Danish Ministry of Transport and Energy

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Fixed Link across the Fehmarn Belt – Effect on Emissions to Air

March 2005

COWI

in cooperation with

DMU

Danish Ministry of Transport and Energy and German Federal Ministry of Transport, Building and Housing

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Appendix

1 Main conclusions

- The establishing of a fixed link across the Fehmarn Belt will imply a reduction of all types of air emissions from transport.

- There will be a reduction of air emissions from transport both immediately after opening of the fixed link and in the long run.

- For the greenhouse gas CO_2 and the two most damaging emission types, NO_x and particulate matter (PM_{10}), the reductions in the year 2040 are:

  - Approx. 220,000 tonnes CO_2.
  - Approx. 600 tonnes NO_x.
  - Approx. 40 tonnes PM_{10}.

- The CO_2 reduction in 2040 equals the present annual per capita CO_2 emissions of approx. 20,000 persons (all sectors included)[1]. The NO_x reduction in 2040 equals the present annual per capita NO_x transport emissions of approx. 40,000 persons[2]. The PM_{10} reduction in 2040 equals approx. 6 million trips in a passenger car from Copenhagen to Hamburg via the fixed link across the Fehmarn Belt[3].

- Based on several sensitivity analyses, the uncertainty of the reduction is assessed to be -20% to +25%.

- The emission reductions will mainly occur in Denmark and Germany and the reduction in these two countries is of the same order of magnitude.

- The largest reduction in emissions comes from the expected closure of the ferry line between Rødby and Puttgarden.

- There will also be a reduction of emissions from freight transport on road and rail. The reason is an expected transfer of road freight to rail and a decrease in the travel distance for rail freight. The travel distance for rail freight will decrease due to the expected rerouting from Jutland to the Fehmarn Belt.

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[1] Danish figures. Source: Danish Ministry of Environment (2003).

[2] Danish figures. Source: Statistics Denmark.

[3] Present vehicle technology (EUROII norm). Source: TEMA2000.

- Emissions from passenger transport on road and rail will increase. This is due to an increase both in the number of passengers and in the travel distance (plus 19 km on the fixed link).

2 Introduction

2.1 Background

In 2004 a report assessing the costs and benefits of a fixed link across the Fehmarn Belt was prepared by COWI in cooperation with the Danish Transport Research Institute for the Danish Ministry of Transport and Energy[4].

The economic assessment included quantification and economic valuation of the effect of the emissions to air (CO_2, SO_2, NO_x, HC, CO and particulate matter) from traffic. Emissions to air were quantified based on emission factors for the existing vehicle fleet.

The Danish Ministry of Transport and Energy has in cooperation with the German Federal Ministry of Transport, Building and Housing asked COWI in cooperation with the Danish National Environmental Research Institute (NERI) to carry out a more detailed analysis of the effect on emissions taking into account the development in emission factors over time.

Besides data from COWI and NERI, the analysis is performed on the basis of data for German road emission factors from the German Federal Highway Research Institute and data for ferry emissions from Consulting Naval Architect and external professor on the Danish Technical University Hans Otto Holmegaard Kristensen.

2.2 Purpose

The purpose of the report is to quantify the effect on air emissions from a changed traffic pattern due to a fixed link across the Fehmarn Belt. The effect in air emissions is quantified in two years:

- 2015
- 2040

2015 is chosen because it is the assumed opening year of the fixed link and 2040 is selected because it represents the year where traffic growth in the cost-

[4] Danish Ministry of Transport (2004b).

benefit analysis is assumed to end and hence that the full annual effect on emissions is phased in.

The results are presented for a fixed link with four road lanes and 2 rail tracks (4+2) as in the economic assessment. The results are independent of the type of fixed link established as the change in traffic pattern is independent of the technical solution.

One aspect of the analysis is to determine where the change in air emissions occurs. The analysis is therefore split as to whether the change in air emissions occurs in Denmark, Germany or other European countries. Based on this distribution, the analysis has been carried out with three geographical perspectives:

- Denmark
- Germany
- All European countries

2.3 Content of the report

The content of the report is as follows. In chapter 3 the applied methodology and assumptions are presented followed by the results of the analysis in chapter 4. Chapter 5 gives a description of the traffic volumes. Then chapter 6 describes the emission factors from ferries Chapters 7-9 describe emission factors from road transport from the three different air pollution models, TEMA2000, HBEFA and COPERT. Finally, chapter 10 describes the emission factors from trains.

Chapters 3 and 4 can be read independently of the remaining parts of the report. Chapters 5-10 give the background of the results and they are aimed at the reader, who wants to go more in-depth with the assumptions of the analysis.

3 Assumptions and methodology

3.1 Reference situation and project alternative

The analysis quantifies the impact on air emissions from transport of a fixed link across the Fehmarn Belt compared to a reference case. The reference case and the project alternative are defined as follows.

Reference case
The reference case is defined by an infrastructure situation as it would be in 2015 and forward, if a fixed link across the Fehmarn Belt were not built. The reference case is identical to the traffic scenario named *Reference Case B* in FTC (2003a)[5].

The ferries on the Fehmarn Belt are rebuilt to a higher capacity and the frequency of the ferries on Gedser-Rostock and Trelleborg-Rostock (fast ferry) is increased by one departure per day compared to the project alternative. The remaining ferry supply is fixed at the same level as the summer of 2002. It is assumed that the travel time is the same as the present travel time.

The Danish railway lines Vamdrup-Vojens and Tinglev-Padborg are upgraded to double tracks. The German railway line Neumünster-Bad Oldesloe is electrified and upgraded to double tracks with a maximum speed of 120 km/h.

Moreover, a number of improvements especially of railway infrastructure are made – e.g. upgrading of the railway line Copenhagen-Ringsted - but these are the same in the reference case and the project alternatives.

Project alternative: Fixed link (4+2)
The project alternative is defined as a fixed link across the Fehmarn Belt with 4 road lanes and 2 railway tracks. The fixed link is assumed to open in 2015. The project alternative is identical to the traffic scenario named *Base Case B* in FTC (2003b)[6].

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[5] The infrastructure assumptions are in line with the German Federal Transport Infrastructure Plan.
[6] The infrastructure assumptions are in line with the German Federal Transport Infrastructure Plan.

The ferry supply is fixed at the same level as the summer of 2002 except for the route Rødby-Puttgarden, which is assumed to be closed when the fixed link opens.

The Danish railway line Ringsted-Rødby is electrified and the railway line Orehoved-Rødby is upgraded to double tracks. In Germany, the railway line Puttgarden-Bad Schwartau is upgraded to double tracks, the railway line Bad Oldesloe-Ahrensburg is upgraded to three tracks and the railway line Ahrensburg-Hamburg-Wandsbek is upgraded to four tracks. Finally, the railway line Lübeck-Puttgarden is electrified.

3.2 The traffic model

Construction of a fixed link across the Fehmarn Belt will have implications for the traffic and travel pattern. The fixed link will reduce travel time thus making transport in the transport corridor more attractive. Therefore, a fixed link will promote traffic in the corridor and also transfer transport from other routes and between modes.

The level of traffic and the expected changes in traffic constitute a key element in the quantification of air emissions from transport. Traffic volumes are analysed by means of a traffic model which consists of a mathematical modelling of the transport demand.

The model describes the available transport system in terms of road and railway networks as well as airline and ferry routes. The model contains data on travel patterns, transport costs and properties of the routes such as travel speed, user fees etc. The model is hence the tool for calculating expected traffic volumes on modes and travel patterns.

The applied traffic model is built specifically to model the traffic consequences of opening a fixed link across the Fehmarn Belt. It is an updated version of the model that was used in the analyses from 1999. The model covers Europe, but it focuses on Eastern Denmark and Northern Germany[7].

The traffic model results in traffic volumes in 2015 for the reference case and the project scenario based on the present traffic level. In calculating the traffic volumes in 2015, a number of assumptions have been applied. Besides the assumptions on ferry traffic and infrastructure projects described above, the main assumptions are:

- The tolls on the fixed link equal the fares on the ferries.

- A fixed link will imply changes in traffic patterns in Northern Europe - partly due to induced traffic partly due to changes in route and mode choices. The assumptions on transfer and growth are based on interviews

[7] See FTC (2003b).

and a number of assumptions on the development in the economic and demographic factors, e.g. the growth in GDP and population[8].

Moreover, the traffic prognosis from the FTC model is based on a number of assumptions such as market access of rail and decrease of border resistance[9].

In general, the traffic volumes applied in the analysis are identical to those applied in the economic analysis.

The modelled traffic volumes are sensitive to the applied assumptions as well as changes in the attitude and preferences of the travellers as these are key input to the model calculations.

The overall change in road and rail traffic volumes can be seen in the table below. Please note that the table is explained further in section 5.2.

Table 3.1 Distances driven between Denmark/Scandinavia and the Continent, 2015, mill. m/year, Case B

	Unit	Reference case	Project alternative (fixed link)	Change
Passenger cars	Vehicle-km	3,613	3,717	2.9%
Busses	Vehicle-km	63	64	0.8%
Passenger trains	Passenger-km	1,044	1,250	19.7%
Lorries	Vehicle-km	3,670	3,649	-0.6%
Freight trains	Tonnes-km	15,419	15,187	-1.5%
Combi trains	Tonnes-km	3,427	3,170	-7.5%

Source: FTC traffic model.

3.3 Emission factors

Emissions to air from transport differ in the reference situation and the project scenario. First of all, traffic is transferred between modes, primarily from the ferries to road and rail across the Fehmarn Belt. Secondly, the distances driven change, because the fixed link is used and because freight and combi trains transfer from the Great Belt fixed link to the Fehmarn Belt. Finally, induced traffic is created implying an increase in transport volumes.

[8] See FTC (2003b) page 51.
[9] See FTC (2003b) page 52.

To calculate the effect on air pollution from the changed transport pattern representative emission factors are set up for the relevant means of transport. These comprise:

- Passenger cars
- Busses
- Passenger trains
- Lorries
- Freight trains
- Combi trains
- Ferries (Rødby-Puttgarden, Gedser-Rostock and Trelleborg-Rostock)

Data on the existing ferries on the three routes, where changes in supply are assumed, have been applied as starting point for estimating the emission factors from ferries. An analysis has been made to analyse the expected future development in ferry technology and in ferry supply on Rødby-Puttgarden. From this analysis future emission factors from the ferries on Rødby-Puttgarden have been estimated. The same development has been assumed on the routes Gedser-Rostock and Trelleborg-Rostock, which are less affected by establishing the fixed link.

For road transport three different models have been used to quantify the emission factors based on existing knowledge of emission norms (EURO norms).

In the base calculation TEMA2000 is applied and the composition of the vehicle fleet is based on the Danish fleet. TEMA2000 is the official model of the Danish Ministry of Transport and Energy.

In a sensitivity analysis the German model HBEFA has been applied. This analysis has been made to account for model differences between HBEFA and TEMA2000 as well as the differences in vehicle composition in Denmark and Germany.

In another sensitivity analysis, the Danish COPERT III based forecast model developed by the Danish National Environmental Research Institute has been applied to analyse how the differences in the models affect the results.

For rail transport the most modern trains of TEMA2000 have been applied as starting point taking into account expected future development in train emissions.

3.4 Overview of base assumptions

Below the base assumptions of the analysis are presented. These assumptions are applied in what is referred to as the "base calculation" or the "best estimate". Detailed explanation and motivation of each assumption can be seen in the report chapters.

Table 3.2 Base assumptions

Parameter	Assumption in the base calculation
Traffic volumes in 2015	FTC prognosis for scenario B (Reference Case B and Base Case B)[10].
Traffic volumes in 2040	Traffic growth in the period 2015-2040 is assumed to be 1.7% p.a. for all modes.
Capacity of ferries in 2015	Increase of capacity of existing ferries in terms of extra platform decks and extra length.
Capacity of ferries in 2040	New ferries of extra length.
Emission factors for ferries in 2015	Installation of catalytic converter reducing NO_x.
Emission factors for ferries in 2040	Installation of catalytic converter reducing, NO_x, HC and PM_{10}. Increase of fuel efficiency.
Emission factors for road transport	Phase in of the EURO norms known at present. Modelled with TEMA2000.
Emission factors for rail transport	Improved energy efficiency of electric trains. Reduced emissions of diesel trains similar to the potential for lorries.
Type of road driving	50/50 motorway and highway
Share of electric trains	90%

A number of sensitivity analyses are carried out where some of the base assumptions are changed. The results of these are presented in section 4.4.

[10] See FTC (2003a) and FTC (2003b) executive summary for further explanation of the B scenarios and the difference between A and B scenarios.

4 Results

In this chapter the results of the analysis of the emissions to air from transport due to a fixed link across the Fehmarn Belt are presented. The analysis is split as to whether the change in air emissions occurs in Denmark, Germany or other European countries. Based on this distribution, the analysis is presented with three geographical perspectives:

- All European countries
- Denmark
- Germany

The results are presented for a fixed link with four road lanes and two rail tracks (4+2). The results are the same for a bridge and a tunnel solution[11].

4.1 Total change in emissions for all countries

The establishing of a fixed link across the Fehmarn Belt will imply a reduction of all types of air emissions from transport compared to the reference case.

The results for all six emission types are shown in the two figures below. The results represent the best estimate. They are based on a number of assumptions on e.g. traffic growth, ferry capacity and specific emission factors. Sensitivity analyses show that the reduction may vary with -20% to +25% compared to the best estimate.

[11] The air emissions are the same. However the distribution and exposure may differ between the bridge and the tunnel solution as some of the air emissions may be captured inside the tunnel and some will be blown out via the ventilation system. It is however beyond the scope of the study to investigate this difference further.

Figure 4.1 Annual reduction of CO_2 transport emissions due to a fixed link ,2015 and 2040, all European countries

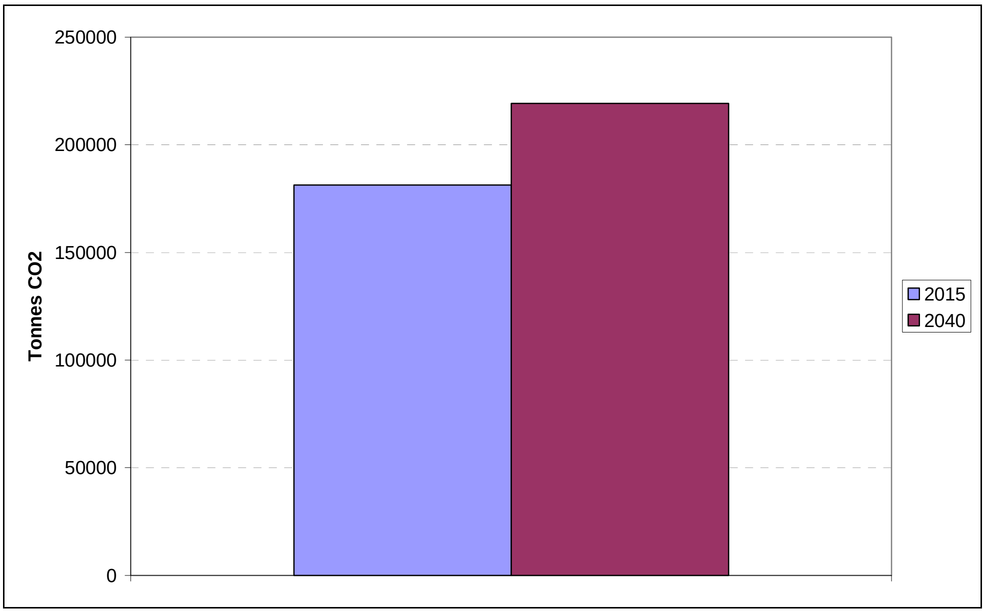
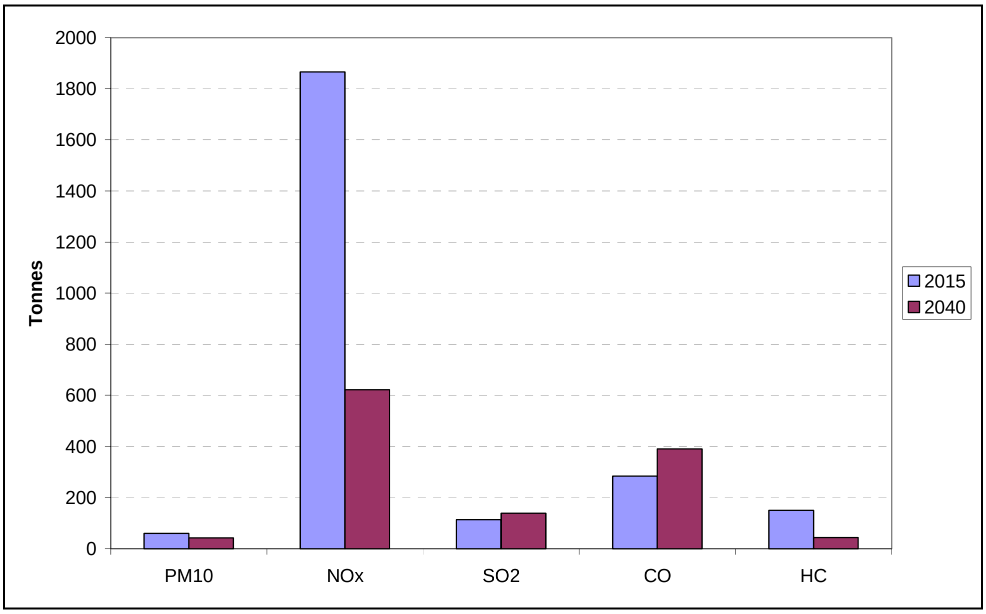


Figure 4.2 Annual reduction of other transport emissions due to a fixed link, 2015 and 2040, all European countries



Changes in total emissions over time are due to two things for each mode included in the analysis and the size of the emission reductions over time can be explained by one of the two things. Firstly, changes in traffic volumes between the project scenario and the reference situation over time. Secondly, changes in emission factors for each mode over time (as described in sections 6-10).

