

EU DG Tren project



ARTEMIS
Sea transport emission modelling

For the European Commission DG Tren

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FOREWORD

On November 11, 1999 the ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems) final contract was signed including 35 contractors. The contract was based on an RTD proposal to the Growth Programme, Key Action KA 2 – Sustainable Mobility and Intermodality, Task 2.2: Infrastructures and their interfaces with transport means and systems, Sector 2.2.2: Environment, Sub- Task 2.2.2/2: Monitoring emissions from transport, including particulates.

The contract covered mainly the road traffic but included Work Package 800; Emissions Estimating Methodology for Ship Transport. The WP was only manned by DTU as the intention was to man up the non road organisation later in the project.

In April 2000 a revised project Technical Annex was produced where MariTerm was included. A contract was drawn up and MariTerm applied for national co financing to cover for the costs which granted by the Swedish Transport & Communications Research Board (Kommunikations-ForskningsBeredningen).

After a prolongation of the originally 42 month contract the project had a final deadline set to the end of February 2005.

We are convinced that the methodology, which is based on our fifteen year long experience from working in this field, will lead to a step forward in producing high quality assessments of ship emissions in Europe and elsewhere.

We would like to thank Lloyd's Register-Fairplay Research for their dedicated efforts and also DTU and TRL for their immense work handling the contract related problems.

Gothenburg February 2005

Anders Sjöbris

SUMMARY

Sea transports is somewhat missed in the environmental assessment of transports. There are many reasons for this. The most important reason is the lack of suitable statistics. Another is the availability of suitable algorithms to be used for assessment based on just basic information.

The aim of this ARTEMIS report is to cover for the later situation when, for example, only port data information is available, GT or DWT and type of ship.

The report presents algorithms that are based on the Lloyd's Register – Fairplay ships register from which selections of relevant data has been drawn. Information of about 45 000 ships is used that have the needed information registered. In addition information from the engine manufacturers given the actual SFC (Specific Fuel Consumption) and emission factors for each specific type of engine is given. Statistics has been built on this information giving the typical engine for each type and size of ship.

Using the age of the ship as a base figure the ship's type of engine installed and linked information have been identified. As a result the development over time of the SFC and the emission factors have been produced and are reported in the Annex to the report.

This is the first time ship's statistics of this amount have been produced and presented. The ARTEMIS project has also trigged the Lloyd's Register – Fairplay to include the environmental information like the SFC and emission factors in the register of ships. This will enable a further development of environmental statistics for sea transportation in the future.

Content

INTRODUCTION **8**

1 DIFFERENT TYPES OF EMISSION ASSESSMENTS **11**

1.1 THE PURPOSE OF ASSESSMENT 12
1.2 THE METHODS OF ASSESSMENT 13
The Swedish 1990 model *13*
The MEET model *15*
The TRENDS model *15*
The Entec model *16*
The ARTEMIS model *16*
Future models *17*
1.3 PORT INFORMATION 18

2 THE METHODOLOGY OF THIS WORK **19**

REGIONAL DATA 19

3 SHIP TYPES AND USED CATEGORISATION **22**

3.1 SHIPS' MAIN DIMENSIONS AND PERFORMANCE 24
3.2 THE DEVELOPMENT OF SHIPS' ENVIRONMENTAL PERFORMANCE 25
3.3 EMISSION FACTORS 27

4 EXHAUST CLEANING EQUIPMENT **28**

4.1 NO_X ABATEMENT SYSTEMS 29
The operation of different systems *31*
4.2 THE REGULATIONS AND THE MEASURES 32
4.3 THE SULPHUR ABATEMENT PROGRAM 34

5 THE METHODOLOGY OF ASSESSMENT **40**

5.1 THE SPATIAL ASSESSMENT 40
5.2 SHIPS' SIMPLIFIED DATA 41

6 HOW TO USE THE INFORMATION IN A SEA **42**

6.1 COMPARISON WITH OTHER EMISSION ASSESSMENT METHODS 50
6.2 THE RELATION BETWEEN ENERGY CONSUMPTION AND SIZE BY SPEED 54
Bulkers *54*
Dry Cargo (General Cargo) *59*
Container ships *63*
Ro/Ro *69*
Reefer *73*
Cargo Ferries *77*
Passenger Ferry *83*
High Speed Ferries *88*
Tanker *90*
Gas Tanker *97*
Cruise vessels *103*
Vehicle Carriers *106*

7 EXAMPLE OF EMISSION ESTIMATION **110**

8 TABLES AND FORMULAS FOR THE CALCULATION OF SHIPS' EMISSIONS **111**

9 SHIPS' STATISTICS **122**

REFERENCES **125**

APPENDIX 1 ..... **126**

Figures

FIGURE 1; THE STRATEGIC TRANSPORT RESEARCH PROGRAMME FP 4, DG VII 11
FIGURE 2; A DESCRIPTION OF THE METHOD TO ASSESS TRANSPORT ROUTES FOR SHIPS 13
FIGURE 3; SHIPPING ACTIVITY IN THE NORDIC AND BALTIC SEA REGION NBSR PRESENTED BY SAI 14
FIGURE 4; EMISSION FACTOR LEVELS AS A FUNCTION OF SHIPS' SIZE 14
FIGURE 5; THE SPLIT OF MAIN TYPE OF COMMODITIES IN THE SOUTH BALTIC SEA 21
FIGURE 6: DIFFERENT KIND OF PASSENGER CARRYING FERRIES 24
FIGURE 7; DISTRIBUTION OF SHIPS IN RELATION TO SPEED 26
FIGURE 8: SCR ARRANGEMENT IN A SHIP AN AFTER-TREATMENT SYSTEM (MUNTERS) 29
FIGURE 9: THE HAM EXHAUST CLEANING SYSTEM, A PRE-TREATMENT SYSTEM (MUNTERS) 30
FIGURE 10: THE PRINCIPLE OF THE NATIONAL DUES IN SWEDEN 33
FIGURE 11; THE DEVELOPMENT OF NO_X AIR EMISSIONS FOR SHIPS' TRAFFIC ON SWEDEN 34
FIGURE 12; HAVING ONLY INCITEMENT FROM ONE COUNTRY THE CHARTERS WILL HAVE TO PUT UP WITH THE COST TO BE ENVIRONMENTAL FRIENDLY 36
FIGURE 13; BUNKER PRICE DEVELOPMENT IN ROTTERDAM OVER THE PAST YEARS 37
FIGURE 14; THE DEVELOPMENT OF SULPHUR EMISSIONS IN SWEDISH WATERS IN THE 80:TIES AND 90:TIES 38
FIGURE 15; THE DEVELOPMENT OF CARBON DIOXIDE, WHICH RELAYS THE TRAFFIC ACTIVITY 39
FIGURE 16; THE DIFFERENCE IN TUNING THE ENGINE TO A ENERGY EFFICIENT BURNING OR NOX MINIMISING BURNING 41
FIGURE 17; NUMBER OF SHIPS BY SIZE AND TYPE 43
FIGURE 18; THE AGE PROFILE OF TANKERS 44
FIGURE 19; THE AGE PROFILE OF OIL TANKERS IN RELATION TO TRANSPORT CAPACITY, DWT 44
FIGURE 20; THE AVERAGE SPEED IN RELATION TO AGE FOR GENERAL CARGO SHIPS 45
FIGURE 21; THE AVERAGE FUEL CONSUMPTION PER YEAR OF BUILT AND TRANSPORT CAPACITY FOR GENERAL CARGO SHIPS 47
FIGURE 22; THE DEVELOPMENT OF NO_X EMISSIONS FOR CARGO FERRIES 47
FIGURE 23; COMPARISON OF METHODS FOR ESTIMATION OF TANKERS FUEL OIL CONSUMPTION/DISTANCE 51
FIGURE 24; COMPARISON OF METHODS FOR ESTIMATION OF GENERAL CARGO SHIPS FUEL OIL CONSUMPTION/DISTANCE 52
FIGURE 25; COMPARISON OF METHODS FOR ESTIMATION OF REEFER SHIPS FUEL OIL CONSUMPTION PER TRAVELLED DISTANCE 52
FIGURE 26; COMPARISON OF METHODS FOR ESTIMATION OF RO/RO SHIPS FUEL OIL CONSUMPTION/DISTANCE 53
FIGURE 27 COMPARISON OF METHODS FOR ESTIMATION OF VEHICLE CARRIERS FUEL OIL CONSUMPTION/DISTANCE 53
FIGURE 28; THE BULK SHIPS' INTALLED POWER AS A FUNCTION OF THE GROSS TONNAGE 54
FIGURE 29; THE SAMPLE OF DIFFERENT SPEEDS OF BULK SHIPS SHOW A CLEAR CONCENTRATION OF SERVICE SPEED AROUND 14-15 KNOTS 54
FIGURE 30; IN THE LAST FEW YEARS THE MARKET HAS BEEN GOOD WHICH SHOWS IN INCREASING SPEED CAPABILITY 55
FIGURE 31; THE ENERGY EFFICIENCY DEVELOPMENT FOR THE BULK SHIPS 55
FIGURE 32; BULK SHIPS USE OF ME POWER IN RELATION TO SIZE GT FOR EACH SPEED GROUP 56
FIGURE 33; FUNCTIONS FOR LARGER VESSELS, ≥20,000 DWT 57
FIGURE 34; BULK SHIPS SIZE (DWT) – ME BY SPEED. FUNTIONS FOR SMALLER VESSELS, < 20,000 DWT 57
FIGURE 35; BULK SHIPS MAIN ENGINE TYPE BASED ON ME OUTPUT 58
FIGURE 36; BULK SHIPS SIZE (DWT) – AE POWER OUTPUT. 850 BULK AND COMBINATION SHIPS 58
FIGURE 37; THE 16,250 GENERAL CARGO SHIPS FORMS A HOMOGENEOUS MASS IN THE CHART 59
FIGURE 38; SPEED/POWER RELATION FOR GENERAL CARGO SHIPS 59
FIGURE 39; THE DISTRIBUTION OF SPEED ON THE GENERAL CARGO SHIP FLEET 60
FIGURE 40; THE SPEED DEVELOPMENT OVER THE PAST DECADES 60
FIGURE 41; THE FUEL CONSUMPTION DEVELOPMENT FOR GENERAL CARGO VESSELS 60
FIGURE 42; NOX EMISSIONS DEVELOPMENT FROM GENERAL CARGO SHIPS 61
FIGURE 43; GENERAL CARGO SHIPS SIZE (GT) – ME BY SPEED LEVEL 61
FIGURE 44; GENERAL CARGO SHIPS SIZE (DWT) – ME BY SPEED LEVEL 62
FIGURE 45; GENERAL CARGO SHIPS MAIN ENGINE TYPE PER ME OUTPUT 62
FIGURE 46; GENERAL CARGO SHIPS SIZE (DWT) – AE POWER OUTPUT. 743 SHIPS 63
FIGURE 47; THE SAMPLE OF 3,640 CONTAINER SHIPS SHOWS A DIRECT RELATION BETWEEN THE SIZE OF THE SHIP AND INSTALLED POWER 64
FIGURE 48; THE SPEED PROFILE OF THE CONTAINER SHIPS 65
FIGURE 49; THE AVERAGE SPEED IN RELATION TO SIZE OF BUILT CONTAINER SHIPS ARE FAIRLY CONSTANT OVER THE YEARS. THE SPEED INCREASE BY SHIPS SIZE 65
FIGURE 50; THE DEVELOPEMENT OF NITROGEN OXIDE EMISSIONS FROM CONTAINER SHIPS 66

