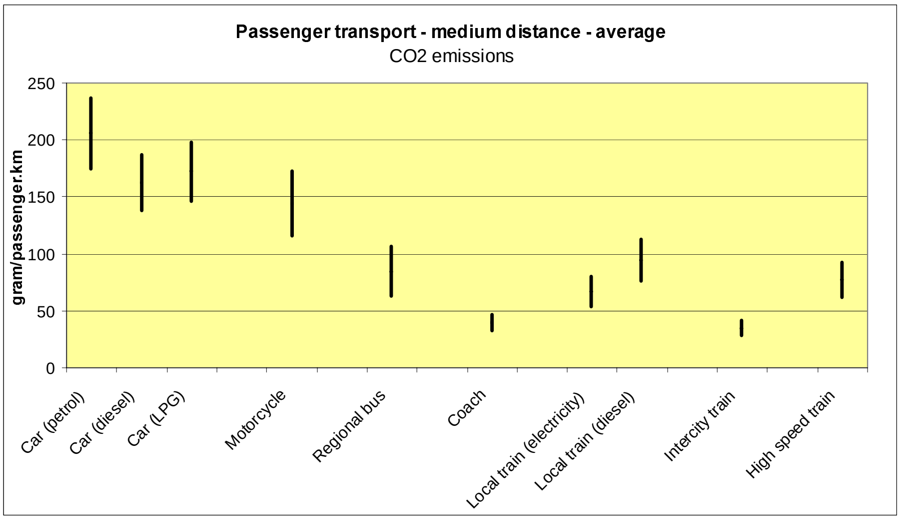
We include transport to and from loading points. The modes are compared on:

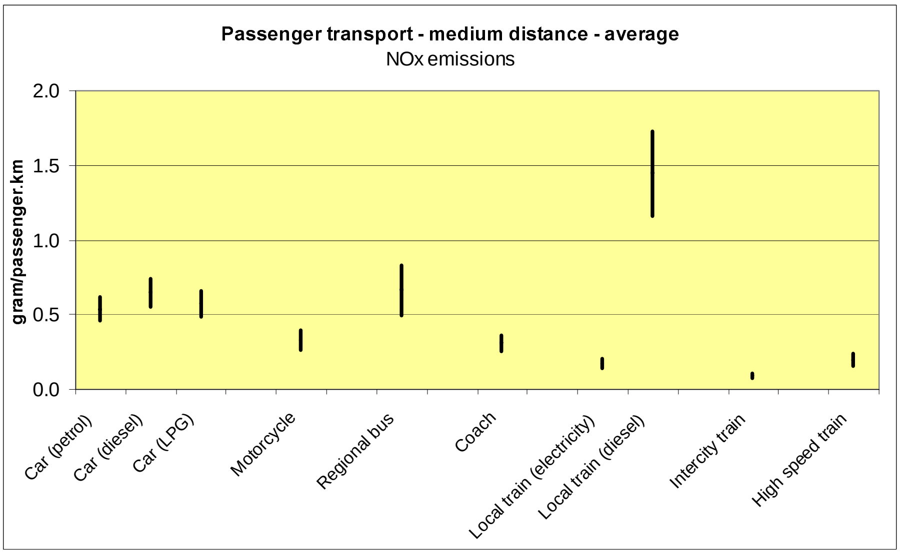
- average emissions (Figure 5);
- marginal emissions during peak (Figure 6);
- marginal emissions during off-peak (Figure 7).

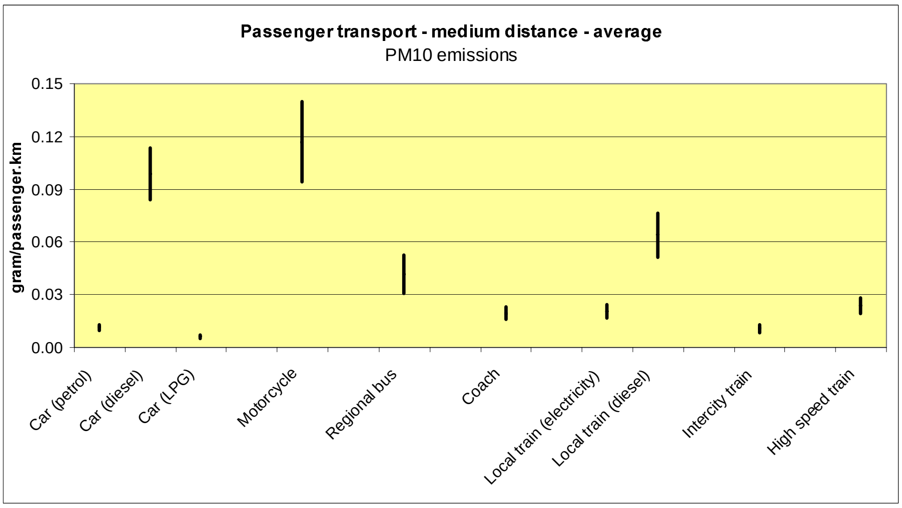
We conclude that inter-city trains show the lowest average emissions per passenger kilometre. Also coaches, electric local trains and high-speed trains have low emissions per passenger kilometre, compared to the other modes. Diesel local trains and regional buses have much higher emissions per passenger kilometre, particularly of NO_x and PM_{10}. Passenger cars have the highest CO_2-emissions of all modes. The NO_x emissions of passenger cars are higher than the NO_x-emissions of most other modes, though much lower than those of diesel stop trains and comparable with those of regional buses. The PM_{10} emissions of petrol and LPG cars are the lowest of all modes, while those of diesel cars are among the highest.

For the marginal emissions *during peak*, we can draw the same conclusions as above. For the marginal emissions during *off-peak*, the public transport modes are relatively more in favour. Particularly electric trains have very low marginal emissions in off-peak. These marginal emissions are only valid if the number of extra passengers in a given situation is small compared to the total number of passengers.

Figure 5 **Average** emissions per passenger-kilometre for **medium distance** passenger transport in 2000

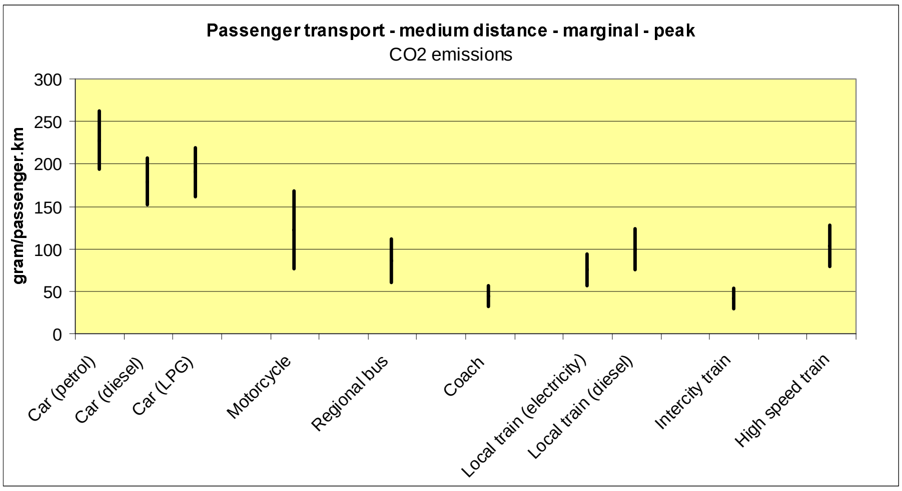


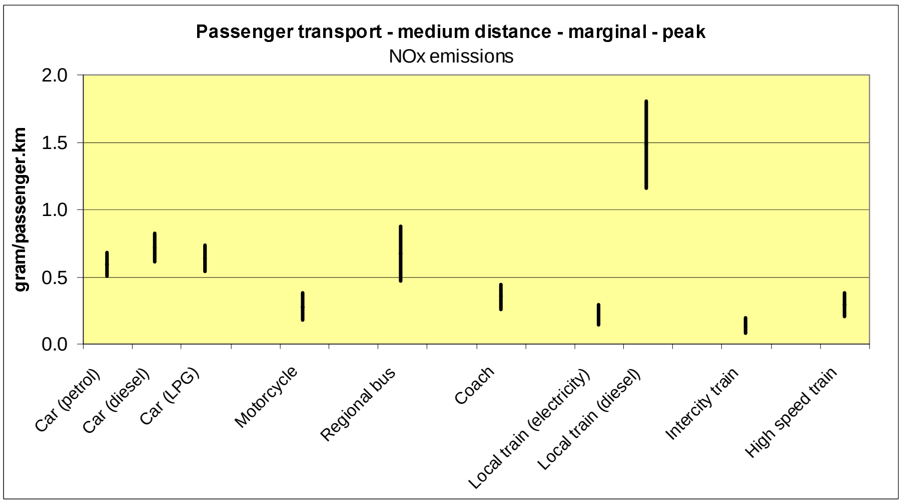


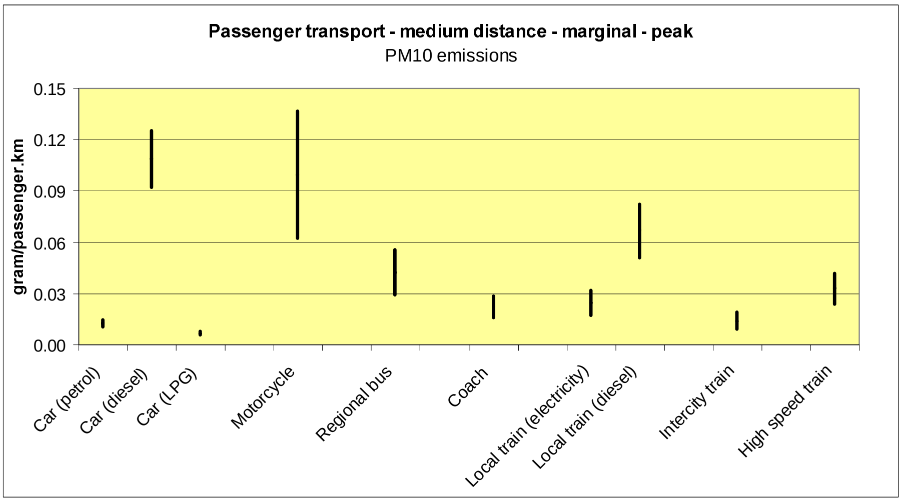


Emissions of electric modes based on electricity production in Europe excluding nuclear power. Electricity production in the Netherlands has 38% lower NO_x and 65% lower PM_{10}-emissions.

Figure 6 **Marginal** emissions per passenger-kilometre for **medium distance** passenger transport in **peak** hours in 2000

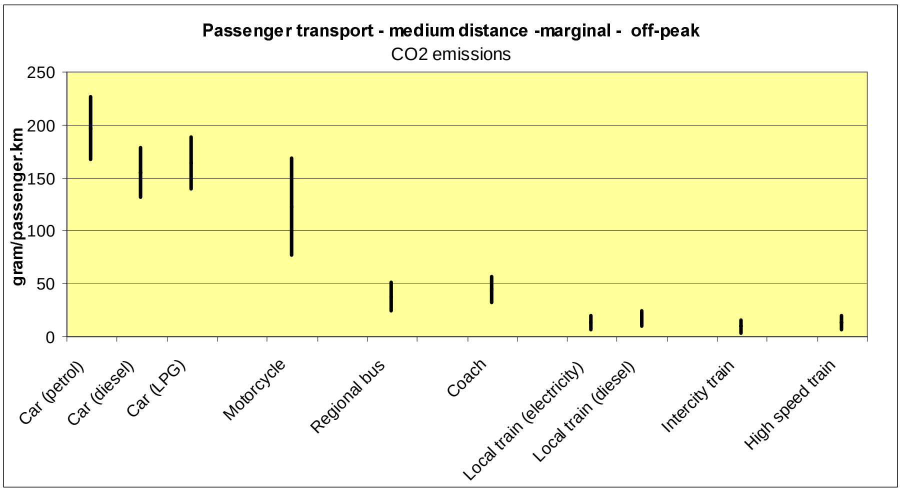


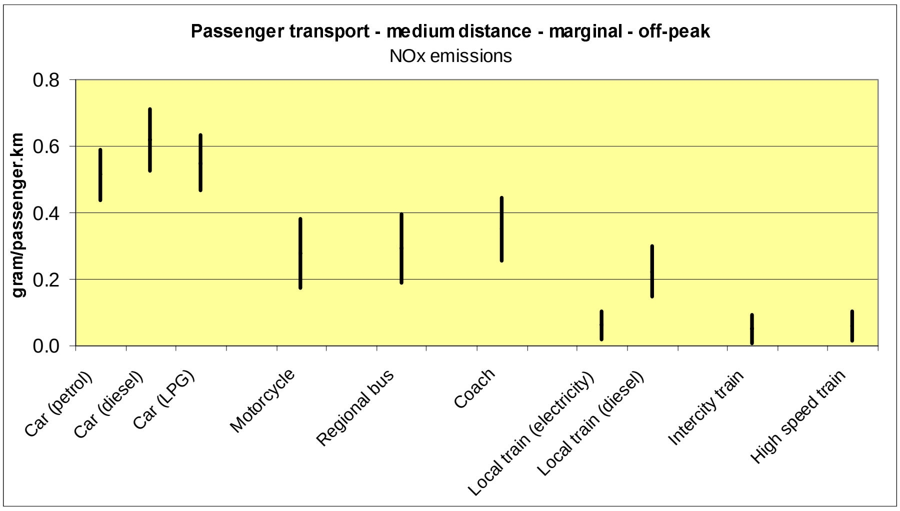


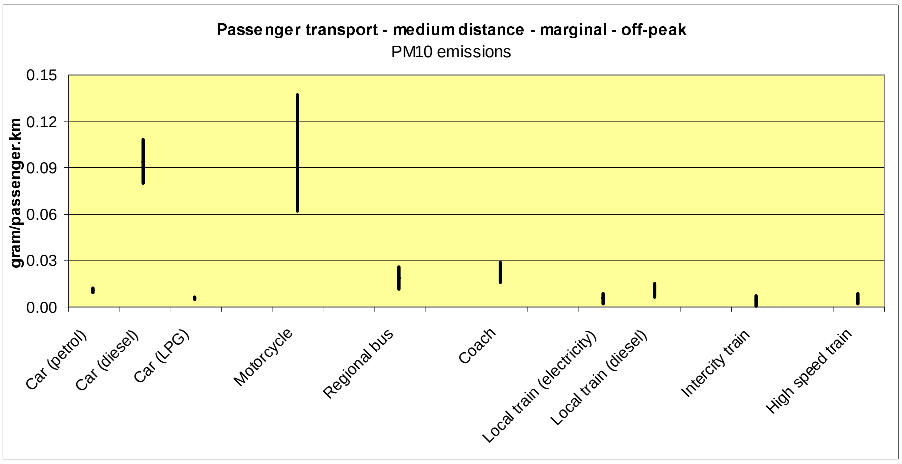


Emissions of electric modes based on electricity production in Europe excluding nuclear power. Electricity production in the Netherlands has 38% lower NO_x and 65% lower PM_{10}-emissions.

Figure 7 **Marginal** emissions per passenger-kilometre for **medium distance** passenger transport in **off-peak** hours in 2000







Emissions of electric modes based on electricity production in Europe excluding nuclear power. Electricity production in the Netherlands has 38% lower NO_x and 65% lower PM_{10}-emissions.

4.4 Long distance

Long transport is defined as trips of more than 250 kilometres. Some typical motives for long distance passenger transport are holidays, business trips or visits.

For long distance, we do not distinguish peak and off-peak. We compare the following modes:

- passenger car - per fuel;
- coach;
- inter-city / International train;
- high speed train;
- aircraft (500 km);
- aircraft (1500 km).

We compare these modes only on their average emissions Thus we do not give data for marginal emissions. We include transport to and from loading points. The emissions of these modes per passenger kilometre are shown in Figure 8.

We conclude that the CO_2-emissions of aircraft are much higher than the CO_2-emissions of other modes. It is important to notice that these aircraft emissions include the other climate change effects than CO_2-emissions only, by using the IPCC factor. Coaches and inter-city trains show the lowest CO_2-emissions. High-speed trains score considerably worse than coaches and inter-city trains.

The large variation in the CO_2-emissions particularly of inter-city trains can be explained by the relative large impact of transport to and from loading point. In the best case we assumed no transport to and from loading points; in the worst case we assumed 15% by petrol car with an average load of 1.53.

The CO_2-emissions of passenger cars are relatively much lower than for short and medium distance, particularly because of the higher load that we assumed (2.5 instead of 1.53). In some cases, the CO_2-emissions of passenger cars are among the ‘best in class’.