The figures show that emission reductions increase over time for CO_2, SO_2 and CO. This is mainly due to the increase in the saving of ferry traffic volumes in the project scenario compared to the reference situation from 2015 to 2040. This effect is larger than the effect from increased fuel efficiency (and following reduced emission factors for SO_2) for ferries. Moreover, there is an emission reduction from lorries due to an increase in the saving of tonne-km on lorries. In return, however, there is a decrease in the reduction of the same size of emissions from passenger cars due to a decrease of the in the saving of passenger-km in passenger cars. See also Figure 4.5 for the detailed figures on modes and the corresponding explanations.

Reductions decrease over time for PM_{10}, NO_x and HC which is mainly due to expected improvement in ferry emission technology (see section 4.3 for the detailed distribution on modes).

For the greenhouse gas CO_2 and the two most damaging emission types NO_x and PM_{10} the reductions are:

- Approx. 180,000 tonnes CO_2 in 2015 and approx. 220,000 CO_2 in 2040.
- Approx. 1,800 tonnes NO_x in 2015 and approx. 600 tonnes NO_x in 2040.
- Approx. 60 tonnes PM_{10} in 2015 and approx. 40 tonnes PM_{10} in 2040.

The CO_2 reduction in 2040 equals the present annual per capita CO_2 emissions of approx. 20,000 persons (all sectors included)[12]. The NO_x reduction in 2040 equals the present annual per capita NO_x transport emissions of approx. 40,000 persons[13]. The PM_{10} reduction in 2040 equals approx. 6 million trips in a passenger car from Copenhagen to Hamburg via the fixed link across the Fehmarn Belt [14].

4.2 Total change in emissions for Denmark and Germany

The establishing of a fixed link across the Fehmarn Belt will imply a reduction of all types of air emissions from transport in both Denmark and Germany compared to the reference case.

The results for all six emission types in 2040 are shown in the two figures below[15]. The results represent the best estimate.

[12] Danish figures. Source: Danish Ministry of Environment (2003).
[13] Danish figures. Source: Statistics Denmark.
[14] Present vehicle technology (EUROII norm). Source: TEMA2000.
[15] See Table 4.1for the similar figures for 2015.

Figure 4.3 Annual reduction of CO_2 transport emissions due to a fixed link, 2040, Denmark and Germany

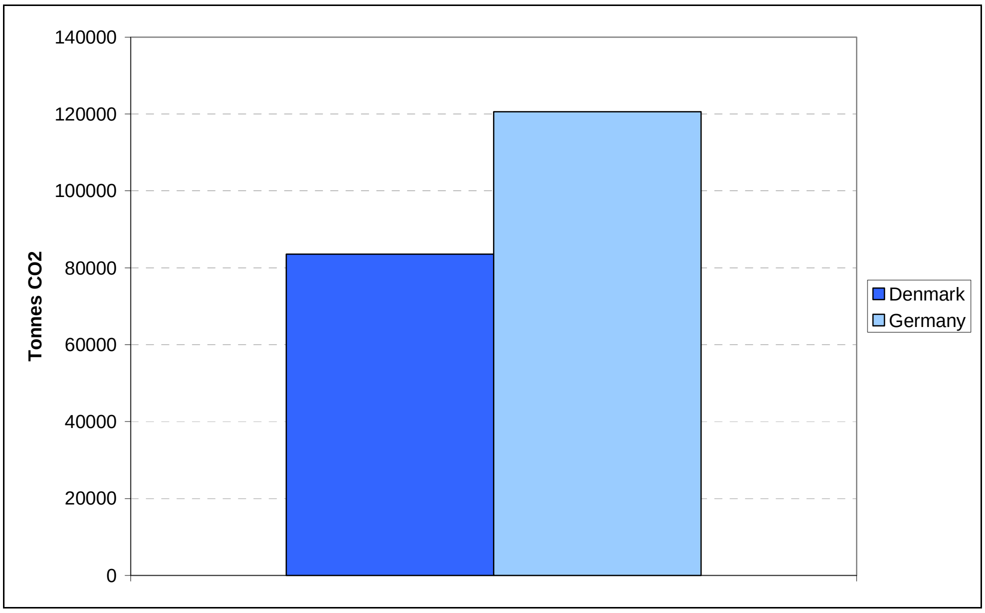
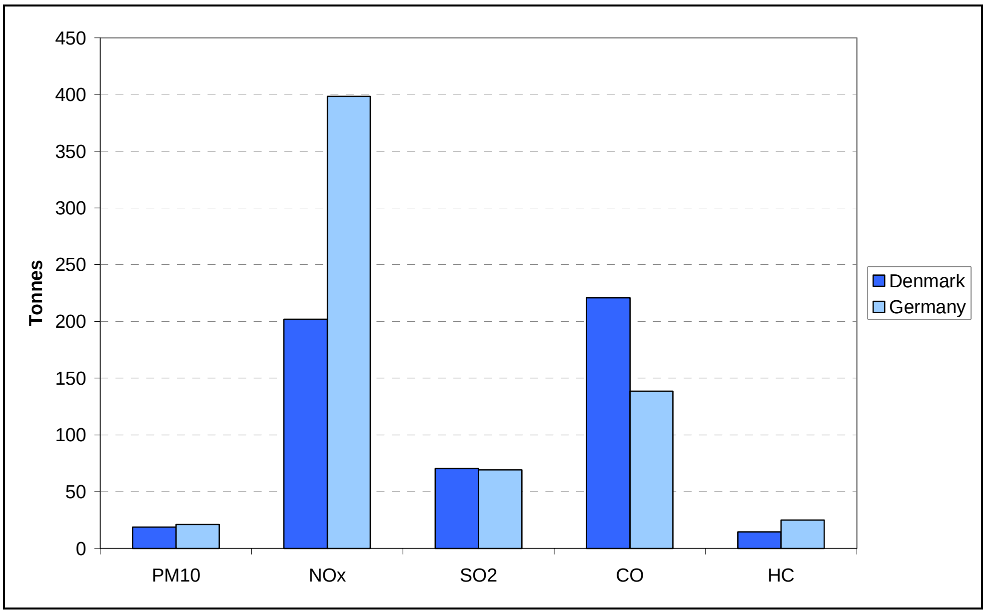


Figure 4.4 Annual reduction of other transport emissions due to a fixed link, 2040, Denmark and Germany



For PM_{10} and SO_2 the emission reductions are of the same order of magnitude in Denmark and Germany. For CO_2, NO_x and HC the reduction is bigger in Germany than in Denmark. This is mainly due to a larger reduction of emissions from lorries in Germany due to a decrease in the number of lorry-km in Germany and a small increase of the number of lorry-km in Denmark. For CO the reduction is bigger in Denmark than in Germany, which is due to a smaller increase of passenger car-km in Denmark than in Germany.

The detailed results for the three geographical perspectives are presented in the table below. The results represent the best estimate.

Table 4.1 Annual reduction of transport emissions due to a fixed link, 2015 and 2040, tonnes

Emission type	Denmark	Germany	Other countries	Total, all European countries
---------- *2015* ----------				
PM_{10}	26	30	3	59
NO_x	734	1,004	128	1,866
SO_2	58	57	-1	114
CO	160	104	20	284
HC	59	77	13	150
CO_2	71,593	97,707	11,908	181,208
---------- *2040* ----------				
PM_{10}	19	21	2	42
NO_x	202	398	22	622
SO_2	70	69	0	139
CO	221	139	31	390
HC	15	25	4	43
CO_2	83,559	120,605	15,100	219,263

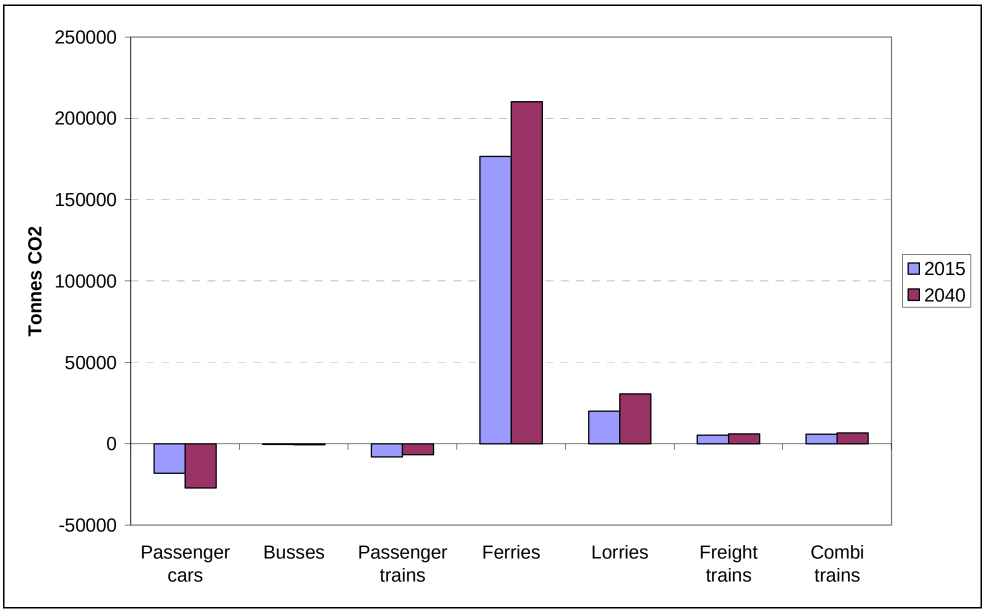
Note: Totals in last column may differ from the sum of the three first columns on the last digit due to rounding off.

The table shows that the main share of the change in emissions from transport occurs in Denmark and Germany and that the effects outside these two countries are small.

4.3 Distribution of emission reductions on modes

The CO_2 emission reductions on modes are shown in the figure below.

Figure 4.5 Annual reduction of CO_2 transport emissions on modes, 2015 and 2040, all European countries



The figure shows that by far the largest CO_2 reduction comes from the decrease in ferry transport on the three routes where changes in the supply are assumed.

There is however also a reduction in CO_2 emissions from freight transport. The reduction for lorries is caused by a decrease in the number of tonnes transported, because road freight is transferred to rail. The reduction in emissions from freight and combi trains is due to a decrease in the distance driven, because these trains are rerouted from the Great Belt fixed link to the Fehmarn Belt fixed[16].

The figure also shows that there is an increase (seen as a negative reduction in the figure) in CO_2 emissions from passenger transport on both road and rail. This is due to an increase in both the number of passengers and the transport distances for road and rail. This traffic is transported by ferry in the reference situation and uses the fixed link across the Fehmarn Belt in the project scenario.

Similar results for NO_x and PM_{10} are presented in the two figures below.

[16] As mentioned in section 3.2, the traffic volumes applied in the present analysis are based on the traffic data. The saving in distance has been estimated to approx. 175 km.

Figure 4.6 Annual reduction of NO_x transport emissions on modes, 2015 and 2040, all European countries

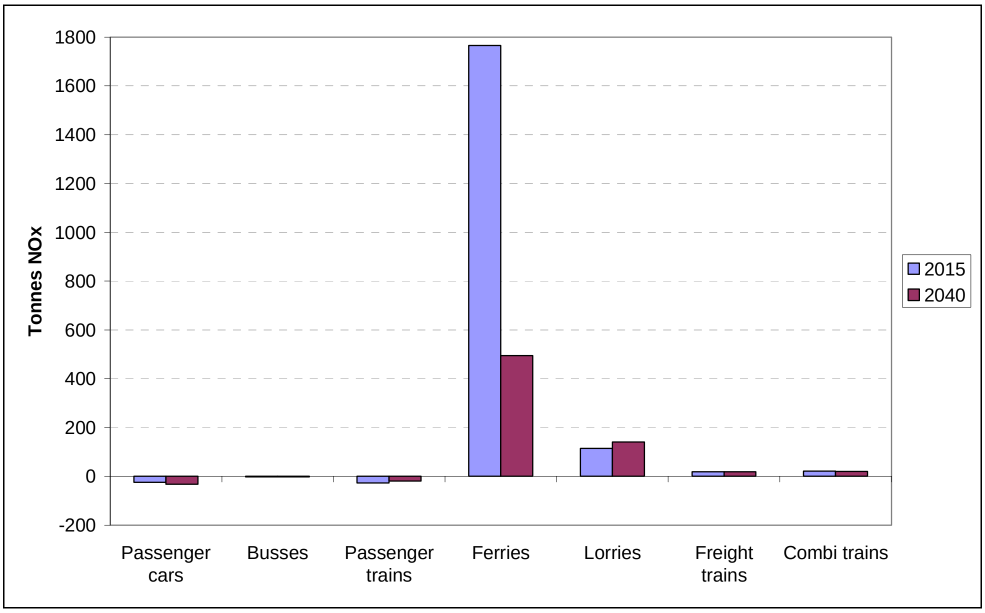
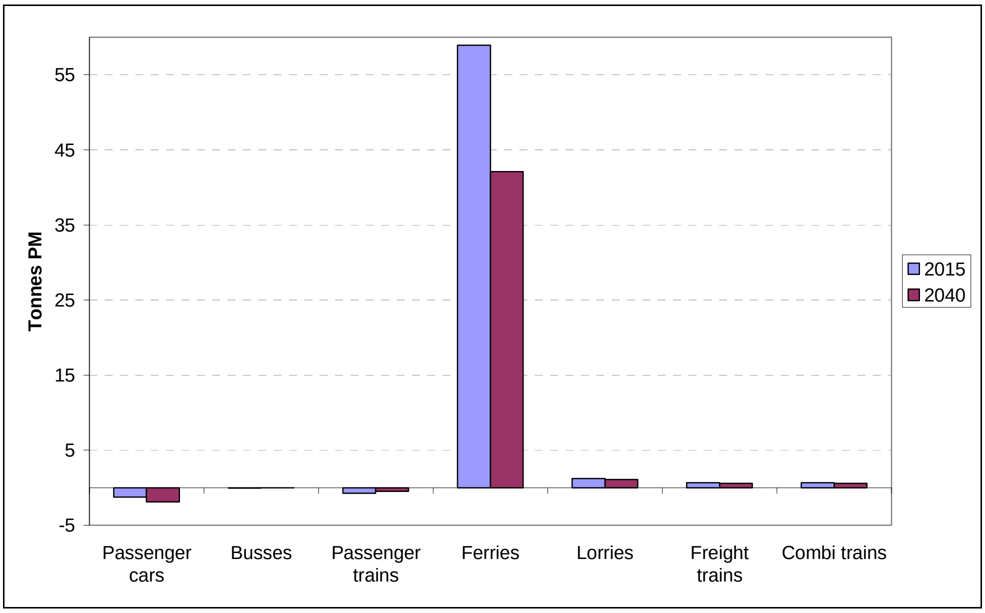


Figure 4.7 Annual reduction of PM_{10} transport emissions on modes, 2015 and 2040, all European countries



The figures show similar patterns to those for CO_2 even though both NO_x and PM_{10} reductions for ferries decrease more in 2040 than for the other modes due to the assumed improvement in ferry technology. A table of the reductions split on modes can be found in Appendix 2.

4.4 Sensitivity analyses

The results presented in the previous sections represent the best estimate (base calculation). To assess the robustness of the results a number of sensitivity analyses have been performed. The sensitivity analyses are shown in the table below. More detailed explanation of the sensitivity analyses are given in the chapters 5-10.