FIGURE 51; CONTAINER SHIPS SIZE (GT) – ME POWER BY SPEED LEVEL 67
FIGURE 52; CONTAINER SHIPS SIZE (DWT) – ME POWER BY SPEED LEVEL....67
FIGURE 53; CONTAINER VESSELS MAIN ENGINE TYPE BASED ON ME POWER OUTPUT....68
FIGURE 54; CONTAINER VESSELS SIZE (DWT) - AE POWER OUTPUT. BASED ON 377 VESSELS. 68
FIGURE 55; THE AGE PROFILE IN NUMBER OF VESSELS TO THE LEFT AND IN LANE METRE CAPACITY TO THE RIGHT....69
FIGURE 56; THE SPEED RANGE OF IS VAST FOR RO/RO SHIPS 69
FIGURE 57; DEVELOPMENT OF SPEED PERFORMANCE OF RO/RO SHIPS 70
FIGURE 58; THE DEVELOPMENT OF FUEL CONSUMPTION FOR RO/RO SHIPS....70
FIGURE 59; THE DEVELOPMENT OF EMISSIONS GIVES AN IMPRESSION OF A STRONG REDUCTION IN LATE AND COMING YEARS....71
FIGURE 60; RO/RO SHIPS RELATIONS SIZE (GT) – ME POWER OUTPUT BY SPEED LEVEL....71
FIGURE 61; RO/RO SHIPS RELATIONS SIZE (DWT) – ME POWER OUTPUT BY SPEED LEVEL....72
FIGURE 62; RO/RO VESSELS MAIN ENGINE TYPE BASED ON ME POWER OUTPUT....73
FIGURE 63; RO/RO VESSELS SIZE (GT) – AE POWER OUTPUT. BASED ON 137 SHIPS. 73
FIGURE 64; THE AGE PROFILE OF REEFER SHIPS BY NUMBER AND CAPACITY 74
FIGURE 65; THE SPEED PROFILE OF REEFER SHIPS 74
FIGURE 66; THE DEVELOPMENT OF THE REEFER SHIPS SHOWS A RELATIVELY STABLE SPEED LEVEL 74
FIGURE 67; THE DEVELOPMENT OF FUEL CONSUMPTION....75
FIGURE 68; REEFER VESSELS SIZE (GT) – ME POWER OUTPUT BY SPEED LEVEL....76
FIGURE 69; REEFER VESSELS SIZE (DWT) – ME POWER OUTPUT BY SPEED LEVEL 76
FIGURE 70; REEFER VESSELS MAIN ENGINE TYPE BASED ON ME POWER OUTPUT 77
FIGURE 71; REEFER VESSELS SIZE (DWT) – AE POWER OUTPUT. BASED ON 140 SHIPS. 77
FIGURE 72; THE CARGO FERRY IN AGE PER NUMBER OF SHIPS AND IN FLEET CAPACITY 78
FIGURE 73; THE SPEED PROFILE OF THE CARGO FERRIES SHOWS A WIDE SPREAD DISTRIBUTION....78
FIGURE 74; THE CARGO FERRY SPEED DEVELOPMENT....79
FIGURE 75; THE DEVELOPMENT OF FUEL CONSUMPTION FOR CARGO FERRIES 79
FIGURE 76; THE DEVELOPMENT OF NO_X EMISSIONS FOR CARGO FERRIES 80
FIGURE 77; THE RELATION BETWEEN ME POWER OUTPUT AND GT FOR CARGO FERRIES....81
FIGURE 78; THE RELATION BETWEEN ME POWER OUTPUT AND DWT FOR CARGO FERRIES....81
FIGURE 79; CARGO FERRIES MAIN ENGINE TYPE BASED ON ME OUTPUT....82
FIGURE 80; CARGO FERRIES SIZE (GT) – AE POWER OUTPUT. BASED ON 226 SHIPS (INCLUDING HIGH SPEED). 82
FIGURE 81; THE AGE PROFILE OF THE PASSENGER VESSELS 83
FIGURE 82; THE SPEED PROFILE OF THE PASSENGER SHIPS 83
FIGURE 83; THE SPEED DEVELOPMENT OF THE PASSENGER FERRIES 84
FIGURE 84; THE FUEL CONSUMPTION DEVELOPMENT OF PASSENGER FERRIES 84
FIGURE 85; THE NO_X EMISSION DEVELOPMENT FOR PASSENGER FERRIES 85
FIGURE 86; THE RELATION BETWEEN GT AND ME POWER OUTPUT FOR PASSENGER FERRIES....86
FIGURE 87; THE RELATION BETWEEN DWT AND ME POWER OUTPUT FOR PASSENGER FERRIES 86
FIGURE 88; PASSENGER FERRIES MAIN ENGINE TYPE BASED ON ME POWER OUTPUT....87
FIGURE 89 PASSENGER FERRIES SIZE (GT) – AE POWER OUTPUT. BASED ON 38 SHIPS (INCLUDING HIGH SPEED)....87
FIGURE 90; THE RELATION BETWEEN GT AND THE ME POWER OUTPUT FOR HIGH SPEED FERRIES....88
FIGURE 91; THE RELATION BETWEEN MAIN ENGINE POWER OUTPUT AND GT FOR HIGH SPEED FERRIES....89
FIGURE 92; THE RELATION BETWEEN MAIN ENGINE POWER OUTPUT AND DWT FOR HIGH SPEED FERRIES 89
FIGURE 93; HIGH SPEED FERRIES MAIN ENGINE TYPE BASED ON ME POWER OUTPUT. GAS TURBINE INCLUDES VESSELS WITH BOTH TURBINE AND DIESEL ENGINES. 90
FIGURE 94; THE AGE PROFILE OF OIL TANKERS IN NUMBER OF SHIPS TO THE LEFT AND IN RELATION TO CAPACITY TO THE RIGHT 91
FIGURE 95; THE SPEED PROFILE FOR TANKERS 91
FIGURE 96; THE SPEED DEVELOPMENT FOR OIL TANKERS 92
FIGURE 97; THE SPEED DEVELOPMENT FOR THE CHEMICAL TANKERS....92
FIGURE 98; THE DEVELOPMENT OF FUEL EFFICIENCY FOR TANKERS 93
FIGURE 99; THE DEVELOPMENT OF NO_X EMISSIONS FOR TANKERS....93
FIGURE 100; OIL AND CHEMICAL TANKERS SIZE GT – ME POWER OUTPUT RELATIONS BY SPEED. TANKERS <25,000 GT 94
FIGURE 101; OIL AND CHEMICAL TANKERS SIZE GT – ME POWER OUTPUT RELATIONS BY SPEED. TANKERS >25,000 GT 94
FIGURE 102; OIL AND CHEMICAL TANKERS SIZE DWT – ME POWER OUTPUT RELATIONS BY SPEED. SMALL TANKERS <10,000 DWT 95
FIGURE 103; OIL AND CHEMICAL TANKERS, DWT – ME POWER OUTPUT RELATIONS BY SPEED. HANDYSIZE TANKERS 10 – 60,000 DWT 95

FIGURE 104; OIL AND CHEMICAL TANKERS SIZE (DWT) – ME POWER OUTPUT RELATIONS BY SPEED. LARGE TANKERS >60,000 DWT 96
FIGURE 105; OIL AND CHEMICAL TANKERS MAIN ENGINE TYPE BASED ON ASSUMED ME POWER OUTPUT....96
FIGURE 106; THE RELATIONS BETWEEN SHIPS CARRYING CAPACITY IN DWT AND INSTALLED AUXILIARY ENGINE POWER FOR 729 OIL TANKERS AND 278 CHEMICAL TANKERS. 97
FIGURE 107; THE AGE PROFILE OF GAS TANKERS IN NUMBER OF SHIPS TO THE LEFT AND IN CAPACITY TO THE RIGHT....97
FIGURE 108; THE PROFILE OF SPEED FOR GAS TANKERS....98
FIGURE 109; THE DEVELOPMENT OF SPEED FOR THE GAS TANKERS 98
FIGURE 110; GAS TANKER, FUEL CONSUMPTION DEVELOPMENT....99
FIGURE 111; LPG TANKERS SIZE GT – ME POWER OUTPUT RELATIONS BY SPEED LEVEL....100
FIGURE 112; LPG TANKERS SIZE DWT – ME POWER OUTPUT RELATIONS BY SPEED LEVEL 100
FIGURE 113; LNG TANKERS SIZE GT – ME POWER OUTPUT RELATIONS BY SPEED LEVEL 101
FIGURE 114; LNG TANKERS SIZE IN DWT – ME POWER OUTPUT RELATIONS BY SPEED LEVEL 101
FIGURE 115; GAS TANKERS MAIN ENGINE TYPE BASED ON ME POWER OUTPUT....102
FIGURE 116 LNG TANKERS SIZE (DWT) – AE POWER OUTPUT. 57 VESSELS. 102
FIGURE 117 LPG TANKERS SIZE (DWT) – AE POWER OUTPUT. 60 VESSELS. 103
FIGURE 118; CRUISE VESSELS SIZE IN GT – ME POWER OUTPUT RELATIONS BY SPEED LEVELS....104
FIGURE 119; CRUISE VESSELS SIZE IN DWT – ME POWER OUTPUT RELATIONS BY SPEED GROUPINGS....104
FIGURE 120; CRUISE VESSELS MAIN ENGINE TYPE BASED ON ME OUTPUT. GAS TURBINE INCLUDES SHIPS WITH A COMBINATION OF DIESEL AND GAS ENGINES. TWO AND FOUR STROKE INCLUDES VESSELS WITH SAIL AND DIESEL ENGINES AS AUXILIARY. 105
FIGURE 121; CRUISE SHIPS SIZE (GT) – AE POWER OUTPUT. 87 SHIPS. 105
FIGURE 122; DISTRIBUTION OF SPEED FOR VEHICLE CARRIERS 106
FIGURE 123; ME POWER OUTPUT BASED ON VESSEL SIZE IN GT FOR VEHICLE CARRIERS 106
FIGURE 124; VEHICLE CARRIERS SIZE IN GT – ME POWER OUTPUT RELATIONS AT SPEED LEVELS....107
FIGURE 125 VEHICLE CARRIERS SIZE IN DWT – ME POWER OUTPUT RELATIONS BY SPEED LEVELS....108
FIGURE 126 VEHICLE CARRIERS MAIN ENGINE TYPE BASED ON ME OUTPUT. 108
FIGURE 127; VEHICLE CARRIERS SIZE (GT) – AE POWER OUTPUT FOR 70 SHIPS. 109

Tables

TABLE 1: SHARE OF SHIP TYPES IN PORT CALLS [8] 22
TABLE 2: DESCRIPTION OF SHIP TYPES 23
TABLE 3: COMPARABLE TYPE OF SHIPS SORTED TO FIT THE PURPOSE OF THE REPORT....25
TABLE 4; THE FUEL CONSUMPTION FOR DIFFERENT TYPES OF SHIPS 26
TABLE 5; EXHAUST CLEANING EQUIPMENT INSTALLED IN SHIPS....28
TABLE 6; THE TEMPERATURE LEVEL FOR SAFE WORK USING DIFFERENT FUELS, MUNTERS 29
TABLE 7; THE PERFORMANCE OF AN SCR SYSTEM ACCORDING TO MANUFACTURER, MUNTERS 29
TABLE 8; EXAMPLES OF COST AND PERFORMANCE FOR DIFFERENT APPLICATIONS, MUNTERS 30
TABLE 9; REDUCTION FACTORS FOR EMISSION CLEANING EQUIPMENT 32
TABLE 10; THE IMO ANNEX VI RESOLUTION 2, NO_x TECHNICAL CODE 32
TABLE 11; THE PERFORMANCE OF THE DME SCRUBBER ACCORDING TO MANUFACTURER DME 35
TABLE 12; AVERAGE POWER OUTPUT FIGURES FOR AUXILIARY ENGINES* 42
TABLE 13; THE AVERAGE SPEED PER SHIP TYPE AND DWT GROUP 43
TABLE 14; THE AVERAGE SPEED PER SHIP TYPE AND GT GROUP....44
TABLE 15;THE AVERAGE EMISSION FACTORS PER SHIP'S TYPE, SIZE AND DAY....46
TABLE 16; STATISTICS OF USED FUEL FOR DIFFERENT TYPE OF SHIPS....48
TABLE 17; THE AVERAGE FUEL CONSUMPTION AND THE RELATION OF CONSUMPTION BETWEEN THE SHIP TYPES 48
TABLE 18; AE POWER BASED ON VESSEL SIZE 49
TABLE 19; MAIN ENGINE SPECIFIC FUEL CONSUMPTION AND EMISSIONS, G/KWH FOR DIESEL ENGINES, BASED ON ME TYPE AND SIZE 50
TABLE 20; BULKERS ME FUNCTIONS....111
TABLE 21; GENERAL CARGO ME FUNCTIONS 111
TABLE 22; CONTAINER VESSEL ME FUNCTIONS....112
TABLE 23; RO/RO ME FUNCTIONS....112
TABLE 24; REEFER ME FUNCTIONS 113
TABLE 25; CARGO FERRIES ME FUNCTIONS 113
TABLE 26; PASSENGER FERRIES ME FUNCTIONS 113
TABLE 27; HIGH SPEED FERRIES ME FUNCTIONS 114
TABLE 28, TANKERS ME FUNCTIONS DWT 114

TABLE 29; TANKERS ME FUNCTIONS GT....114
TABLE 30; LNG TANKERS ME FUNCTIONS....115
TABLE 31; LPG TANKERS ME FUNCTIONS....115
TABLE 32; CRUISE VESSELS ME FUNCTIONS....115
TABLE 33; VEHICLE CARRIERS ME FUNCTIONS....115
TABLE 34; VALIDATION OF USED SPEED CURVES FOR THE RELATIONS BETWEEN SIZE OF SHIP AND MAIN ENGINE....116
TABLE 35; STATISTICS OF TYPE OF ENGINE IN BULK SHIPS....117
TABLE 36; STATISTICS OF TYPE OF ENGINE IN GENERAL CARGO SHIPS....117
TABLE 37; STATISTICS OF TYPE OF ENGINE IN CONTAINER SHIPS....117
TABLE 38; STATISTICS OF TYPE OF ENGINE IN RO/RO SHIPS....118
TABLE 39; STATISTICS OF TYPE OF ENGINE IN REEFER SHIPS....118
TABLE 40; STATISTICS OF TYPE OF ENGINE IN CARGO FERRIES....118
TABLE 41; STATISTICS OF TYPE OF ENGINE IN PASSENGER FERRIES....119
TABLE 42; STATISTICS OF TYPE OF ENGINE IN HIGH SPEED FERRIES....119
TABLE 43; STATISTICS OF TYPE OF ENGINE IN TANKERS....119
TABLE 44; STATISTICS OF TYPE OF ENGINE IN GAS TANKERS....120
TABLE 45; STATISTICS OF TYPE OF ENGINE IN CRUISE VESSELS....120
TABLE 46; STATISTICS OF TYPE OF ENGINE IN VEHICLE CARRIERS....120
TABLE 47; SULPHUR CONTENT IN FUEL....121
TABLE 48; REDUCTION FACTORS FOR EXHAUST CLEANING EQUIPMENT....121

Introduction

In the environmental assessment and performance of transports the focus has slowly turned to the sea transport sector and the emissions from ships. Very small funds (approx 2 % of the EU funds for environmental research) are given to the sea transport researchers to assess the emissions and give prognosis of the development.