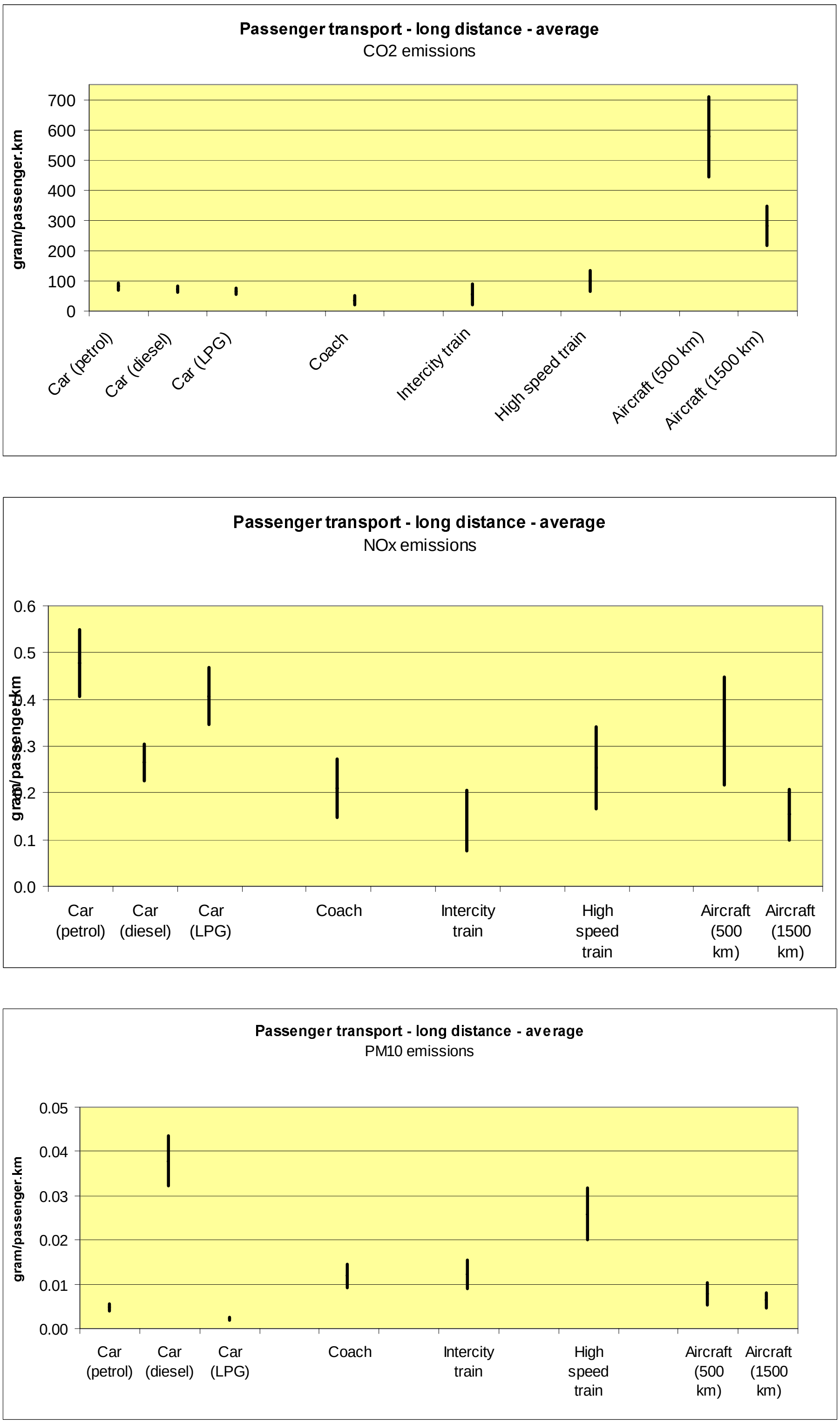
The NO_x-emissions of diesel cars are comparable with coaches, high-speed trains and aircraft (500 km). Inter-city trains and aircraft (1,500 km) score slightly better, while petrol and LPG cars score worse.

Comparing modes, we can conclude that the load factor and the transport to and from loading points (mode, distance, load factor) are decisive which modes have the lowest CO_2 and NO_x-emissions.

The PM_{10} emissions show a less diffuse picture. The PM_{10} emissions of petrol and LPG cars are the lowest of all modes, while those of diesel cars and high-speed trains are the highest.

For aircraft, all NO_x and PM_{10}-emissions only include the LTO emissions. If we would also include the emissions of the cruise flight, these emissions would be considerably higher.

Figure 8 **Average** emissions per passenger-kilometre for **long distance** passenger transport in 2000



Emissions of electric modes based on electricity production in Europe excluding nuclear power. Electricity production in the Netherlands has 38% lower NO_x and 65% lower PM_{10}-emissions.

5 Results freight transport

5.1 Introduction and assumptions

In this chapter we compare the emission of several modes for freight transport. For short distance freight transport, road transport is very dominant because of the very large competitive advantages. In most cases, road transport is the only option for short distance freight transports. Therefore, we only compare the different freight modes for long and medium distance (100 kilometres and more). However, this covers the major part of all freight transport.

For freight transport we compare the different modes both for 2000 and 2010. As already indicated in section 2.5, we do not distinguish marginal and average values. We only give average values and assume that the marginal values will generally be equal to them. We compare the emissions per tonne kilometre of the competing modes. We do not distinguish peak and off-peak.

Two important market segments in the freight transport market are bulk and non-bulk. Bulk transports are transports of large quantities of liquids or solids. Non-bulk transports can be transports of containers or cargo. Non-bulk transport usually has a lower density than bulk transport. Last decades, the non-bulk market has been a much faster growing market than the bulk market[12].

Just like for consumer advice, we distinguish a *best case* and a *worse case*. We introduce this bandwidth to show the effect of transport to and from loading points, detours and of variations in load factors. We do not pretend to present the absolutely best and worst cases, because this would result in a too large variation in emissions caused by some extreme assumptions that hardly occur.

The used differences between best case and worst case are:

1. For best case we assume no transport to and from loading points; for worst case, we assume 0% to 15% for bulk and 0% to 20% for non-bulk, depending on the mode. For all modes transport to and from loading points is assumed to go by large trucks (> 20 tons).
2. For best case we assume no detour factors; for worst case, we assume a detour factor of 0% to 10%, depending on the mode.
3. For utilisation factors (the product of the load factor and percentage productive rides) we use an uncertainty margin of 15%. For all modes, the best case is the average load factor multiplied with 1.15; the worst case is the average load factor multiplied with 0.85.

The precise assumptions that we have used for each mode in the best case and worst case scenario can be found in Annex B.

The speed of a transport has a large effect on the energy use and emissions per ton-kilometre. In this study we do not compare different speeds. It is important to realise that higher or lower speeds than the average speeds can

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[12] Based on a comparison of the increase of transhipment in Dutch seaports between 1996 and 2001. This increase was 20% for bulk, 100% for containers and 30% for all goods in total [AVV, 1996] and [AVV, 2001].

lead to different results than presented in this chapter. This is particularly the case for rail transport wherefore the speeds can vary a lot.

5.2 Long and medium distance - bulk transport in 2000

Some typical goods for long distance bulk transport are coal, gravel, oil, petrol and chemicals. We compare the following modes:[13]

- truck (>20 tons);
- truck (trailer);
- freight train (electric);
- freight train (diesel);
- inland vessel (several weight classes);
- sea vessel (bulk carriers and tankers, several weight classes).

The emissions of these modes per tonne kilometre are shown in Figure 9. To limit the number of modes in the figure and because the larger sea vessels do hardly compete with the other modes, for sea vessel only the two smallest categories have been plotted[14]. We do not include the smaller trucks, because they are hardly used for long distance bulk transport.

Looking at the results, the first conclusion is that the variation in the emissions per tonne kilometre within one transport mode is often larger than the differences between modes. The emissions per tonne kilometre of inland vessels and sea vessels depend very much on the size of the vessel and the emissions per tonne kilometre of diesel trains are much higher than of electric trains. The variation within road transport is smaller, but this is particularly because the smaller trucks are not included here.

The larger sea vessels (OB2 and OC2 and larger) show the lowest emissions per tonne kilometre of all modes[15].

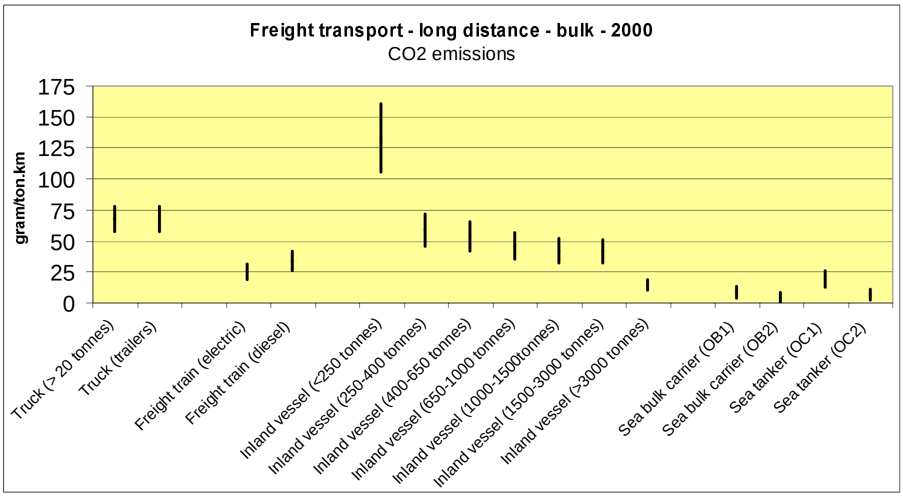
The emissions per tonne kilometre of electric trains are in the same range, except for the higher CO_2-emissions. The emissions per tonne kilometre of the smallest sea vessels (OB1 and OC1) and the largest inland vessels are also among the 'best in class'. Smaller inland vessels show higher CO_2, but particularly higher NO_x and PM_{10}-emissions. The smallest inland vessels (<250 tons) have the highest emissions of all modes. Road transport has high CO_2 and NO_x-emissions. The PM_{10}-emissions of road transport are lower than most inland vessels and comparable with those of diesel trains.

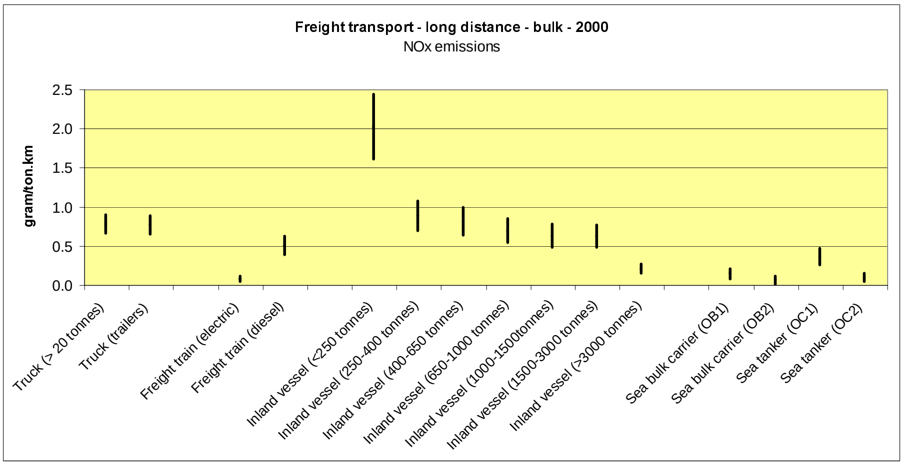
[13] For bulk freight transport pipelines can also be an important way of transport. But in this study, pipelines are not included.

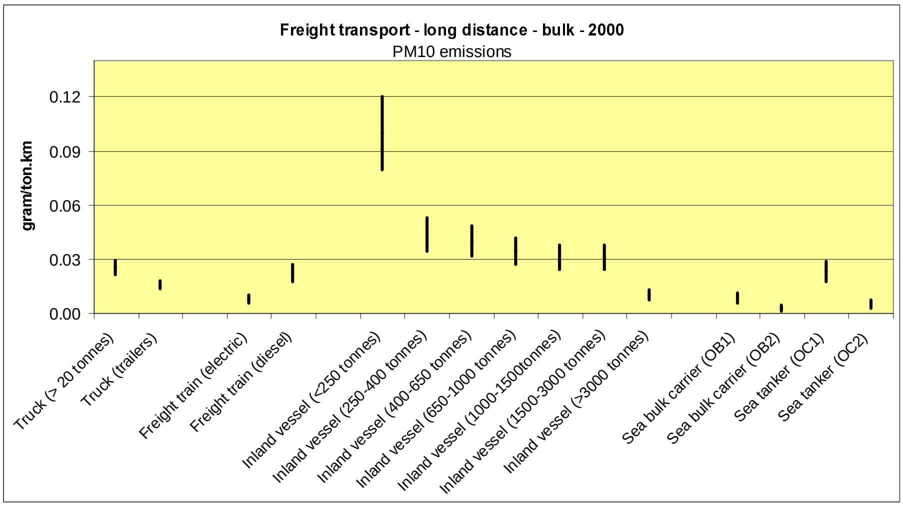
[14] OB1 and OC1: GRT < 1,100 tons (about 75 meters long); OB2 and OC2: GRT < 6,500 tons (about 100-125 meters long).

[15] Except for the SO_2 emissions of sea ship, which are generally higher than of other modes, but SO_2 was not included in this comparison.

Figure 9 Average emissions per ton-kilometre for long distance **bulk** freight transport **in 2000**







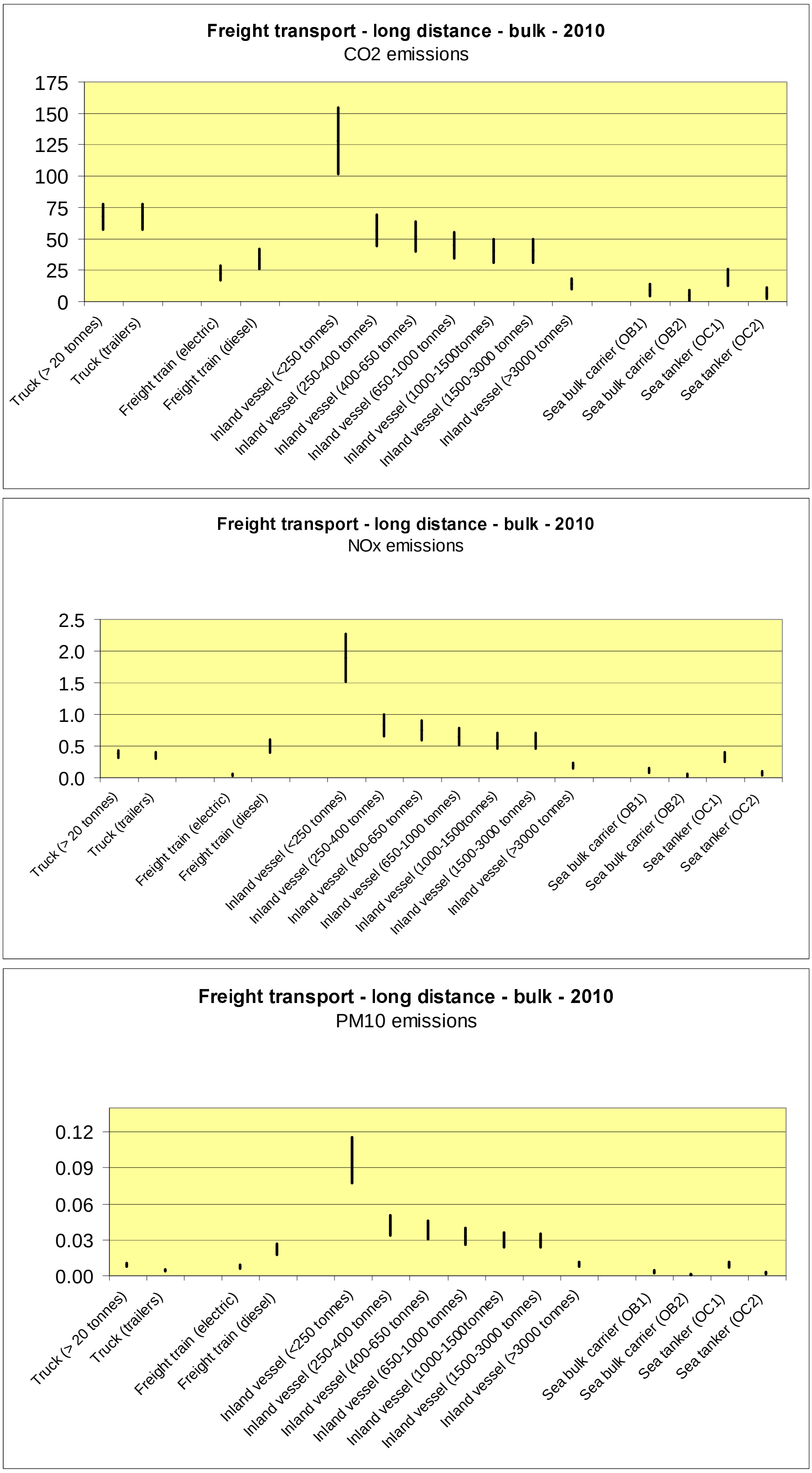
Emissions of electric modes based on electricity production in Europe excluding nuclear power. Electricity production in the Netherlands has 38% lower NO_x and 65% lower PM_{10}-emissions.

5.3 Long and medium distance - bulk transport in 2010

In this section we compare the same modes in the same market segment as in the previous section, but this time we use the emission values for 2010. This comparison is particularly relevant for the European discussions on modal shift in freight transport.

If we compare the results for 2010 as presented in Figure 10, with the results for 2000 as presented in Figure 9, we can conclude that the emissions of most modes hardly change, except from road transport. The emissions of road transport will decrease substantially (except for CO_2) compared to 2000. The NO_x of road transport are still higher than of electric trains, but lower than diesel trains and almost all inland vessels. The PM_{10}-emissions of trucks are in 2010 close to the 'best in class'.

Figure 10 Average emissions per ton-kilometre for long distance **bulk** freight transport **in 2010**



Emissions of electric modes based on electricity production in Europe excluding nuclear power. Electricity production in the Netherlands has 38% lower NO_x and 65% lower PM_{10}-emissions.

5.4 Long and medium distance - non-bulk transport in 2000

Typical types of long distance non-bulk transport are containers and cargo. We compare the following modes:

- truck (all categories)[16];
- freight train (electric);
- freight train (diesel);
- inland vessel (all weight classes);
- sea vessel (container vessels, two lowest weight classes).

The emissions of these modes per tonne kilometre are shown in Figure 11. Comparing these figures with those for bulk transport, it is important to notice that they have a different scale. For all modes the emissions per tonne kilometre for non-bulk are considerably higher than for bulk. For road transport this difference is much smaller than for the other modes.

For road transport we show the emissions of all trucks. In the market for long distance transport of non-bulk freight, the largest two categories are the most important. For sea vessels, we only include the lowest two weight classes, because the larger sea vessels do hardly compete with the other modes.

Just like for bulk transport, we conclude that the variation in the emissions per tonne kilometre within one transport mode is often larger than the differences between modes. The emissions per tonne kilometre of trucks and inland vessels depend very much on the vehicle size and the emissions per tonne kilometre of diesel trains are much higher than of electric trains.

Electric trains show the lowest emissions per tonne kilometre of all modes, except for CO_2 (roughly between 30 and 50 g/ton-km). The CO_2-emissions of sea vessels (C1 and C2) are in the same order and sometimes score even better[17]. The emissions per tonne kilometre of smaller trucks and smaller inland vessels are higher than of all other modes.

The CO_2-emissions of large trucks, diesel trains and the largest inland vessels are all close to each other: somewhere around 60 g/ton-km. Also the NO_x and PM_{10}-emissions of these modes are all in the same range, except for the PM_{10}-emissions of trailers which are considerably lower (in the same range as those of electric trains). This leads to the important conclusion that it depends on the specific case which of these modes scores best.