Table 4.2 Sensitivity analyses

Analysis	Explanation
Low traffic growth	0.7% p.a. for vehicles/wagons 2015-2040.
High traffic growth	2.7% p.a. for vehicles/wagons 2015-2040.
Road emissions from COPERT	Effect of the emission model applied (road).
Road emissions from HBEFA	As above. Takes into account German emission factors.
Low ferry capacity in 2015	Effect of the expected ferry supply in 2015.
High ferry capacity in 2015	As above.
Electricity share for trains 100%	Uncertainty about the share of electric trains.
Electricity share for trains 50%	As above.
Road emissions 100% motorway	Uncertainty about the distribution of road traffic.
Road emissions 100% highway	As above.
Diesel share for passenger cars	25% instead of present level.

The results of the sensitivity analyses for 2040 for all European countries are presented in the figures below. In Appendix 3 the detailed numbers behind the figures are presented. The figures illustrate the change of the reduction in each of the sensitivity analyses. For instance, a value of 80% means that the reduction is 20% lower than the reduction in the base calculation.

Figures illustrating the sensitivity analyses for 2015 are presented in Appendix 4 along with the detailed numbers.

Figure 4.8 Result of the sensitivity analyses for CO_2, PM_{10} and NO_x, all European countries, 2040

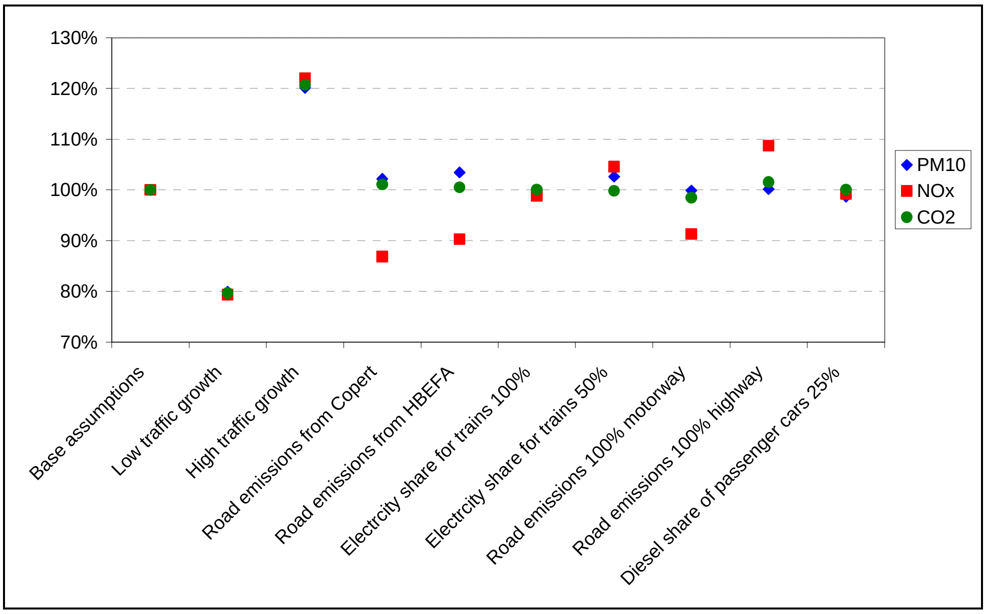
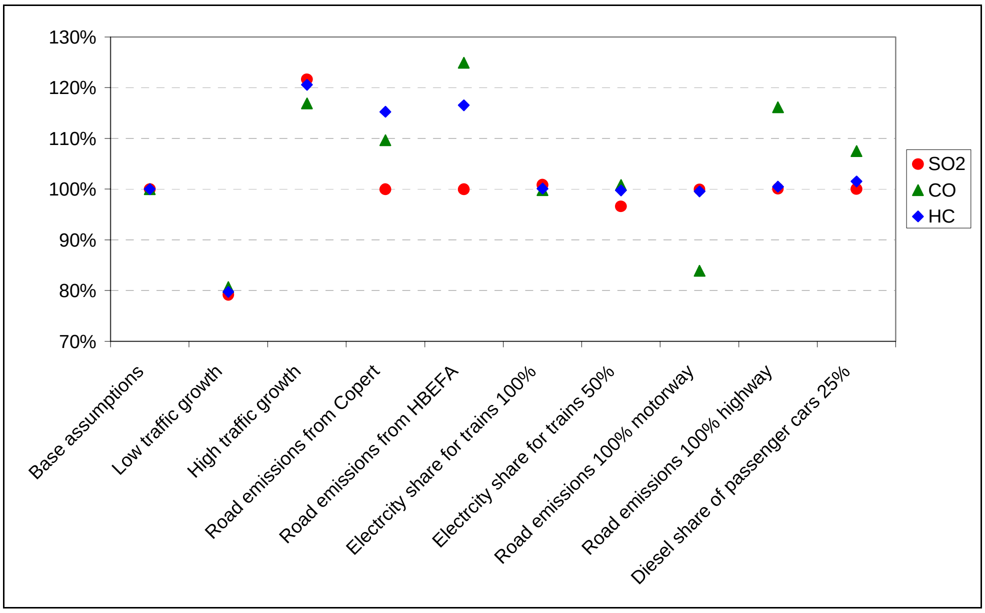


Figure 4.9 Result of the sensitivity analyses for SO_2, CO and HC, all European countries, 2040



The figures show that for all sensitivity analyses the reduction in emissions remain positive. The largest deviations compared to the base calculation are between -20% and +25%.

Across emission types, the sensitivity analyses with the largest effect on the results are the analyses on different traffic growth. As the base calculation shows a reduction in the total emissions and therefore in average across modes there is a reduction of emissions. Hence, lower traffic growth (where traffic volumes of all modes a decreased similarly) compared to the base calculation will imply lower emission reductions. Similarly a higher traffic growth will imply a higher reduction, again because the reduction is proportional to the traffic volumes.

The emission models for road transport are of some importance to the results. If COPERT or HBEFA are applied instead of TEMA2000 the NO_x reduction due to the fixed link is 10% smaller, but the HC and CO reductions are 10%-25% larger. For CO_2, PM_{10} and SO_2 there is practically no effect of applying either of these two models instead of TEMA2000.

Finally, the assumed distribution of road transport on motorway and highway has effect on PM_{10} emissions where pure motorway driving implies a 10% lower reduction and pure highway driving implies a 10% higher reduction. For CO the effect is the same, with a 15% lower reduction with pure motorway driving and 15% higher reduction with pure highway driving.

The remaining sensitivity analyses have an effect of less than ±10%.

The two sensitivity analyses for the ferry capacity in 2015 are not included in the figures above, because they have no effect in 2040. In 2015 these two analyses have an effect of up to ±17% on the reduction in total emissions. For CO_2, PM_{10} and NO_x a lower ferry capacity (increased utilisation or lower traffic volumes) will imply approx. 10% lower emission reductions than in the base calculation and vise versa for a higher capacity. For SO_2 and HC the effect is ±12% and for CO the effect is ±17%.

4.5 Conclusions

- The establishing of a fixed link across the Fehmarn Belt will imply a reduction of all types of air emissions from transport.

- There will be a reduction of air emissions from transport both immediately after opening of the fixed link and in the long run.

- For the greenhouse gas CO_2 and the two most damaging emission types, NO_x and particulate matter (PM_{10}), the reductions in the year 2040 are:

  - Approx. 220,000 tonnes CO_2.
  - Approx. 600 tonnes NO_x.
  - Approx. 40 tonnes PM_{10}.

- The CO_2 reduction in 2040 equals the present annual per capita CO_2 emissions of approx. 20,000 persons (all sectors included). The NO_x reduction in 2040 equals the present annual per capita NO_x transport emissions of approx. 40,000 persons. The PM_{10} reduction in 2040 equals approx. 6 million trips in a passenger car from Copenhagen to Hamburg via the fixed link across the Fehmarn Belt.

- Based on several sensitivity analyses, the uncertainty of the reduction is assessed to be -20% to +25%.

- The emission reductions will mainly occur in Denmark and Germany and the reduction in these two countries is of the same order of magnitude.

- The largest reduction in emissions comes from the expected closure of the ferry line between Rødby and Puttgarden.

- There will also be a reduction of emissions from freight transport on road and rail. The reason is an expected transfer of road freight to rail and a decrease in the travel distance for rail freight. The travel distance for rail freight will decrease due to the expected rerouting from Jutland to the Femarn Belt.

- Emissions from passenger transport on road and rail will increase. This is due to an increase both in the number of passengers and in the travel distance (plus 19 km on the fixed link).

5 Traffic volumes

5.1 Data from the traffic model

The traffic is analysed by means of the traffic model specifically developed for the purpose of analysing the traffic across the Fehmarn Belt.

Dimensions
Passenger and freight transport is modelled separately. Data for passenger and freight traffic are differentiated on a number of dimensions including those mentioned below:

- Scenario (reference, project)
- Origin (5 zones north of Fehmarn Belt and 8 zones south of Fehmarn Belt)
- Destination (5 zones north of Fehmarn Belt and 8 zones south of Fehmarn Belt)
- Route (Rødby-Puttgarden and other routes)
- Means of transport for passenger traffic (passenger car, passenger train, bus, ferry (walk-on))
- Means of transport for freight traffic (lorries, freight train, combi train)

The combination of these variables for passenger and freight transport, respectively, constitutes the possible passenger and freight trips.

Data for the number of passengers and tonnes, means of transport as well as travel time and distance exist for each combination. These data form the basis for quantifying the traffic volumes measured in km for each means of transport.

Geographical distribution of travel distance for freight transport
In the applied data for passenger traffic, the travel distance is split on distances travelled in Denmark, Germany and other European countries. This information is applied in the quantification of emissions in these countries.

Data for freight transport do, however, not explicitly contain this split of travel distances on countries. Instead the distribution is estimated based on a distribution on the OD combinations by applying the same distribution on OD combinations as for passenger transport. This approach is identical to the approach applied in the cost-benefit analysis of the fixed link[17].

In the following section, the applied traffic volumes for 2015 and 2040 are described.

5.2 Traffic volumes in 2015 and 2040

The analysis is based on the recent analyses of traffic carried out by Fehmarnbelt Traffic Consortium (FTC). Below the main assumptions and results of the traffic analyses are presented. Further details can be seen in FTC (2003a) and FTC (2003b).

Traffic volumes in 2015

Traffic model calculations have been carried out for a number of scenarios. The analysis of air emissions from transport is based on the same scenarios as the economic assessment, “Reference scenario B” and “Base Case B”[18].

The tables below show the number of passengers and tonnes between Denmark/Scandinavia and the Continent with (project alternative) and without a fixed link (reference situation).

Table 5.1 Annual number of passengers between Denmark/Scandinavia and the Continent, 2015, Case B, 1,000 passengers

	Reference	Project	Change
Passenger cars	11,587	12,422	7.2%
Busses	2,974	2,938	-1.2%
Walk-ons	2,395	1,855	-22.8%
Passenger trains	1,067	1,423	33.4%
Total	18,023	18,638	3.4%

Source: FTC traffic model.

Note that air traffic is not included.

[17] See Danish Ministry of Transport (2004a).

[18] See FTC (2003a) and FTC (2003b).

Table 5.2 Annual number of tonnes between Denmark/Scandinavia and the Continent, 2015, Case B, 1000 tonnes

	Reference	Project	Change
Lorries	35,736	35,381	-1.0%
Freight trains	8,340	8,677	4.0%
Combi trains	1,847	1,865	1.0%
Total	45,923	45,923	0%

Source: FTC traffic model.

The first table shows that there will be an increase in passengers between Denmark/Scandinavia and the Continent. This covers a small decrease in passengers in busses and a large decrease in walk-on passenger on the one hand, and a large increase in the number of train passengers and an increase in the number of passengers in cars on the other hand.

The second table shows that there will be no increase in freight between Denmark/Scandinavia and the Continent. This does however cover redistribution of freight volumes, so that freight on lorries is reduced and freight on trains is increased.

The tables below show the passenger and freight volumes across the Fehmarn Belt with and without a fixed link (reference case).

Table 5.3 Annual number of passengers across the Fehmarn Belt, 2015, Case B, 1,000 passengers

	Reference	Project	Change
Passenger cars	4,949	6,809	37.6%
Busses	1,404	1,638	16.7%
Walk-ons	711	-	-
Passenger trains	560	1,386	147.5%
Total	7,624	9,833	32.1%

Source: FTC traffic model.

Table 5.4 Annual number of tonnes across the Fehmarn Belt, 2015, Case B, 1,000 tonnes

	Reference	Project	Change
Lorries	6,665	7,206	8.1%
Freight/combi trains	7,207*	7,983	10.8%
Total	-	15,189	-

Source: FTC traffic model.

* This traffic volume is transported via the Great Belt fixed link.

The tables show that there will be an increase in both passenger and freight volumes transported via the Fehmarn Belt after construction of a fixed link.

In calculating the air emissions it is, however, the distances driven that is the key information. These data are presented in the following table.

Table 5.5 Distances driven between Denmark/Scandinavia and the Continent, 2015, mill. km, Case B

	Unit	Reference	Project	Change
Passenger cars	Vehicle-km	3,613	3,717	2.9%
Busses	Vehicle-km	63	64	0.8%
Passenger trains	Passenger-km	1,044	1,250	19.7%
Lorries	Vehicle-km	3,670	3,649	-0.6%
Freight trains	Tonnes-km	15,419	15,187	-1.5%
Combi trains	Tonnes-km	3,427	3,170	-7.5%

Source: FTC traffic model.

The table shows that for passenger transport the distances driven increase for all modes. For passenger cars and trains the increase is due to the increase in number of passengers transported and the fact that the passenger cars and trains now drive on the fixed link instead of using the ferry. The busses also drive on the fixed link instead of using the ferry and this effect is stronger than the decrease in number of busses.

The table also shows a decrease in distances driven for all freight modes. For lorries there is a reduction in number of tonnes due to a transfer of freight to rail. At the same time the lorries use the fixed link (implying longer distances driven), but there is a reduction in the distances driven due to a transfer of traffic from other routes. For trains the effect from the increase in number is exceeded by the fact that the trains no longer drive through Jutland and thereby saves driving distance[19].

[19] As mentioned in section 3.2, the traffic volumes applied in the present analysis are based on the traffic data. The saving in distance has been estimated to approx. 175 km.

Even though flight transport is not included in the tables it is important to note that air transport is modelled in the traffic model on equal terms as the other modes. However, the traffic data for the calculations do not include air transport, which means that air pollution consequences from air transport is not included in the analysis. It is assessed that the effect from not including air transport in the analysis is small. According to the 1999 traffic prognosis the number of flight passengers will be reduced a little, which implies a reduction in emissions from air transport, if the number of flights is reduced accordingly.

Traffic volumes in 2040

In the economic assessment of the fixed link, traffic growth is included in the period 2015-2040. The same assumptions on traffic growth are made in calculating the emissions to air.

The applied traffic growth factors for the number of vehicles/trains have been set to 1.7% annually by the Danish Ministry of Transport and Energy. Sensitivity analyses are made for 0.7% and 2.7% annually. These assumptions are the same as those in the economic assessment.

Ferries

The growth in traffic volumes affects the necessary future ferry capacity. The following information is used to assess the necessary ferry capacity in 2015.

Table 5.6 Annual ferry traffic between Rødby-Puttgarden, 1,000 passengers or vehicles

	2001	2015	Change	PCE *)
Train passengers	352	560	59%	0.1
Walk-on passengers	718	711	-1%	0.1
Passenger cars	1,357	1,912	41%	1
Busses	32	41	27%	5
Lorries	274	417	52%	5
Total			40%	

Source: FTC (2003a) and Danish Ministry of Transport (2000).

*) Passenger car equivalents.

The table shows that the necessary extra capacity in 2015 is approximately 40% assuming the same utilisation as today. The percentage is based on the conversion of each passenger or vehicle type into passenger car equivalents in accordance with TEMA2000 conventions. For vehicles the passenger car equivalents are based on the space that the vehicles take up on the car deck compared to a passenger car. A passenger is allocated 1/50 of a bus (based on the number of seats).

For the traffic growth between 2015 and 2040 it is in the present analysis assumed that demand for ferry capacity is similar to the growth in traffic on other modes. This means a growth in capacity of approx. 50% (average), 20% (low) and 95% (high), respectively from 2015 to 2040.

6 Ferry emission factors

6.1 Ferry supply on Rødby-Puttgarden

In 2003 the five ferries on the Rødby-Puttgarden route made approx. 34,000 single crossings, or in average 94 crossings per 24 hours. The largest share (94%) of these crossings was carried out by four big relatively new ferries with a capacity of approx. 290 cars each. The smallest ferry on the route (Holger Danske) has only a capacity of approx. 50 cars and is solely used for carriage of dangerous goods. Therefore this ferry is disregarded in the analysis.