On the heavy road vehicle side, that gets about 80 % of all the research funds, the manufacturing industry gives all data and information of the vehicles that is used for the assessment of the emissions and the performance of the vehicles. The emission modelling is mainly to describe the local conditions in every country and at all kind of traffic situations.

Lloyds' Register – Fairplay has decided to include the ships' environmental performance starting with the manufacturers' emission factors in the register of ships. This will be listed in the part that concerns the ship engines in the register. The information is undisputable as this is the figures of ships emissions measured at the bench in the same way as it is recorded for the road vehicles. The emission factors could be given both as energy optimised factors and emission optimised factors. It should be noted that the shipping world today have a very limited concern of emissions. In some areas where the demand for reduction of emissions is of interest (the Baltic Sea, parts of the North Sea) the subject is more topical. However, as the subject of emissions and use of energy have come to focus especially in the US and Canada as well as in EU and Japan the attention to the problem has increased. One reason for this could be the latent potential for the industry to use sea transports as a trading partner in the potential emission trading scheme. Today the heavy competing shipping services are more concerned of keeping down the operational costs to keep the market share.

The petroleum industry is concerned of the development. They use the shipping industry to consume the residues from the crackers and is providing it at a low cost. To the petroleum industry the demand for low sulphur fuel will only give increased costs, which also results in increased fuel costs for the shipping industry. No industry is taking such steps voluntarily. It demands an even play field in the game of competition to introduce costs increase of this range. Only the industry that charters their ships on long term contracts invests in an environmental friendly operation. But as it seems today also this has an upper limit if they cannot prove credits of the investment.

This part of ARTEMIS has further developed the information built up by the COST 319 and the MEET projects to a better standard that comes closer to the real operation of ships. The information built up by ARTEMIS will not give out the information of individual ships or ship engines but present algorithms that enables emission assessment from sea transports based on statistics. To use the ARTEMIS method the input data should be type of ship (Bulker, Tanker, Ferry, etc), size (DWT, GT) or similar available information and speed.

This report is outlining the state of the art in emissions from ships as they are registered and in operation in 2004. The information is based on Lloyds Register – Fairplay's information of ships' type, GT, DWT, installed power, speed and engine specifications.

A Guide for the reader

The report recapitulates and evaluates different types of emission assessment methods, and comments on the potential of future methods as well as on the information collection process by the ports within the EU community.

Information regarding the data used and the work behind the achieved result is presented.

A section regarding existing exhaust gas cleaning and regulations regarding the matter are also presented. Here some information from the experience of environmental dues and its progress are presented as this is the major launched test of implentation that exists.

Information needed to perform a qualified exhaust emission assessment is presented. The figures and functions is based on statistics from the world largest database of ships.

How to use the report for and emissions evaluation are presented and exemplified in Chapter 7

The calculations can be based on the following parameters;

- Vessel type
- Vessel size
- Vessel speed
- Vessel engine power

Speed: The speed is used together with the type of ship to determine the power of the ship and the type of engine. If the vessels service speed is not known, it can be estimated based on the vessel's type and size in GT or DWT. Tables for typical speed for each vessel type per size are presented in Chapter 6.2.

With information on a vessel's type, size and speed an estimation of its likely main engine size, in kW, can be made. These algorithms are based on data on engine power on a large amount of existing ships.

Knowing the necessary main engine power output the most likely engine type can be established based on tables for each ship type.

The final emissions depend on the fuel consumption and fuel type. Average specific fuel consumption (SFC) and emission factors are stated for eight different diesel engine sizes, for both two stroke and four stroke engines. These values are presented in preformed work, g/kWh.

Sulphur Oxides (SO_x) depend solely on the sulphur content of the used fuel, if the fuel grade is not known it can be estimated from the area of operation, as certain trading areas have tougher restrictions on sulphur content than others.

The emissions of Carbon Dioxide (CO_2) relate directly to the fuel consumption, roughly 3.2 times the amount of fuel in tons.

An overview of the usage of different fuel types is presented, more specific information regarding the fuel quality and usage can be found in Ref. [10].

1 Different types of emission assessments

The first emission assessments from sea transports were made in the beginning of 1990:ties. At this time the sea transports were recognised to be a potential emission hazard for the future as:

- Measures were put on the road transports to lower the emission
- The quality of fuel in sea transports were studied and especially the high level of sulphur in the fuel
- The strong focus on the acidification problem in Scandinavia
- Focus was also put on the emissions from the coal fired power stations in the UK and Germany

The emission modelling for the road traffic had been the target for some years and starting up the 4:th FP the Commission allocated funds for a more thorough analysis of the total scope of an SEA, short for Strategic Environmental Assessment. A program was presented as illustrated in Figure 1:

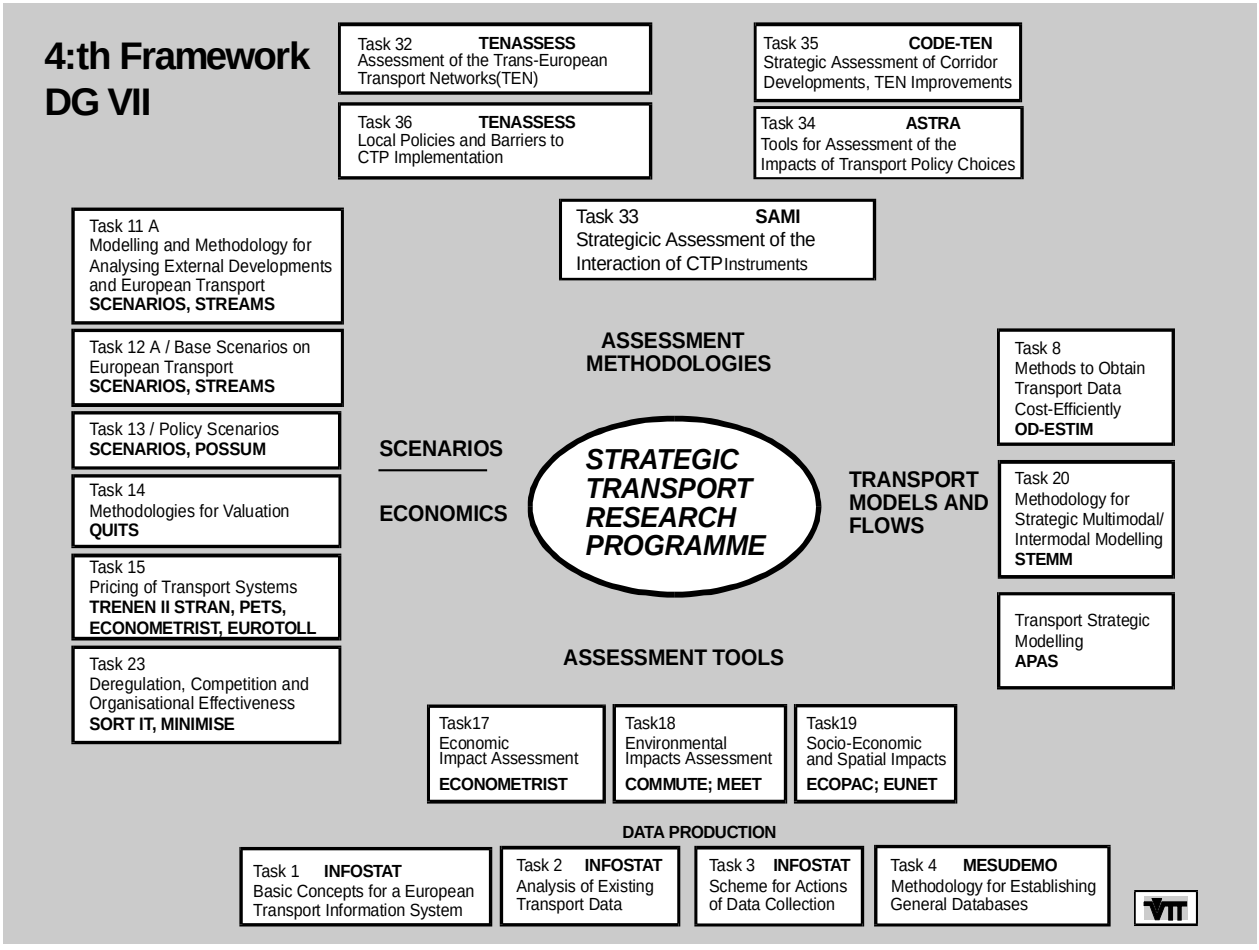

Figure 1; The Strategic Transport Research Programme FP 4, DG VII

The program tried to cover all aspects of the assessment. However, some problems lurked around the corner as the models were plentiful but the proper information to feed the models with was not available.

In Task 18, see Figure 1, the MEET and COMMUTE projects were to build up the assessments, where MEET would provide with the basic algorithms and COMMUTE would create the model and the assessment tool.

MEET was sprung from the COST 319 project where the assessment models had been initiated. The budget was roughly 80 % to the road, 16 % to the air and the rest 4 % were equally shared between sea transports and rail transports. The same split of the cost applied in FP 5.

The major work in COST and MEET was to identify the emission factors of ships. The base of this was some measurements made by Lloyds Register.

A study was produced in Sweden 1990-91 by MariTerm AB on commission of the Swedish maritime environment headed by the Swedish Maritime Administration and the Swedish Ship Owners Association. The study was later translated to English, edited and published in 1993 [5].

The report covered in principal three parts; The state of the art as regards ships engines, fuels and emissions; An assessment of the emissions in the Baltic Sea Area based on port information collected from the Administrations; An outline of the technical possibilities to take measures to reduce the emissions including some estimates of costs.

In the assessment, models were created to identify the ships' use of fuels as a function of their size and type. The same applied for the "normal" type of engine installed in the ships as a function of the same factors.

The outcome of the study applies still to some degree and can be summarised as:

- The ships' movements are poorly registered and there is no reliable database that covers the ships movements. Ferries and trading ships are only partly covered in the same database
- There is no register of the ships' use of fuels by type and amount
- Emission factors for ships engines are not measured and the manufacturer keeps no record on emission factors for each engine
- Most of the ships have energy optimised engines giving a high NO_x level, but measurements on engines gives a high spread of emission levels not only between engines but also between cylinders in the engine
- Ships were used as a resource to dump oil residues from the refineries
- There was no concern about the sulphur content in the ships' fuel. Sulphur was regarded as a necessity for the engine.

1.1 The purpose of assessment

The user of an assessment system normally has a purpose to summarise the ships' emissions for a port or a region of any size. The assessment is often preferred to give an answer in a total sum of:

- Consumed energy
- CO_2 emissions
- CO emissions
- NO_x emissions
- HC emissions
- SO_2 emissions
- Particulates

If the emission assessment is done as a part of an area the emission is preferred to be presented in linear loads from the fairway/routes or as point loads from positions in ports where also the height of the funnel becomes an important factor. The latter type of assessments is growing as the cities are assessing the emissions from traffic and likes to include the port activities. The information will be used in a diffusion model to determine the range of pollution in the area.

1.2 The methods of assessment

The Swedish 1990 model

The method of assessment used in is described at large as follows:

The ships travelling distance is summarised as the distance from the ports to open waters and then the closest route to the North Sea alternatively, if the port of destination is within the BSA half the distance to the next port. See Figure 2.