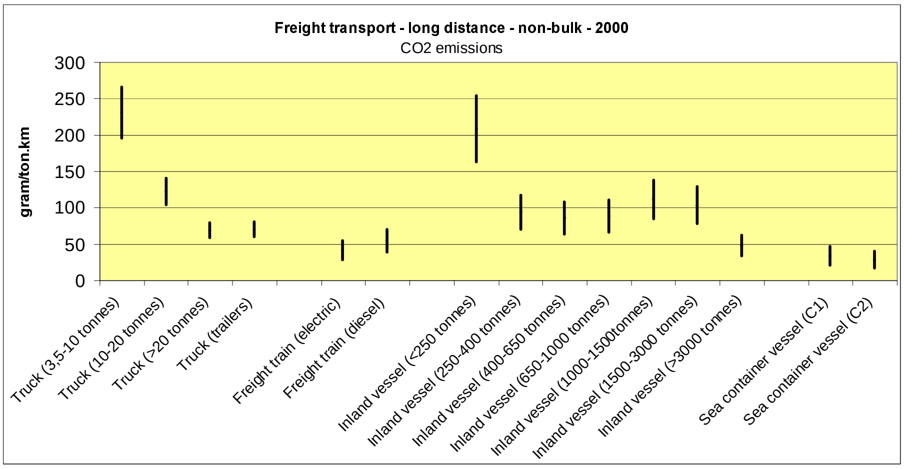
We also calculated the emissions of long distance transport of non-bulk freight by aircraft, but the results are not plotted in the figures. The reason for this is that the CO_2 emissions of aircraft are extremely high compared to all modes: even more than ten times higher than those of trucks from 3.5 to 10 tons. For NO_x and PM_{10}, we calculated the LTO-emissions of aircraft. For short flights (500 km) the NO_x LTO emissions are in the same order of the emissions of trucks from 3.5 to 10 tons, while for long flights (6000 km), they are below 0.5 g/ton-km. The PM_{10}-emissions are between 0.59 and 0.03. The exact data can be found in Annex B. If we would not only look at the

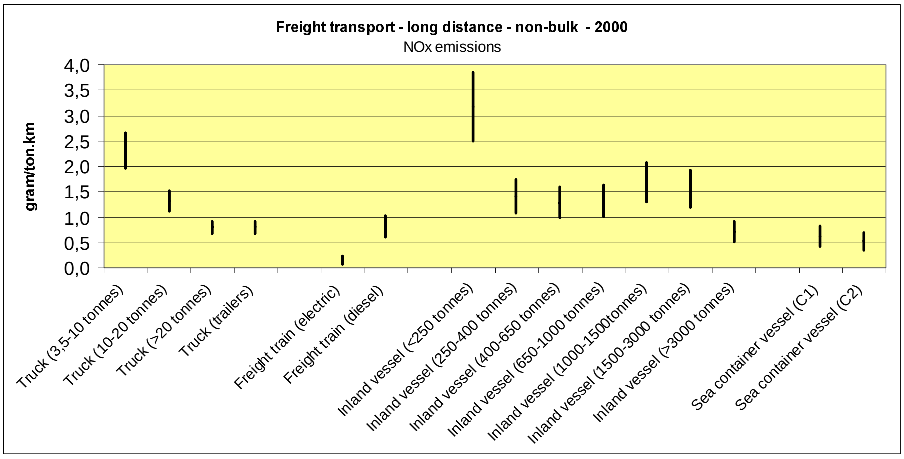
[16] To give a complete overview we include all truck categories, however trucks smaller than 20 tonnes are mostly used for local distribution and deliveries. In the medium and long distance freight market usually only the largest two truck categories are used.

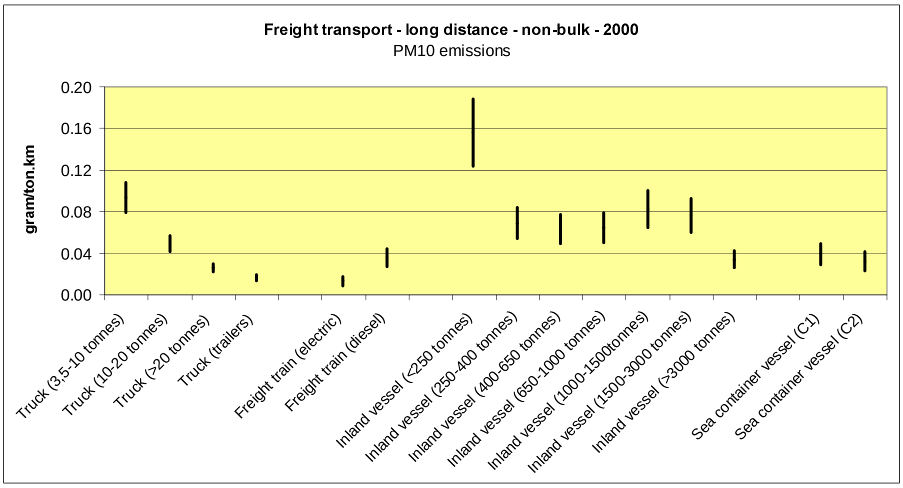
[17] The SO_2-emissions of sea ship are generally higher than of other modes, but SO_2 was not included in this comparison.

LTO emissions but also include the emissions of the cruise flight, the NO_x and PM_{10} emissions of aircraft would be considerably higher.

Figure 11 Average emissions per ton-kilometre for long distance **non-bulk** freight transport **in 2000**







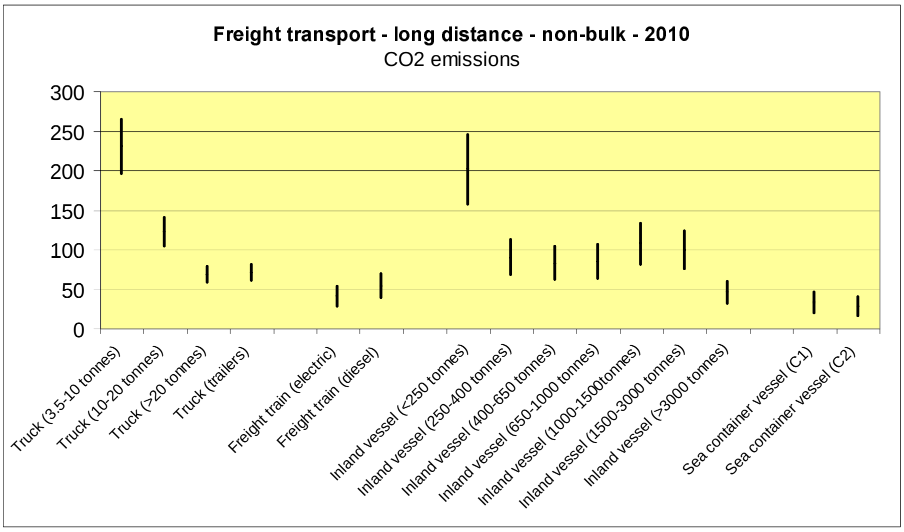
Emissions of electric modes based on electricity production in Europe excluding nuclear power. Electricity production in the Netherlands has 38% lower NO_x and 65% lower PM_{10}-emissions.

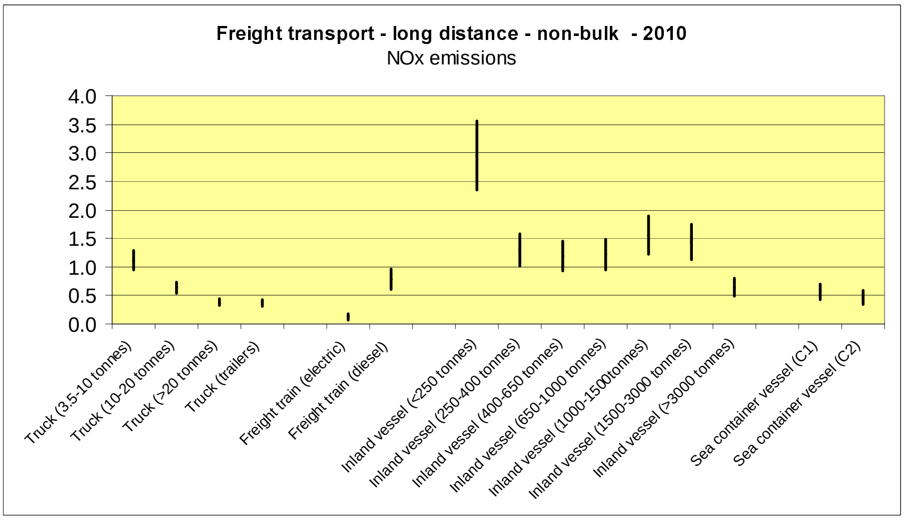
5.5 Long and medium distance - non-bulk transport in 2010

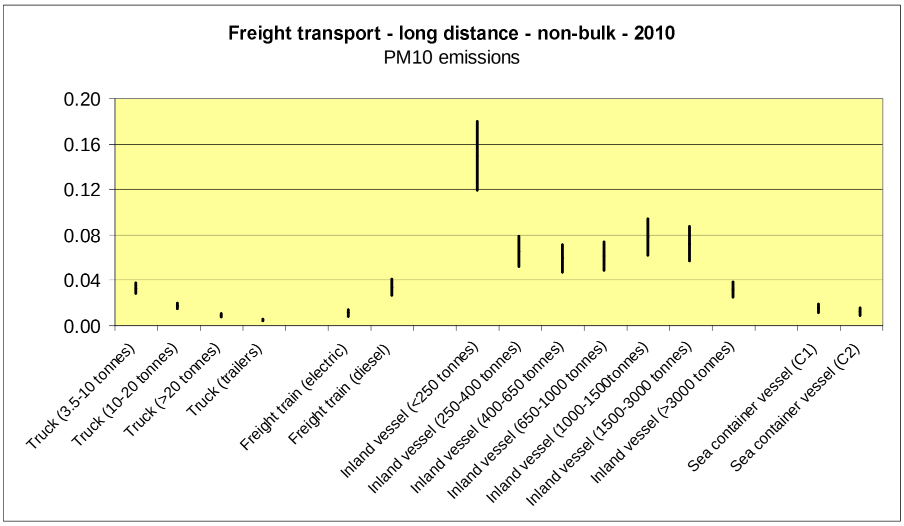
In this section we compare the same modes in the same market segment as in the previous section, but this time we use the emission values for 2010. This comparison is particularly relevant for the European discussions on modal shift in freight transport.

If we compare the results for 2010 as presented in Figure 12, with the results for 2000 as presented in Figure 11, we can conclude that the emissions of most modes hardly change, except from road transport. The emissions of road transport will decrease substantially (except for CO_2) compared to 2000. Both the NO_x and PM_{10} of the largest trucks are in 2010 lower than all other modes, except for the NO_x emissions of electric trains.

Figure 12 Average emissions per ton-kilometre for long distance **non-bulk** freight transport **in 2010**







Emissions of electric modes based on electricity production in Europe excluding nuclear power. Electricity production in the Netherlands has 38% lower NO_x and 65% lower PM_{10}-emissions.

6 How to use the results for comparing transport policies?

6.1 Transport policies

This report deals with the comparison of the emissions of transport modes. So far, we compared the *emissions per tonne kilometre or passenger kilometre* of different transport modes. But how can we use these data to compare the expected environmental effects of different transport policies? What is the ultimate environmental effect if we try to increase the market share of ‘clean’ transport modes and decrease the market shares of the ‘dirty’ ones? In this chapter we will answer this question.

Governments influence transport and traffic in many ways. In this study we distinguish three types of policy:
- pricing;
- infrastructure investments; and
- emission standards.

Fuel taxes, kilometre charges, parking fees, subsidies for public transport, infrastructure investments and emissions standards, they all affect the transport market and also the overall environmental effects of it. The parameters that are effected can be diverse. Fuel efficiency, emissions rates, utilisation rates, the modal split and the total transport volume can all be effected by transport policy decisions.

It is difficult to predict the overall effects of a transport policy decision, because there are many mechanisms that play a role in it. In section 6.3 we discuss the mechanisms that determine the ultimate effects of policy measures, using a conceptual model.

To illustrate this conceptual model, we give some examples of typical policy measures. We focus on measures that cause changes in the modal split because they are the most relevant with respect to the subject of this report: comparison of transport emissions of different modes. In three cases, we discuss the effects that can be expected, by describing the following what-if scenarios:
1 Investment in new railways.
2 Kilometre charging for trucks.
3 Lower fares for public transport.

These cases are presented in section 6.4, 6.5 and 6.6. The effects on the total transport volume will be part of it. This report does not give a reliable quantification of the volume effects, but only illustrative examples of these effects.

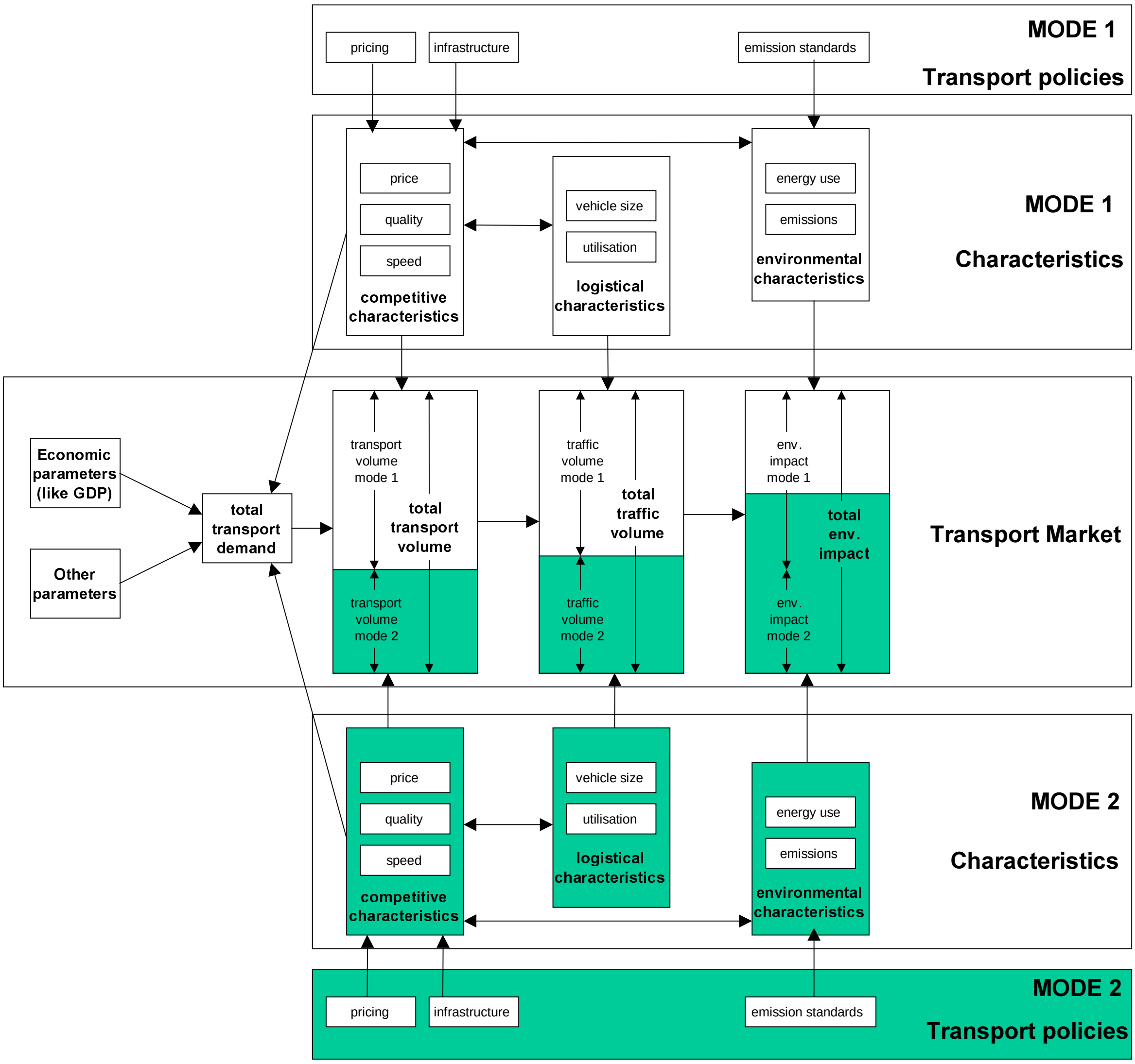
6.2 Conceptual model for the transport market

In this section we present a conceptual model that explains the most important mechanisms in the transport market, that determine the ultimate environmental impact.

Figure 13 shows the relationship between transport policies, different drivers in the transport market and its environmental impact. The different mechanisms have been worked out for two modes. If there are more modes available for a certain transport situation, the same mechanisms apply to these other modes.

At the top of the figure we see the policies that influence the characteristics of mode 1 which are indicated below. In the same way, at the bottom of the figure the relevant policies and characteristics of mode 2 are indicated. The middle of the figure indicates the transport market where mode 1 and mode 2 compete.

Figure 13 Conceptual model for the transport market and its environmental effects



In this figure, we distinguish for each mode three types of transport policy. These transport policies have an effect on the characteristics that are indicated below it:

- *competitive characteristics* that determine the competitiveness of a transport mode and thus also effect the *transport volume* per mode;

- *logistical characteristics* that determine the *traffic volume* that is used to transport the transport volume of that mode;
- *environmental characteristics* that determine *the environmental impacts* per traffic volume.

The unprocessed data presented in this report are logistical characteristics and environmental characteristics.

Below these three types of characteristics we find the *transport volume*, *traffic volume* and *environmental impacts*. The transport volumes are defined as the number of passenger-kilometres or ton-kilometres, the traffic volumes as the number of vehicle-kilometres and the environmental effects as the total emissions.

The model considers the transport sector as a market where the competitiveness of the different modes determines the market share of each mode. The total transport volume, total traffic volume and total environmental impacts of a certain market segment are the sum of the contributions of all different modes that compete in that market segment.