Ferry supply in 2015

Reference for the forecast of supply in 2015 and 2040 is the transport work done in 2003 by the four double-ended ferries on the route. The ferries were built in 1997 which implies that they should still have more than 20 years expected operation left before scrapping seen from a statistical point of view. Therefore, these ferries are considered in operation in 2015.

In the base calculation, two of the four ferries are lengthened by 40 m increasing the giving a car capacity to 500, whereas the two other ferries are assumed fitted with a hoistable platform deck increasing the car capacity from 290 to approximately 350. In total this gives an extra capacity of 47% compared to the present (2003) situation.

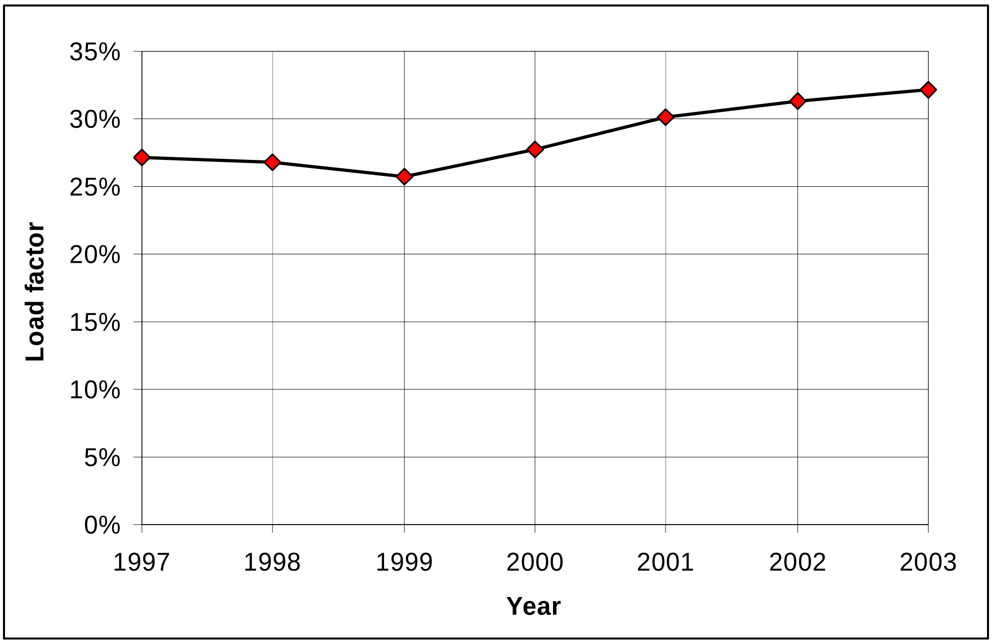
For sensitivity analysis two scenarios have been set up in which the capacity of the ferries differ from the base calculation. In one scenario (low capacity) all four ferries are solely fitted with the hoistable platform deck giving 21% extra total capacity than the present situation. In another scenario (high capacity) all four ferries are lengthened by 40 m giving 72% extra total capacity than the present situation.

Ferry supply in 2040

In 2040 all the existing ferries are assumed replaced by new ferries with a capacity of 500 cars assuming that the ferries have the same main dimensions as the existing ferries however with the 40 m extra length. These assumptions mean that the existing ferry berth facilities have only to undergo minor modifications. In the base calculation, 5 of such ferries are necessary to accommodate the traffic volumes, whereas 4 ferries are necessary with low traffic growth and 6 ferries are necessary with high traffic growth.

The necessary number of ferries has been determined under the condition that the average utilisation is unchanged compared to the utilisation in 2003. This may be a somewhat pessimistic assumption as utilisation has increased in the later years (see Figure 6.1), but assuming an increase in utilisation is at the same time considered optimistic due to the general uncertainty in traffic development for ferries.

Figure 6.1 Development in the load factor of the ferries on Rødby-Puttgarden



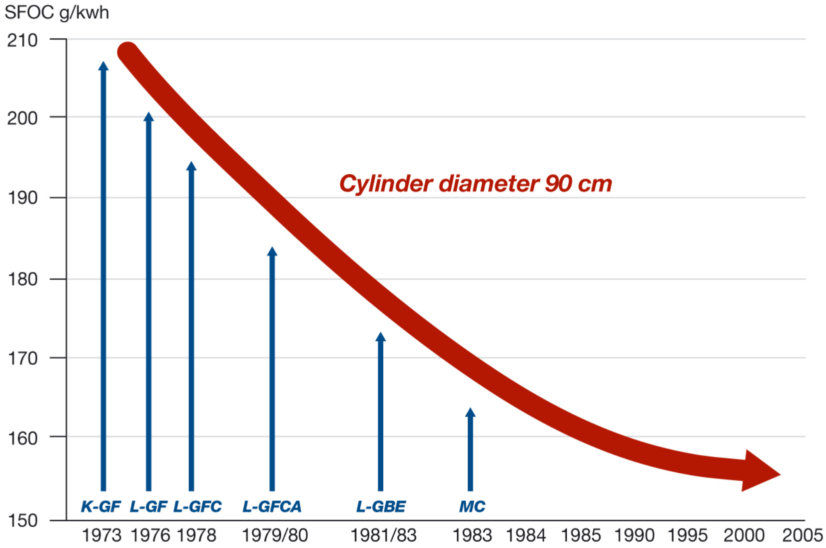
6.2 Modelled ferry types on Rødby-Puttgarden

Development of engine technology

For the existing ferries it is assumed that the propulsion engines (diesel-electric machinery) will remain unchanged with respect to oil consumption over the rest of the operating period extending beyond 2015.

For the ferries put into operation in 2040 the engines are assumed to be more fuel efficient than the existing ferries with a total reduction of specific oil consumption of 15% compared with the consumption in 2003. This assumption is based on the fact that diesel engines during recent years have been under steady development with respect to emissions, but especially with respect to specific oil consumption (see Figure 6.2 and Danish Ministry of Transport (2000) (Figure 37) where an increase of efficiency of 0.8 % per year is observed).

Figure 6.2 Development of specific fuel oil consumption for large MAN B&W 2-stroke engines



Note: A similar trend is valid for smaller 4 stroke engines (for ferries), although the consumption is approx. 20 % higher than for 2-stroke engines.

Ferry types

The different ferry types used in the present analysis are as follows:

- Type 0: Existing ferry type on the route in 2003.
- Type I: Existing ferry type with an extra platform deck giving extra passenger car capacity.
- Type II: Existing ferry type in lengthened version (+40 m).
- Type III: New ferry type in lengthened version (+40 m), 2040.

Their characteristics are summarised in Table 6.1.

The ferry alternatives are realistic alternatives for each of which a detailed route analysis has been carried out to calculate the necessary propulsion power in order to calculate the fuel oil consumption taking into account the assumed engine technology as already described (see Appendix 1).

Table 6.1 Size and capacity for the ferry alternatives used in the analysis

Ferry type	Length (m)	Breadth (m)	Car capacity	Lanes for lorries (m)	Equivalent car capacity *)	Relative fuel oil consumption
0	134	24	128	580	290	100%
I	134	24	265	290	350	102%
II	174	24	95	1420	500	130%
III	174	24	95	1420	500	111%

*) The equivalent car capacity has been calculated by the factors from TEMA 2000.

6.3 Ferry emissions on Rødby-Puttgarden

The emissions for the Rødby-Puttgarden route at present have been calculated by using the emission factor from TEMA2000. From Scandlines it is known that the fuel oil used on the ferries has a sulphur content of 0.75% and that 1.1 tons fuel oil is in average used per single trip. The estimated present emission factors are shown in the table below.

Table 6.2 Emission factors for present ferries on Rødby-Puttgarden, kg/trip/ferry

	PM_{10}	NO_x	SO_2	CO	HC	CO_2
Rødby-Puttgarden	1.5	69	17	9	3	3,487

Source: TEMA2000.

There is strong focus on the emissions from shipping especially on NO_x and SO_2 emissions. On 19 May 2005 the new MARPOL Annex IV regulations will enter into force which means that the Baltic Sea will become a so-called special emission area with a sulphur limit of 1.5 % in the fuel oil used on the ships sailing in this area. The diesel engines shall fulfil special requirements with regards to NO_x emissions which have been known for some years, such that many engines built since 2000 are already fulfilling these NO_x requirements.

In the coming years the engine technology becomes more and more refined such that the engines will be governed still more electronically (known as “common rail” technology). This implies that the combustion process can be controlled to minimise the emissions, especially NO_x. Another measure to reduce the emissions (also the other products than NO_x) is the use of catalysts.

One of the leading companies in this market is the Danish company Haldor Topsøe A/S, which has developed catalysts not only for NO_x reduction but also for reduction of unburned hydrocarbons (HC) and particles (PM_{10}).

Typical reductions which can be obtained today are as shown in the table below.

Table 6.3 Reductions of emissions that can be obtained with present technology

	NO_x	HC	PM_{10}
Reduction share	80%-95%	80%-90%	30%-50%

Source: Information from Haldor Topsøe A/S.

Using catalysts and other technical measures for reduction of emissions increases the price of ships and the operating costs. When these measures become more and more common the price will decrease.

There will most likely also be a clear political and environmental pressure which means that it will probably become quite normal to use low sulphur fuel oil and engines with low emissions. The international regulations (from EU or IMO) may also impose such strict requirements if not in 2015 then at least in 2040. Therefore the assumptions shown in the table below have been used with respect to reduction of emissions.

Table 6.4 Emission reductions for ferries compared to the present levels

Emission product	Existing ferries in 2015	New ferries in 2040
NO_x	50%	90%
HC	0%	80%
CO	0%	0%
PM_{10}	0%	40%

Note: 0% means no change compared to the present level.

Based on the emission factors from TEMA2000 and the table above, revised emission factors have been calculated. These factors have been used for calculations of the emissions shown in section 6.5 (see also Appendix 1).

6.4 Ferries on other routes

According the traffic model, the other routes where changes in supply are assumed due to establishing the fixed link across the Fehmarn Belt comprise Gedser-Rostock and Trelleborg-Rostock[20]. The implication on the frequencies on these routes is, however, only one departure per day per direction and therefore a detailed analysis has not been made. Instead emission factors have been calculated based on emissions factors for the present ferries from the economic assessment and the same relative change in emissions as for Rødby-Puttgarden described in the previous section.

The emission factors for the present ferries on the two routes are shown in the table below. The distances sailed are approx. 50 km for Gedser-Rostock and approx. 150 km for Trelleborg-Rostock compared to approx. 19 km on Rødby-

[20] Reference is made to FTC (2003a) table 3.1 and FTC (2003b) table 4.1.

Puttgarden. On Trelleborg-Rostock the ferry involved is according to the traffic model the fast ferry.

Table 6.5 Emission factors for present ferries on other routes, kg/trip/ferry

	PM_{10}	NO_x	SO_2	CO	HC	CO_2
Gedser-Rostock *)	5	234	58	31	10	11,722
Trelleborg-Rostock (fast ferry)	9	718	94	7	33	35,354

Source: Danish Ministry of Transport (2004b).

*) The CO_2 emissions are based on the data from the above-mentioned source, whereas the remaining emission factors are calculated with the same relative relation to the CO_2 emission as for Rødby-Puttgarden.

6.5 Emission factors in 2015 and 2040

Based on the assumptions and data presented in the previous sections, the two tables below summarise the emission factors applied in the analysis.

Table 6.6 Emission factors for ferries, 2015, kg/trip/ferry

	PM_{10}	NO_x	SO_2	CO	HC	CO_2
Rødby-Puttgarden						
Low capacity (4 type I: 350 pce/ferry)	1.3	35.4	2.4	9.4	3.0	3,557
Base calculation (2 type I + 2 type II: 425 pce/ferry in average)	1.4	40.3	2.7	10.7	3.4	4,045
High capacity (4 type II: 500 pce/ferry)	1.6	45.2	3.0	12.0	3.8	4,533
Gedser-Rostock						
Low capacity	4.3	119.1	7.9	31.8	9.9	11,957
Base calculation	4.8	135.5	9.0	36.1	11.3	13,598
High capacity	5.4	151.8	10.1	40.5	12.7	15,239
Trelleborg-Rostock (fast ferry)						
Low capacity	7.9	366.0	12.8	7.0	33.7	36,062
Base calculation	9.0	416.2	14.5	7.9	38.3	41,011
High capacity	10.1	466.4	16.3	8.9	42.9	45,961

Table 6.7 Emission factors for ferries, 2040, kg/trip/ferry

	PM_{10}	NO_x	SO_2	CO	HC	CO_2
Rødby-Puttgarden						
4/5/6 type III (500 pca/ferry)	0.8	9.0	2.6	12.0	0.8	3,853
Gedser-Rostock	2.8	30.4	8.6	40.5	2.5	12,953
Trelleborg-Rostock (fast ferry)	5.2	93.3	13.8	8.9	8.6	39,067

7 Road emissions factors from TEMA2000

7.1 Description of TEMA2000

TEMA2000 is the official emission calculation model of the Danish Ministry of Transport and Energy. The first version of the model was issued in 1996 and the latest version of the model was issued in 2000.

The abbreviation TEMA stands for “emissions from transport under alternative assumptions”. TEMA is a user model implemented in its latest version as a PC tool with a user interface. The model can be used to calculate emissions from specific means of transports under a range of user-defined assumptions, i.a. different driving speeds for road transport. The model calculates energy consumption and emissions of CO_2, SO_2, NO_x, HC, CO and particulate matter.

TEMA2000 is specifically adapted to Danish conditions and the scope of the model is to perform calculations for vehicles operating inside Denmark. However, for road vehicles the emission factors are just as applicable for vehicles operating outside Denmark fulfilling the same emission norms.

For passenger cars and vans the emissions are based on data from the German/Swiss Handbook of Emissions version 1.1a from 1997 and version 1.2 from 1999.

For busses and lorries the emissions are based on data from the Danish model SEEK (simulating energy consumption and emissions with variable vehicle configuration) developed by the Danish Technological Institute for the Danish Ministry of Transport, Denmark’s Road Safety and Transport Agency and the Greater Copenhagen Authority (HUR). The emission data have been obtained from tests performed at the Danish Technical University.

For the road transport, the model covers the means of transport and detailed types shown in the table below.

Table 7.1 Detailed types of road vehicles in TEMA2000

Means of transport	Detailed types
Passenger car	Petrol, diesel Engine size <1.4 l, 1,4-2 l, >2 l Pre-EURO, EUROI, EUROII, EUROIII, EUROIV
Busses	Diesel City, regional, long distance, tourist Pre-EURO, EUROI, EUROII, EUROIII, EUROIV
Vans	Petrol, diesel Pre-EURO, EUROI, EUROII, EUROIII, EUROIV
Lorries	Diesel 10 t, 25 t, 48 t (articulated) gross weight Pre-EURO, EUROI, EUROII, EUROIII, EUROIV

7.2 Data and assumptions

In calculating emission factors for 2015 and 2040, the task is to weight the emission factors of the detailed vehicle types together to obtain emission factors from a representative vehicle. Hence, TEMA2000 is used to calculate emission factors for each of the detailed means of transport. Thereafter representative emission factors are calculated based on weights for the composition of the fleet.

The traffic model is uninformative about the road types of the traffic in question. However, as the main part of the traffic involved is long distance traffic it is assumed that the traffic takes place either on motorways or highways. Therefore, emission factors are calculated for the typical driving pattern for each of these road types. The default driving cycle speeds for the two road types are applied in the calculations.

In calculating the effect on air emissions from road transport the emission factors for motorways and highways are weighted together. A 50/50 split is assumed in the basic calculation and sensitivity analysis is performed for this weighting.

All diesel vehicles are assumed to use low sulphur diesel.

Passenger cars

For passenger cars, emissions are calculated with default outdoor temperature and one cold start per trip. The vast majority of trips crossing the Fehmarn Belt are long distance transport. The trip length is set to 100 km (which is probably conservative) and therefore the cold start has practically no influence on the emission factor per km. The mileage of the car is set to 107,000 km, which implies maximum possible deterioration of the catalysts. This corresponds to the mileage of a 4 year old car.

The split of passenger cars on fuel types in 2004 is shown in the table below. This share has increased from approx. 4.6% in the late 1990ies to 8.3% in 2004.

In the analysis the present diesel share is applied for both 2015 and 2040. However, there may be a further increase in the share of diesel cars in the future, as the diesel share of the new cars bought has increased (approx. 25% in the later years). Hence, as a sensitivity analysis a diesel share of 25% is applied.

Table 7.2 Distribution of passenger cars on fuel type

Fuel type	Share
Petrol	91.7%
Diesel	8.3%

Source: Statistics Denmark.

The split of passenger cars on engine size is shown in the table below. This split is applied for both 2015 and 2040.