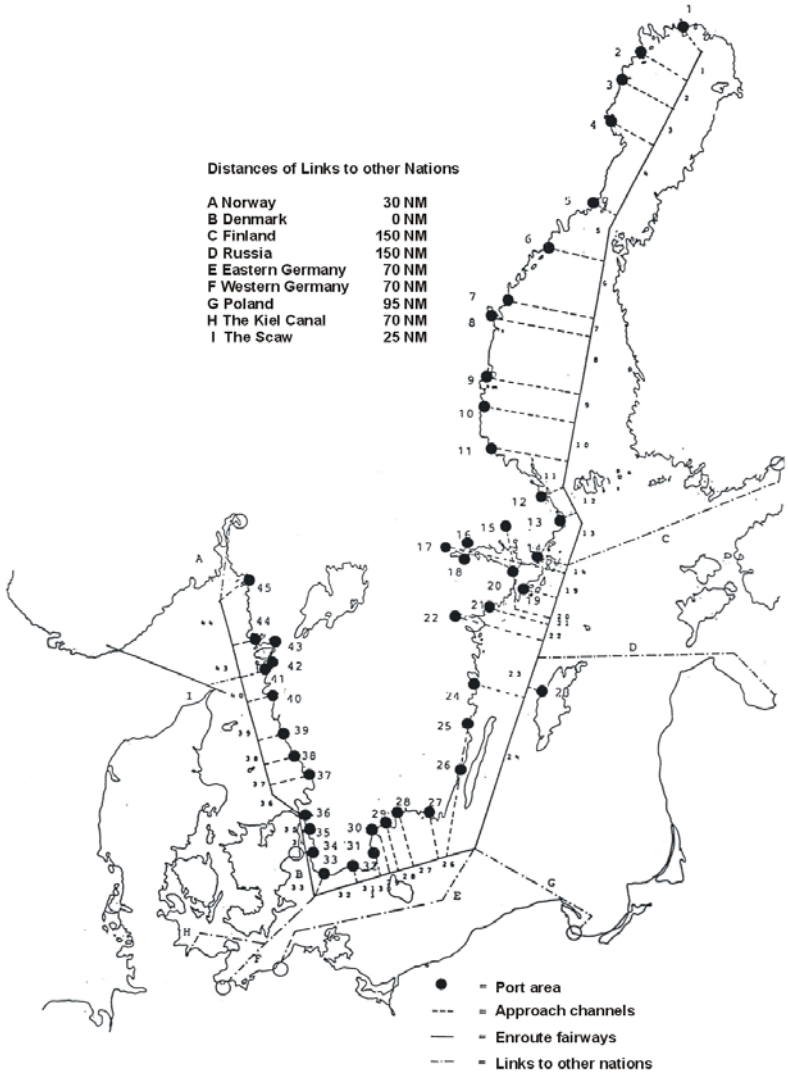

Figure 2; A description of the method to assess transport routes for ships

The identification of ships movements is always a total coverage of all ships movements. In the Baltic Sea Area the number o ship activities can be seen in Figure 3.



Figure 3; Shipping activity in the Nordic and Baltic Sea Region NBSR presented by SAI

The input to the model was port call information directly from the ports. As there is no standard yet for registering the ships in the European ports as it was not in the port of concern at the time.

Each ship's size was identified. As most of the ports used GRT[1] for port dues the size of the ships were assigned in groups in accordance to their GRT.

The emission factor were designed as a function of the size, see Figure 4.

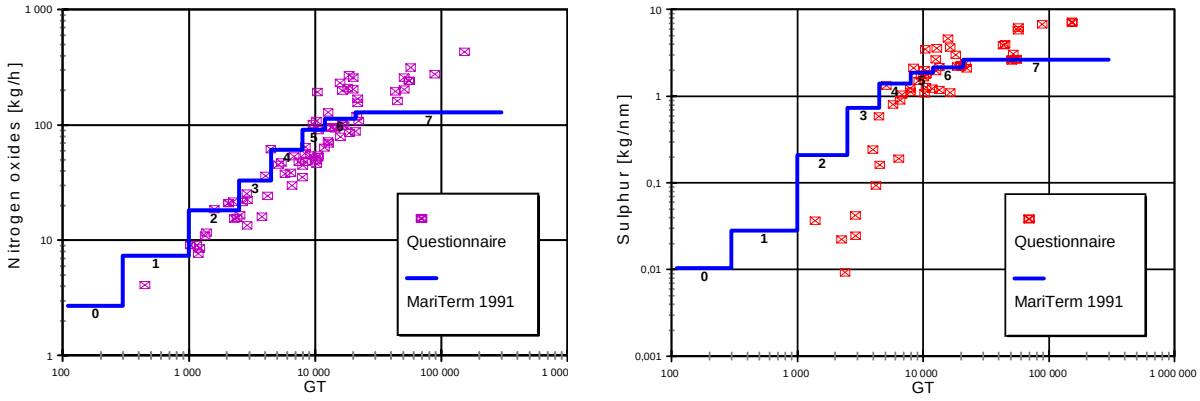

Figure 4; Emission factor levels as a function of ships' size

Each ship's GT class was also assigned; an average installed power for propulsion, power of the auxiliary engines and a speed in knots at 80 % MCR.

The assessment is made by compiling all the information and summarise the emissions of a chosen port(s) or area. The method is very simple and as can be seen in Figure 4. From a validation point of view it was quite reliable for the NO_x but a bit too high for sulphur and smaller ships.

It should be noted that the major problem over the last decade has not been to achieve proper figures that gives a decent level of the emissions produced. The major problem has been to get a quality of the traffic data that allows a follow up of such quality that the general trend can be

[1] GRT Gross Tonnage according to the Oslo Convention which was the relevant at the time

presented between the years. No method has presented this so far. It is possible to do this for port statistics collected in countries where this is obtainable. It gives the limitation of only assessing the emissions in the national waters as the previous port and next port information is not commonly available as the ports protects the integrity of the port's clients is held high. However, by having the ships identification at all ports calls and the time of the port call the intra European ship traffic is potentially possible to be recorded by a central European function, Eurostat for example. The question is if all ports can deliver a record of ship information calling the ports that can be used to process in a data format.

One of the major results of the analysis was that the ferry traffic in the Baltic Sea Area represented more than 60 % of all emissions. This traffic is easy to identify. In the assessment model the ferry service was modelled based on information from the operators regarding the ships' timetable. The speed of the passage was modelled in 5 steps; starting up and departure, depart from port, speed on route, approach and berthing.

The assessment methods used by MariTerm for the Swedish Maritime Administration from year 2000 are based on traffic information recorded by the LMIS (Lloyds Maritime Information Services Ltd) information of ship movements, the energy consumption from ships' operation as a function of the GT^2 of the ship and the ship's speed which was put in relation to the GT using MEET[6] Algorithms.

In the system all ferry services are added from the Shippax traffic database. As there is some information that coincides between the two sources there is a special application that identifies these and let the operator chose which one to be used.

A computer application runs all movements and allocate the emissions to pre defined areas using the Veson port distance database, the North Sea, the Baltic Sea and ship movements on Sweden.

The MEET model

In the 4:th frame work program the SEA modelling was carried out as shown in Figure 1. The emission assessments for sea transports were made by COMMUTE[7] and MEET where MEET set up the emission factors and consumption models for ship types. COMMUTE did the methodology for the assessment that was built up in a computer application.

MEET based the models on information from Lloyds Maritime Information Services Ltd that covered about 15,000 vessels where of 11,000 had an assigned GT. The modelling was based on a statistical average of the population and consumption at full power in tons/day as a function of the GT.

MEET also presents an option to calculate the emissions/fuel consumption in more detail giving a fraction of the fuel consumption for different states of operation, cruising, manoeuvring and hotelling.

The pollutant emissions are presented from a scanning of the literature.

Emission factors are also given for Auxiliary engines for the supply of electricity. The emissions given are a function of the rated output of the engine and a load factor in per cent.

The TRENDS model

TRENDS (Transport and Environment Database System) produced a report "Development of a Database System for the Calculation of Indicators of Environmental Pressure Caused by Maritime

[2] GT, Gross Tonnage according to the London Convention 1969

and Inland Shipping Transport" DTU July 2002. The type of ships are to a large extent based on Lloyds Register of shipping and the discussed relations between the fuel consumption and the size of ships are related to GT (This is somewhat uncertain as it is merely described as GRT) and the deadweight (DWT) of the ships.

Ships data used are from Eurostat 1970 – 2002 both as regards maritime freight transport as well as maritime passenger transports. Some gaps in the statistics are covered by national sources. The distance between ports is built on port pairs to which the distance between the ports is added from distance tables.

The project shows an ambition to include the type of cargo shipped as a part of the assessment method. The demand for aggregated cargo and commodity flows comes from similar assessment for road transports. In road operation this can be handled by statistics as the vehicles are standardised and have a statistical distribution as regards emissions etc.

In a sea transport where one ship represents maybe 300 trailers each carrying one or several types of commodities it can either be a projection of the road operation on the ferry lines that links road ends or as individual ships and the type of products they carry.

TRENDS tries to allocate the ships characteristics to countries and ports, which will give a poor result as the use of the ships vary with the market. The project shall be regarded as a test case to use Eurostat information as a base for the emission assessment. However it demands more information to enable an allocation of the emissions to commodities. The ports have the information but are prevented from using it for several reasons.

The Entec model

The assessment Entec performed and published 2002 on commission from DG Envir was entirely based on the LMIU (Lloyds Maritime Intelligence Unit, former LMIS) information. The information is based on observed movements of ships of 500 GT an above by the LMIU observers. The study covers the freight ships' movements during four months in the year 2000. The study features a distribution of the emissions in a GIS grid where the distribution comes from the shortest distance between the ports.

The study gives a market survey of the availability of low sulphur fuel oils in Europe and in broad lines world wide. The study is very thorough and results in a statement saying that the availability of low sulphur fuel oil is high in Europe as well as in North America. Bunker companies in the Far East do not easily supply low sulphur fuels which is a problem as they are one of the major suppliers of marine fuels.

In a mix of manufacturers' specification and measurements from different sources the study arrives at three tables; at sea, in port and manoeuvring, stating the used emission factors for the different ship types.

The assessment is understood as; assigning time to the stay in port and to the manoeuvring, the cruising in open sea is assigned as a linear load on the shortest route between the ports. The emissions are recorded and assigned to the grid areas the line is passing.

The ARTEMIS model

The ARTEMIS model described in the same simplified way does not concern the traffic information as such but focus on the emission factors and how information can be used to do a high quality assessment.

The ships' characteristics have been produced by running Lloyd's Register – Fairplay's ship database covering some 95,000 vessels whereof the 66,000 built after 1980 have been selected to be processed.

The selection is limited due lack of coverage in the database. Thus the analysis of ships' use of fuel will only cover some 28,000 ships. In the speed/power analyses a fleet of more than 50,000 ships are processed.

The method is to determine the speed/power relation for each type of ships and present this as algorithms. In order not to confuse the results qualitative evaluations are made by sorting out ships having extreme values and relate the used curves to a theoretical distribution between the speeds.

The emission factors have been collected from the ship engine manufacturers and the information has been added to the database.

The user of the information should be able to get proper energy consumption and emission factors if he knows; the type of ship, the speed of the ship and the size of the ship in GT or DWT

Future models

In the traffic information area useful, stable and reliable information has to be developed. The standard today is not acceptable if the SEA should be possible to be used for follow up of trends and development in the performance of ship emissions. As Eurostat is bound to the policy taken by the Decision (2001/423/EC) that lays down that "the highest level of detail in which data may be published or disseminated is the level of port to and from maritime coastal area", there is no possible way that the information can be the source for the assessment demanded by the Commission. By this the Commission has to use external sources. This has been the case in projects that have been produced on the account of DG Envir.

The most technically sophisticated, inclusive and reliable source today is the AIS (Automatic Information System) that is compulsory from 1 July, 2004 for all ships of 500 GT or larger. The system aims at relaying as much information as possible regarding the ships and gives a continuous update of each individual ship's speed etc. The ship's identity is disclosed as well as the previous and next port of destination.

An important feature of the AIS-system is however the possibility of getting a detailed assessment of the ships fuel consumption and performance using the continuously reported information. Examples are the ship's speed, position and heading, which together with weather information will make it possible to estimate the power used and the ships fuel consumption. The exact route of the ships will also allow assessing emissions in specific sensitive areas.

However, the main increase in quality will come from the reliability of ships' movements and ships identity. The emission factors are still to be added in as external information unless it cannot be produced directly from algorithms using a ships database.

When restrictions are introduced on emissions the accuracy in the emissions will become higher as control systems will give emissions limits. These limits have to be monitored in some way. Having such monitoring system will assist the engineers of the vessels to tune in the engines. It will thus not be a function of the condition of the engine or how the chief engineer of the ship tunes "his" engine that guides the emissions. The situation will become more like the situation on road traffic. The same applies to diesel locomotives on the rail road service.

In short the situation for SEA and the follow up of the international emissions is very positive and systems will soon be available that can assess the emissions automatically without violating the integrity of the ship owners or the shipping operation.

1.3 Port information

The port information related to sea transports includes information that is of interest for the port to know when planning for the ship's handling in the port, where to berth and which equipment to use etc. Normally the basic ship information concerns main dimensions and the gross tonnage that is used as a basis for charging the fairway and port dues.

The ports are normally reluctant to give away the information of the ships. However, the ship's identity when calling a port is often spread on the Internet[3].

To prouce a more thorough assessment, more specific information than just the dimensions and size in GT of the ship is called for. It is generally better to collect the ships identity and then get the other specifications from a trusted register than to collect all information each time and in each port. Decision 2001/423/EC becomes by this quite pointless. The fact that most of the information is commercially available from different sources points in the same direction.