In this figure the *total transport demand* is defined in terms of passenger-kilometres and ton-kilometres and is always equal to the total transport volume. It depends on economic parameters like the GDP, other parameters like geographical characteristics and on the competitive characteristics of each mode. This means that the transport demand (and consequently also the total transport volume) may increase when some modes become faster or less expensive or decrease when some modes become slower or more expensive.

The *transport volume* of each mode depends on the total transport demand and on the competitive characteristics (price, speed and quality[18]) of that mode and of all competing modes.

The *traffic volume* of a mode depends on the transport volume of that mode and of the logistical characteristics of that mode. The *environmental impacts* of a mode depend on the traffic volume and environmental characteristics of that mode.

6.3 Mechanisms that determine the total effects of policy measures

Using this model, we can identify different mechanisms that are important for transport policies. To be able to predict the total environmental impact of a policy measure, we should investigate all types of effects that can occur and that directly or indirectly effect the environmental impact:
- **environmental efficiency effects** (effects on environmental characteristics);
- **transport efficiency effects** (effects on the logistical characteristics);
- **substitution effects** (modal shift, caused by the competitive characteristics:);
- **volume effects** (effects on the total transport volume).

The environmental impact of the last two effects can be calculated by using the emissions per tonne kilometre or passenger kilometre of the different

[18] Quality is defined as speed, comfort, reliability and safety.

transport modes. The first two effects cause changes in the emissions per tonne kilometre or passenger kilometre themselves.

An increase of the environmental efficiency or transport efficiency results in a lower environmental impact, while an increase of the total transport volume results in higher environmental impact. Substitution to a cleaner mode results in lower environmental impact, while substitution to a less clean mode results in higher environmental impact.

All 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.

From the model we can see that both for pricing policies and infrastructure policies, all environmental impacts are *indirect effects*. Only emission standards *directly* effect the environmental impact. At the other hand, emission standards can also have many side effects on price, quality and speed, caused by the capital costs of required technical measures to meet the emission levels or by the increase in fuel use of these technical measures. By doing so, emission standards can ultimately even effect the competitive characteristics, the modal split and the total transport volume.

In the next three sections we apply the mechanisms that were presented above to three different cases. These cases show applications of the data for the most typical transport decisions.

The importance of available time and money

Two major factors in transport decisions are the available financial budget and the available time. A family who plans a vacation only considers destinations that are within their time and money budget. But if an air company offers budget tickets, it can happen that some destinations that where no option before, because of too long travel time or too high costs, become a serious option.
Similarly the import of fruit from New-Zealand to Europe is only possible if the transport can be quick enough (by air) and for a reasonable price. From this point of view, it would be interesting to compare the different modes on their emissions per travel hour or per Euro. This has not been worked out in this report, but could be subject of further study.

6.4 Case: investment in new railways

The most important example of infrastructure policy is investments in new infrastructure, though infrastructure policy can also be measures to improve the use of existing infrastructure. The *direct effect* of infrastructure policy is that it improves the quality and speed of one or more transport modes compared to other modes that cannot take advantage of the improved or new infrastructure.

Table 2 shows the different effects of investments in a new railway link. Effects that cause a decrease of the ultimate environmental impacts (and thus improve the environmental performance) are labelled with a plus; effects that cause an increase of the ultimate environmental impacts are labelled with a minus.

The transport volume that passes the new link will partly come from other modes (substitution) and will partly be new generated transport. The overall effect of a new railway link depends on which effect dominates.

Table 2 Direct and indirect effects of rail infrastructure investment

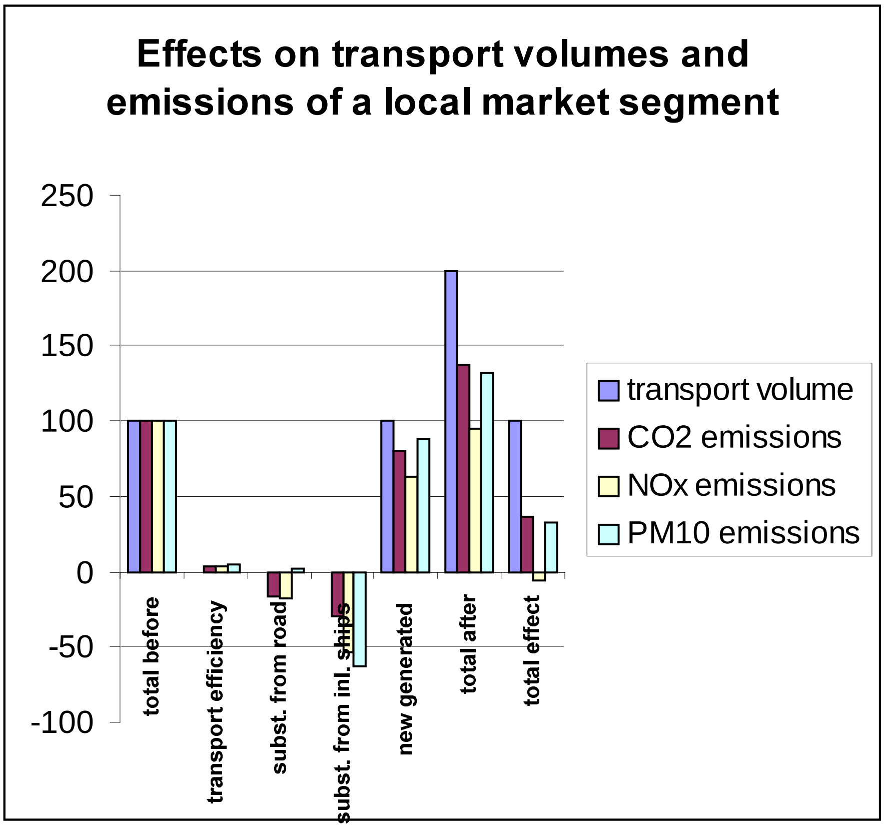
Effects on	***Description of the effects***
Environmental efficiency	No effect[19]
Transport efficiency	**-** Less pressure to improve logistical characteristics
Substitution	**+/-** Modal shift to rail because of relatively better competitive position (increase of the quality and speed of rail). The environmental effect depends on the type of rail transport (electric or diesel), the transport to and from loading points and the environmental characteristics of the mode that is substituted.[20]
Transport volume	**-** Increase of the total transport volume, because of new transport options that compete on speed, price or quality.
+	*Effects that cause a decrease of the ultimate environmental impacts.*
-	*Effects that cause an increase of the ultimate environmental impacts.*

Figure 14 gives an illustrative example how the different effects can be summarised. The total emissions before have been set on 100. We assumed that 50% of the new transport volume by rail comes from substitution from road (20%) or inland vessels (30%). The other 50% in this example is new generated transport volume. We assumed that the transport efficiency by rail decreased with 5%. We used the emission values for 2000. In this example, the total effect is an increase of the total emissions, except form the NO_x-emissions, which slightly decrease.

19 The environmental impact would decrease if trains need to make less stops because of less congestion in the railway net. At the other could an extra railway link at a certain location cause extra congestion on the railway net at another location, because of increased railway usage.

20 In a specific situation, this can be calculated using the results of this study.

Figure 14 Example of how the different effects of a new railway link can be summarised



6.5 Case: kilometre charge for trucks

The *direct effect* of every pricing instrument is that it influences the price of one or more transport modes. Thus pricing makes some transport modes more expensive compared to other modes. An example is this is any increase of parking fees but also the new congestion charge in London City. In these examples passenger cars, vans and trucks become relatively more expensive than all other modes. However, one should always be aware that the effect of a governmental pricing measure can (partly) be compensated by market reactions ('rebound mechanisms').

Pricing can also affect the relative price of market segments within one mode. This is the case with a kilometre charge that is differentiated for regions or for vehicle characteristics like weight or emission class.

Table 3 shows the different effects of a kilometre charge for trucks. Contrary to the other cases, most effects of kilometre charge for trucks cause a decrease of the environmental impact. This can be explained by the fact that this is a policy measure that worsens the competitive position of a transport mode, instead of improving it.

In this example, we assume that the kilometre charge is fully additional to existing taxes and fees. If the introduction of kilometre charge for trucks is combined with changes in existing pricing instruments, the effects of these changes in other instruments should of course also be taken into account.

Table 3 Direct and indirect effects of kilometre charge for trucks

Effects on	***Description of the effects***
Environmental efficiency	**+** Improve of fuel efficiency to lower the price
Transport efficiency	**+** Improve of logistical characteristics to lower the price
Substitution	**+/-** Smaller market share for road because of relatively worse competitive position (increase of the price). The environmental effect depends on particularly on the mode which transport volume increases because of the substitution.[21]
Transport volume	**+** Decrease of the total transport volume, because of a higher price for transport
+	*Effects that cause a decrease of the ultimate environmental impacts.*
-	*Effects that cause an increase of the ultimate environmental impacts.*

6.6 Case: lower fares for public transport

The *direct* effect of lower fares for public transport is an improvement of the competitive position of public transport. In this example, we assume that the lower fares are because of extra subsidies by the government.

Table 4 gives an overview of all different effects of this policy measure. The transport volume generated by the lower fares will partly come from other modes (substitution) and will partly be new generated transport. The overall effect depends on which effect dominates. However, the substitution effect of lower fares for public transport is generally much smaller than the transport generating effect.

According to Van der Waard, the elasticity for the long-term effect of changes in the train fare on number of passenger kilometres is -0,77 for the train passengers and +0,02 for car drivers [Van der Waard, 1990]. This means that a decrease of the train fare by 1% results in 0,77% more passenger-kilometres of train passenger and 0,02% less passenger-kilometres of car drivers. With the current modal split in the Netherlands (about 90 billion passenger kilometres by car and 15 billion by train) a 1% decrease of the train fare would result in 0,1 billion passenger kilometres extra by train and 0,02 billion passenger kilometres less by car. This means that of every five new train passengers only one used to travel by car and the other four are new travellers.

[21] In a specific situation, this can be calculated using the results of this study.

Table 4 Direct and indirect effects of extra subsidies for public transport

Effects on	***Description of the effects***
Environmental efficiency	No effect
Transport efficiency	More demand for public transport both in peak and off-peak: generally no effect on transport efficiency
Substitution	**+** Larger market share for public transport because of relatively better competitive position (because of a lower price than before the measure)
Transport volume	**-** Increase of the total traffic volume, because of higher frequencies and/or more seats.
+	*Effects that cause a decrease of the ultimate environmental impacts.*
-	*Effects that cause an increase of the ultimate environmental impacts.*

7 Conclusions

Methodological conclusions
Transport modes are often compared on the average emissions per passenger kilometre or tonne kilometre of each mode, based on average load factors and average environmental performances. However, a comparison of transport modes only makes sense for well-defined homogeneous market segments and when the whole transport chain is considered.

It is important to distinguish the energy use and emission factors of an average passenger or tonne and those of a hypothetical extra passenger or tonne in a given situation. The second are called marginal values and can be very different from the average values. A typical situation when one should use marginal emission values is when predicting the environmental effects of a certain pricing policy, like lower prices for public transport or changes in fuel tax. Calculating the effects of new emission standards, average emission values should be the basis.

To ensure correct processing of these raw data we developed a seven-step approach which was applied in this study and which we also recommend for further analysis of this topic:

1 Define competing transport market sub-*segments*, for example bulk freight transport over medium distances.
2 Define a complete transport *chain* from origin to destination, including transport to and from loading point. If the transport mode to and from loading points is unknown, this report provides default emission estimates.
3 Decide whether comparison is to be based on an average passenger or tonne (*average* emissions) or a hypothetical extra passenger or tonne in a given situation (*marginal* emissions). Marginal emissions are of interest in the evaluation of measures that primarily affect the demand side, like individual travel advice or lowering of road fuel prices. Average emissions should be used for evaluation of measures that primarily affect the supply side, like train schedules or new infrastructure. If the marginal approach is adopted, average emissions should be multiplied by vehicle usage elasticities[22].
4 Decide on *logistical* parameters like load factors, percentage of so-called ’non-productive rides’ and detour factors. Default values are provided.
5 Decide on the year in which modes are to be compared.
6 Decide whether newly marketed vehicles in that year are to be compared or ’fleet-average’ vehicles.
7 Decide on the environmental impacts to be compared. The most relevant emissions are usually CO_2, PM_{10} and NO_x. Noise nuisance and safety impacts may also often have to be compared.

Comparing the overall environmental impact of particular policy alternatives only makes sense if all potential factors of influence, direct or indirect, are duly accounted for, in particular:

- **environmental efficiency effects** (effects on environmental characteristics);
- **transport efficiency effects** (effects on logistical characteristics);

[22] When the number of hypothetical passengers becomes large, marginal emissions come to approximate average emissions.

- **substitution effects** (modal shift, due to competitive characteristics);
- **volume effects** (effects on total transport volume).

The environmental impact of the last two of these effects can be calculated from the emissions per passenger kilometre or tonne kilometre of the respective transport modes. The first two effects cause direct changes in emissions per passenger kilometre or tonne kilometre. All policy measures have different types of effect, often working in opposing directions. The overall impact of a given policy measure depends on all the direct and indirect effects on the mode to which the policy measure specifically applies, and on the response of all other modes.

Conclusions on environmental performance of transport modes
This study presents and compares the quantitative emissions per passenger kilometre or tonne kilometre of CO_2, NO_x and PM_{10} for several well-defined, homogeneous transport market segments. The main conclusions of these comparisons are as follows:
- from an environmental perspective it makes no sense to speak of ‘clean’ or ‘dirty’ modes of transport. Environmental performance generally depends more on installed technology and logistical characteristics than on mode *per se*;
- the results of any environmental comparison depend on the policy question for which an answer is sought. If, on a particular route, rail transport has lower emissions per tonne kilometre than road transport, say, this does not imply that building a new rail link will reduce the environmental burden.

*Medium and long distance **freight** transport*
We start with an in-depth discussion on road and inter-modal transport of non-bulk goods (such as maritime containers) for the year 2010 over distances of over 100 km. This specific freight transport sub-segment represents the main market opportunity for rail and water transport. As such, it is essential in achieving the EU's policy target of stabilising the 1998 market share of rail and water transport.

The main conclusions of this specific comparison and for freight in general are:
- In **2010**, long-distance road transport will outperform **non-bulk intermodal** water and diesel-powered rail transport with respect to air pollution. Differences in CO_2-emissions between modes are relatively small in this segment. Which mode scores best depends on the specific case. Road transport generally scores several dozen per cent worse than rail and sea, but a little better than inland shipping.
- The picture is more favourable for rail and water transport when **bulk** transport and/or the year **2000** are considered. Crucial factors for rail and water appear to be type of traction (electrical power is far 'cleaner' than diesel), environmental performance of diesel engines (currently lagging behind road transport), logistical efficiency and vessel size.
- More generally, the differences in environmental performance between transport modes *in homogeneous and **competing** freight markets* are smaller than the differences between the *average emissions* of the modes in question. This is because the relatively cleanest sub-segment of road transport – long-distance transport with relatively new, well-filled and large trucks – is precisely the segment that competes with rail and water transport.
- The CO_2-emissions per tonne kilometre of freighter **aircraft** are extremely high compared with all other modes: from over *ten times higher*

than the worst of all other non-bulk freight modes, up to *sixty times higher* than the best of these modes.

We compared the emissions of CO_2, NO_x and PM_{10} for some well-defined homogeneous market segments. The main conclusions of these comparisons are listed below.

Short and medium distance ***passenger*** *transport (in 2000)*[23]

- In these markets, passenger cars have by far the highest CO_2-emissions of all modes (thus contributing significantly to climate change). The NO_x-emissions of passenger cars are higher than the NO_x-emissions of most other modes, though much lower than those of diesel stop trains (medium distance) or local buses (short distance) and comparable with those of regional buses (medium distance). The PM_{10} emissions of petrol and LPG cars are the lowest of all modes, while those of diesel cars are among the highest.
- Electric modes (tramway, subway and inter-city trains) show by far the lowest *average* emissions per passenger kilometre. For short distance, also mopeds show low emissions. For medium distance, coaches, electric local trains and high-speed trains have low emissions per passenger kilometre compared with other modes. Local buses (short distance) and diesel local trains and regional buses (medium distance) have much higher air pollutant emissions per passenger kilometre than most other modes.
- If *marginal* emissions are the yardstick, the figures for *off-peak* public transport become much more favourable, with those for public transport *in the peak* somewhat less favourable.
- For the year 2010, differences between modes become substantially smaller, as most modes, particularly cars and buses, will become cleaner. Diesel-powered trains are probably an exception to this rule.

Long distance ***passenger*** *transport (in 2000)*

- The load factor and the transport to and from loading points (mode, distance, load factor) are decisive in determining which modes have the lowest emissions in this market.
- The climate impact of passenger transport by air is much higher than that of all other modes, particularly because this impact is not limited to CO_2-emissions alone. Coaches and inter-city trains show the lowest CO_2-emissions. High-speed trains score considerably worse.
- The CO_2-emissions of passenger cars on long distance trips are far lower than over short and medium distances, mainly because of the usually higher load factors achieved. In some cases the CO_2-emissions of passenger cars are among the 'best in the class'.

[23] The results of short and medium distance passenger transport are fairly similar and are therefore taken together here.

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To shift or not to shift, that's the question

The environmental performance of the principal modes of freight and passenger transport in the policy-making context

Annexes

Report

Delft, March 2003

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A Unprocessed data

This annex contains all unprocessed data. The acknowledgement of these data and the references to the used data sources can be found in Annex B.