Table 7.3 Distribution of passenger cars on engine size

Engine size, l	Petrol	Diesel
< 1.4	40%	n.a.
1.4-2.0	39%	79%
> 2.0	21%	21%
Total	100%	100%

Source: COWI's car database.

The distribution of passenger cars on norm types is based on data for the age distribution of passenger cars at the end of 2003. Moreover, the annual mileage for each one year age group is taken into account because new cars normally drive more than the older ones. These data are compared with the dates of enforcement of the EURO norms in order to obtain the expected representation of passenger cars on EURO norms in 2015 and 2040. The distribution is shown in the following table.

Table 7.4 Distribution of passenger cars on EURO norms

EURO norm	Date of enforcement	2015	2040
Pre-EURO	01.10.86	0.3%	0.0%
EURO I	01.10.90 *)	0.3%	0.0%
EURO II	01.01.97	2.1%	0.0%
EURO III	01.01.01	14.9%	0.0%
EURO IV	01.01.06	82.5%	100.0%

Source: Calculations based on Statistics Denmark.

*) In the EU this norm was enforced in 1993.

Busses

The busses that are relevant in the Fehmarn Belt traffic is long distance and tourist busses. These two types of busses have the same emission factors in TEMA2000 and therefore no distinction is made between theses types of busses.

The distribution of busses on norm types is based on data for the age distribution of busses at the end of 2003. No information is available about the annual mileage of busses. These data are compared with the dates of enforcement of the EURO norms in order to obtain the expected distribution of busses on EURO norms in 2015 and 2040. The distribution is shown in the following table.

Table 7.5 Distribution of busses on EURO norms

	Date of enforcement	2015	2040
EURO 0	01.10.86	0.1%	0.0%
EURO I	01.10.93	0.5%	0.0%
EURO II	01.10.96	2.8%	0.0%
EURO III	01.10.01	20.5%	0.0%
EURO IV	01.01.06	29.6%	0.0%
EURO V	01.10.09	46.4%	100.0%

Emission factors for EURO V are not included in TEMA2000. Therefore the reduction percentages below are applied for busses and lorries when calculating emission factors of EURO V.

Table 7.6 Reduction of EURO IV emission factors to obtain EURO V emission factors

	PM_{10}	NO_x	SO_2	CO	HC	CO_2
Busses and lorries	0%	43%	0%	0%	0%	0%

Source: Danish Ministry of Transport (1999).

Lorries and vans

Lorries and vans are weighted together in one category because the traffic model only operates with one group called lorries.

The split of vans on fuel types is shown in the table below. It is based on the distribution in 2004.

Table 7.7 Distribution of vans on fuel type

Fuel type	Share
Petrol	26.3%
Diesel	73.7%

Source: Statistics Denmark.

The freight transport across the Fehmarn Belt is different from the national Danish traffic, because the main share is long distance transport which implies bigger lorries.

Therefore, the data collected in interviews when the traffic model was established are applied when weighting the lorries of different size and vans together. The data for the traffic model is divided on 5 tonnes intervals applying for the net weight on the vehicle (i.e. the weight of the vehicle itself). The weight groups of TEMA2000 apply to the gross weight of the vehicle (i.e. the weight of the vehicle itself plus maximum load). These two groups do not match and therefore the below assumption has been made as to the match of these two groups.

Table 7.8 Distribution of lorries on weight categories

Net weight, tonnes	Share	Vehicle type in TEMA2000
0-4	1%	Van
5-9	4%	10 tonnes gross weight
10-14	18%	24 tonnes gross weight
15-19	67%	48 tonnes gross weight
20-24	7%	48 tonnes gross weight
25-29	1%	48 tonnes gross weight
30-34	0%	48 tonnes gross weight
>35	1%	48 tonnes gross weight
Total	100%	

Source: FTC (1999) table 2.4.4.

The distribution of lorries and vans on norm types is based on data for the age distribution of lorries and vans at the end of 2003. No information is available about the annual mileage of lorries. These data are compared with the dates of enforcement of the EURO norms in order to obtain the expected distribution of lorries and vans on EURO norms in 2015 and 2040. The distribution is shown in the following table.

Table 7.9 Distribution of lorries and vans on EURO norms

	Date of enforcement *)	2015	2040
EURO 0	01.10.86	0.2%	0.0%
EURO I	01.10.93	0.2%	0.0%
EURO II	01.10.96	2.9%	0.0%
EURO III	01.10.01	15.7%	0.0%
EURO IV	01.01.06	26.1%	0.0%
EURO V	01.10.09	55.0%	100.0%

*) For lorries.

7.3 Emission factors in 2015 and 2040

Based on the data presented above, the following emission factors have been calculated for the three vehicle types in 2015 and 2040 respectively.

Table 7.10 TEMA2000 emission factors in 2015, g/km

	PM_{10}	NO_x	SO_2	CO	HC	CO_2
Highway						
Car	0.01	0.17	0.01	0.89	0.06	162
Bus	0.08	3.39	0.03	0.31	0.33	875
Lorry	0.06	6.43	0.03	0.87	0.31	1,010
Motorway						
Car	0.01	0.32	0.01	1.67	0.06	190
Bus	0.08	3.39	0.03	0.31	0.33	875
Lorry	0.06	4.61	0.03	0.73	0.31	930

Table 7.11 TEMA2000 emission factors in 2040, g/km

	PM_{10}	NO_x	SO_2	CO	HC	CO_2
Highway						
Car	0.01	0.14	0.01	0.87	0.05	159
Bus	0.04	2.10	0.03	0.28	0.29	875
Lorry	0.03	5.87	0.03	0.89	0.29	1,010
Motorway						
Car	0.01	0.26	0.01	1.62	0.05	186
Bus	0.04	2.10	0.03	0.28	0.29	875
Lorry	0.03	3.06	0.03	0.67	0.28	930

8 Road emission factors from HBEFA

8.1 Description of HBEFA

TREMOD (Transport Emission Estimation Model) is the official emission calculation model of the German Federal Ministry of Transport, Building and Housing. It is developed by the ifeu (Institut für Energie- und Umweltforschung) and used by the German Federal Highway Research Institute. The latest version of the model was issued in October 2002.

TREMOD is a prognosis model for the emissions from the German transport in the period 1980-2020. Emissions of CO, HC, NO_x, PM_{10}, CO_2, SO_2, lead and benzene are calculated. TREMOD is specifically adapted to German conditions. However as for TEMA2000, for road vehicles the emission factors are just as applicable for vehicles operating outside Germany fulfilling the same emission norms.

The model applies emission data from the German HBEFA (Handbook of Emission Factors for Road Transport) version 2.1 from February 2004. The total emissions are based on a detailed mapping of the German vehicle fleet. The model distinguishes between motorway, rural and urban driving. For the present calculations motorway is applied for motorway and rural driving is applied for highway. In the prognosis the average slope of the road network is taken into account.

For the road transport, the model covers the means of transport and detailed types shown in the table below.

Table 8.1 Detailed types of road vehicles in TREMOD

Means of transport	Detailed types
Passenger car	Petrol, diesel Engine size <1.4 l, 1.4-2 l, >2 l EUROI, EUROII, EUROIII, EUROIV
Busses	Diesel Bus <18 t, bus >18 t, coach <18 t, coach >18 t EUROI, EUROII, EUROIII, EUROIV, EUROV
Vans	Petrol, diesel M+N1-I, N1-II EUROI, EUROII, EUROIII, EUROIV
Lorries	Diesel Solo <7.5 t, solo 7.5-12 t, solo 12-14 t, solo 14-20 t, solo 20-26 t, solo 28-32 t, solo >32 t, trailer <28 t, trailer 28-34 t, trailer >34 t (all gross weight) EUROI, EUROII, EUROIII, EUROIV, EUROV

8.2 Data and assumptions

In calculating emission factors for 2015 and 2040, the task is to weight the emission factors of the detailed vehicle types together to obtain emission factors from a representative vehicle. Both emission data and vehicle fleet data are provided by the German Federal Highway Research Institute.

The same approach as for TEMA2000 is applied to obtain the representative emission factors (see chapter 7). Below the detailed weighting is presented.

As TREMOD does only cover the period until 2020, data for 2020 are in the calculations applied for 2040. The uncertainty associated with this approach is considered minor since the most restrictive norms are almost fully implemented already in 2020.

Passenger cars

The split of passenger cars on fuel types in 2015 and 2040 is shown in the table below. The table reflects that diesel cars are much more common in Germany than in Denmark.

Table 8.2 Distribution of passenger cars on fuel type

Fuel type	2015	2040
Petrol	57%	55%
Diesel	43%	45%

Source: German Federal Highway Research Institute, data from HBEFA.

The split of passenger cars on engine size for 2015 and 2040 is shown in the table below.

Table 8.3 Distribution of passenger cars on engine size

Engine size, l	Petrol 2015	Petrol 2040	Diesel 2015	Diesel 2040
< 1.4	27%	27%	n.a.	n.a.
1.4-2.0	49%	48%	64%	64%
> 2.0	25%	26%	36%	36%
Total	100%	100%	100%	100%

Source: German Federal Highway Research Institute, data from HBEFA.

The distribution of passenger cars on norm types is shown in the following table.

Table 8.4 Distribution of passenger cars on EURO norms

EURO norm	Date of enforcement	2015	2040
EURO I	01.10.93	0.1%	0.0%
EURO II	01.01.97	0.3%	0.0%
EURO III	01.01.01	4.0%	0.4%
EURO IV	01.01.06	95.6%	99.6%

Source: German Federal Highway Research Institute, data from HBEFA.

Busses

The busses that are relevant in the Fehmarn Belt traffic are coaches which are normally used for long distance transport.

The distribution of busses on sizes is shown in the following table.

Table 8.5 Distribution of busses on sizes

Weight	2015	2040
<18 t	12%	9%
>18 t	88%	91%

The distribution of busses on norm types is shown in the following table.

Table 8.6 Distribution of busses on EURO norms

	Date of enforcement	2015	2040
EURO I	01.10.93	0%	0%
EURO II	01.10.96	6%	0%
EURO III	01.10.01	12%	4%
EURO IV	01.01.06	14%	6%
EURO V	01.10.09	68%	89%

Source: German Federal Highway Research Institute, data from HBEFA.

Lorries and vans
Lorries and vans are weighted together in one category because the traffic model only operates with one group called lorries.

The split of vans on fuel types is shown in the table below. The table reflects that diesel vans are more common in Germany than in Denmark.

Table 8.7 Distribution of vans on fuel type

Fuel type	2015	2040
Petrol	10%	10%
Diesel	90%	90%

Source: German Federal Highway Research Institute, data from HBEFA.

The freight transport across the Fehmarn Belt is different from the national German traffic, because the main share is long distance transport which implies bigger lorries.

Therefore, the data collected in interviews when the traffic model was established are applied when weighting the lorries of different size and vans together. The data for the traffic model is divided on 5 tonnes intervals applying for the net weight on the vehicle (i.e. the weight of the vehicle itself). The weight groups of TREMOD apply to the gross weight of the vehicle (i.e. the weight of the vehicle itself plus maximum load). These two groups do not match and therefore the below assumption has been made as to the match of these two groups.

Table 8.8 Distribution of lorries on weight categories

Net weight, tonnes	Share	Vehicle type in TREMOD
0-4	1%	Van
5-9	4%	Solo <7.5 t, solo 7.5-12 t, solo 12-14 t
10-14	18%	Solo 14-20 t, solo 20-26 t, solo 28-32 t, trailer <28 t
15-19	67%	>32 solo, trailer 28-34, trailer >34
20-24	7%	>32 solo, trailer 28-34, trailer >34
25-29	1%	>32 solo, trailer 28-34, trailer >34
30-34	0%	>32 solo, trailer 28-34, trailer >34
>35	1%	>32 solo, trailer 28-34, trailer >34
Total	100%	

Source: FTC (1999) table 2.4.4.

The distribution of lorries and vans on norm types is shown in the following table.

Table 8.9 Distribution of lorries and vans on EURO norms

	Date of enforcement *)	2015	2040
EURO I	01.10.93	0%	0%
EURO II	01.10.96	3%	1%
EURO III	01.10.01	11%	3%
EURO IV	01.01.06	7%	2%
EURO V	01.10.09	79%	94%

Source: German Federal Highway Research Institute, data from HBEFA.

*) For lorries.

8.3 Emission factors in 2015 and 2040

Based on the data presented above, the following emission factors have been calculated for the three vehicle types in 2015 and 2040 respectively. The tables show model differences between TEMA2000 and HBEFA and the effect of these are analysed in a sensitivity analysis.

Table 8.10 HBEFA emission factors in 2015, g/km

	PM_{10}	NO_x	SO_2	CO	HC	CO_2
Highway						
Car	0.003	0.14	0.001	0.39	0.01	121
Bus	0.058	3.76	0.004	1.05	0.36	793
Lorry	0.051	3.34	0.004	1.06	0.33	789
Motorway						
Car	0.005	0.22	0.001	0.97	0.02	164
Bus	0.054	3.61	0.005	0.85	0.42	897
Lorry	0.042	2.72	0.004	0.89	0.36	770

Table 8.11 HBEFA emission factors in 2040, g/km

	PM_{10}	NO_x	SO_2	CO	HC	CO_2
Highway						
Car	0.002	0.14	0.001	0.38	0.01	109
Bus	0.043	2.91	0.004	1.01	0.38	808
Lorry	0.040	2.76	0.004	1.03	0.34	794
Motorway						
Car	0.003	0.22	0.001	0.94	0.02	147
Bus	0.040	2.84	0.005	0.82	0.43	911
Lorry	0.032	2.18	0.004	0.86	0.37	776

9 Road emissions factors from COPERT

9.1 Description of COPERT

COPERT III[21] (COmputer Programme to calculate the Emissions from Road Transport) is the European road traffic emission calculation model, which the Danish National Environmental Research Institute (NERI) uses to make the official Danish emission estimates as prescribed by EU and the Climate and Geneva conventions. The fuel use and emission data and model approaches for COPERT III are also used by NERI to make the official Danish emissions forecasts.

The NERI forecast model[22] is used in the present project to simulate the emission factors for passenger cars, coaches and lorries in the years 2015 and 2040 (based on data for 2030). The emission factor simulations are made for operationally hot engines taking into account gradually stricter emission standards for all vehicle types (EURO norms), emission degradation due to catalyst wear and the evaporation of hydrocarbons from gasoline vehicles.

The emission effects of cold start are not incorporated in the present emission factor results. Cold start effects are assumed to be marginal since for road traffic the present project only assesses the emissions for motorways and highways.

9.2 Data for fleet, mileage and emission factors

The present simulations use information of the Danish vehicle stock and annual mileage projections provided by the Danish Road Directorate[23]. For aggregation purposes this covers data for the number of vehicles and annual mileage driven on highways and motorways and the respective average speeds. The number of vehicles and annual mileages respectively, are provided per first registration year for all vehicle types.

Corresponding to the COPERT fleet classification all vehicles in the Danish traffic are grouped into vehicle layers. This is a sub-division of all vehicle

[21] See Ntziachristos et al. (2000)
[22] See Illerup et al. (2002)
[23] See Ekman (2003)

classes into groups of vehicles with the same average fuel use and emission behaviour. The vehicle layers are shown in the table below.

Table 9.1 Detailed types of road vehicles in COPERT III

Vehicle type	Layers
Passenger car	Petrol: <1.4 l. 1.4-2 l. >2 l; Pre-ECE, ECE 15/00-01, ECE 15/02, ECE 15/03, ECE 15/04, EUROI, EUROII, EUROIII, EUROIV
	Diesel: < 2l and > 2l.; Pre-EURO, EUROI, EUROII, EUROIII, EUROIV
Busses	Diesel; City, tourist; Pre-EURO, EUROI, EUROII, EUROIII, EUROIV, EUROV
Vans	Petrol, diesel; Pre-EURO, EUROI, EUROII, EUROIII, EUROIV
Lorries	Diesel: 3.5-7.5, 7.5-16, 16-32, > 32 t.
	Pre-EURO, EUROI, EUROII, EUROIII, EUROIV, EUROV

For each projection year, the vehicle numbers are summed up in layers by using the correspondence between layers and first registration year. Total mileages per layer and road type are calculated as the respective sums of all rural and highway km driven per first registration year, divided with the total number of vehicles in the specific layer.

As regards three-way catalyst passenger cars and vans the emissions of NO_X, NMVOC and CO gradually increase due to catalyst wear and are therefore modified as a function of total mileage by the so-called deterioration factors. Even though the emission curves may be serrated for the individual vehicles, on average the emissions from catalyst cars stabilise after a given cut-off mileage (120.000 km in most cases) is reached due to OBD (On Board Diagnostics) and the Danish inspection and maintenance programme.