The ports can use their resources better and more efficient than filling in forms and reports but that is another matter that can be solved by better and simpler reporting systems.

Prior to the open internal EU market, all commodities were registered at the countries' borders. This gave quite good information of how the commodities were moving in a detailed level. The same applies to local national follow up of how goods and commodities are transported between regions. The difference is that after the Schengen agreement came into force this kind of collection of statistics of intra EU trade is not allowed.

For the future it should be evaluated if the knowledge of how the products are transported in the intra EU relations is more important to know than it is to safeguard the complete integrity of the shippers. In the perspective of the consequences it may have on the shippers if the politicians in the name of creating the future sustainable transport system, introduce measures that increase costs for the shippers, it would be a small sacrifice to let the same administrations have better knowledge of the actual transport flows to enable them making better decisions.

[3] Some examples: http://www.portofkotka.fi ; http://www.portofrauma.fi/english.htm; http://www.terminalwest.se;

2 The methodology of this work

The ambition of this work is to present figures that are highly relevant and practical to use together with actual statistics from the market and port/national ship statistics.

Figures presented in this report are based on Lloyds-Register Fairplay's Register of Ships that lists some 90,000 ships. From this statistics information is drawn showing the "typical" ship of its type, size and speed. The output is presented as the energy consumption and the emissions as a function of size and speed.

The focus is entirely on commercial ships that transport commodities in the world. The European market is the prime target but information of all ships in the world is used as a base for the calculation. The information is international as the world fleet call on all countries and the ships are being built everywhere in the world.

The information is presented as functions. For each ship type a regression is made giving the function between ship's type and size and its energy consumption and emissions. In this way it should be possible to do assessment of ships emissions on the base of ship type and size given in either GT[4] or DWT[5].

In order to harmonise between transport modes a survey of emission factors for each type of engines used and identified in the ships has been done. The emission factors are those reported by the manufacturer from tests and trials. In case no emission factors are measured the typical emission factors for that type of engine have been used.

Sulphur emission factors are presented as a function of the sulphur content in the fuel oil. The sulphur emissions are given as SO_x.

The emission reduction from emission cleaning equipment is presented according to manufacturers' specification of the cleaning equipment. If there is an additive in consumption related to the function this is specified.

The approach of this study is to mirror the emission factors from known machines on similar types, same type of process and same rotation speed and size. The results are the presented for each type of ship as a function of size making it possible to produce adequate emission information from all types of ships listed in a statistical way using a minimum of information. The required information is type of ship, size (in DWT or GT) and preferably also speed.

Regional data

For sea going ships there is no point of assessing the activities by country or domicile as the sea transport activity is world wide. Ships from a country may never call the domicile at all and some ship owners have the main trading area between other countries or continents.

The assessment of shipping activity has to be built on reliable and simple information. The problem of records, classes and relation to the cargo statistics are discussed in the final report of TRENDS [1].

There is still a lack of system in the general statistics of sea transports. The reason for this is believed to be lack of records. Freight statistics and the commodity statistics have never been

[4] GT; Gross Tonnage according to IMO Convention London 1969, figure used so assign a size of a ship. The GT is related to the enclosed volume of the ship but is a constructed figure.

[5] DWT; Deadweight tons, a figure that includes the ships carrying capacity in metric tons including cargo, bunker and stores.

harmonised for sea transports. In comparison to the statistical distribution of cargo on different land transport modes, which gives a profile of the split between the transport modes, the sea transport has a difficulty to build up such information. This problem will probably increase as the refinement of the sea transport systems allows a variety of products to be shipped in cargo units that are transported on all different types of ships.

The extended use of different types of load carriers results also in statistics that concerns the cargo carrier rather than the content in the unit. This will not assist in the building up of statistics in a rational way that connects commodity flow statistics to sea transports. It would require a much more detailed freight statistic. A few examples can illustrate the complexity.

Example 1) Paper manufactured in mid of Sweden for export to South America is by one company transported from the mill in specialised large containers in a combined rail – sea service that brings the products to the sea port by rail. The units are transhipped to the Continent and the cargo is stripped and reloaded into containers that are shipped to the port of destination.

Example 2) A paper mill in north Sweden load a transocean going ship directly at the side of the mill for direct sea transport to the port of destination.

Example 3) A paper mill in mid of Sweden sends paper by road to a port on the Swedish west coast where it is stuffed in a container to be loaded on to a feeder ship that takes it down to a container hub on the continent to be reloaded on to a container ship that calls on South America.

As the examples show the variety of options of transport routes would require a huge database in order to keep a track on by what type of ship and by what transport means the commodity was moved. Probably it will not be practical and realistic to keep a track on the ways the cargo is moved in detail. It could possibly be handled statistically but also this demands information to base statistics on and to keep track of changes.

Another example can be a container moved from an industry in mid England to Rotterdam. The container can:

- Be transported to the closest port and transferred by a container feeder ship to Rotterdam
- Be transported by rail to Rotterdam via the Euro tunnel
- Be trucked to a port in the English Channel to be ferried across the channel and delivered by truck
- Be shipped in a regular general cargo service through a nearby port to Rotterdam
- For that matter the products in the container can be containerised in Rotterdam

On the road where the trailer is carrying 20 tons[6] of cargo you can have a fair idea of the type of commodity that is transported and use this as statistics. On the sea, however, when load carriers like containers are carried, these may contain anything from cars to software or bulk.

The only way of getting a simple and fair picture of how the commodities are moved by sea is to study the type of ships that moves between the ports and link them to the commodity flows that are known to be shipped in the same relations.

So is:

- Fluids in bulk shipped in Chemical or Product Tankers
- Oil and petroleum shipped in Tankers or Product Tankers
- Crude oil shipped in Crude oil tankers

[6] ton is in this report equal to metric ton if nothing else is stated.

- Road vehicles shipped on ferries or on Ro/Ro-ships in ferry services. (The relations are in this respect not more than it is simple and possible to keep a track on them and follow the records of number of trailers carried per year etc.) The commodities on the road vehicle are assumed to be the same as the commodity on the same vehicle on the road.
- Containers carried on Container Ships or Feeder Ships. Some containers are carried on Ferries in ordinary services (virtual bridges).
- Trains shipped on Railway Ferries, the cargo is the same that is transported on the railway
- Dry free flowing bulk commodities shipped in Bulkers or General Cargo Vessels

The vast majority of all commodities shipped by sea are wet and dry bulk. In a study from the Baltic Sea [2] the split of the commodity had the proportion as shown in :

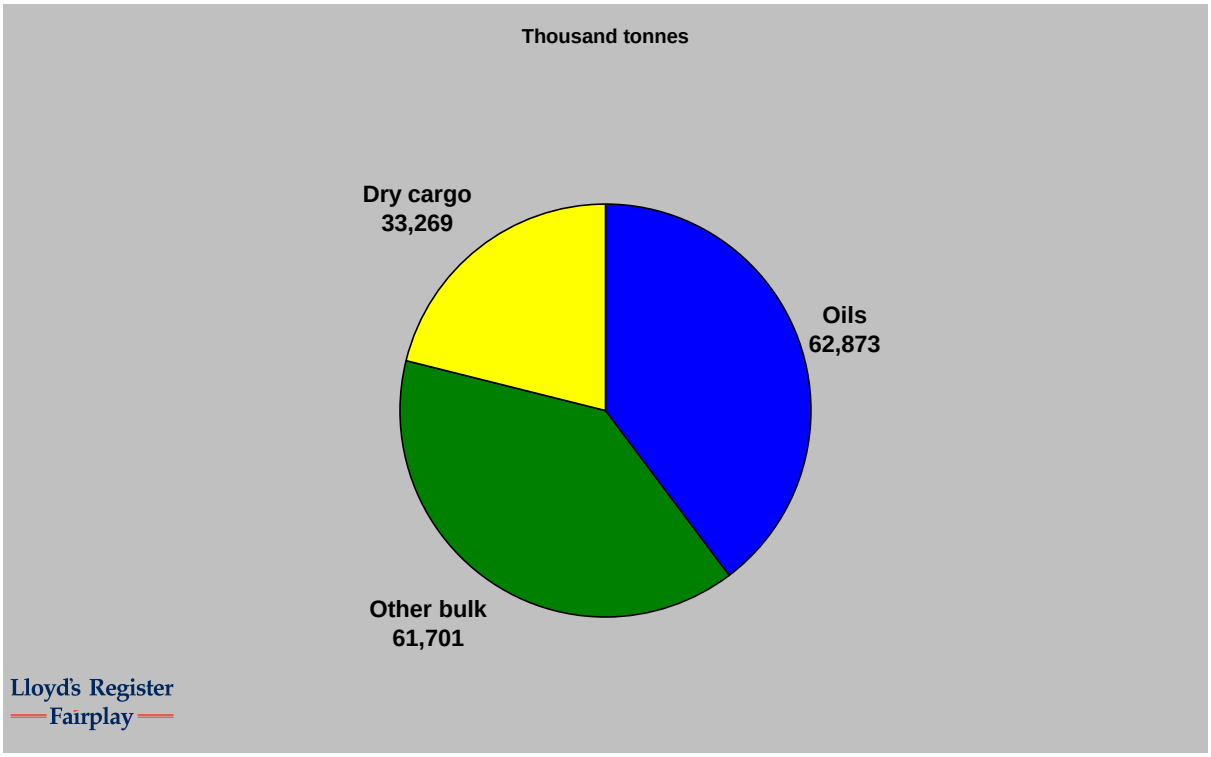

Figure 5; The split of main type of commodities in the South Baltic Sea

In the General cargo part all ferry services, container and other general cargo transports of high to medium value cargo are included.

The figure gives a picture of the relevance as concerns what type of sea transport activities that are of importance when assessing the sea transport environmental figures. In addition to this another sea transport operation is of importance, the sea transports that calls the urban areas. These services are normally the Product Tankers, the Ferries and the container services.

Statistics from the ferry operation is simple and better recorded. The total activity is made by a controllable number of ships and the frequency of port calls is high. The vast majority of services are pendulum service between two ports.

3 Ship types and used categorisation

The intention of this work is to produce a useful tool for the assessment of emissions and other environmental issues from ships that are related to the ship's fuel consumption under service. The ships concerned in the work are limited to commercial ships of 100 GT and above.

The character of a ship is the type to which it belongs. The ship's type is normally determined when building the ship and is a part of the ship's classification. The character is related to the typical speed, size and volume of the ship. Ships of different types can have the same character from energy use point of view. If ships of a certain size and DWT run at the same speed it is very likely that the ship will roughly consume the same amount of fuel. At the same time different ship types of same DWT may differ extensively if the speed differs. A ship designed for high speed will normally consume less energy at low speed than a ship that is designed to run at low speed.

The ship's character is recorded in the Register of Ships that is set up by the classification society. Today the largest Ships' Register is produced by Lloyds Register – Fairplay and it comprises some 90,000 ships.

The class determines the technical standard of the ship and consequently the ship's capacity and operational safety performance. The ship is built to meet a class assignment that is presented by the Classification society. This will normally set the type of ship.

In best of cases the ship's type can directly relate to the type of commodity she normally carries. In some cases the actual type tells what type of cargo that is carried. A container ship will almost only carry containers and a crude oil tanker will only carry crude oil, etc.

To get a fair idea of the different ship type's representation in European ports a summary of the ships' call at the ports is presented for the year 2001. The basic statistic comes from ports in North Europe, which represents a fair picture of the total shipping activities.

Table 1: Share of ship types in port calls [8]

Bulker	Combination	Dry Cargo	Container	Ro/Ro	Reefer	Passenger Ferry
53 363	710	102 508	35 712	57 175	6 445	4 940
16%	0%	30%	10%	17%	2%	1%

Crude Oil Tanker	Product Tanker	Chemical Tanker	Gas Tanker	Misc. Tankers	Offshore	Others
6 122	32 229	26 352	8 450	139	280	6 847
2%	9%	8%	2%	0%	0%	2%

Total
341 272
3 541 272*

* incl. regular ferry service abt 3 200 000 calls

Commodities can be related to ship types in a general way but not in detail. The relation can be described as:

Table 2: Description of ship types

Bulker	Free flowing dry bulk of all types and of low value
Combination	Dry or wet free flowing bulk – low value bulk or petroleum products. Several combinations are possible depending on ships size and performance. (This is a small category of ships)
Dry Cargo	All types of unitised cargo (non rolling), free flowing bulk, project cargo etc. Average ship size about 3 500 DWT handling smaller quantities in many cases directly to industries.
Container	Traditionally high value cargo. The containerisation of the world results in a widening of the products handled. Mainly palletised and unitised cargo, but it can be everything from digital cameras to big bags of fertilizer.
Ro/Ro	Road vehicles and rolling terminal vehicles carrying unitised cargo or cargo units. Medium to high value cargo.
Vehicle Ro/Ro	A Ro/Ro ship specially designed for the shipping of new cars. Some larger Vehicle Ro/Ro's can handle large, rolling, project cargoes on a couple of decks.
Reefer	Refrigerated or temperature controlled cargo on pallets/hanging or unitised. Mainly food. To large extent loosing market to container ships
Passenger ferry	Ships having passenger carrying capacity. Others are various forms depending on the market. See Figure 6
Cruise	A ship that only carries passengers.
Crude oil Tanker	Pure crude oil carrier
Product Tanker	Carries various types of refined oil products, smaller tanks to carry a variety of products at the same time.
Chemical Tanker	Built to carry oxidising and hazardous products in specially coated tanks. Smaller tanks. Often competing in the product tanker market
Gas Tankers	LPG and LNG tankers, carries liquid gas under pressure
Misc. Tankers	Tankers for special purpose, Asphalt/Bitumen Tankers, etc.
Offshore	Ships in offshore services, anchor handling, supply ships, etc.