Passenger car (1)	**Energy**	**Emission factors per vehicle**						**Share in fleet-km**	**Detour factor (%)**	
(per vehicle kilometre)		***CO2***	***NOx***	***CO***	***VOC***	***SO2***	***PM10***		***min***	***max***
refining not included	(MJ/km)	(g/km)						(%)		
fleet average in 2000										
city roads									0%	15%
petrol	3,78	274	0,64	8,99	3,04	0,012	0,008	66%		
diesel	3,03	222	0,86	1,31	0,23	0,048	0,144	26%		
LPG	3,55	236	0,75	3,34	0,64	0,000	0,004	8%		
motorways								*24%*	0%	0%
petrol	2,45	177	1,06	3,04	0,27	0,008	0,006	66%		
diesel	2,19	161	0,57	0,12	0,05	0,037	0,090	26%		
LPG	2,19	145	0,92	0,52	0,31	0,000	0,003	8%		
other roads								*37%*	0%	0%
petrol	2,07	150	0,50	2,41	0,41	0,007	0,005	66%		
diesel	1,75	129	0,52	0,19	0,06	0,032	0,071	26%		
LPG	1,89	126	0,51	0,90	0,21	0,000	0,003	8%		
total								*39%*		
petrol	2,63	190	0,75	4,24	0,99	0,009	0,006	66%		
diesel	2,23	164	0,62	0,43	0,10	0,038	0,096	26%		
LPG	2,40	160	0,73	1,34	0,35	0,000	0,003	8%		
								100%		
new cars in 2000										
city roads										
petrol	3,73	270	0,14	3,49	0,76	0,012	0,001	54%		
diesel	2,41	176	0,81	1,05	0,19	0,038	0,086	41%		
LPG	3,64	242	0,33	2,77	0,28	0,000	0,001	5%		
motorways								*24%*		
petrol	2,36	170	0,05	1,67	0,03	0,008	0,001	54%		
diesel	1,72	126	0,49	0,02	0,02	0,029	0,057	41%		
LPG	2,18	145	0,39	0,33	0,01	0,000	0,001	5%		
other roads								*37%*		
petrol	2,02	146	0,05	1,28	0,06	0,007	0,001	54%		
diesel	1,38	101	0,48	0,06	0,03	0,025	0,040	41%		
LPG	1,91	127	0,22	0,66	0,03	0,000	0,001	5%		
total								*39%*		
petrol	2,56	185	0,07	1,97	0,21	0,009	0,001	54%		
diesel	1,76	129	0,56	0,28	0,07	0,030	0,058	41%		
LPG	2,43	161	0,31	1,04	0,08	0,000	0,001	5%		
								100%		
fleet average in 2010 (ReferentieRaming 2010)										
city roads										
petrol	3,35	242	0,10	4,19	0,93	0,007	0,001	*50%*		
diesel	2,62	192	0,41	0,33	0,12	0,006	0,046	*45%*		
LPG	2,99	199	0,17	3,78	0,18	0,000	0,001	*5%*		
motorways								*24%*		
petrol	2,16	156	0,17	1,42	0,08	0,005	0,001	50%		
diesel	1,89	139	0,27	0,03	0,03	0,004	0,029	45%		
LPG	1,84	122	0,21	0,59	0,09	0,000	0,001	5%		
other roads								*37%*		
petrol	1,83	133	0,08	1,13	0,12	0,004	0,001	50%		
diesel	1,51	111	0,25	0,05	0,03	0,004	0,023	45%		
LPG	1,60	106	0,11	1,01	0,06	0,000	0,001	5%		
total								*39%*		
petrol	2,33	168	0,12	1,98	0,30	0,005	0,001	50%		
diesel	1,93	141	0,30	0,11	0,05	0,004	0,031	45%		
LPG	2,03	135	0,16	1,51	0,10	0,000	0,001	5%		
								100%		

Passengers per car	
commuting	1,16
business visit	1,14
services/personal care	1,49
shopping	1,58
education	1,66
visit	1,89
touring/hiking	1,98
social/recreative-other	2,28
international	2,50
total	1,53
peak hours	
7-9 h & 16-18 h	
total-peak	1,38
total-off-peak	1,60
7-9 h	
total-peak	1,27
16-18 h	
total-peak	1,50

Passenger car (2)	**Energy**	**Emission factors per vehicle**						**Share in fleet-km**
(per vehicle kilometre)		***CO_2***	***NOx***	***CO***	***VOC***	***SO_2***	***PM_{10}***	
	(MJ/km)	(g/km)						(%)
fleet average in 2020 (EC)								
city roads								
petrol	2.79	202	0.06	2.97	0.70	0.006	0.001	*50%*
diesel	2.32	170	0.32	0.17	0.07	0.005	0.022	*45%*
LPG	2.43	162	0.10	3.33	0.10	0.000	0.001	*5%*
motorways								*24%*
petrol	1.80	130	0.10	1.01	0.06	0.004	0.001	50%
diesel	1.68	123	0.21	0.02	0.02	0.004	0.014	45%
LPG	1.50	99	0.12	0.52	0.05	0.000	0.001	5%
other roads								*37%*
petrol	1.53	110	0.05	0.80	0.09	0.004	0.001	50%
diesel	1.34	98	0.19	0.02	0.02	0.004	0.011	45%
LPG	1.30	86	0.07	0.89	0.03	0.000	0.001	5%
total								*39%*
petrol	1.94	140	0.07	1.40	0.23	0.005	0.001	50%
diesel	1.71	125	0.23	0.05	0.03	0.004	0.014	45%
LPG	1.65	109	0.09	1.33	0.05	0.000	0.001	5%
								100%
fleet average in 2020 (EC-plus)								
city roads								
petrol	2.79	202	0.03	1.49	0.35	0.006	0.001	*50%*
diesel	2.32	170	0.16	0.08	0.04	0.005	0.011	*45%*
LPG	2.43	162	0.05	1.67	0.05	0.000	0.001	*5%*
motorways								
petrol	1.80	130	0.05	0.50	0.03	0.004	0.001	*50%*
diesel	1.68	123	0.11	0.01	0.01	0.004	0.007	*45%*
LPG	1.50	99	0.06	0.26	0.02	0.000	0.001	*5%*
other roads								
petrol	1.53	110	0.02	0.40	0.05	0.004	0.001	*50%*
diesel	1.34	98	0.10	0.01	0.01	0.004	0.005	*45%*
LPG	1.30	86	0.03	0.45	0.02	0.000	0.001	*5%*
total								
petrol	1.94	140	0.04	0.70	0.11	0.005	0.001	*50%*
diesel	1.71	125	0.12	0.03	0.02	0.004	0.007	*45%*
LPG	1.65	109	0.05	0.67	0.03	0.000	0.001	*5%*
								100%

Motorcycle/moped	Energy	Emission factors per vehicle						Passengers per vehicle	Detour factor (%)	
(per vehicle kilometre)		*CO_2*	*NOx*	*CO*	*VOC*	*SO_2*	*PM_{10}*		*min*	*max*
refining not included	(MJ/km)	(g/km)								
MOTORCYCLES								1.15	0%	10%
fleet average 2000	1.9	135.9	0.3	22.3	6.3	0.0	0.1			
fleet average 2010	1.9	136.0	0.3	8.0	4.2	0.0	0.1			
fleet average 2020 (EC)	1.9	136.0	0.3	8.0	4.2	0.0	0.1			
fleet average 2020 (EC-plus)	1.9	136.0	0.2	2.3	0.2	0.0	0.1			
MOPEDS								1.1	0%	0%
fleet average 2000	0.82	59	0.05	10.00	8.66	0.00	0.04			
fleet average 2010	0.82	59	0.05	1.00	3.15	0.00	0.04			
fleet average 2020 (EC)	0.82	59	0.05	1.00	3.15	0.00	0.04			
fleet average 2020 (EC-plus)	*no data available*									

Bus (diesel)	Energy	Emission factors per bus						Passengers per bus			Nonpro-ductive rides (%)	Elasticity (marg.)		Detour factor (%)	
(per vehicle kilometre)		***CO_2***	***NOx***	***CO***	***VOC***	***SO_2***	***PM_{10}***	***average***	***peak***	***off-peak***		***peak***	***off-peak***	***min***	***max***
refining not included	(MJ/km)	(g/km)													
CITY BUS								13	16	10	7%	1	0.3	0%	25%
	(assumed: 100% city driving)														
fleet average 2000	14.7	1080	8.46	2.66	2.15	0.23	0.64								
new buses 2000	14.7	1080	4.94	1.04	0.60	0.23	0.11								
fleet average 2010	14.3	1045	5.21	1.77	0.90	0.03	0.24								
fleet average 2020 (EC)	14.3	1049	3.42	1.52	0.78	0.03	0.19								
fleet average 2020 (EC-plus)	14.3	1049	2.05	1.52	0.78	0.03	0.19								
REGIONAL BUS								14	17	11	7%	1	0.3	0%	25%
	(assumed: 50% city and 50% rural driving)														
fleet average 2000	13.6	998	8.04	2.05	1.56	0.21	0.52								
new buses 2000	13.6	998	4.68	0.90	0.50	0.21	0.10								
fleet average 2010	13.2	966	4.95	1.37	0.65	0.03	0.20								
fleet average 2020 (EC)	13.2	969	3.25	1.18	0.57	0.03	0.16								
fleet average 2020 (EC-plus)	13.2	969	1.95	1.18	0.57	0.03	0.16								
COACH								38			24%			0%	5%
	(assumed: 25% city, 25% rural and 50% highway driving)														
fleet average 2000	11.6	850	7.87	1.77	1.15	0.18	0.42								
new buses 2000	11.6	850	5.17	0.98	0.45	0.18	0.10								
fleet average 2010	11.2	822	4.85	1.18	0.48	0.03	0.16								
fleet average 2020 (EC)	11.3	825	3.18	1.01	0.42	0.03	0.12								
fleet average 2020 (EC-plus)	11.3	825	1.91	1.01	0.42	0.03	0.12								
For coaches, no difference is made between peak and off-peak															

Tram/subway	Seat capacity	Energy (primary)	Load factor			Nonproductive rides (%)	Elasticity (marg.)		Detour factor (%)	
(per seat kilometre)			***average***	***peak***	***off-peak***		***peak***	***off-peak***	***min***	***max***
		(MJ/seatkm)	(%)	(%)	(%)	(%)				
ELECTRIC TRAM	120									
fleet average 2000		0.21	25%	30%	20%	5%	1	0.3	0%	15%
fleet average 2010		*0.21*								
fleet average 2020 (EC)		*0.21*								
fleet average 2020 (EC-plus)		*0.21*								
SUBWAY	180									
fleet average 2000		0.24	29%	35%	23%	3%	1	0.3	0%	10%
fleet average 2010		*0.24*								
fleet average 2020 (EC)		*0.24*								
fleet average 2020 (EC-plus)		*0.24*								

Passenger train	Seat capa-city	Energy (primary)	Load factor			Nonproductive rides	Share of total seat kms in NL	Elasticity (marg.)			Detour factor	
(per seat kilometre)			*average*	*peak*	*off-peak*	average	*total*	*peak*	*off-peak*	*long-distance*	min	max
			(%)			(%)					(%)	
LOCAL TRAIN												
fleet average 2000	252		33%	40%	26%	2.50%		1.21	0.1		0%	10%
diesel		0.35					6%					
electric		0.31					47%					
fleet average 2010												
diesel		0.35										
electric		0.31										
fleet average 2020 (EC)												
diesel		0.35										
electric		0.31										
fleet average 2020 (EC-plus)												
diesel		0.35										
electric		0.31										
INTERCITY TRAIN /												
INTERNATIONALTRAIN	434											
fleet average 2000		0.22	44%	53%	35%	2.50%	47%	1.21	0.1	1	0%	10%
fleet average 2010		0.22										
fleet average 2020 (EC)		0.22										
fleet average 2020 (EC-plus)		0.22										
HIGH SPEED TRAIN	377											
fleet average 2000		0.53	49%			2.50%		1.21	0.1	1	0%	10%
fleet average 2010		0.53										
fleet average 2020 (EC)		0.53										
fleet average 2020 (EC-plus)		0.53										
MAGNET TRAIN	336											
fleet average 2010/2020		0.62		49%		2.50%		1.21	0.1	1	0%	10%

LOCAL DIESEL TRAIN	Emission factors (g/MJ fuel)					
	CO_2	*NOx*	*CO*	*VOS*	*SO_2*	*PM_{10}*
fleet average 2000	73.3	1.19	0.25	0.08	0.08	0.05
fleet average 2010	73.3	1.19	0.25	0.08	0.05	0.05
fleet average 2020 (EC)	73.3	1.19	0.25	0.08	0.05	0.05
fleet average 2020 (EC-plus)	73.3	1.01	0.25	0.08	0.05	0.04

Passenger aircraft	**Seat capaci-ty**	**Energy**	**Emission factors per plane**						**LTO-emissions**					**IPCC factor**	**Freight factor**	**Load factor**	**Detour factor**	
(per seat kilometre)			*CO_2*	*NOx*	*CO*	*VOS*	*SO_2*	*PM_{10}*	*NOx*	*CO*	*VOS*	*SO_2*	*PM_{10}*				**min**	**max**
refining not included		(MJ/seatkm)	(g/seatkm)						(g/seat)						(%)	(%)		(%)
LOCAL (500 KM)																		
fleet average 2000	99	1.8	134	0.35	0.40	0.23	0.04	0.05	58	82	5	2.7	1.1	2.7	4%	70%	0%	10%
fleet average 2010		1.6	115	0.31	0.25	0.10	0.03	0.05	51	50	2.1	2.3	1.1					
fleet average 2020 (EC)		1.4	104	0.28	0.16	0.09	0.03	0.05	46	32	1.8	2.1	1.0					
fleet average 2020 (EC-plus)		1.4	104	0.25	0.16	0.09	0.03	0.05	41	32	1.8	2.1	1.0					
CONTINENTAL (1500 KM)																		
fleet average 2000	255	1.3	92	0.44	0.10	0.04	0.03	0.01	106	66	15	3.1	6	2.7	27%	75%	0%	5%
fleet average 2010		1.1	79	0.39	0.06	0.02	0.02	0.01	92	40	7	2.6	6					
fleet average 2020 (EC)		1.0	71	0.35	0.04	0.01	0.02	0.01	84	25	6	2.4	5					
fleet average 2020 (EC-plus)		1.0	71	0.31	0.04	0.01	0.02	0.01	75	25	6	2.4	5					
INTERCONTINENTAL (6000 KM)																		
fleet average 2000	445	1.2	89	0.47	0.04	0.01	0.03	0.01	101	137	29	1.8	24	2.7	31%	80%	0%	2%
fleet average 2010		1.1	77	0.41	0.02	0.01	0.02	0.01	88	84	13	1.6	23					
fleet average 2020 (EC)		1.0	70	0.37	0.01	0.01	0.02	0.01	79	50	11	1.4	21					
fleet average 2020 (EC-plus)		1.0	70	0.33	0.01	0.01	0.02	0.01	71	50	11	1.4	21					

The IPCC factor is the multiplier for the non CO_2 greenhouse gas effects (particularly because of condensation)

The freight factor indicates how much of the emissions and energy consumption of passenger planes are assumed to be for freight transport.

Ferry	Energy		Emission factors						Load factor	Nonproductive
(per seat kilometre)			CO_2	*NOx*	*CO*	*VOC*	SO_2	PM_{10}		travels (%)
refining not included	(MJ/passkm)	(MJ/seatkm)	(g/MJ fuel)							
			refining not included							
fleet average 2000			76.1	1.4	0.2	0.1	0.0	0.1		
normal speed	1.9	1.1							56%	2.50%
high speed	6.4	3.6							56%	2.50%
fleet average 2010			76.1	1.4	0.2	0.1	0.0	0.1		
normal speed	1.9	1.1								
high speed	6.4	3.6								
fleet average 2020 (EC)			76.1	1.4	0.2	0.1	0.0	0.1		
normal speed	1.9	1.1								
high speed	6.4	3.6								
fleet average 2020 (EC-plus)			76.1	1.4	0.2	0.1	0.0	0.1		
normal speed	1.9	1.1								
high speed	6.4	3.6								

Trucks	Average GVW	Load capacity	Energy			Emission factors per truck					
Energy &emissions			**full load**	**empty**	**average load**	***CO2***	***NOx***	***CO***	***VOC***	***SO2***	***PM10***
(per vehicle kilometre)	(tonne)	(tonne)	(MJ/km)			(g/MJ fuel)					
refining not included											
fleet average 2000											
< 3.5 tonnes (van)	1.8	1.5	3.6	3.6	3.6	73	0.29	0.17	0.05	0.02	0.05
3.5-10 tonnes	7.1	4.0	5.2	3.7	5.1	73	0.77	0.20	0.12	0.02	0.03
10-20 tonnes	14.5	10.0	8.5	5.6	7.1	73	0.83	0.18	0.10	0.02	0.03
>20 tonnes	36.4	27.3	14.7	8.6	11.6	73	0.89	0.14	0.07	0.02	0.03
trailers	39.2	27.0	15.1	8.5	12.2	73	0.88	0.12	0.03	0.02	0.02
new trucks 2000											
< 3.5 tonnes (van)			3.6	3.6	3.6	73	0.24	0.13	0.03	0.02	0.02
3.5-10 tonnes			5.2	3.7	5.1	73	0.63	0.14	0.07	0.02	0.01
10-20 tonnes			8.5	5.6	7.1	73	0.68	0.13	0.06	0.02	0.01
>20 tonnes			14.7	8.6	11.6	73	0.74	0.10	0.04	0.02	0.01
trailers			15.1	8.5	12.2	73	0.80	0.10	0.02	0.02	0.01
fleet average 2010 (EC)											
< 3.5 tonnes (van)	1.8	1.5	2.9	2.9	2.9	73	0.15	0.07	0.01	0.00	0.01
3.5-10 tonnes	7.1	4.0	5.2	3.7	5.1	73	0.35	0.11	0.04	0.00	0.01
10-20 tonnes	14.5	10.0	8.5	5.6	7.1	73	0.38	0.10	0.03	0.00	0.01
>20 tonnes	36.4	27.3	14.7	8.6	11.6	73	0.41	0.08	0.02	0.00	0.01
trailers	39.2	27.0	15.4	8.5	12.5	73	0.38	0.07	0.01	0.00	0.00
fleet average 2020 (EC)											
< 3.5 tonnes (van)			2.8	2.8	2.8	73	0.11	0.06	0.01	0.00	0.01
3.5-10 tonnes			5.2	3.7	5.1	73	0.23	0.09	0.04	0.00	0.01
10-20 tonnes			8.5	5.6	7.1	73	0.25	0.08	0.03	0.00	0.01
>20 tonnes			14.7	8.6	11.6	73	0.27	0.07	0.02	0.00	0.01
trailers			15.0	8.5	12.2	73	0.24	0.06	0.01	0.00	0.00
fleet average 2020 (EC-plus)											
< 3.5 tonnes (van)			2.8	2.8	2.8	73	0.05	0.03	0.00	0.00	0.00
3.5-10 tonnes			5.2	3.7	5.1	73	0.14	0.09	0.04	0.00	0.01
10-20 tonnes			8.5	5.6	7.1	73	0.15	0.08	0.03	0.00	0.01
>20 tonnes			14.7	8.6	11.6	73	0.16	0.07	0.02	0.00	0.01
trailers			15.0	8.5	12.2	73	0.14	0.06	0.01	0.00	0.00