For the forecast years the deterioration factors are calculated per first registration year by using emission type specific deterioration coefficients and cut-off mileages, as given in COPERT III for the corresponding layer. Secondly the deterioration factors are aggregated into layers by taking into account the vehicle numbers and annual mileages per first registration year. For further explanation of the simulation principles, please refer to the COPERT III methodology description.

In 2040 all gasoline cars are assumed to be equipped with catalytic converters, and this is also the case for the vast majority of gasoline vehicles in 2015. Catalyst cars have evaporation control, and therefore fuel evaporation is almost solely due to running loss – vapour emissions generated in the fuel tank during operation. In the present project, emission factors for VOC are simulated with and without fuel evaporation. For further explanation of the simulation principles, please refer to the COPERT III methodology description.

Per layer, the years of implementation and emission factors are shown in Annex 1 together with vehicle numbers, and total highway and motorway mileages for the years 2015 and 2030 (the basis for 2040 simulations).

An assessment of the 2030 fleet and mileage data reveals that the EURO IV mileage shares for passenger cars and vans, and the EURO V mileage shares for lorries and busses are dominant. Therefore it has been decided to let the 2030 data for these technologies be the basis for the further 2040 simulations of emission factors, due to lack of fleet and mileage data for the latter year.

Passenger cars

The distributions of total mileages per vehicle layer used in the emission factor aggregations for passenger cars are shown in the table below for 2015 and 2040. The same distribution is valid for highway and motorway.

Table 9.2 Total mileage distribution into layers for passenger cars for 2015 and 2040

Year	EURO norm	Gasoline	Gasoline	Gasoline	Diesel	Diesel	Sum
		< 1.4 l	1.4-2 l	> 2 l	< 2 l	> 2 l	
2015	Pre-EURO	0.4%	0.3%	0.0%	0.1%	0.0%	0.8%
	EURO I	1.6%	2.0%	0.2%	0.4%	0.0%	4.3%
	EURO II	3.4%	4.6%	0.4%	0.9%	0.0%	9.4%
	EURO III	7.6%	10.4%	0.9%	1.9%	0.1%	21.0%
	EURO IV	23.3%	32.1%	2.9%	5.9%	0.3%	64.6%
	Sum	36.4%	49.5%	4.5%	9.2%	0.5%	100.0%
2040	EURO IV	36.1%	49.7%	4.5%	9.2%	0.5%	100.0%

Busses

The distributions of total mileages per vehicle layer used in the emission factor aggregations for busses are shown in the table below for 2015 and 2040. The same distribution is valid for highway and motorway.

Table 9.3 Total mileage distribution into layers for busses for 2015 and 2040

EURO norm	2015	2040
Pre-EURO	1.2%	0%
EURO I	3.8%	0%
EURO II	13.1%	0%
EURO III	21.6%	0%
EURO IV	17.0%	0%
EURO V	43.2%	100%

Vans and lorries

For vans, the distributions of total mileages per vehicle layer used to calculate aggregated highway and motorway emission factors are shown in the table below for 2015 and 2040. The same distribution is valid for highway and motorway.

Table 9.4 Total mileage distribution into layers for vans for 2015 and 2040

Year	EURO norm	Gasoline	Diesel	Sum
2015	Pre-EURO	0.1%	0.4%	0.5%
	EURO I	0.9%	3.9%	4.8%
	EURO II	1.5%	6.4%	8.0%
	EURO III	4.2%	17.4%	21.6%
	EURO IV	12.6%	52.5%	65.1%
	Sum	19.3%	80.7%	100.0%
2040	EURO IV	19.8%	80.2%	100.0%

For lorries the same mileage distribution per EURO norm (see table below) is used irrespective of lorry gross vehicle weight to calculate the highway and motorway emission factors per lorry size.

Table 9.5 Total mileage distribution into layers for lorries for 2015 and 2040

EURO norm	2015	2040
Pre-EURO	0.9%	0%
EURO I	1.8%	0%
EURO II	11.2%	0%
EURO III	21.5%	0%
EURO IV	17.8%	0%
EURO V	46.8%	100%

A final emission factor aggregation produces the results for lorries. The aggregation of the emission factors for lorries and vans are solely made according to the number-wise share of vehicles in unladen weight intervals taken from the traffic model behind the project, as given in the table below.

Table 9.6 Distribution of lorries from traffic simulations into COPERT categories

Net weight in tonnes (traffic model)	Share	COPERT III category
0-4	1%	Light duty vehicles
5-9	4%	Diesel 7.5-16 tonnes
10-14	18%	Diesel 16 – 32 tonnes
15-19	67%	Diesel > 32 tonnes
20-24	7%	Diesel > 32 tonnes
25-29	1%	Diesel > 32 tonnes
30-34	0%	Diesel > 32 tonnes
>35	1%	Diesel > 32 tonnes
Total	100%	

9.3 Emission factors in 2015 and 2040

The tables below present the emission factors for the years 2015 and 2040. The tables show model differences between TEMA2000 and COPERT and the effect of these are analysed in a sensitivity analysis.

Table 9.7 COPERT emission factors in 2015, g/km

	PM_{10}	NO_x	SO_2	CO	HC *)	CO_2
Highway						
Car	0.003	0.17	0.001	0.63	0.03 (0.02)	134
Bus	0.058	2.10	0.004	0.68	0.45	678
Lorry	0.067	2.87	0.006	0.68	0.40	898
Motorway						
Car	0.005	0.24	0.001	2.09	0.03 (0.02)	149
Bus	0.047	1.98	0.004	0.68	0.38	627
Lorry	0.055	2.45	0.005	0.71	0.34	869

*) Figures in parenthesis do not include evaporative emissions.

Table 9.8 COPERT emission factors in 2040, g/km

	PM_{10}	NO_x	SO_2	CO	HC *)	CO_2
Highway						
Car	0.002	0.09	0.001	0.42	0.01 (0.01)	133
Bus	0.015	1.04	0.004	0.52	0.34	678
Lorry	0.020	1.53	0.006	0.55	0.32	898
Motorway						
Car	0.004	0.14	0.001	1.50	0.01 (0.01)	149
Bus	0.012	0.99	0.004	0.54	0.29	627
Lorry	0.017	1.31	0.005	0.58	0.27	869

*) Figures in parenthesis do not include evaporative emissions.

10 Rail emission factors

This chapter gives the approach and data sources for the calculation of emission factors for rail transport.

10.1 Data and assumptions

The primary corridors affected in Denmark are Copenhagen-Padborg and Copenhagen-Rødby. Copenhagen-Padborg is fully electrified at present and Copenhagen-Rødby is assumed to be electrified as a part of the fixed link project.

The basic source for calculation of emission factors is TEMA2000.

For 2015 the emission factors for passenger transport are based on the most modern trains in TEMA2000, the IC3 diesel train and the electric ER/Intercity train.

Emission factors for passenger transport are given in gram per passenger kilometre, assuming a utilisation of seating capacity of 95 passengers per IC3 train[24], corresponding to a utilisation rate of 33%[25]. The ER trains do have higher seating capacity (466 seats). For these trains there has been assumed a utilisation of 153 passengers, also corresponding to a utilisation rate of 33% of total seating capacity. The utilisation rate of 33% is higher than the overall average utilisation rate of 24% reported in TEMA2000. However, this corresponds well to the fact that the relevant trips in the present study are more long distance trips relative to the average trip in Denmark.

The applied emission factors for passenger trains in 2015 are shown in the table below.

Table 10.1 Emission factors for passenger trains in 2015, g/passenger-km

Type	PM_{10}	NO_x	SO_2	CO	HC	CO_2
Electric	0.002	0.08	0.07	0.03	0.002	38.4
Diesel	0.016	0.61	0.00	0.09	0.041	43.3

[24] Calculated on the basis of FTC (2003b) pp. 16-20.

[25] According to TEMA2000 IC3 trains between Copenhagen and Padborg include two train sets of a capacity of 144 passengers each.

For freight transport, emission factors are based on a 30 wagon train with a load of 509 tonnes per train[26]. The average tara weight per wagon is 16.3 ton, resulting in a total weight of 998 tons, including load and excluding locomotive.

The applied emission factors for freight trains in 2015 are shown in the table below.

Table 10.2 Emission factors for freight trains in 2015, g/tonnes-km

Type	PM_{10}	NO_x	SO_2	CO	HC	CO_2
Electric	0.001	0.05	0.044	0.02	0.001	22.9
Diesel	0.014	0.40	0.001	0.05	0.013	22.4

International and long distance rail freight transport is carried out almost exclusively by electric traction. Therefore diesel locomotive is treated here only as an option in case no el-locomotive is available. For this purpose it is assumed that 10% of the transportations will be pulled by diesel locomotives.

Emissions from electricity production are calculated based on the method developed by the Danish Energy Agency.

For 2040 important technology changes has been included in the emission factor calculations:

- Improved energy efficiency of trains.
- Improved cleaning technology for diesel trains.

The improvement in energy efficiency has been estimated based on Danish Energy Authority (2000). In this survey it has been estimated that there will be a reduction of 35% for passenger train energy consumption. For freight trains the estimated reduction is 25%.

Furthermore, it is expected that there will be some improvement in cleaning technology on the diesel trains. This improvement is assumed to be of the same magnitude as for large lorries. This reduction is shown below.

Table 10.3 Reduction in emissions of diesel engines from 2015 to 2040

Reduction emissions	PM_{10}	NO_x	CO
Diesel engine	37%	30%	7%

[26] Calculated on the basis of FTC (2003b) pp. 16-20.

10.2 Emission factors in 2015 and 2040

This section gives the emission factors for passenger and freight transport using the approach and data sources described above.

The following two tables show the average emission factors assuming 10% diesel.

Table 10.4 Emission factors for trains in 2015 (90% electricity)

		PM_{10}	NO_x	SO_2	CO	HC	CO_2
Passenger trains	g/pass-km	0.004	0.13	0.07	0.03	0.006	38.9
Freight/ combi trains	g/tonnes-km	0.003	0.08	0.04	0.02	0.003	22.9

Table 10.5 Emission factors for trains in 2040 (90% electricity)

		PM_{10}	NO_x	SO_2	CO	HC	CO_2
Passenger trains	g/pass-km	0.002	0.07	0.04	0.02	0.004	25.3
Freight/ combi trains	g/tonnes-km	0.002	0.05	0.03	0.01	0.002	17.2

For sensitivity analyses electricity shares of 100% and 50% for both passenger and freight trains are included.

To illustrate the importance of the share of electricity trains, sensitivity analysis for passenger trains are shown below.

Table 10.6 Emission factors for passenger trains in 2015 by alternative assumptions for electricity share

		PM_{10}	NO_x	SO_2	CO	HC	CO_2
50% el	g/pass-km	0.009	0.34	0.04	0.06	0.02	40.8
90% el	g/pass-km	0.004	0.13	0.07	0.03	0.01	38.9
100% el	g/pass-km	0.002	0.08	0.07	0.03	0.00	38.4

As can be seen from the above table, CO_2 emissions are almost unaffected by the electricity share. On the other hand, the more locally toxic emissions like NO_x, CO and particulate matters increase significantly when the electricity share is reduced.

11 Literature

Danish Energy Authority (2000): *Technology catalogue on Technical Possibilities for Energy Savings in the Transport Sector.* March 2000. *[Teknologikatalog over tekniske muligheder for energibesparelser i transportsektoren]*.

Danish Ministry of Environment (2003): *Account of Denmark's greenhouse gasses 1990-2001 - forecasts for 2002-2017. [Danmarks drivhusgasopgørelser 1990-2001 - fremskrivninger 2002-2017]*.

Danish Ministry of Transport (2004a): *Economic Assessment of a Fixed Link across the Fehmarn Belt.* Summary Report.

Danish Ministry of Transport (2004b): *Economic Assessment of a Fixed Link across the Fehmarn Belt [Samfundsøkonomisk vurdering af en fast forbindelse over Fermern Bælt]*.

Danish Ministry of Transport (2000). *TEMA2000 Technical Report [Teknisk Rapport]*.

Danish Ministry of Transport (1999). *Valuation of the external costs of transport. Air pollution. [Værdisætning af trafikkens eksterne omkostninger. Luftforurening]*.

Ekman, B. (2003): *Unpublished data material from the Danish Road Directorate*.

Fehmarnbelt Traffic Consortium, FTC (2003a): *Fehmarn Belt Forecast 2002 - Reference Cases.* November 2003.

Fehmarnbelt Traffic Consortium, FTC (2003b): *Fehmarn Belt Forecast 2002*. Final Report. April 2003.

Fehmarnbelt Traffic Consortium, FTC (1999): *Fehmarnbelt Traffic Demand study*. Final Report. January 1999.

Illerup et al. (2002): *Projection Models, 2010. Danish Emissions of SO_2, NO_X, NMVOC and NH_3.* NERI technical report no. 414. National Environmental Research Institute. 192 pp.

INFRAS AG (2004): *HBEFA, Handbook of Emission Factors for Road Transport, version 1.2*. February 2004.

Ntziachristos, L. & Samaras, Z. (2000): *COPERT III Computer Programme to Calculate Emissions from Road Transport - Methodology and Emission Factors (Version 2.1)*. Technical report No 49. European Environment Agency, November 2000, Copenhagen. Available at: http://reports.eea.eu.int/Technical_report_No_49/en (June 13, 2003).

Appendix 1: Detailed data on ferries

Table 11.1 Emission factors for 2015 and 2040

Ferry type		Type 0	Type I	Type II	Type III
Number of car units per ferry	(-)	290	350	500	500
Reduction in specific fuel oil consumption	(%)	0	0	0	15
Specific fuel consumption	(g/kWh)	190	190	190	162
Energy consumption per trip	(%)	100	102	130	111
CO2 emission factor	(g/kg oil)	3167	3167	3167	3167
CO2 emission factor	(g/kWh)	602	602	602	511
CO2 emission factor	(g/MJ)	74,0	74,0	74,0	74,0
NOx emission factor	(g/kWh)	12	6	6	1,2
NOx emission factor	(g/kg oil)	63	32	32	7
NOx emission factor	(g/MJ)	1,48	0,74	0,74	0,17
Sulphur content	(%)	0,75	0,1	0,1	0,1
SO2 emission factor	(g/kWh)	2,99	0,40	0,40	0,34
SO2 emission factor	(g/kg oil)	15,8	2,1	2,1	2,1
SO2 emission factor	(g/MJ)	0,368	0,049	0,049	0,049
HC catalytic reduction	(%)	0	0	0	80
Normal HC emission factor	(g/kWh)	0,50	0,50	0,50	0,50
Catalytic HC emission factor	(g/kWh)	0,50	0,50	0,50	0,10
Catalytic HC emission factor	(g/kg oil)	2,63	2,63	2,63	0,62
Catalytic HC emission factor	(g/MJ)	0,061	0,061	0,061	0,014
CO emission factor	(g/kWh)	1,6	1,6	1,6	1,6
CO emission factor	(g/kg oil)	8,4	8,4	8,4	9,9
PM catalytic reduction	(%)	0	0	0	40
Particulate emission factor (PM)	(g/kg oil)	1,37	1,13	1,13	1,13
Particulate emission factor (PM)	(g/kWh)	0,26	0,21	0,21	0,18
Catalytic PM emission factor	(g/kg oil)	1,37	1,13	1,13	0,68
Catalytic PM emission factor	(g/MJ)	0,032	0,026	0,026	0,016

Ferry types

Type 0	Existing ferry type on Rødby-Puttgarden
Type I	Existing ferry type on Rødby-Puttgarden with extra platform deck
Type II	Existing ferry in lengthened version (+ 40 m)
Type III	New ferry in longer version (+ 40 m) - 2040

Table 11.2 Calculated emissions for Rødby-Puttgarden in 2015 and 2040

Year		**2003**	**2015**	**2015**	**2040**	**2040**	**2040**
Assumed number of ferries	(-)	4	4	4	4	5	6
Assumed ferry types on the route		4 x Type 0	4 x Type I	4 x Type II	4 x Type III	5 x Type III	6 x Type III
Transport capacity for all ferries per crossing	(cars)	1160	1400	2000	2000	2500	3000
Transport capacity in percentage	(%)	100	121	172	172	216	259
Total oil consumption	(tons/year)	35485	36195	46130	39211	49014	58816
Total energy consumption	(TJ/year)	1519	1549	1974	1678	2098	2517
Total CO_2 emissions	(tons/year)	112487	114737	146233	124298	155373	186447
Total NOx emissions	(tons/year)	2241	1143	1457	291	364	437
Total SO_2 emissions	(tons/year)	559	76	97	82	103	124
Total HC emissions	(tons/year)	93	95	121	24	30	36
Total CO emissions	(tons/year)	299	305	388	388	486	583
Total PM emissions	(tons/year)	49	41	52	27	33	40