Others	Ships that do not fit into any the above types

The number of port calls does not describe the total transport activity of the ship type. This is also related to the size of the ship. The largest ships are the crude oil tankers and in the bulker and combined ship types. The combined ships are very much comparable to a bulker in size as the hull is roughly the same. The difference is the interior arrangement, some bulkheads etc, and possibly a larger GT in relation to the DWT for the combined ship.

From environmental, speed and emission point of view the two types can be located to the Bulker type. The same applies to the Product Tanker and Chemical Tanker ship types. The difference is manly the use of steel and coatings in tanks, the tank arrangement and the use of different types of pumps aboard the ship. These can be the same type of ship from environmental, emissions and energy point of view.

	Ro-ro	Ferry; cargo			Ferry; non cargo	
		RoPax		High speed		High speed
						
	Open Liner		Cruise		Ferry	
						
Cargo	Yes	Yes	Yes	Rarely	No	No
Trailers	Yes	Yes	Yes	Rarely	No	No
Passenger	12 drivers	200 - 600	500 - 2000	200 - 600	500 -	100-1000
Train	Occasionally	Occasionally	No	No	No	No
Cars	Limited	Yes	Yes	Yes	No	No
Day cruise	No	Occasionally	Yes	Rarely	Yes	Occasionally
Conference	No	Yes	Yes	No	Yes	Rarely
Entertainment	No	Occasionally	Yes	Occasionally	Yes	Occasionally

Figure 6: Different kind of passenger carrying ferries

3.1 Ships' main dimensions and performance

Most of the ship types have a very narrow span as concerns speed. The speed is determined as a function of the ship's size in Figure 7.

By adding in the speed into the selection of ship types we can rationalise the table and identify the comparable types.

The shadowed fields in Table 3 will be omitted as the frequency of ships calling the ports is very poor and/or the number of ships is small. Some types are included in a main type if it is not relevant to have them separately.

Combined ships are handled as bulkers. The combined vessels are few today and the fleet is diminishing. The combined ships are designed to carry either wet or dry bulk.

All types of tankers will be in the same group and handled as tanker. The difference in type of tanker is to some extent a matter of how they are equipped. The hull of the tankers is very much the same. The speed is in a quite short range that in very few cases passes 18 knots and has a

density of population between 13 – 16 knots. Gas tankers are special as the carry low density cargo. The cargo gives also special demand on the equipment onboard to keep the products floating.

It is worth noting that the ship type is rather an assignment of the ship guided by the ship's equipment and the class notation. Ships of the same type may vary substantially in performance.

The ferries are divided into three groups, cargo carrying and pure passengers and a group of High speed ferries, having a speed over 30 knots. The high speed ferries will be addressed to their DWT size whether they are cargo carrying or not as the weight of the fast ferry is ruling the speed performance and hence the fuel consumption.

Table 3: Comparable type of ships sorted to fit the purpose of the report

	Lloyds-Register Fairplay types
Bulker	Bulker Combined
Dry Cargo	Dry cargo
Container	Container
Ro/Ro	Ro/Ro
Vehicle Ro/Ro	Vehicle Ro/Ro
Reefer	Reefer
Cargo Ferry	Ferry cargo < 30kn
Passenger Ferry	Ferry non cargo Cruise < 30kn
Fast Ferry	Ferry cargo Ferry non cargo > 30 kn
Tanker	Chemical, Product, Crude Oil, Misc. Tanker
Product Tanker	
Gas Tanker	LPG LNG
Misc. Tankers	
Offshore	
Others	

From an emission point of view the speed is essential. However the speed is not known in all cases. The registered speed is in the LRF database the "service speed" stated as the speed "which the ship is stated to be capable of maintaining at sea in normal weather and at normal service draught". The record can also give the fuel consumption of the ship expressed in tons of fuel per day. The figures are as stated by "the owner or as obtained from other reliable sources".

This approach will be used as a base for the assessment of emissions from ships. The emissions are thus a function of its; Type, Energy consumption, speed, DWT and/or GT respectively.

The base for these figures will be those that are registered and readily available.

3.2 The development of ships' environmental performance

Looking at a sample of the ships in the register it shows clearly that the majority of the ships are of a kind that shows good environmental standards. Looking at ships' fuel consumption it shows quite clearly that good energy performance is obtained for ships having a speed lower than 17 knots. The lower the speed, the better the fuel economy. In Figure 7 it can be seen that the majority of the ships have a service speed less than 16 knots. From 16 knots and above the number of ships is declining fast. The reason for this is of course the cost of operation. Fuel is one of the most substantial costs for a ship's operation and in competition this has to be kept low.

However, there are exemptions for this. In Table 4 it can be noted that the fuel consumption for tankers is roughly the same as for container ships but the number of tankers are only half of the container ships. In fact the container operation is done on a fixed schedule. When this modern fast growing activity increased the size of the ships also increased. A larger ship has to stay longer in

the ports to handle the cargo why it needs to sail at a higher speed to keep the time table. The relation between a container ship's loading capacity in TEU and the installed horsepower is approximately constant.

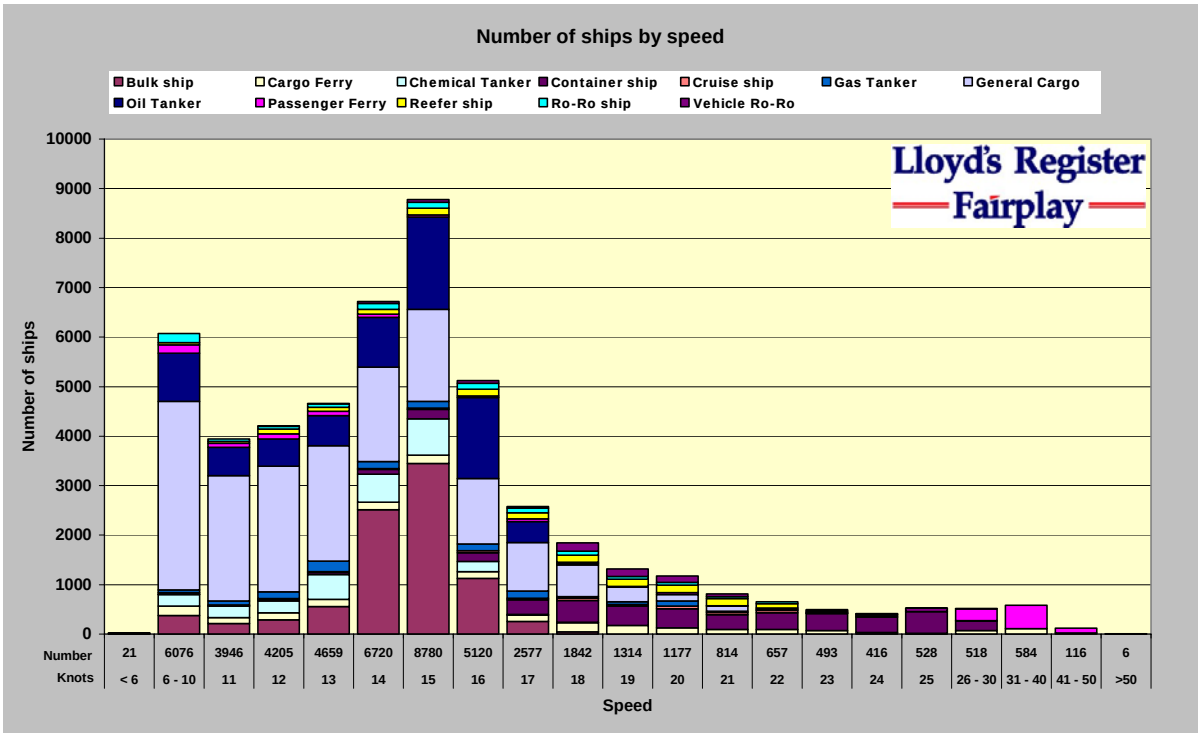

Figure 7; Distribution of ships in relation to speed

The majority of the ships, the tankers, the general cargo ships and the bulkers, are slow speed ships that mainly operate in 15 knots or less. Many of these ships are big in size and carry a huge amount of cargo.

Table 4; The fuel consumption for different types of ships

Ship types		Type of Fuel MDO	Average	MGO	Average	RO	Average	Total	Average Tons/day
Oil Tanker	Number of ships	2 963	31	24	20	1 611	74	**4 598**	56
	Sum of Fuel Consumption T/Day	92 857		477		119 961		**213 295**	
Chemical Tanker	Number of ships	1 058	18	45	23	148	26	**1 251**	19
	Sum of Fuel Consumption T/Day	18 930		1 048		3 785		**23 763**	
LNG	Number of ships	19	137	7	100	49	108	**75**	116
	Sum of Fuel Consumption T/Day	2 612		702		5 307		**8 620**	
LPG	Number of ships	432	18	13	18	94	23	**539**	19
	Sum of Fuel Consumption T/Day	7 755		236		2 184		**10 175**	
Bulker	Number of ships	3 697	30	3	10	1 435	29	**5 135**	30
	Sum of Fuel Consumption T/Day	110 589		31		41 083		**151 702**	
Combination	Number of ships	232	44			123	79	**355**	61
	Sum of Fuel Consumption T/Day	10 113				9 676		**19 789**	
Container	Number of ships	1 567	67	21	29	279	74	**1 867**	68
	Sum of Fuel Consumption T/Day	104 304		615		20 657		**125 576**	
Reefer	Number of ships	694	23			163	25	**857**	23
	Sum of Fuel Consumption T/Day	15 622				4 018		**19 640**	
General Cargo	Number of ships	7 915	11	132	10	2 521	18	**10 568**	13
	Sum of Fuel Consumption T/Day	84 482		1 381		45 585		**131 448**	
Vehicle Ro-Ro	Number of ships	348	26	2	18	58	38	**408**	28
	Sum of Fuel Consumption T/Day	9 000		37		2 178		**11 215**	
Cargo Ro-Ro	Number of ships	552	23	22	23	100	37	**674**	26
	Sum of Fuel Consumption T/Day	12 715		504		3 674		**16 893**	
Cargo Ferry	Number of ships	1 082	30	41	60	152	49	**1 275**	35
	Sum of Fuel Consumption T/Day	32 567		2 472		7 488		**42 528**	
Passenger Ferry	Number of ships	413	7	15	23	28	20	**456**	10
	Sum of Fuel Consumption T/Day	2 935		348		557		**3 839**	
Cruise	Number of ships	188	63	7	205	71	86	**266**	81
	Sum of Fuel Consumption T/Day	11 901		1 437		6 095		**19 433**	
Total Number of ships		**21 160**		**332**		**6 832**		**28 324**	
Total Sum of Fuel Consumption T/Day		**516 382**		**9 288**		**272 246**		**797 916**	

A relation that more considers the carrying capacity (passenger ships disregarded) and that gives energy efficiency per DWT will show best result for tankers, and half the efficiency for Bulkers and Gas Tankers and a quarter for Container Carriers and General Cargo ships.

It should however be noted that Ro/Ro ships in ferry service normally do not utilise the DWT. A 160 m Ro/Ro vessel of 8,400 tons DWT has a stowage capacity of about 2,000 lane meters. This corresponds to roughly about 2,500 tons of cargo in trailers plus 800 tons of trailer tare weight. The energy efficiency of this kind of transport cannot compete with a direct pull on the road of the trailer even if the speed of the ship is moderate.

Ro/Ro ships are popular in industry shipping as the port loading /discharging productivity is high. In industry shipping the DWT of the vessels is normally fully utilised.

3.3 Emission factors

The emission factors from the engines are obtained from the manufacturer of the engine. In the register the make of the engine, the type, the type of fuel used and the fuel consumption at service speed are noted. The emission factors are collected from the manufacturer by enquiring for the test results and measurements from each specific engine. This information is added to the register for each ship when and if the information is available and given.

Vessels speed and consumption is noted as well as the total fuel consumption of the engines and type of fuel used. These figures will be used for the estimate of the sulphur content in the fuel in accordance to the market survey of fuel oils made by Entec 2002 (DG Envir.).

The effect of exhaust cleaning equipment has also been collected and added to the register stating the type, manufacturer, reduction factors of HC, NO_x, Particles and Sulphur SO_x. If additives are used for its function this has also to be registered and the consumption of additives is noted as a function of fuel consumption. Residues from the cleaning equipment are also to be registered if it is significant as a comment to the function of the equipment.