Trucks (2)	Loadfactor		Productive rides (%)		Share road types in kilometers			Detour factor (%)		Utilisation		Energy consumption	
Logistical characteristics	***bulk***	***non-bulk***	***bulk***	***non-bulk***	***urban***	***rural***	***highway***	***min***	***max***	***bulk***	***non-bulk***	**bulk**	**non-bulk**
												MJ/tonnekm	MJ/tonnekm
< 3.5 tonnes (van)		39%		76%				0%	0%		29%		8.04
3.5-10 tonnes		50%		77%	30%	30%	40%	0%	0%		38%		2.82
10-20 tonnes		61%		76%	20%	30%	50%	0%	0%		46%		1.50
>20 tonnes	91%	62%	58%	83%	10%	30%	60%	0%	0%	75%	51%	0.83	0.84
trailers	91%	62%	58%	83%	10%	30%	60%	0%	0%	75%	51%	0.84	0.86

Freight train	**Energy**		**Load capacity**	**Load factor**	**Productive rides (%)**	**Utilisation factor**	**Detour factor (%)**		**Energy cons. all trips**
(per train kilometre)	***full load***	***no load***					***min***	***max***	
refining not included	(MJ/train km)	(MJ/train km)	(tonnes)						MJ/tonnekm
fleet average 2000									
bulk - electric	425	84	1,705	80%	51%	41%	0%	10%	0.32
bulk - diesel	489	96	1,705	80%	51%	41%			0.37
non-bulk - electric	226	88	790	44%	80%	35%			0.49
non-bulk - diesel	259	101	790	44%	80%	35%			0.56
fleet average 2010	*idem 2000*								
fleet average 2020 (EC)	*idem 2000*								
fleet average 2020 (EC-plus)	*idem 2000*								

FREIGHT TRAIN diesel- Emission factors	**Emission factors (g/MJ fuel)**					
	CO_2	***NOx***	***CO***	***VOS***	***SO_2***	***PM_{10}***
fleet average 2000	73.3	1.19	0.12	0.08	0.08	0.05
fleet average 2010	73.3	1.19	0.12	0.08	0.05	0.05
fleet average 2020 (EC)	73.3	1.19	0.12	0.08	0.05	0.05
fleet average 2020 (EC-plus)	73.3	1.01	0.12	0.08	0.05	0.04

Freight aircraft	**Load capacity**	**Energy**	**Emission factors per plane**						**LTO-emissions**					**IPCC factor**	**Load factor**	**Detour factor**	
(per tonne kilometre)			CO_2	NOx	CO	VOS	SO_2	PM_{10}	NOx	CO	VOS	SO_2	PM_{10}			*min*	*max*
refining not included	(tonne)	(MJ/tonnekm)	(g/tonnekm)						(g/tonne load capacity)					(%)	(%)	(%)	
LOCAL (500 KM)																	
fleet average 2000	83.3	11.9	867	2.3	2.6	1.5	0.3	0.3	541	733	158	10	127	2.7	75%	0%	10%
fleet average 2010		10.2	747	2.0	1.6	0.7	0.2	0.3	469	447	72	8	125				
fleet average 2020 (EC)		9.3	676	1.8	1.0	0.6	0.2	0.3	424	266	61	8	113				
fleet average 2020 (EC-plus)		9.3	676	1.6	1.0	0.6	0.2	0.3	382	266	61	8	113				
CONTINENTAL (1500 KM)																	
fleet average 2000	83.3	9.0	657	3.2	0.7	0.3	0.2	0.1	541	733	158	10	127	2.7	75%		
fleet average 2010		7.7	566	2.8	0.4	0.1	0.2	0.1	469	447	72	8	125				
fleet average 2020 (EC)		7.0	512	2.5	0.3	0.1	0.2	0.1	424	266	61	8	113				
fleet average 2020 (EC-plus)		7.0	512	2.3	0.3	0.1	0.2	0.1	382	266	61	8	113				
INTERCONTINENTAL (6000 KM)																	
fleet average 2000	83.3	7.9	578	3.1	0.3	0.1	0.2	0.1	541	733	158	10	127	2.7	75%		
fleet average 2010		6.8	498	2.7	0.2	0.0	0.1	0.1	469	447	72	8	125				
fleet average 2020 (EC)		6.2	451	2.4	0.1	0.0	0.1	0.1	424	266	61	8	113				
fleet average 2020 (EC-plus)		6.2	451	2.2	0.1	0.0	0.1	0.1	382	266	61	8	113				
The IPCC factor is the multiplier for the non CO_2 greenhouse gas effects (particularly because of condensation)																	

Inland vessel	**Energy**	**Emission factors per vessel**						**Capacity per vessel**		**Load factor**		**Productive travels**	**Average load per vessel**			**Utilisation**		**Detour factor**		**Energy cons. all trips**	
(per vessel kilometre)		***CO_2***	***NOx***	***CO***	***VOC***	***SO_2***	***PM_{10}***	***bulk***	***non-bulk***	***bulk***	***non-bulk***		***average***	***bulk***	***non-bulk***	***bulk***	***non-bulk***	***min***	***max***	***bulk***	***non-bulk***
refining not included	(MJ/km)	(g/MJ fuel)						tonnes		(%)		(%)	(tonnes)			(%)		(%)		MJ/tonnekm	
fleet average 2000		73,3	1,17	0,19	0,07	0,08	0,06														
< 250 tonnes	124							130	130	85%	55%	74%	59	81	52	62%	40%	0%	10%	1,54	2,39
250 - 400 tonnes	133							320	320	85%	55%	74%	150	199	128	62%	40%			0,67	1,03
400 - 650 tonnes	188							500	480	85%	55%	74%	240	311	192	62%	40%			0,61	0,94
650 - 1000 tonnes	281							820	860	84%	45%	79%	366	539	305	66%	36%			0,52	0,97
1000 - 1500 tonnes	376							1250	1410	83%	31%	78%	548	802	341	64%	24%			0,47	1,24
1500 - 3000 tonnes	623							2250	2575	78%	32%	76%	985	1330	621	59%	24%			0,47	1,15
> 3000 tonnes	856							9200	6000	85%	25%	75%	1605	5831	1125	63%	19%			0,15	0,50
fleet average 2010		73,3	1,14	0,19	0,07	0,05	0,06														
< 250 tonnes	120							130	130	85%	55%	74%	59	81	52	62%	40%	0%	10%	1,48	2,30
250 - 400 tonnes	128							320	320	85%	55%	74%	150	199	128	62%	40%			0,64	1,00
400 - 650 tonnes	182							500	480	85%	55%	74%	240	311	192	62%	40%			0,59	0,91
650 - 1000 tonnes	271							820	860	84%	45%	79%	366	539	305	66%	36%			0,50	0,93
1000 - 1500 tonnes	363							1250	1410	83%	31%	78%	548	802	341	64%	24%			0,45	1,20
1500 - 3000 tonnes	600							2250	2575	78%	32%	76%	985	1330	621	59%	24%			0,45	1,11
> 3000 tonnes	826							9200	6000	85%	25%	75%	1605	5831	1125	63%	19%			0,14	0,48
fleet average 2020 (EC)		73,3	1,06	0,19	0,07	0,05	0,06														
< 250 tonnes	116																				
250 - 400 tonnes	124																				
400 - 650 tonnes	176																				
650 - 1000 tonnes	263																				
1000 - 1500 tonnes	352																				
1500 - 3000 tonnes	582																				
> 3000 tonnes	800																				
fleet average 2020 (EC-plus)		73,3	0,84	0,19	0,07	0,05	0,05														
< 250 tonnes	116																				
250 - 400 tonnes	124																				
400 - 650 tonnes	176																				
650 - 1000 tonnes	263																				
1000 - 1500 tonnes	352																				
1500 - 3000 tonnes	582																				
> 3000 tonnes	800																				

Sea vessel	capacity	energy	emission factors per vessel (g/MJ fuel)						load per vessel	productive	Detour factor (%)		utilisation	energy cons.
(per vessel kilometre)	per vessel		CO2	NOx	CO	VOC	SO2	PM10	per vessel	travels (%)	min	max		MJ/tonnekm
refining not included	(# TEU's)	J/vesselkm)							(%)					
CONTAINER VESSEL	*10 tonne/TEU*													
fleet average 2000			75	1,64	0,06	0,18	0,94	0,11	75%	80%	0%	10%	60%	
C1	350	620												0,30
C2	800	1145												0,24
C3	1600	2020												0,21
C4	2600	3113												0,20
C5	4000	4418												0,18
fleet average 2010			75	1,59	0,06	0,18	0,53	0,04						
C1	350	620												0,30
C2	800	1145												0,24
C3	1600	2020												0,21
C4	2600	3113												0,20
C5	4000	4418												0,18
fleet average 2020 (EC)			75	1,56	0,06	0,18	0,53	0,04						
C1	350	620												0,30
C2	800	1145												0,24
C3	1600	2020												0,21
C4	2600	3113												0,20
C5	4000	4418												0,18
fleet average 2020 (EC-plus)			75	0,78	0,06	0,18	0,53	0,04						
C1	350	620												0,30
C2	800	1145												0,24
C3	1600	2020												0,21
C4	2600	3113												0,20
C5	4000	4418												0,18
	capacity	**energy**	**emission factors per vessel (g/MJ fuel)**						**load per vessel**	**productive**	**Detour factor (%)**		**utilisation**	**energy cons.**
			CO2	NOx	CO	VOS	SO2	PM10		travels (%)	min	max		MJ/tonnekm
TANKER	(tonnes)	J/vesselkm)	*refining not included*						(% of maximum load)					
fleet average 2000			75	1,64	0,06	0,18	0,94	0,11	50%	80%	0%	10%	40%	
OC1	1022	1082												0,176
OC2	8783	1563												0,030
OC3	71329	2329												0,005
OC4	166806	3250												0,003
OC5	373465	3708												0,002
fleet average 2010			75	1,59	0,06	0,18	0,53	0,04						
OC1	1022	1082												0,176
OC2	8783	1563												0,030
OC3	71329	2329												0,005
OC4	166806	3250												0,003
OC5	373465	3708												0,002
fleet average 2020 (EC)			75	1,56	0,06	0,18	0,53	0,04						
OC1	1022	1082												0,176
OC2	8783	1563												0,030
OC3	71329	2329												0,005
OC4	166806	3250												0,003
OC5	373465	3708												0,002
fleet average 2020 (EC-plus)			75	0,78	0,06	0,18	0,53	0,04						
OC1	1022	1082												0,176
OC2	8783	1563												0,030
OC3	71329	2329												0,005
OC4	166806	3250												0,003
OC5	373465	3708												0,002
	capacity	**energy**	**emission factors per vessel (g/MJ fuel)**						**load per vessel**	**productive**	**Detour factor (%)**		**utilisation**	**energy cons.**
			CO2	NOx	CO	VOS	SO2	PM10		travels (%)	min	max		MJ/tonnekm
BULK CARRIER	(tonnes)	J/vesselkm)	*refining not included*						(% of maximum load)					
fleet average 2000			75	1,64	0,06	0,18	0,94	0,11	50%	80%	0%	10%	40%	
OB1	1635	562												0,057
OB2	14053	946												0,011
OB3	114127	2009												0,003
OB4	266889	3376												0,002
OB5	597544	4486												0,001
fleet average 2010			75	1,59	0,06	0,18	0,53	0,04						
OB1	1635	562												0,057
OB2	14053	946												0,011
OB3	114127	2009												0,003
OB4	266889	3376												0,002
OB5	597544	4486												0,001
fleet average 2020 (EC)			75	1,56	0,06	0,18	0,53	0,04						

Refining	Energy	Emission factors					
		CO_2	NOx	CO	VOC	SO_2	PM_{10}
	(MJ/MJ fuel)	(g/MJ fuel)					
REFINING							
2000							
petrol	5.00	9.2	0.042	0.005	0.210	0.072	0.002
diesel	2.85	6.8	0.036	0.005	0.088	0.052	0.001
LPG	3.02	6.2	0.032	0.004	0.056	0.033	0.001
kerosine		6.6	0.037	0.005	0.088	0.057	0.001
fuel oil		5.4	0.032	0.004	0.077	0.029	0.001
2010 (EC)	*idem 2000*						
2020 (EC)	*idem 2000*						
2020 (EC-plus)	*idem 2000*						
Electricity production							
ELECTRICITY (the Netherlands)	**Energy**	**Emission factors (g/MJ electricity)**					
2000	**return (%)**	CO_2	NOx	CO	VOC	SO_2	PM_{10}
production	42%	176	0.28	0.03	0.03	0.19	0.02
distribution	90%						
total	38%						
2010							
production	42%	156	0.18			0.14	0.02
distribution	90%						
total	38%						
2020 (EC)							
production	42%	123	0.10			0.08	
distribution	90%						
total	38%						
2020 (EC-plus)	*no data available*						
ELECTRICITY (EU- nuclear power included)	**Energy**	**Emission factors (g/MJ electricity)**					
2000	**return (%)**	CO_2	NOx	CO	VOC	SO_2	PM_{10}
production	42%	127	0.33	0.02	0.02	0.74	0.04
distribution	90%						
total	38%						
2010	*no data available*						
2020 (EC)	*no data available*						
2020 (EC-plus)	*no data available*						
ELECTRICITY (EU- nuclear power excluded)	**Energy**	**Emission factors (g/MJ electricity)**					
2000	**return (%)**	CO_2	NOx	CO	VOC	SO_2	PM_{10}
production	42%	178	0.45	0.03	0.03	1.04	0.05
distribution	90%						
total	38%						
2010		158	0.29				0.05
production	42%						
distribution	90%						
total	38%						
2020 (EC)	*no data available*						
2020 (EC-plus)	*no data available*						

B Acknowledgement of unprocessed data

B.1 Passenger Transport

PASSENGER CAR

Energy use and emission factors
Fleet average 2000: [Taksforce Traffic and Transport, 2002].
Fleet average 2010: [RIVM/ECN, 2001].
Fleet average 2020: [RIVM, 2000].
New cars in 2000: [Taksforce Traffic and Transport, 2002].

Fleet average 2020+: assumed that emissions of new car, both petrol and diesel, will have to be reduced by 50% compared to Euro 4 in 2010 ('Euro 5 –legislation'). Besides emissions have to be reduced by another 50% compared to Euro 5 in 2015 ('Euro 6'). We assumed average fleet emissions in 2020+ to be 50% lower compared to the reference scenario.

Logistical characteristics
Source: OVG [CBS, 2000].

MOTORCYCLE/MOPEDS

Energy use and emission factors
Fleet average 2000: [Taksforce Traffic and Transport, 2002].
Fleet average 2010: [RIVM/ECN, 2001].
Fleet average 2020: [RIVM, 2000].
New cars in 2000: [Taksforce Traffic and Transport, 2002].

Fleet average 2020+: emissions of motorcycles are on average equal to Phase 2 emission legislation, which is equal to Euro 3 standards for cars. Other emissions equal to 'fleet average 2020'.

Logistical characteristics
Own estimation based on the following sources:

Occupancy	*BTS, USA [BTS, 2002]*	*The Center for Transportation Analysis, USA [CTA,2002]:*	*Efficient prices for transport [CE, 1999]*	*External costs of transport [INFRAS - IWW, 2000]*
Motorcycles	1.18	1.37	1.2	1.12 (for EU)
Mopeds		1.04	1.2	

BUSES

Energy use and emission factors
Fleet average 2000: [Taksforce Traffic and Transport, 2002].
Fleet average 2010: [RIVM/ECN, 2001].
Fleet average 2020: [RIVM, 2000].
New cars in 2000: [Taksforce Traffic and Transport, 2002].

Fleet average 2020+: Euro6 emission legislation in 2013/2014 (1.5 g/kWh NO_x). The fleet average emission factor in 2020+ is assumed to be 60% (1.5/2.5) of the emission factor in the reference scenario.

City bus
emissions factor = 1.0 * emission factor for 'city driving'
Regional bus
emissions factor = 0.5 * emission factor for 'city driving' +
0.5 * emission factor for rural driving
Coach
emissions factor = 0.25 * emission factor for 'city driving' +
0.25 * emission factor for 'rural driving' +
0.50 * emission factor for 'highway driving'

Logistical characteristics
Own estimation based on the following sources:

	Energy use and emissions per transport mode [RIVM, 1997]	*OV op eigen benen [TUD, 2000]*	*Personen-verkeer en milieu [SNM, 2001]*	*Efficient prices for transport [CE, 1999]*	*External costs of transport [INFRAS - IWW, 2000]*	*Statistics of passenger transport [CBS, 1999]*
City bus						
Occupancy	*13.1*	*8.0*	*40.1*	*13*	*15*	
Nonproductive rides	*7%*	*5%*				
Regional bus						
Occupancy	*13.7*	*10.4*	*13*	*13.3*	*20*	
Nonproductive rides	*7%*	*5 % - 15%*				
Coach	*31.7*			*37*		*44*[24]
	24%					

The load factors for peak hours are calculated by adding 20% to the average load factor. The load factors for off-peak hours are calculated by subtracting 20% from the average load factor. This estimation is based on the average results of "OV op eigen benen" (TUD, 2000).

TRAMS/SUBWAY

Energy use
Data have been obtained from from RIVM (1997). Energy use is assumed to be equal for all future years.

Logistical characteristics
Own estimation based on the following sources:

	Energy use and emissions per transport mode [RIVM, 1997]	*OV op eigen benen [TUD, 2000]*	*Personenverkeer en milieu [SNM, 2001]*	*Milieubelasting van mobiele bronnen: 4 vergeten categorieën [CE, 1999]*
Tram				
Occupancy	*24.90%*	*12.50%*	*50%*	*23.4 %*
Nonproductive rides	*4.50%*	*2.50%*		
Subway				
Occupancy	*28.80%*	*18.00%*	*50%*	*20.7%*
Nonproductive rides	*3%*	*2.50%*		

[24] Top-down calculation, only for international coach transport.