Ferry types

Type 0	Existing ferry type on Roedby-Puttgarden
Type I	Existing ferry type on Roedby-Puttgarden with extra platform deck
Type II	Existing ferry in lengthened version (+ 40 m)
Type III	New ferry in longer version (+ 40 m) - 2040

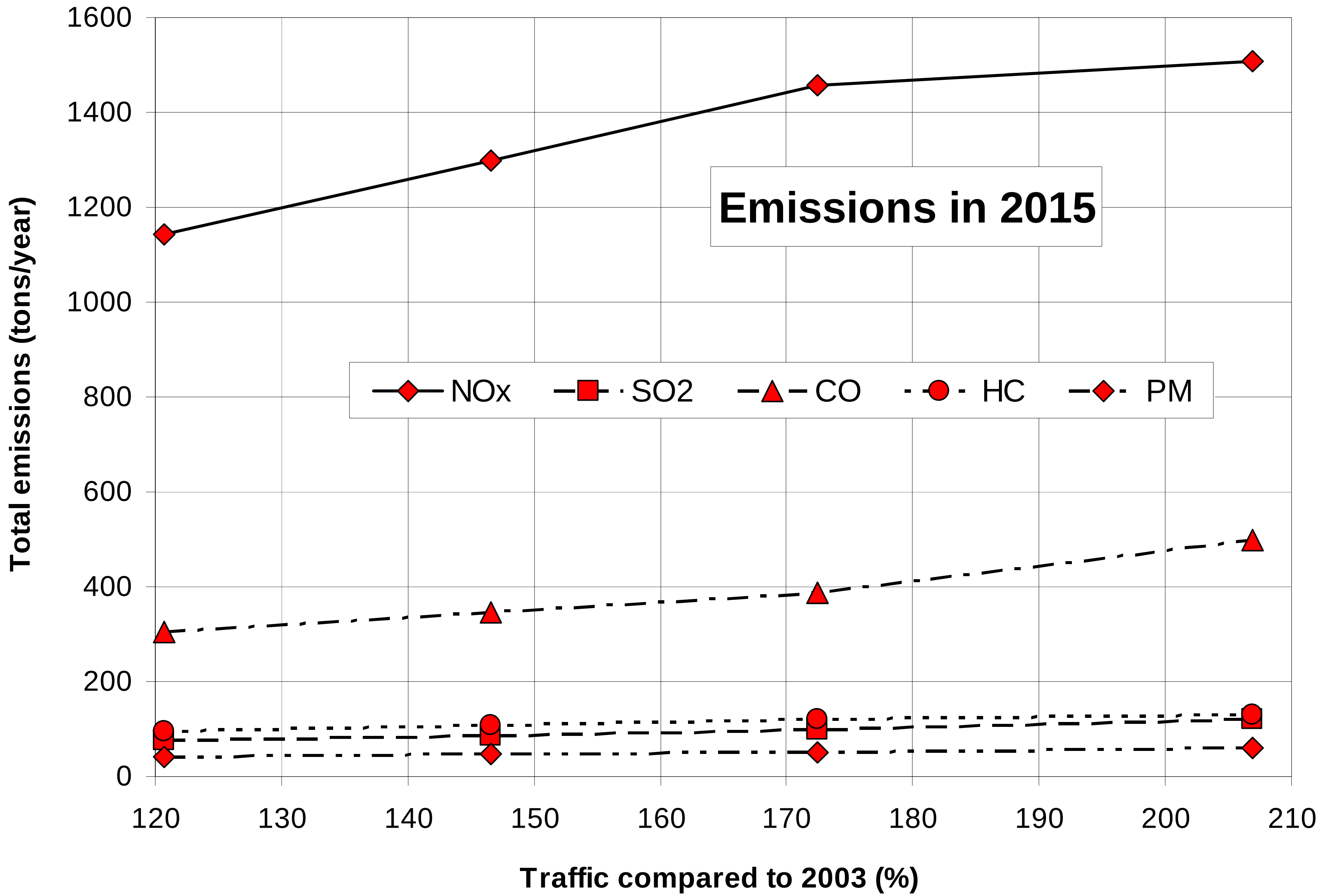


Figure 11.1 Estimated emissions in 2015 on the ferry route Rødby - Puttgarden

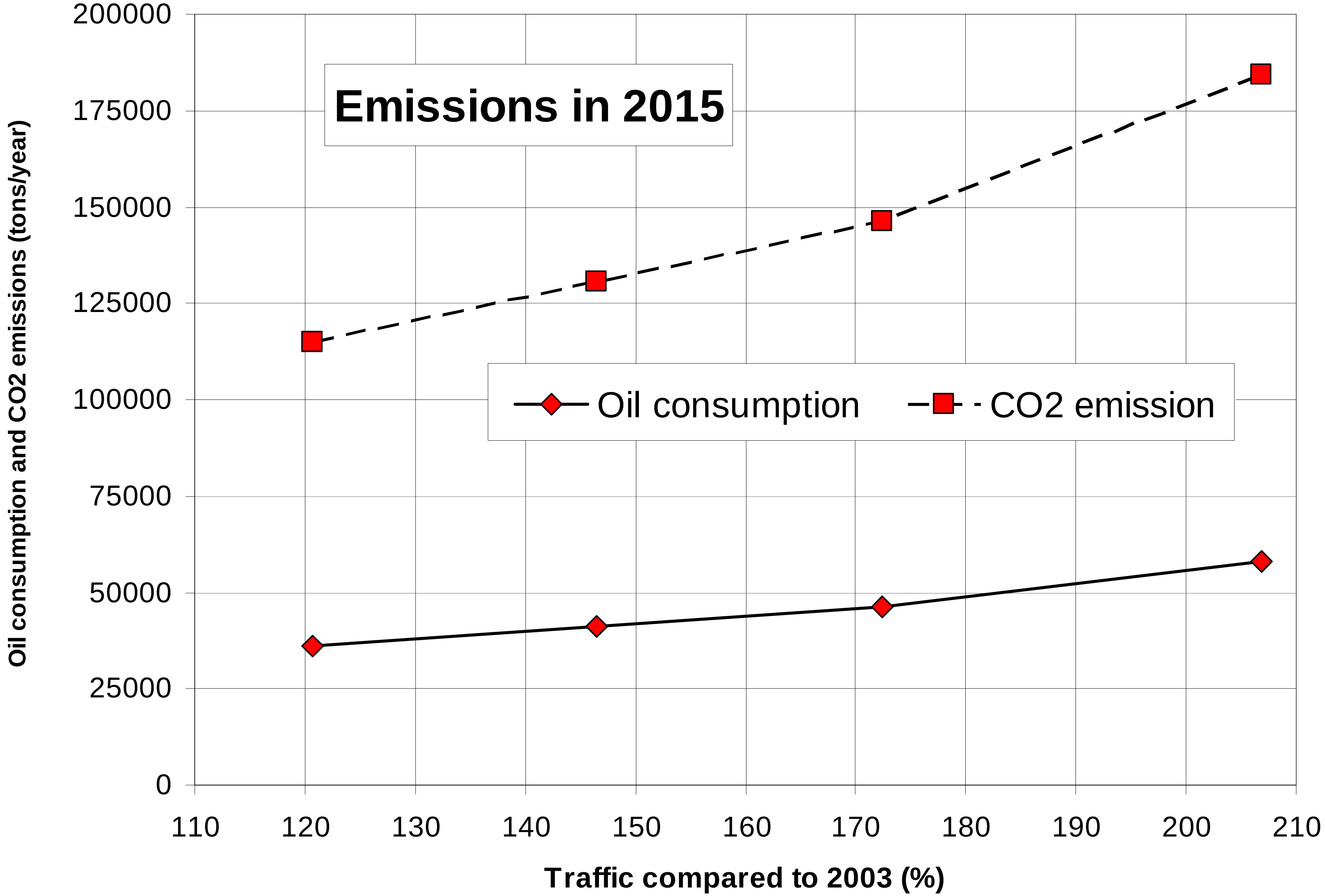


Figure 11.2 Estimated oil consumption and CO2 emissions in 2015 on the ferry route Rødby - Puttgarden

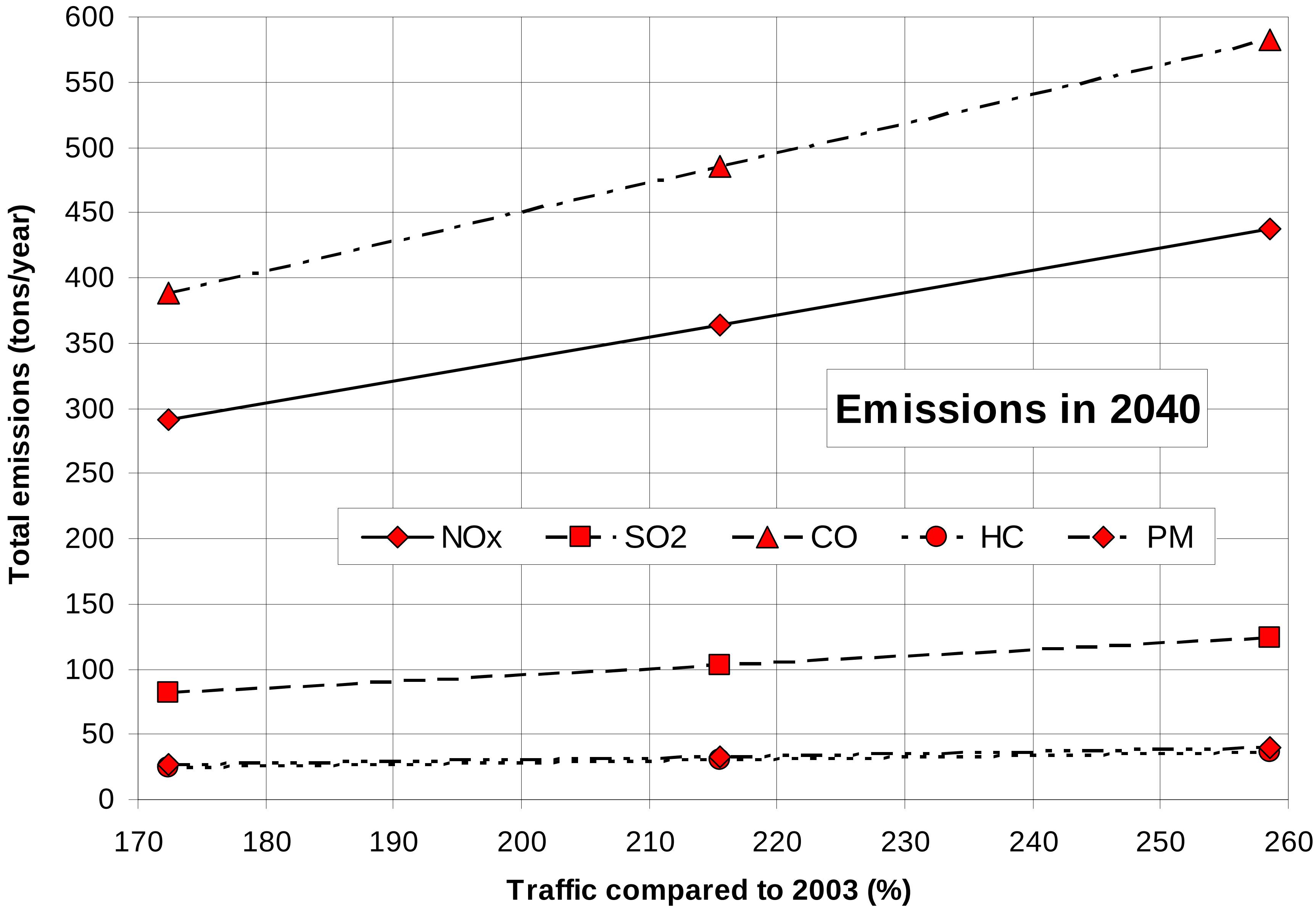


Figure 11.3 Estimated emissions in 2040 on the ferry route Rødby - Puttgarden

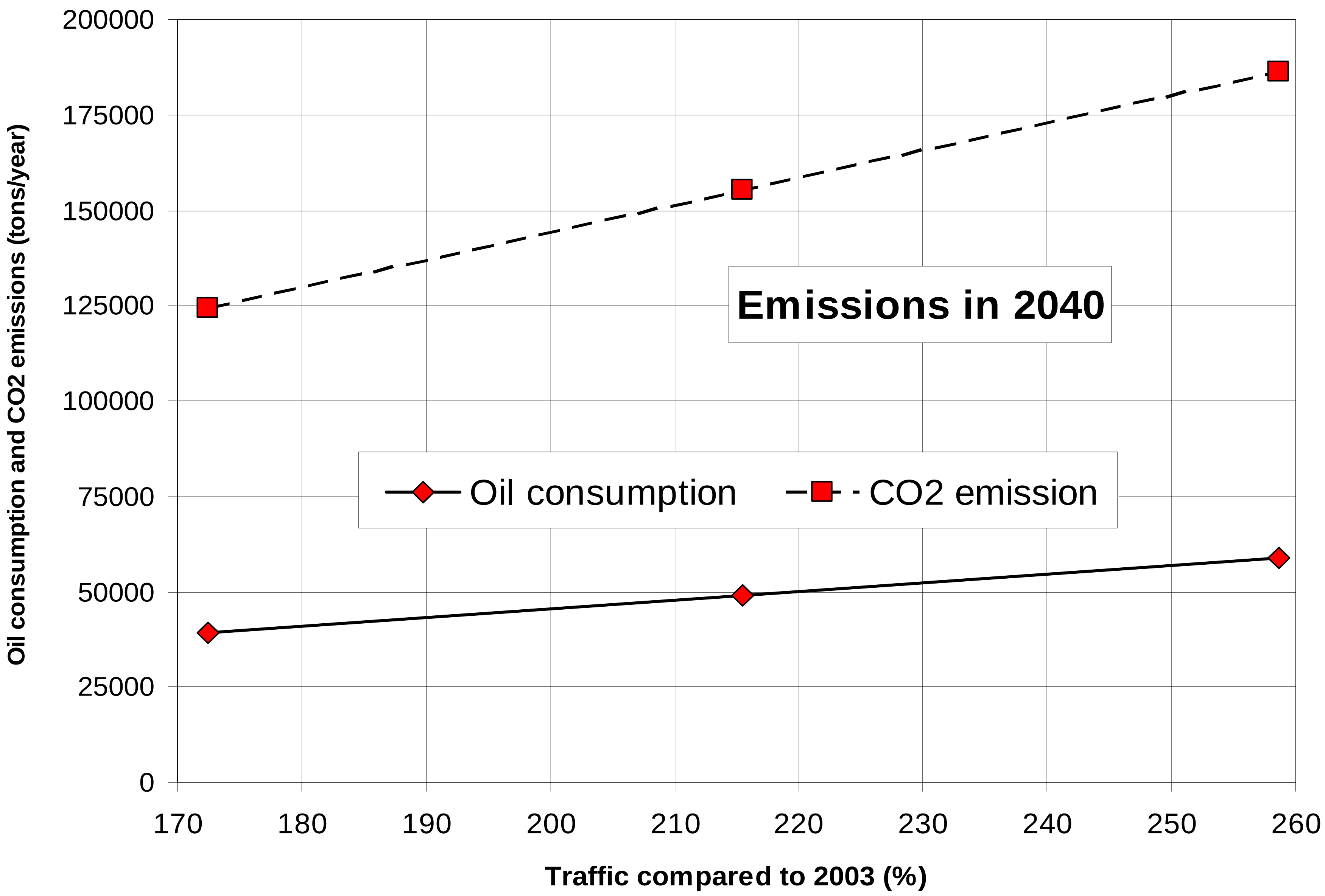


Figure 11.4 Estimated oil consumption and CO2 emissions in 2040 on the ferry route Rødby - Puttgarden

Appendix 2: Detailed results on modes

The following tables show the detailed results on modes. In addition to the reductions in emissions due to a fixed link ("-" indicates an increase in emissions compared to the reference situation), the tables also show the total emissions in the reference situation (without a fixed link). These emissions are calculated as the total traffic volumes in the reference situation (as modelled in the traffic model) multiplied by the same emission factors as for the reduction in emissions.

Emission data for ferry lines in the traffic model, which are not affected by the establishment of the fixed link, are not included in the analysis, because there will be no change in emissions between the reference situation and the project alternative for these ferries. Therefore total emissions for ferries in the reference situation are not included in the table.

It should be noted that the total emissions in the tables only cover traffic which is included in the traffic model. This means that it covers traffic between Denmark/Scandinavia and the Continent.