4 Exhaust cleaning equipment

The number of installed exhaust cleaning equipments is still marginal in relation to the total deliveries of ships, but it is slowly growing. As per end of 2004 the following ships are equipped with or have ordered exhaust cleaning systems.

Table 5; Exhaust cleaning equipment installed in ships

Ship reference	Ship type	No ships	Yard.	Year	Owner	Operator	No of Engines	Supplier	Type
Posco	Cargo	4	New building	89-92	USA	USA	MS x 1	HT	SCR
Aurora	Ferry	1	Langsten nb157	92	Sweden	Sweden	MS x 1	Munters	SCR+Oxi
Silja Symphony	Ferry	1	Retrofit	94	Sweden	Sweden	MS x 1	HT	SCR
Scandica	Supply	1	Retrofit	94	Sweden	Sweden	MS x 2 + HSx4	Munters	SCR+Oxi
Silja Serenade	Ferry	1	RetrofIt	95	Finland	Finland	MS x 1	HT	SCR
Navy	Frigate	1	Test bed	95	UK	UK	MS x 1	Munters	SCR+Oxi/IS
Nils Dacke	Ferry	1	Finnyards nb 411	95	Germany	Germany	MS x 1	Siemens	SCR
Jutlandica	Ferry	1	Giessen nb 967	96	Sweden	Sweden	MS x 8	HT	SCR
Atle	Icebreaker	1	RetrofIt	95	Sweden	Sweden	MS x 10	Munters	SCR+Oxi/IS
Gabriella	Ferry	1	RetrofIt	97	Finland	Åland	MS x 1	Siemens	SCR
Gotland	Fast Ferry	1	L&Lotz nb L31	97	Sweden	Sweden	MS x 4+ HSx3	Siemens	SCR
Thjelvar	Ferry	1	RetrofIt	97	Sweden	Sweden	MS x 6	Siemens	SCR
Visby	Ferry	1	RetrofIt	97	Sweden	Sweden	SS x 4 + MSx3	Siemens	SCR
Hertug	Ferry	1	RetrofIt	97	Norway	Norway	MS x 1	Siemens	SCR
FG-Ship	RoPax	2	AESA n.b 78/79	97	Finland	Finland	MS x 7	Munters	SCR+Oxi
Coflexip	Pipelayer	1	Retrofit	98	USA	USA	MS x 2	Munters	SCR+Oxi
Cellus	Carrier	1	Peters nb 653	98	Germany	Germany	SS x 1+ HSx1	Siemens	SCR
STORA/Wagenborg	RoRo	3	Flender nb 676/7/8	98	Netherlands	Netherlands	SS x 1+ MSx2	Munters	SCR+Oxi/IS
STENA	RoPax	2	AESA nb 80/81	98	Sweden	UK	MS x 7	Munters	SCR+Oxi
Birka Princess	Cruiser	1	RetrofIt	98	Finland	Finland	MS x 6	Siemens	SCR
B&N /Viking AS	Supply/Icebreaker	3	Leirvik nb 282/3/4	98	Sweden	Norway	MS x 4 + HSx2	Munters	SCR+Oxi/IS
Ortviken	RoRo	1	RetrofIt	99	Sweden	Sweden	MS x 2 + MSx3	Siemens	SCR+Oxi
Wörden	Cargo	3	SLK nb 5102-5104	99	Germany	Germany	MS x 1	Siemens	SCR
Eheler / Holwerda	Container	3	Sietas 1134/57/58	99	Germany	Germany	MS x 1+ MSx2	Munters	SCR+Oxi/IS
Timbus + Forester	Carrier	2	Peters nb + retrofit	99	Germany	Germany	MS x 1 + HSx1	Siemens	SCR
Slija Europa	Ferry	1	RetrofIt	99	Finland	Finland	MS x 4	Siemens	SCR
Silja Serenade/Symphony	Ferry	2	Retrofit	99	Finland	Finland	MS x 4	Wärtsilä	DWI
Mistral/Miranda/Seaguard	Ro-Ro	4	Sietas 1183/84/87	99	Finland	Finland	MS x 1	Wärtsilä	DWI
Friedrich/Elisabeth Russ	Ro-Ro	2	Sietas 1185/86	99	Germany	Finland	MS x 1	Wärtsilä	DWI
Caroline/Pauline Russ	Ro-Ro	2	Sietas 1188/89	99	Germany	Finland	MS x 1	Wärtsilä	DWI
Rederi AB Gotland	Ro-Ro	2	Guangzho	00	Sweden	Sweden	MS x 4 + HSx3	Siemens	SCR
Coastguard	Oil defender	1	Retrofit	00	Sweden	Sweden	HS x 1	Munters	HAM
Granö	Ro-Ro	1	Retrofit	00	Finland	Finland	MS x 1	Siemens	SCR
Mariella	Ferry	1	Retrofit	01	Finland	Åland	MS x 4	Munters	HAM
Mikael With	Cargo	1	Vaagland 130	01	Norway	Norway	MS x 1	Munters	SCR+Oxi/IS
Silja Festival	Ferry	1	Retrofit	01	Finland	Finland		HT	SCR
Navion Dania	Prod tanker	1	Retrofit	01	Norway	Norway	SS x 1	HT	SCR
STENA	RoPax	2	HHI 1392 / 1393	01 / 02	Sweden	UK	MS x 4+ MSx4	Munters	SCR+Oxi
Styrsö	Ro-Ro	1	Retrofit	02	Finland	Finland	MS x 1	Siemens	SCR
Norfjord	Ferry	1	Fiskerstrand 48	02	Norway	Norway	MS x 2	Munters	SCR+Oxi/IS
Hamnö	Ro-Ro	1	Retrofit	02	Finland	Finland	MS x 1	Siemens	SCR
HMS Karlskrona	Mine layer	1	Retrofit	02	Sweden	Sweden		Siemens	SCR
Sigyn	RoRo	1	Retrofit	02	Sweden	Sweden		Siemens	SCR
Paybrink	Ferry	1	Langsten	02	Norway	Norway		Siemens	SCR
DFDS / Flensburg	Ro-Ro	5	Flensburg 721 - 725	03 / 04	Denmark	Denmark	MS x 4	Munters	SCR+Oxi/IS
Havilia Supply	Supply	1	Leirvik nb 077	03	Norway	Norway	MS x 4	Munters	SCR+Oxi/IS
Pride of Kent/Canterbury	Ferry	2	Retrofit	03/04	UK	UK	MS x 4	DWE	Scrubber IS
Wagenborg	Ro-Ro	2	Volharding 528 /529	03 / 04	Netherlands	Netherlands	MS x 1	Munters	SCR
Obbola/Östrand	RoRo	2	RetrofIt	04	Sweden	Sweden	MS x 2 + MSx3	Siemens	SCR+Oxi
Tallink	Ferry	1	Aaker	04	Estland	Estland		Siemens	SCR
Birka	Cruise Ferry	1	Aaker	04	Finland	Finland		Siemens	SCR
Pearl of Scandinavia	Cruise Ferry	1	Retrofit	04	Denmark	Denmark	MS x 3	Munters	SCR+Oxi
Crown of Scandinavia	Cruise Ferry	1	Retrofit	04	Denmark	Denmark	MS x 3	Munters	SCR+Oxi/IS
Viking Cinderella	Cruise Ferry	1	Retrofit	03	Sweden	Åland	MS x 4+ MS x 4	Munters	SCR
FMV	Mine sweeper	1	Retrofit	04	Sweden	Sweden	MS x 2 + HS x 2	Siemens	SCR
Princess of Scandinavia	Cruise Ferry	1	Retrofit	04	Denmark	Denmark	MS x 2	Munters	SCR+Oxi
Broströms	Tanker	4	Jinling	05	Sweden	Sweden	SS x 2 + MS x2	Munters	SCR+Oxi/IS
DFDS / Flensburg	Ro-Ro	1	Flensburg 730	06	Denmark	Denmark	MS x 4	Munters	SCR+Oxi/IS
	Sum	**90**	**Ships**						

MariTerm AB

SS = Slow Speed
MS = Medium Speed
HS = High Speed
IS= Integrated Silencer

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In Table 5 the following abbreviations are used:

SCR – Selective Catalytic Reduction, Urea is injected and the exhaust is passing a catalyst that reduce the NO_x to N_2 and H_2O (NO_x reduction about 95%)

Oxi – Oxidising catalyst, consumes the last HC

HAM – Humid Air Motor, the inlet air is saturated with warm water

Scrubber – The exhaust is passed though a scrubber where it is washed

DWI – Direct Water Injection

Some of the ships shown in Table 5 are not using the equipment in daily service.

4.1 NO_x abatement systems

The NO_x abatement equipment in practical operation on ships are the SCR, the HAM and water injection technique. The latter is tested on auxiliary engines, engines of a size less than 3 MW.

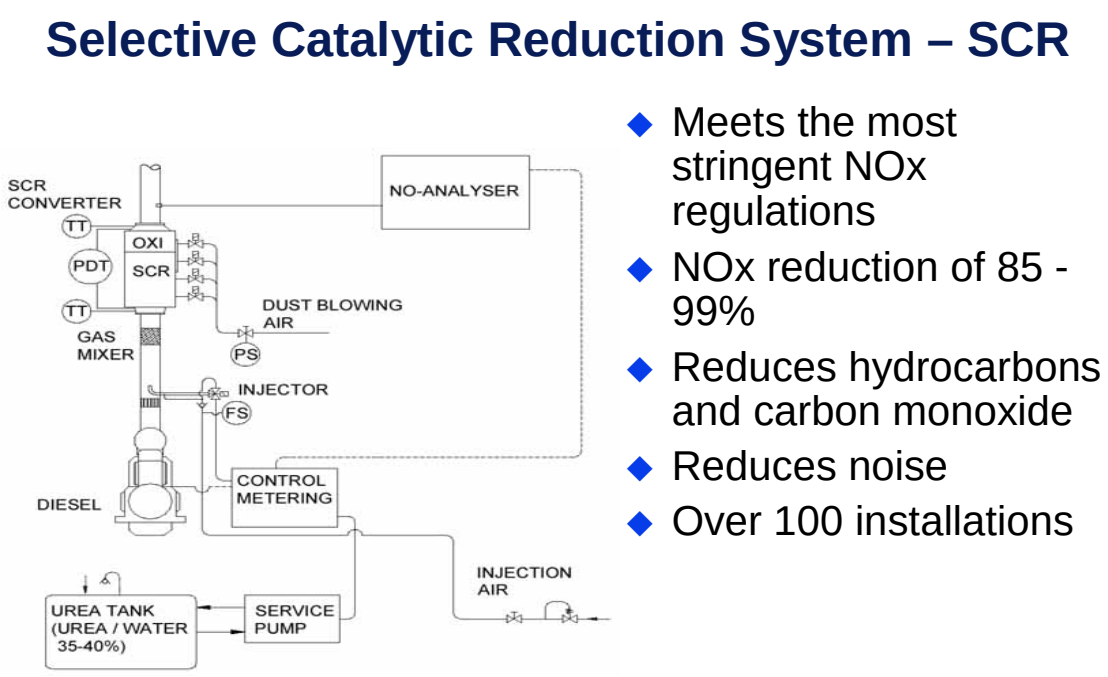


Figure 8: SCR arrangement in a ship an after-treatment system (Munters)

The SCR Converters will be working with urea injection under the following temperature conditions.