The load factors for peak hours are calculated by adding 20% to the average load factor. The load factors for off-peak hours are calculated by subtracting 20% from the average load factor. This estimation is based on the average results of "OV op eigen benen" [TUD, 2000)]

PASSENGER TRAINS

Energy use

Local trains

Source: [RIVM, 2002].

Main assumptions:

- maximum speed: 140 km/h;
- distance between stops: 7 km.

Inter-city trains

Source: [RIVM, 2002].

Main assumptions:

- maximum speed: 140 km/h;
- distance between stops: 26 km.

High-speed trains

Source: [RIVM, 2002].

Main assumptions:

- maximum speed: 260 km/h;
- distance between stops: 47 km.

Magnetic trains

Source: [RIVM, 2001a].

Main assumptions:

- maximum speed: 400 km/h;
- distance between stops: 47 km.

Energy use is assumed to be equal for all future years.

Emission factors

Diesel trains

Emission factors in 2000: [Taskforce Traffic and Transport, 2002].
Emission factors in 2010/2020: equal to 2000.

Logistical characteristics

For local trains and inter-city trains: based on [RIVM, 2001c].
For HST: based on occupancy rates of 8 EU countries, according to TERM 2001 [EEA, 2001].
For magnet trains, the values for HST have been used.

The load factors for peak hours are calculated by adding 20% to the average load factor. The load factors for off-peak hours are calculated by subtracting 20% from the average load factor. This estimation is based on the average results of "OV op eigen benen" [TUD, 2000].

PASSENGER AIRCRAFT

Energy use and emission factors in 2000

Source: CORINAIR-database [TFEI, 2000].

Short distance (~ 500 km).

Average of aircraft with less than 125 seats (for example: Fokker 100, BAe146).

Continental (~ 1500 km).

Average of aircraft with more than 200 seats but less than 300 seats (for example: Boeing 757, Airbus 310).

Intercontinental (~ 6000 km).

Average of aircraft with more than 400 seats (for example: Boeing 747).

The LTO emissions have been calculated for Boeing a 737-400, 767-200 and 747-400, using the ICAO emission database.

The source for the IPCC factor is: [IPCC, 1999].

Energy use and emission factors 2010 and 2020
Energy use per LTO and per cruise kilometre in 2000: equal to 1995.
Energy use per LTO and per cruise kilometre in 2010: 14% less than in 1995 assuming 1,5% reduction per year from 1995 [CE, 1997b].
Energy use per LTO and per cruise kilometre in 2020: 22% less than in 1995 assuming 1,5% reduction per year from 1995 [CE, 1997b].

Table 5 Emission factors (g/kg fuel) in 2010 and 2020 (index: 2000 = 100)

	2010		2020	
	LTO	cruise	LTO	cruise
NO_x	105	100	105	100
VOC	53	52	51	49
CO	71	71	51	43
PM10	110	114	110	114
SO2	100	100	100	100

source: [Peeters, 1997], [TNO-MEP, 1998]

Energy use and emission factors 2020+
Energy use: equal to 2020.
Emission factors: assumed emission legislation: 20% reduction in NO_x emissions (per unit of thrust) from 2009. We assumed NO_x emissions per kg fuel in 2020+ to be 10% less than in the reference scenario in 2020. The decrease in NO_x per kg fuel is less than 20% because of an expected further increase in average engine thrust.

Logistical characteristics
The freight factors of a Boeing a 737-400, 767-200 and 747-400, from the ICAO emission database.

Average load factor in passenger transport is 79% [KLM, 2002].

FERRY
Energy use per passenger kilometre
High speed
According to [Kato, 1997] energy use of high speed ferry is between 5 and 20 seatkilometres per liter fuel. This is equal to 2 to 7 MJ per seatkilometer. We assume high-speed ferry to produce 10 seatkilometres per liter fuel, which corresponds to 3.6 MJ/seatkm. Assuming a load factor of around 56% [CE, 1997a] we have derived an energy use per passenger kilometre of 6.4 MJ/passengerkm.

Slow speed
According to [CE, 1997a] a slow speed ferry uses between 80 and 110 kg of fuel per vehicle kilometre. These ferries transport on average around 700 passengers, around 150 cars and 20 trucks. [CE, 1997a] assume passengers to weigh 100 kg, cars 1 tonne and trucks 25 tonnes. So, around 30 to 35% of total load (passengers + cars) can be assigned to passenger transport, the rest to freight transport. Energy use per passenger kilometre of slow speed ferries equal to 1,9 MJ/passenger kilometer.

Emission factors (per kg fuel)
Source: CE (1997a).

Logistical characteristics
Source: CE (1997a).

B.2 Freight transport

TRUCk
Energy use per vehicle kilometre and emission factors (per veh km)
Fleet average 2000: [Taksforce Traffic and Transport, 2002].
Fleet average 2010: [RIVM/ECN, 2001].
Fleet average 2020: [RIVM, 2000].
New cars in 2000: [Taksforce Traffic and Transport, 2002].

Fleet average 2020+: Euro6 emission legislation in 2013/2014 (1.5 g/kWh NO_x). The fleet average emission factor in 2020+ is assumed to be 60% (1.5/2.5) of the emission factor in the reference scenario.

< 3.5 tons (van)
Emissions factor = 0.5 * emission factor for 'city driving' +
0.3 * emission factor for 'rural driving' +
0.2 * emission factor for 'highway driving'
3.5 – 10 tons
Emissions factor = 0.3 * emission factor for 'city driving' +
0.3 * emission factor for 'rural driving' +
0.4 * emission factor for 'highway driving'
10 – 20 tons
Emissions factor = 0.2 * emission factor for 'city driving' +
0.3 * emission factor for 'rural driving' +
0.5 * emission factor for 'highway driving'
> 20 tons
Emissions factor = 0.1 * emission factor for 'city driving' +
0.3 * emission factor for 'rural driving' +
0.6 * emission factor for 'highway driving'
Articulated truck
Emissions factor = 0.1 * emission factor for 'city driving' +
0.3 * emission factor for 'rural driving' +
0.6 * emission factor for 'highway driving'

Logistical characteristics
Based on "Vergelijkingskader modaliteiten" [NEA/Sterc/Transcare, 2002]). For bulk and for non-bulk the average load capacities, load factors and percentages productive rides of this study have been calculated.

FREIGHT TRAIN
Energy use at full and empty load
Based on results of 'Milieuwinst op het spoor' [CE/RIVM/TNO, 2000].

Emission factors diesel
Fleet 2000, 2010 and 2020: [Taksforce Traffic and Transport, 2002].

Fleet 2020+: assumed emission legislation:
- NO_x: 6 g/kWh from 2006; 2.5 g/kWh from 2012;
- PM_{10}: 0.20 g/kWh from 2006; 0.02 g/kWh from 2012.

Logistical characteristics
Based on “Vergelijkingskader modaliteiten” [NEA/Sterc/Transcare, 2002]). For bulk and for non-bulk the average load capacities, load factors and percentages productive rides of this study have been calculated.

FREIGHT AIRCRAFT
Energy use

Intercontinental
Information from KLM and Lufthansa about load capacity of Boeing 747 full freighter. Load capacity of these aircraft is around 120 tonnes [TUD, 1993]. The load factor is around 70% (KLM, 2002). The range of energy use per tonne kilometre is 6 to 11 MJ/tonkm. We use the average number, being approximately 8 MJ/tonkm.

Continental
Also B747 full freighter. Correction for shorter distance by using data on B747 full passenger from CORINAIR database [TFEI, 2000].

Local
Also B747 full freighter. Correction for shorter distance by using data on B747 full passenger from CORINAIR database [TFEI, 2000].

Emission factors
Equal to emission factors of B747-300/400 from CORINAIR database [TFEI, 2000].

Logistical characteristics
Average load factor in freight transport is 69% [KLM, 2002].

INLAND SHIPPING
Energy use
Based on [CBS, 2002], but assuming average power setting is 85% instead of 100% which is assumed by CBS.

Emission factors
Fleet average 2000: [Dutch 'Task Force Traffic', 2002].
Fleet average 2010: [RIVM/ECN, 2001].
Fleet average 2020: [RIVM, 2000].
Fleet average 2020+: assumed emission legislation:
- NO_x: 7.0 g/kWh from 2007; 2.5 g/kWh from 2012;
- PM_{10}: 0.20 g/kWh from 2007; 0.02 g/kWh from 2012.

Logistical characteristics
Based on “Vergelijkingskader modaliteiten” [NEA/Sterc/Transcare, 2002]. For bulk and for non-bulk the average load capacities, load factors and percentages productive rides of this study were calculated.

SEA SHIPPING
Energy use

Table 6 Data on energy use at sea for sea-going vessels from [CE, 1996]. Power setting while sailing at sea is 85% of maximum engine power

	cat. 1	cat. 2	cat. 3	cat. 4	cat. 5
Container vessel					
maximum engine power (kW)	3,000	6,100	12,100	19,700	30,000
max. number of TEU's	350	800	1,600	2,600	4,000
engine efficiency	47%	49%	51%	51%	51%
energy use per vehicle km (MJ)	620	1,145	2,020	3,113	4,418
tanker					
maximum engine power (kW)	4,000	6,000	10,000	14,000	16,000
Gross Register Tonnage (GRT)	1,100	6,500	40,000	85,000	175,000
engine efficiency	47%	49%	51%	51%	51%
energy use per vehicle km (MJ)	1,082	1,563	2,329	3,250	3,708
energy use per GRT per km (gram)	23.0	5.6	1.4	0.9	0.5
bulk carrier					
maximum engine power (kW)	2,000	3,500	8,000	13,500	18,000
Gross Register Tonnage (GRT)	1,100	6,500	40,000	85,000	175,000
engine efficiency	47%	47%	51%	51%	51%
energy use per vehicle km (MJ)	562	946	2,009	3,376	4,486
energy use per GRT per km (gram)	12.0	3.4	1.2	0.9	0.6

Energy use per GRT was converted to energy use per tonne kilometre using:

- a correlation between Net Register Tonnage[25] (NRT) and Gross Register Tonnage[26] (GRT, see Table 7); and
- an assumption for the average density of freight (tanker: 1.0 kg/dm^3 (= oil) and bulk carrier: 1.7 kg/dm^3 (= sand)).

Table 7 Correlation between GRT and NRT

	cat. 1	cat. 2	cat. 3	cat. 4	cat. 5
NRT/GRT	33%	48%	63%	69%	75%

source: internet information on GRT and NRT of cargo vessels (for example: http://www.amisco.ee/bodyeng.php3?page=2,43)

Emission factors
Fleet average 2000: [Dutch 'Task Force Traffic', 2002].
Fleet average 2010: [RIVM/ECN, 2001].
Fleet average 2020: [RIVM, 2000].
Fleet average 2020+: We assumed a NO_X emission fee which will result in an emission reduction of 50%, according to [BMT, 2000].

Logistical characteristics
Own estimations, partly based on "Vergelijkingskader modaliteiten" [NEA/Sterc/Transcare, 2002].

25 Volume of the cargo compartment only.

26 Volume of the whole vessel.

B.3 Refineries and electricity production

REFINING OIL PRODUCTS

Data on emission of extraction and transport of oil and refining to fuels according to [Lewis, 1997].

NATURAL GAS

Data on emissions caused by distribution of natural gas from [IEA/AFIS, 1996]. Data on CH_4-leakage by [Dutch Emission Inventory, 2000].

ELECTRICITY PRODUCTION

Data on emissions of electricity production in EU member states according to [Lewis, 1997].

Emission reduction in the Netherlands between 1998 and 2010/2020 from [RIVM, 2001b].

Share of nuclear power generation in EU member states in 1999 and 2010 from [OECD/IEA, 2000].

C Assumptions and data for the cases

Assumptions for transport to/from loading point

Best case scenario:
In all cases: no transport to/from loading point.

Worst case scenario:
The worst case scenario for transport to and from the loading point depends on the case and the mode:

Case 1 (passenger transport <10 km)
Also in worst case we assume no transport to/from loading point.

Case 2 (passenger transport 10-250 km)
Cars and motorcycles: 0%
no transport to/from loading point
Regional bus: 15%
typical travel distance 20 km
transport to/from loading point: 3 km by city bus
Coach: 15%
typical travel distance 100 km
transport to/from loading point: 15 km by city bus
Local train: 15%
typical travel distance 40 km
transport to/from loading point: 6 km by city bus
Inter-city train: 15%
typical travel distance 100 km
transport to/from loading point: 15 km by city bus
HST: 15%
typical travel distance 100 km
transport to/from loading point: 15 km by city bus

For the load factor of the city bus car used for the transport to/from loading point we choose the peak value for case 2a and the off-peak value for case 2b.

Case 3 (passenger transport >250 km)
Cars: 0%
no transport to/from loading point
Coach: 10%
typical travel distance 500 km
transport to/from loading point: 50 km by passenger car (petrol)
Inter-city train: 15%
typical travel distance 500 km
transport to/from loading point: 75 km by passenger car (petrol)
HST: 15%
typical travel distance 500 km
transport to/from loading point: 75 km by passenger car (petrol)
Aircraft 500 km: 20%
typical travel distance 500 km
transport to/from loading point: 100 km by passenger car (petrol)

Aircraft 1500 km: 10%

typical travel distance 1500 km
transport to/from loading point: 150 km by passenger car (petrol)

For the load factor of the passenger car used for the transport to/from loading point we choose the average load factor.

Case 4 freight transport
For all modes except road transport and sea shipping the worst case scenario for transport to/from loading point is:

- bulk: 5% transport to/from loading point by truck (> 20 tons);
- non-bulk: 15% transport to/from loading point by truck (> 20 tons).

For sea shipping the worst case scenario for transport to/from loading point is:

- bulk: 10% transport to/from loading point by truck (> 20 tons);
- non-bulk: 20% transport to/from loading point by truck (> 20 tons).

Assumptions for detour factors

For all modes, the *best case scenario* for the detour factor is 0%

The detour factor in the *worst case scenario* depends on the mode:

Mode	Maximum detour factor
Passenger transport	
Car (only in the city):	15%
Motorcycle (only in the city)	10%
City bus	25%
Regional bus	25%
Coach	5%
Tram	15%
Subway	10%
Local train	10%
Inter-city	10%
HST	10%
Aircraft 500 km	10%
Aircraft 1500 km	5%
Freight transport	
Truck	0%
Train	10%
Inland vessel	10%
Sea vessel	10%
Aircraft 500 km	10%
Aircraft 1500 km	5%
Aircraft 6000 km	2%

The detour factor of coaches is because of picking up and dropping passengers. The detour factor of aircraft includes the circling while waiting for a free landing strip.

Uncertainty in load factors

For load factors, we choose to use a uncertainty margin of 15%. The best case is the average load factor multiplied with 1.15; the worst case is the average load multiplied with 0.85.

Passenger transport - short distance 2000

	detour factor		load / load factor	elasticity	best case				worst case			
MARGINAL peak	best case	worst case			Energy (MJ$_{primary}$/passenger.km)	CO2 (g/passenger.km)	NOx	PM10	Energy	CO2	NOx	PM10
Passenger car	0%	15%										
petrol			1.38	not relevant	2.38	193.81	0.51	0.011	3.70	301.55	0.79	0.017
diesel			1.38	not relevant	1.91	152.65	0.61	0.093	2.97	237.50	0.95	0.144
LPG			1.38	not relevant	2.23	161.97	0.54	0.006	3.47	252.00	0.84	0.009
Moped	0%	0%										
			1	not relevant	0.82	67.04	0.08	0.04	0.82	67.04	0.08	0.04
			2	not relevant	0.41	33.52	0.04	0.02	0.41	33.52	0.04	0.02
City bus	0%	25%										
diesel			16	1	0.86	68.99	0.53	0.038	1.46	116.67	0.89	0.065
Tramways	0%	15%										
electricity			30%	1	0.63	42.31	0.11	0.013	0.98	65.83	0.17	0.020
Subway	0%	10%										
electricity			35%	1	0.61	41.01	0.10	0.013	0.91	61.03	0.16	0.019
					best case				**worst case**			
MARGINAL off-peak	detour factor: best case	worst case	load / load factor	elasticity	Energy (MJ$_{primary}$/passenger.km)	CO2 (g/passenger.km)	NOx	PM10	Energy	CO2	NOx	PM10
Passenger car	0%	15%										
petrol			1.60	not relevant	2.05	167.27	0.44	0.009	3.19	260.26	0.68	0.014
diesel			1.60	not relevant	1.64	131.75	0.52	0.080	2.56	204.98	0.82	0.124
LPG			1.60	not relevant	1.93	139.79	0.47	0.005	3.00	217.49	0.73	0.008
Moped	i.e. peak											
City bus	0%	25%										
diesel			10	0.3	0.41	33.11	0.25	0.02	0.70	56.00	0.43	0.03
Tramways	0%	15%										
electricity			20%	0.3	0.28	19.04	0.05	0.01	0.44	29.62	0.08	0.01
Subway	0%	10%										
electricity			23%	0.3	0.27	18.16	0.05	0.01	0.40	27.03	0.07	0.01
AVERAGE	detour factor: best case	worst case	load / load factor	elasticity	Energy (MJ$_{primary}$/passenger.km)	CO2 (g/passenger.km)	NOx	PM10	Energy	CO2	NOx	PM10
Passenger car	0%	15%										
petrol			1.53	not relevant	2.15	175.30	0.46	0.010	3.35	272.74	0.71	0.015
diesel			1.53	not relevant	1.72	138.07	0.55	0.084	2.68	214.81	0.86	0.130
LPG			1.53	not relevant	2.02	146.49	0.49	0.005	3.14	227.93	0.76	0.008
Moped	0%	0%										
			1.1	not relevant	0.65	52.99	0.07	0.03	0.88	71.70	0.09	0.04
City bus	0%	25%										
diesel			13	not relevant	1.06	84.91	0.65	0.047	1.79	143.59	1.09	0.080
Tramways	0%	15%										
electricity			25%	not relevant	0.76	50.98	0.13	0.016	1.18	79.31	0.20	0.024
Subway	0%	10%										
electricity			29%	not relevant	0.72	48.34	0.12	0.015	1.07	71.95	0.18	0.022