Table 11.3 Annual transport emissions on modes in the reference situation and reduction due to a fixed link, all European countries, tonnes (part I)

	2015		2040	
	Total (reference situation)	Reduction	Total (reference situation)	Reduction
Passenger cars				
PM_{10}	43	-1	65	-2
NO_x	871	-25	1,108	-32
SO_2	21	-1	31	-1
CO	4,627	-133	6,846	-196
HC	206	-6	270	-8
CO_2	636,542	-18,235	947,741	-27,151
Busses				
PM_{10}	5	0	4	0
NO_x	214	-2	203	-2
SO_2	2	0	3	0
CO	20	0	27	0
HC	21	0	28	0
CO2	55,322	-443	84,336	-676
Passenger trains				
PM_{10}	4	-1	3	-1
NO_x	139	-27	99	-20
SO_2	69	-14	57	-11
CO	34	-7	28	-5
HC	6	-1	5	-1
CO_2	40,570	-8,005	33,550	-6,620
Ferries				
PM_{10}	n.a.	59	n.a.	42
NO_x	n.a.	1,765	n.a.	494
SO_2	n.a.	108	n.a.	129
CO	n.a.	397	n.a.	557
HC	n.a.	150	n.a.	42
CO_2	n.a.	176,623	n.a.	210,311

Table 11.4 Annual transport emission on modes in the reference situation and reduction due to a fixed link, all European countries, tonnes (part II)

	2015		2040	
	Total (reference situation)	Reduction	Total (reference situation)	Reduction
Lorries				
PM_{10}	215	1	194	1
NO_x	20,266	114	24,977	141
SO_2	114	1	174	1
CO	2,929	17	4,354	25
HC	1,136	6	1,592	9
CO_2	3,560,527	20,094	5,426,574	30,625
Freight trains				
PM_{10}	39	1	36	1
NO_x	1,283	19	1,254	19
SO_2	609	9	696	10
CO	297	4	333	5
HC	39	1	44	1
CO_2	352,605	5,313	403,064	6,073
Combi trains				
PM_{10}	9	1	8	1
NO_x	285	21	279	21
SO_2	135	10	155	12
CO	66	5	74	6
HC	9	1	10	1
CO_2	78,357	5,861	89,570	6,700
All				
PM_{10}	n.a.	59	n.a.	42
NO_x	n.a.	1,866	n.a.	622
SO_2	n.a.	114	n.a.	139
CO	n.a.	284	n.a.	390
HC	n.a.	150	n.a.	43
CO_2	n.a.	181,208	n.a.	219,263

Appendix 3: Detailed results for sensitivity analysis for 2040

Table 11.5 Annual transport emission reduction on modes due to a fixed link, all European countries, sensitivity analyses, 2040, tonnes (part I)

	Base assump tions	Low traffic growth	High traffic growth	Road emissi-ons from Copert	Road emissi-ons from HBEFA	Electr-city share for trains 100%	Electr-city share for trains 50%	Road emissi-ons 100% motor-way	Road emissi-ons 100% high-way	Diesel share of pas-senger cars 25%
Passenger cars										
PM_{10}	-2	-1	-2	0	0	-2	-2	-2	-2	-2
NO_x	-32	-25	-41	-18	-29	-32	-32	-41	-22	-37
SO_2	-1	-1	-1	0	0	-1	-1	-1	-1	-1
CO	-196	-153	-250	-151	-104	-196	-196	-256	-137	-167
HC	-8	-6	-10	-1	-3	-8	-8	-8	-8	-7
CO_2	-27,151	-21,208	-34,675	-22,273	-20,240	-27,151	-27,151	-29,266	-25,035	-27,018
Busses										
PM_{10}	0	0	0	0	0	0	0	0	0	0
NO_x	-2	-1	-2	-1	-2	-2	-2	-2	-2	-2
SO_2	0	0	0	0	0	0	0	0	0	0
CO	0	0	0	0	-1	0	0	0	0	0
HC	0	0	0	0	0	0	0	0	0	0
CO_2	-676	-528	-863	-504	-664	-676	-676	-676	-676	-676
Passenger trains										
PM_{10}	-1	0	-1	-1	-1	0	-1	-1	-1	-1
NO_x	-20	-17	-23	-20	-20	-14	-43	-20	-20	-20
SO_2	-11	-10	-13	-11	-11	-13	-6	-11	-11	-11
CO	-5	-5	-6	-5	-5	-4	-10	-5	-5	-5
HC	-1	-1	-1	-1	-1	0	-4	-1	-1	-1
CO_2	-6,620	-5,747	-7,619	-6,620	-6,620	-6,536	-6,955	-6,620	-6,620	-6,620
Ferries										
PM_{10}	42	34	51	42	42	42	42	42	42	42
NO_x	494	396	593	494	494	494	494	494	494	494
SO_2	129	103	154	129	129	129	129	129	129	129
CO	557	445	668	557	557	557	557	557	557	557
HC	42	34	50	42	42	42	42	42	42	42
CO_2	210,311	168,249	252,373	210,311	210,311	210,311	210,311	210,311	210,311	210,311

Table 11.6 Annual transport emission reduction on modes due to a fixed link, all European countries, sensitivity analyses, 2040, tonnes (part II)

	Base assumptions	Low traffic growth	High traffic growth	Road emissions from Copert	Road emissions from HBEFA	Electricity share for trains 100%	Electricity share for trains 50%	Road emissions 100% motorway	Road emissions 100% highway	Diesel share of passenger cars 25%
Lorries										
PM_{10}	1	1	1	1	1	1	1	1	1	1
NO_x	141	110	180	45	78	141	141	97	185	141
SO_2	1	1	1	0	0	1	1	1	1	1
CO	25	19	31	18	30	25	25	21	28	25
HC	9	7	11	9	11	9	9	9	9	9
CO_2	30,625	23,922	39,112	27,881	24,775	30,625	30,625	29,373	31,877	30,625
Freight trains										
PM_{10}	1	0	1	1	1	0	1	1	1	1
NO_x	19	15	24	19	19	13	44	19	19	19
SO_2	10	8	13	10	10	12	6	10	10	10
CO	5	4	6	5	5	4	9	5	5	5
HC	1	1	1	1	1	0	2	1	1	1
CO_2	6,073	4,744	7,756	6,073	6,073	6,085	6,026	6,073	6,073	6,073
Combi trains										
PM_{10}	1	0	1	1	1	0	1	1	1	1
NO_x	21	16	27	21	21	14	48	21	21	21
SO_2	12	9	15	12	12	13	6	12	12	12
CO	6	4	7	6	6	5	9	6	6	6
HC	1	1	1	1	1	0	2	1	1	1
CO_2	6,700	5,233	8,557	6,700	6,700	6,713	6,648	6,700	6,700	6,700
Total										
PM_{10}	42	34	50	43	43	42	43	42	42	41
NO_x	622	494	759	540	562	615	651	568	676	617
SO_2	139	110	170	139	139	141	135	139	140	140
CO	390	315	456	428	487	389	393	327	453	419
HC	43	35	52	50	50	43	43	43	43	44
CO_2	219,263	174,665	264,642	221,569	220,335	219,372	218,829	215,896	222,631	219,396

Appendix 4: Sensitivity analysis for 2015

The results of the sensitivity analyses for 2015 are presented in the figures below. The figures illustrate the change of the reduction in each of the sensitivity analyses. For instance, a figure of 80% means that the reduction is 80% of the reduction in the base calculation.

Figure 11.5 Result of the sensitivity analyses for CO_2, PM_{10} and NO_x, all European countries, 2015

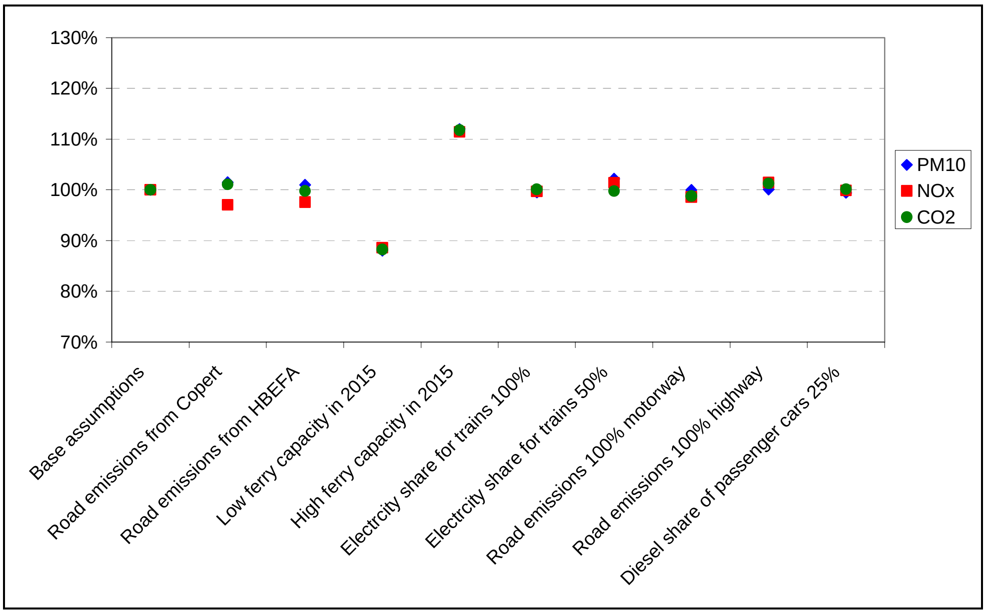


Figure 11.6 Result of the sensitivity analyses for SO_2, CO and HC, all European countries, 2015

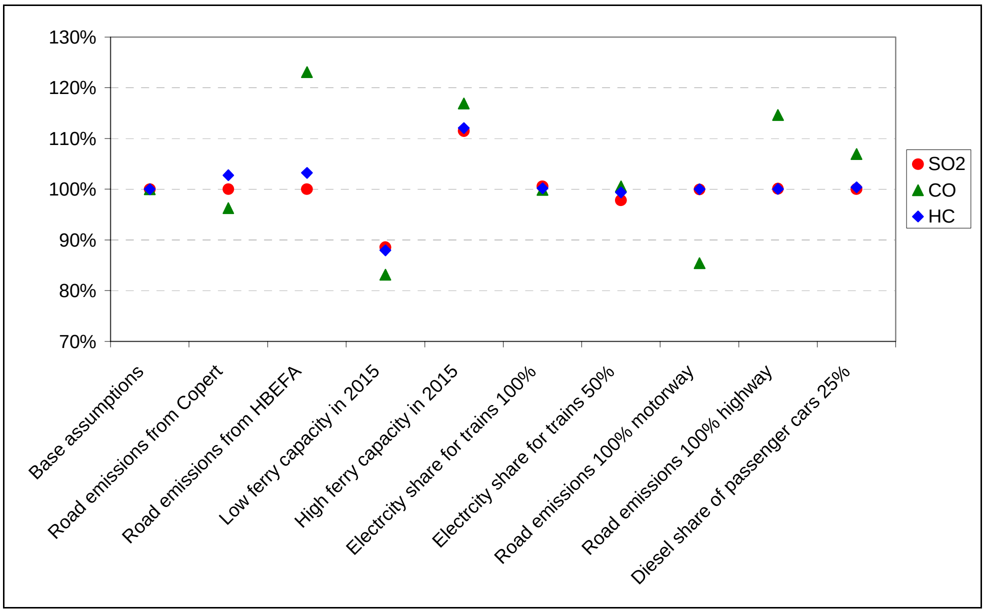


Table 11.7 Annual transport emission reduction on modes due to a fixed link, all European countries, sensitivity analyses, 2015, tonnes (part I)

	Base assumptions	Road emissions from Copert	Road emissions from HBEFA	Low ferry capacity in 2015	High ferry capacity in 2015	Electrcity share for trains 100%	Electrcity share for trains 50%	Road emissions 100% motorway	Road emissions 100% highway	Diesel share of passenger cars 25%
Passenger cars										
PM_{10}	-1	0	0	-1	-1	-1	-1	-1	-1	-2
NO_x	-25	-21	-19	-25	-25	-25	-25	-33	-17	-27
SO_2	-1	0	0	-1	-1	-1	-1	-1	-1	-1
CO	-133	-141	-70	-133	-133	-133	-133	-173	-93	-113
HC	-6	-3	-2	-6	-6	-6	-6	-6	-6	-5
CO_2	-18,235	-14,631	-14,734	-18,235	-18,235	-18,235	-18,235	-19,681	-16,790	-18,020
Busses										
PM_{10}	0	0	0	0	0	0	0	0	0	0
NO_x	-2	-1	-2	-2	-2	-2	-2	-2	-2	-2
SO_2	0	0	0	0	0	0	0	0	0	0
CO	0	0	0	0	0	0	0	0	0	0
HC	0	0	0	0	0	0	0	0	0	0
CO_2	-443	-331	-428	-443	-443	-443	-443	-443	-443	-443
Passenger trains										
PM_{10}	-1	-1	-1	-1	-1	0	-2	-1	-1	-1
NO_x	-27	-27	-27	-27	-27	-17	-71	-27	-27	-27
SO_2	-14	-14	-14	-14	-14	-15	-8	-14	-14	-14
CO	-7	-7	-7	-7	-7	-5	-12	-7	-7	-7
HC	-1	-1	-1	-1	-1	0	-4	-1	-1	-1
CO_2	-8,005	-8,005	-8,005	-8,005	-8,005	-7,903	-8,410	-8,005	-8,005	-8,005
Ferries										
PM_{10}	59	59	59	52	66	59	59	59	59	59
NO_x	1,765	1,765	1,765	1,552	1,978	1,765	1,765	1,765	1,765	1,765
SO_2	108	108	108	95	121	108	108	108	108	108
CO	397	397	397	350	445	397	397	397	397	397
HC	150	150	150	132	168	150	150	150	150	150
CO_2	176,623	176,623	176,623	155,307	197,940	176,623	176,623	176,623	176,623	176,623

Table 11.8 Annual transport emission reduction on modes due to a fixed link, all European countries, sensitivity analyses, 2015, tonnes (part II)

	Base assump tions	Road emissi-ons from Copert	Road emissi-ons from HBEFA	Low ferry capaci-ty in 2015	High ferry capaci-ty in 2015	Electr-city share for trains 100%	Electr-city share for trains 50%	Road emissi-ons 100% motor-way	Road emissi-ons 100% high-way	Diesel share of pas-senger cars 25%
Lorries										
PM_{10}	1	1	1	1	1	1	1	1	1	1
NO_x	114	55	63	114	114	114	114	96	133	114
SO_2	1	0	0	1	1	1	1	1	1	1
CO	17	14	20	17	17	17	17	15	18	17
HC	6	8	7	6	6	6	6	6	6	6
CO_2	20,094	18,293	16,146	20,094	20,094	20,094	20,094	19,273	20,915	20,094
Freight trains										
PM_{10}	1	1	1	1	1	0	2	1	1	1
NO_x	19	19	19	19	19	11	52	19	19	19
SO_2	9	9	9	9	9	10	5	9	9	9
CO	4	4	4	4	4	4	8	4	4	4
HC	1	1	1	1	1	0	2	1	1	1
CO_2	5,313	5,313	5,313	5,313	5,313	5,323	5,272	5,313	5,313	5,313
Combi trains										
PM_{10}	1	1	1	1	1	0	2	1	1	1
NO_x	21	21	21	21	21	12	58	21	21	21
SO_2	10	10	10	10	10	11	6	10	10	10
CO	5	5	5	5	5	4	9	5	5	5
HC	1	1	1	1	1	0	2	1	1	1
CO_2	5,861	5,861	5,861	5,861	5,861	5,872	5,816	5,861	5,861	5,861
Total										
PM_{10}	59	60	60	52	66	59	61	59	59	59
NO_x	1,866	1,811	1,820	1,653	2,079	1,859	1,891	1,839	1,892	1,863
SO_2	114	114	114	101	127	114	111	114	114	114
CO	284	273	349	236	332	284	285	242	325	304
HC	150	154	155	132	168	150	149	150	150	150
CO_2	181,208	183,124	180,776	159,891	202,524	181,331	180,716	178,941	183,474	181,424

Appendix 5: List of abbreviations

CO	Carbon oxide
CO_2	Carbon dioxide
COPERT	Computer programme to calculate emissions from road transport
ER train	Electric regional train
EU	European Union
FTC	Fehmarnbelt Traffic Consortium
HBEFA	Handbook of emission factors for road transport
HC	Hydro carbon
IC3	Inter City 3
IMO	International Maritime Organisation
n.a.	Not applicable
NERI	National Environmental Research Institute
NMVOC	Non-methane volatile organic carbon
NO_x	Nitrogen oxides
OD	Origin-destination
PCE	Passenger car equivalents
PM_{10}	Particulate matter of a diameter less than 10 µm.
SEEK	Simulating energy consumption and emissions with variable vehicle configuration
SO_2	Sulphur dioxide
TEMA2000	Emissions from transport under different assumptions