Passenger transport - medium distance 2000

MARGINAL peak	detour factor best case	detour factor worst case	load / load factor	elasticity	best case Energy [MJ$_{primary}$/passenger km]	best case CO2 (g/passenger km)	best case NOx	best case PM10	worst case Energy	worst case CO2	worst case NOx	worst case PM10
Passenger car	0%	0%										
petrol			1.38	not relevant	2.30	193.01	0.61	0.011	3.22	262.22	0.68	0.015
diesel			1.38	not relevant	1.91	152.66	0.61	0.093	2.68	206.62	0.82	0.126
LPG			1.38	not relevant	2.20	161.97	0.54	0.006	3.02	219.13	0.73	0.009
Motorcycle	0%	10%										
Petrol			1	not relevant	1.90	153.22	0.35	0.12	2.07	168.55	0.38	0.14
			2	not relevant	0.94	76.61	0.17	0.06	1.03	84.27	0.19	0.07
Regional bus	0%	25%										
diesel			17	1	0.75	59.90	0.47	0.029	1.40	111.79	0.87	0.056
Coach	0%	5%										
diesel			38	not relevant	0.41	32.65	0.26	0.016	0.71	57.00	0.44	0.029
Local train	0%	10%										
electricity			40%	1.21	0.84	56.64	0.14	0.017	1.38	94.66	0.29	0.032
diesel					0.95	75.79	1.16	0.051	1.54	123.15	1.81	0.082
Intercity train	0%	10%										
electricity			53%	1.21	0.44	29.61	0.08	0.009	0.79	54.40	0.19	0.019
High speed train	0%	10%										
electricity			49%	1.21	1.17	78.91	0.20	0.024	1.88	127.80	0.38	0.042

MARGINAL off-peak	detour factor best case	detour factor worst case	load / load factor	elasticity	best case Energy [MJ$_{primary}$/passenger km]	best case CO2 (g/passenger km)	best case NOx	best case PM10	worst case Energy	worst case CO2	worst case NOx	worst case PM10
passenger car	0%	0%										
petrol			1.60	not relevant	2.05	167.27	0.44	0.009	2.78	226.31	0.59	0.013
diesel			1.60	not relevant	1.64	131.75	0.52	0.080	2.23	170.24	0.71	0.100
LPG			1.60	not relevant	1.93	139.79	0.47	0.005	2.61	189.13	0.63	0.007
Motorcycle	i.e. 2a											
Regional bus	0%	25%										
diesel			11	0.3	0.30	24.05	0.19	0.012	0.64	51.03	0.40	0.026
Coach	i.e. 2a											
diesel												
Local train	0%	10%										
electricity			28%	0.1	0.10	6.85	0.02	0.002	0.28	20.55	0.10	0.009
diesel					0.12	9.64	0.15	0.007	0.31	24.70	0.38	0.015
Intercity train	0%	10%										
electricity			36%	0.1	0.05	3.62	0.01	0.001	0.21	15.60	0.09	0.007
High speed train	0%	10%										
electricity			49%	0.1	0.09	6.20	0.02	0.002	0.27	19.59	0.10	0.009

AVERAGE	detour factor best case	detour factor worst case	load / load factor	elasticity	best case Energy [MJ$_{primary}$/passenger km]	best case CO2 (g/passenger km)	best case NOx	best case PM10	worst case Energy	worst case CO2	worst case NOx	worst case PM10
Passenger car	0%	0%										
petrol			1.53	not relevant	2.16	176.30	0.46	0.010	2.91	237.17	0.62	0.013
diesel			1.53	not relevant	1.72	138.07	0.55	0.084	2.33	185.79	0.74	0.113
LPG			1.53	not relevant	2.02	146.49	0.49	0.005	2.73	195.20	0.66	0.007
Motorcycle	0%	10%										
			1.15	not relevant	1.42	115.06	0.26	0.09	2.12	172.43	0.39	0.14
Regional bus	0%	25%										
diesel			14	not relevant	0.79	62.99	0.49	0.031	1.33	106.63	0.83	0.052
Coach	0%	5%										
diesel			38	not relevant	0.41	32.65	0.26	0.016	0.58	46.64	0.36	0.023
Local train	0%	10%										
electricity			33%	not relevant	0.80	53.94	0.14	0.017	1.19	80.27	0.21	0.025
diesel			33%	not relevant	0.95	75.92	1.16	0.051	1.41	112.98	1.73	0.077
Intercity train	0%	10%		not relevant								
electricity			44%		0.42	28.02	0.07	0.009	0.62	41.71	0.11	0.013
High speed train	0%	10%		not relevant								
electricity			49%		0.92	61.99	0.16	0.019	1.37	92.26	0.24	0.028

Passenger transport - long distance 2000					best case				worst case			
AVERAGE	detour factor		load / load factor	elasticity	Energy	CO2	NOx	PM10	Energy	CO2	NOx	PM10
	best case	worst case			($MJ_{primary}$/passenger.km)	(g/passenger.km)						
passenger car	0%	0%										
petrol			2.5	not relevant	0.85	69.33	0.41	0.004	1.15	93.79	0.55	0.005
diesel			2.5	not relevant	0.76	61.11	0.23	0.032	1.03	82.68	0.30	0.044
LPG			2.5	not relevant	0.76	55.18	0.35	0.002	1.03	74.66	0.47	0.003
Coach	0%	5%										
diesel			38	not relevant	0.24	18.96	0.15	0.009	0.63	50.66	0.27	0.015
Intercity train	0%	10%										
electric			44%	1	0.44	29.48	0.08	0.009	1.09	79.45	0.21	0.015
High speed train	0%	10%										
electric			49%	1	0.97	65.21	0.17	0.020	1.88	132.63	0.34	0.032
Aircraft												
500 km	0%	10%	70%	not relevant	2.18	444.54	0.22	0.005	3.83	709.02	0.45	0.010
1500 km	0%	5%	75%	not relevant	1.06	216.47	0.10	0.005	1.87	345.87	0.21	0.008

Freight transport - long and medium distance 2000					best case				worst case			
***AVERAGE 2000* bulk**	detour factor		load factor	elasticity	Energy	CO2	NOx	PM10	Energy	CO2	NOx	PM10
	best case	worst case			km)	(g/tonne.km)						
Truck (diesel)	0%	0%										
< 3.5 tonnes			n.r.t.	n.r.t.								
3.5 - 10 tonnes			n.r.t.	n.r.t.								
10 - 20 tonnes			n.r.t.	n.r.t.								
> 20 tonnes			35%	n.r.t.	0.72	57.80	0.67	0.022	0.97	77.80	0.90	0.029
trailers			35%	n.r.t.	0.73	57.00	0.66	0.013	0.99	77.54	0.89	0.018
Freight train	0%	10%										
bulk - electric			90%	n.r.t.	0.28	18.74	0.05	0.006	0.46	31.76	0.12	0.010
bulk - diesel			90%	n.r.t.	0.32	26.67	0.39	0.017	0.53	42.09	0.63	0.027
Inland vessel	0%	10%										
< 250 tonnes			58%	n.r.t.	1.34	105.30	1.61	0.080	2.04	160.64	2.44	0.120
250 - 400 tonnes			58%	n.r.t.	0.58	45.66	0.70	0.035	0.91	71.84	1.08	0.053
400 - 650 tonnes			58%	n.r.t.	0.53	41.50	0.63	0.031	0.83	65.70	0.99	0.048
650 - 1000 tonnes			48%	n.r.t.	0.45	35.71	0.55	0.027	0.72	57.04	0.86	0.042
1000 - 1500 tonnes			31%	n.r.t.	0.41	32.14	0.49	0.024	0.66	51.72	0.78	0.038
1500 - 3000 tonnes			32%	n.r.t.	0.41	32.05	0.49	0.024	0.65	51.59	0.77	0.038
> 3000 tonnes			25%	n.r.t.	0.13	10.05	0.15	0.008	0.24	18.85	0.27	0.013
Sea bulk carrier	0%	10%	60%									
OB1				n.r.t.	0.050	3.99	0.08	0.006	0.171	13.72	0.21	0.011
OB2				n.r.t.	0.010	0.78	0.02	0.001	0.112	8.94	0.11	0.005
OB3				n.r.t.	0.003	0.20	0.00	2.9E-04	0.101	8.08	0.10	0.003
OB4				n.r.t.	0.002	0.15	0.00	2.1E-04	0.100	8.00	0.09	0.003
OB5				n.r.t.	0.001	0.09	0.00	1.2E-04	0.099	7.91	0.09	0.003
Sea tanker	0%	10%	60%									
OC1				n.r.t.	0.153	12.29	0.26	0.017	0.326	26.07	0.47	0.029
OC2				n.r.t.	0.026	2.07	0.04	0.003	0.136	10.85	0.15	0.007
OC3				n.r.t.	0.005	0.38	0.01	5.4E-04	0.104	8.34	0.10	0.004
OC4				n.r.t.	0.003	0.23	0.00	3.2E-04	0.101	8.12	0.10	0.003
OC5				n.r.t.	0.001	0.12	0.00	1.6E-04	0.099	7.96	0.09	0.003
					best case				worst case			
***AVERAGE 2000* non-bulk**	detour factor		load factor	elasticity	Energy	CO2	NOx	PM10	Energy	CO2	NOx	PM10
Truck (diesel)	0%	0%										
< 3.5 tonnes			30%	n.r.t.	6.99	550.06	2.27	0.340	9.46	757.72	3.07	0.459
3.5 - 10 tonnes			50%	n.r.t.	2.46	196.29	1.97	0.080	3.32	265.67	2.67	0.108
10 - 20 tonnes			61%	n.r.t.	1.30	104.43	1.13	0.042	1.77	141.39	1.52	0.057
> 20 tonnes			62%	n.r.t.	0.73	58.70	0.68	0.022	0.99	79.52	0.92	0.030
trailers			62%	n.r.t.	0.75	59.95	0.68	0.014	1.01	81.13	0.93	0.019
Freight train	0%	10%										
container - electric			44%	n.r.t.	0.43	28.69	0.07	0.009	0.78	54.63	0.25	0.018
container - diesel			44%	n.r.t.	0.49	39.25	0.60	0.027	0.88	70.31	1.03	0.044
Inland vessel	0%	10%										
< 250 tonnes			95%	n.r.t.	2.07	163.31	2.50	0.124	3.24	254.97	3.85	0.189
250 - 400 tonnes			95%	n.r.t.	0.90	70.79	1.08	0.054	1.49	117.35	1.75	0.084
400 - 650 tonnes			95%	n.r.t.	0.82	64.40	0.98	0.049	1.37	107.77	1.60	0.077
650 - 1000 tonnes			94%	n.r.t.	0.84	66.10	1.01	0.050	1.40	110.30	1.64	0.079
1000 - 1500 tonnes			83%	n.r.t.	1.08	85.11	1.30	0.065	1.76	138.60	2.07	0.101
1500 - 3000 tonnes			79%	n.r.t.	1.00	78.40	1.20	0.059	1.63	128.73	1.92	0.093
> 3000 tonnes			95%	n.r.t.	0.43	33.90	0.52	0.026	0.79	62.50	0.91	0.043
Sea container vessel	0%	10%	75%									
C1				n.r.t.	0.26	20.55	0.43	0.029	0.58	46.53	0.82	0.049
C2				n.r.t.	0.21	16.62	0.35	0.024	0.51	40.64	0.73	0.041
C3				n.r.t.	0.18	14.05	0.31	0.021	0.47	37.71	0.64	0.037
C4				n.r.t.	0.17	13.90	0.29	0.020	0.46	36.59	0.62	0.035
C5				n.r.t.	0.16	12.82	0.27	0.018	0.44	34.99	0.58	0.033
Aircraft												
500 km	0	10%	75%	not relevant	10.32	2091.08	1.58	0.306	15.46	3112.13	2.45	0.666
1500 km	0	10%	75%	not relevant	7.82	1585.07	0.87	0.187	11.69	2358.92	1.34	0.209
6000 km	0	10%	75%		6.89	1395.24	0.32	0.032	10.27	2076.45	0.50	0.068

Freight transport - long and medium distance 2010

AVERAGE 2010 bulk	detour factor best case	detour factor worst case	load factor	elasticity	best case Energy (MJ/tonne km)	best case CO2 (g/tonne km)	best case NOx	best case PM10	worst case Energy	worst case CO2	worst case NOx	worst case PM10
Truck (diesel)	0%	0%										
< 3.5 tonnes			n.r.t.	n.r.t.								
3.5 - 10 tonnes			n.r.t.	n.r.t.								
10 - 20 tonnes			n.r.t.	n.r.t.								
> 20 tonnes			91%	n.r.t.	0.72	57.50	0.32	0.006	0.97	77.88	0.43	0.010
trailers			91%	n.r.t.	0.74	57.68	0.30	0.004	1.01	78.04	0.40	0.005
Freight train	0%	10%										
bulk - electric			80%	n.r.t.	0.28	16.69	0.05	0.006	0.46	28.72	0.07	0.009
bulk - diesel			80%	n.r.t.	0.32	25.07	0.39	0.017	0.53	42.09	0.61	0.026
Inland vessel	0%	10%										
< 250 tonnes			56%	n.r.t.	1.29	101.53	1.52	0.077	1.97	154.89	2.39	0.115
250 - 400 tonnes			56%	n.r.t.	0.56	44.01	0.66	0.033	0.88	69.29	1.00	0.050
400 - 650 tonnes			56%	n.r.t.	0.51	40.04	0.60	0.030	0.81	63.47	0.91	0.046
650 - 1000 tonnes			45%	n.r.t.	0.44	34.43	0.51	0.026	0.70	55.13	0.79	0.039
1000 - 1500 tonnes			31%	n.r.t.	0.39	30.98	0.46	0.024	0.63	50.08	0.71	0.036
1500 - 3000 tonnes			32%	n.r.t.	0.39	30.69	0.46	0.023	0.63	49.87	0.71	0.035
> 3000 tonnes			25%	n.r.t.	0.12	9.69	0.14	0.007	0.23	18.31	0.24	0.011
Sea bulk carrier	0%	10%	50%									
OB1				n.r.t.	0.050	3.99	0.06	0.002	0.171	13.72	0.16	0.004
OB2				n.r.t.	0.010	0.78	0.02	0.000	0.112	8.94	0.07	0.002
OB3				n.r.t.	0.003	0.20	0.00	1.2E-04	0.101	8.08	0.05	0.001
OB4				n.r.t.	0.002	0.15	0.00	8.4E-05	0.100	8.00	0.05	0.001
OB5				n.r.t.	0.001	0.09	0.00	5.0E-05	0.099	7.91	0.05	0.001
Sea tanker	0%	10%	50%									
OC1				n.r.t.	0.153	12.29	0.25	0.007	0.325	26.07	0.41	0.011
OC2				n.r.t.	0.026	2.07	0.04	0.001	0.136	10.85	0.11	0.003
OC3				n.r.t.	0.005	0.38	0.01	3.2E-04	0.104	8.34	0.05	0.001
OC4				n.r.t.	0.003	0.23	0.00	1.3E-04	0.101	8.12	0.05	0.001
OC5				n.r.t.	0.001	0.12	0.00	6.6E-05	0.099	7.96	0.05	0.001

AVERAGE 2010 non-bulk	detour factor best case	detour factor worst case	load factor	elasticity	best case Energy	best case CO2	best case NOx	best case PM10	worst case Energy	worst case CO2	worst case NOx	worst case PM10
Truck (diesel)	0%	0%										
< 3.5 tonnes			39%	n.r.t.	5.83	461.23	1.04	0.073	7.62	630.48	1.41	0.099
3.5 - 10 tonnes			50%	n.r.t.	2.45	196.29	0.95	0.026	3.32	265.97	1.28	0.038
10 - 20 tonnes			61%	n.r.t.	1.30	104.51	0.54	0.015	1.77	141.39	0.73	0.020
> 20 tonnes			62%	n.r.t.	0.73	58.78	0.33	0.006	0.99	79.52	0.44	0.011
trailers			62%	n.r.t.	0.78	60.90	0.31	0.004	1.03	82.48	0.43	0.006
Freight train	0%	10%										
container - electric			44%	n.r.t.	0.40	28.69	0.07	0.009	0.79	54.63	0.10	0.015
container - diesel			44%	n.r.t.	0.49	39.23	0.60	0.027	0.88	70.31	0.96	0.041
Inland vessel	0%	10%										
< 250 tonnes			85%	n.r.t.	2.00	157.42	2.36	0.120	3.13	280.21	3.86	0.180
250 - 400 tonnes			85%	n.r.t.	0.87	68.24	1.02	0.052	1.44	113.48	1.58	0.079
400 - 650 tonnes			85%	n.r.t.	0.79	62.08	0.93	0.047	1.32	104.31	1.45	0.072
650 - 1000 tonnes			84%	n.r.t.	0.81	63.72	0.95	0.048	1.35	106.78	1.48	0.074
1000 - 1500 tonnes			83%	n.r.t.	1.04	82.05	1.23	0.062	1.70	134.83	1.89	0.094
1500 - 3000 tonnes			78%	n.r.t.	0.96	75.68	1.13	0.058	1.58	124.52	1.75	0.087
> 3000 tonnes			85%	n.r.t.	0.42	32.75	0.49	0.025	0.77	60.87	0.79	0.039
Sea container vessel	0%	10%	75%									
C1				n.r.t.	0.26	20.58	0.42	0.012	0.58	46.53	0.71	0.020
C2				n.r.t.	0.21	16.62	0.34	0.009	0.51	40.64	0.59	0.016
C3				n.r.t.	0.18	14.66	0.30	0.008	0.47	37.71	0.53	0.015
C4				n.r.t.	0.17	13.90	0.28	0.008	0.46	36.59	0.51	0.014
C5				n.r.t.	0.16	12.82	0.26	0.007	0.44	34.99	0.48	0.013
Aircraft												
500 km	0	10%	75%	not relevant	8.09	1801.16	1.37	0.299	13.33	2880.64	2.16	0.544
1500 km	0	10%	75%	not relevant	6.74	1395.25	0.65	0.104	10.08	2031.86	0.91	0.204
6000 km	0	10%	75%		5.93	1201.79	0.26	0.031	8.86	1798.58	0.43	0.065