Table 6; The temperature level for safe work using different fuels, Munters

Fuel type	DO	MDO	HFO	HFO
Sulphur content	< 0,1 %	< 0.25 %	< 1 %	< 5 %
Urea injection, min temp.	270°C	280°C	290°C	300°C

Table 7; The performance of an SCR system according to manufacturer, Munters

Performance	
NO_x reduction	90 - 99 % at MCR
HC reduction	75 - 90 % at MCR
CO reduction	5 - 90 % at MCR
Noise reduction	20 - 35 dB(A)
Operation	
Temp span	270 - 500 °C
Fuel	MDO/HFO
Installation	
Weight	Silencer + 20 - 50 %
Volume	Silencer ± 20 %
Consumables	

Urea solution 40%	1.5 liter / kg NOx
Catalyst life span	12,000-100,000 h
Cost	
Investment cost	USD 35-75 per MW
Operating cost	USD 3-4 per MWh
NO_x cost	USD 0.5 per kg NOx

Table 8; Examples of cost and performance for different applications, Munters

Plant	Ferry	Cargo	Ferry	Land Power generator
Equipment	SCR	SCR	HAM	SCR
Power	39 MW	10 MW	23 MW	125 MW
Load/Time	75 / 75%	90 / 95%	75 / 75%	100 / 95%
BL NO_x	14 g/kWh	20 g/kWh	14 g/kWh	2.5 g/kWh
NO_x red.	95%	95%	80%	95%
NO_x red.	2600 t/y	1400 t/y	1300 t/y	2500 t/y
Invest / MW	45 kEUR	77 kEUR	118 kEUR	70 kEUR
Run cost / ton NO_x	200 EUR	200 EUR	-	200 EUR
NO_x red.	2,600 t/y	1,400 t/y	1,300 t/y	2,500 t/y
Tot cost / ton NO_x 10 years	268 EUR	255 EUR	209 EUR	550 EUR

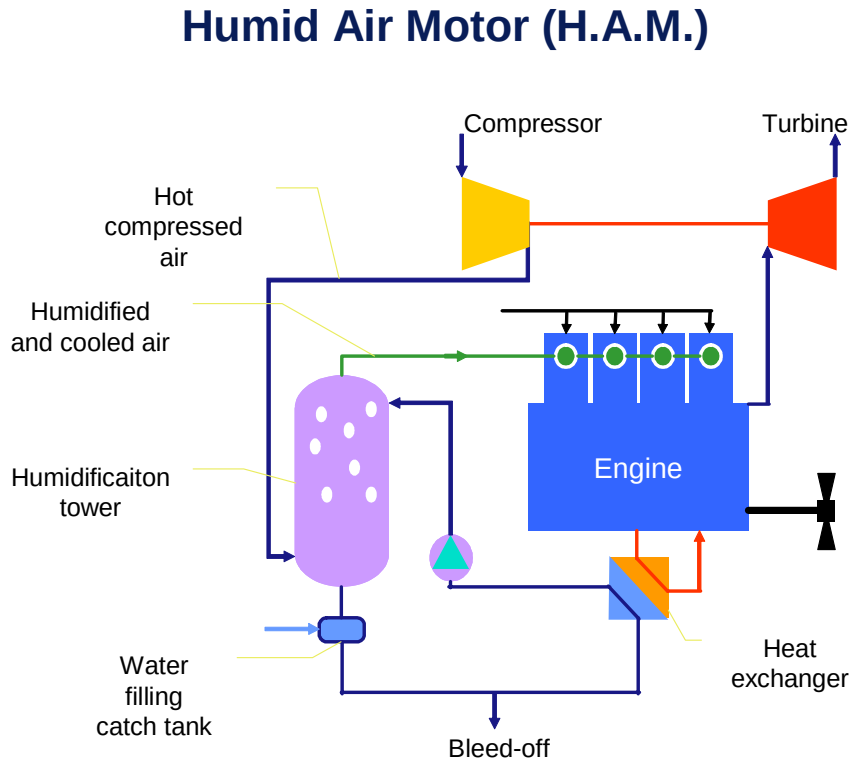


Figure 9: The HAM exhaust cleaning system, a pre-treatment system (Munters)

The HAM – Humid Air Motor runs on heavy humidified inlet air, which reduces the NO_x. The NO_x reduction is about 60 -70%. The contribution to the process is the increased mass flow through the engine. This mass flow can be used to increase the charging. The effect eliminates the efficiency loss of a cooler burning process. The process is quite complicated and is still subject to be further analysed.

Water injection is another method used that aims at reducing the temperature in the combustion. Wärtsilä has developed and are marketing Direct Water Injection (DWI) for some of their diesel engines and claims a NO_x reduction of 50 – 60 % without "adversely affecting the power output or engine components". The amount of evaporated or technical water needed is slightly over half of the fuel oil consumption. According to Wärtsilä, more than 50 marine engines with DWI are installed or in order. The first installations were made on the cruise ferries Silja Symphony and Silja Serenade in 1999. The systems measure a NO_x reduction of about 60 % (NO_x emission of 5.8 g/kWh). The ship owner is satisfied with the system.

Wärtsilä will not develop the DWI technique any further since they presently are looking into the technique of adding in humidity in the air supply.

There are other exhaust cleaning systems that are technically possible but not practical to operate. The total cleaning effect on sea transports today from the equipment are almost negligible.

The operation of different systems

There is a major difference between systems that treat the emissions after it has passed the engine and the ones that affects the process of the engine. It is quite natural that the engine manufacturers are reluctant, to say the least, to guarantee an engine that has been manipulated. The guarantee of the engine is crucial for the ship owner and it affects not only the cost side but also the reliability of the engine. For this reason there are practically two options; to process the emissions after the outlet of the engine or use a system that is delivered by the engine manufacturer. This is a serious obstacle for the development of ships' emission cleaning that can be as big as the added cost for the operation of the cleaning system or for the use of low sulphur and more expensive fuel oils.

The SCR technology is the most common emission abatement technology. SCR equipment is in operation since the beginning of 1990. Aurora a ferry in the Öresund is equipped with SCR cleaning on one of four main engines. The equipment has by the end of 2004 been in operation for more than 70,000 hrs and the reduction factor is still around 95 %.

The cost of reducing NO_x is around € 0.5 per kg NO_x all included. In practical operation the cost of running a SCR type in a ship has showed a cost increase of around 1 % of operations.

The HAM technology is running on full scale on one ship. The technique is proved. However, looking at Table 8 the figures indicates a substantial investment in the machine to make it accept the water load. ABB has calculated this to be so high that the total cost will be as high as for SCR equipment. The reason is that the ship owner has to cover for the cost of having the engine prepared for a system that is a part of the engine's cycle. This will demand equipments and special parts to prepare the engine for the HAM process which is costly.

The DWI technique developed by Wärtsilä is found to be suitable for their bigger engines. The technique will reduce NO_x by 50 – 60 % and do not affect other emissions.

Wärtsilä is looking at developing a system that is based on adding in water into the air prior to the combustion. Trials using this method are carried out in full scale. The system is called CUS and is a way of injecting water under high pressure to the air on the inlet side. The water has to be of fine quality not to cause effects on the engine or to produce unwanted new hazardous substances to the exhaust.

The following table presents a summary of the emission reduction factors that can be accounted on form the different systems. These factors are discussed with manufacturers and IVL, Gothenburg Sweden who have done some measurements on systems.

Table 9; Reduction factors for emission cleaning equipment

Type of equipment	NOx	HC	CO	PM	SOx	NH3	Noise	Additives	Fuel quality	Comments	
SCR* ex. Oxi	95%		+ 50%	0 - 20%		+ 0,1 g/kWh				Proved technique Does not affect engine	
SCR* with oxidiser	95%	80%**	70%**	1 - 20%		+ 0,1 g/kWh	30dB	Urea 40% solution 1,5 lit/kg NOx	MGO - HFO	Proved technique Does not affect engine	
HAM	70%		+ 20%				20dB	Water/Sea water	MGO - HFO	Technique under develop Affects engine	Use of water amounts to 10 times the fuel
DWI	60%								MGO - HFO	Technique under develop Affects engine	Fuel increase
Scrubber				80%	90%		35%	Sea water	MGO - HFO	Small engines Under development	
*The techniques are affected by the level of Sulphur, however SCR demands higher exhaust gas temperatures by increased Sulphur **Oxidiser Factors noted with + gives the value in added emissions											

4.2 The regulations and the measures

IMO has in the Marpol Annex VI, which enters in force May 19, 2005, regulated the maximum use of sulphur content in marine fuel to 4.5 % in general and in "SO_x Emission Control Areas" the limit is 1.5 %. The North Sea including the Baltic Sea is such area.

NO_x emission limits are set for diesel engines. The emission factors range from 9.8 to 17 g/kWh depending on the engine maximum operating speed.

Table 10; The IMO Annex VI Resolution 2, NO_x Technical Code

MARPOL Annex VI NOx Emission Limits	
	maximum g/kWh
n < 130 rpm	17.0
130 rpm ≤ n < 2000 rpm	$45 \cdot n^{-0.2}$
n ≥ 2000 rpm	9.8

Further technical details pertaining to NO_x emissions, such as emission control methods, are included in the mandatory "NO_x Technical Code", which has been adopted under the cover of "Resolution 2".

The measure range from 17 to about 12 g/kWh NO_x and is considered to be maintained by control of the engine's performance.

Some ports and countries stimulate the use of exhaust cleaning and give credits on the port dues if cleaning equipment is installed and used. These are called "environmentally differentiated dues". There is no ruling system of how to design the differentiated dues. The Swedish Maritime Administration adopted its own system in 1998 where credits were given both for lower sulphur contents in the fuel and a reduction of the NO_x. However, there is no such system today that covers for the cost of running on either low sulphur fuel or running any type of NO_x abatement equipment.

The EU Directive 1999/32/EC covers the sulphur content of marine fuels. The directive gives reference to the IMO Marpol Annex VI that demands the member states to ratify the 1997 Protocol. As the Annex has been ratified it will enter into force on 19 May 2005 adding designated Sulphur Oxide Emission Control Areas such as the Baltic Sea which has retain a status as a PSSA (Particularly Sensitive Sea Area). An agreement is in the process where the North Sea including the English Channel is included in the designation [9].

However, EU's ambition is higher than so. The Directive also includes an Article 3 where the Member States are obliged to take necessary steps to ensure that from 1 January 2003 heavy fuel oil having a sulphur content that exceeds 1 % is not used within the territory. This only concerns

the land used heavy oil. The Directive states in Article 4a on the other hand a demand on sulphur content in the marine fuel on any vessel in the territories that falling in the control zone of SO_x Emission Control Areas do not exceed 1.5 %. This applies also them that calls the Member States from a destination outside Europe. With effect from 1 January 2010[7] the Member State is to take all necessary steps to ensure that vessels in inland waterway operation and all ships that berth in Community ports do not use fuel oil with a sulphur concentration exceeding 0.1 % of mass.

As Scandinavia is an area particularly sensitive to acidification the Swedish government has by using its National Ship Dues enforced means aimed at providing incitement for the ship owners, and particularly the high frequent traffic, to take measures to reduce the sulphur content in the fuel.

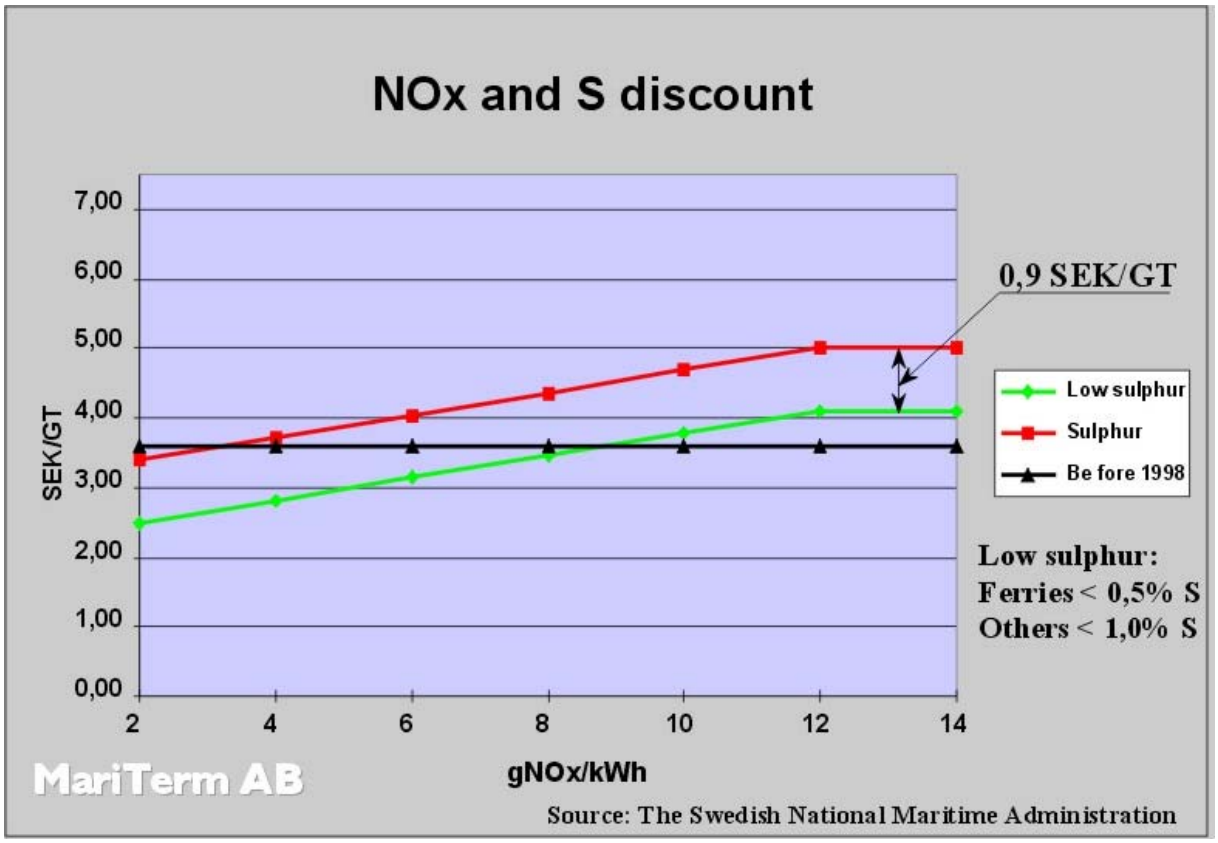


Figure 10: The principle of the National dues in Sweden

The Swedish national ship fairway due was 5 SEK/GT for a ship 1998 – end 2004. This was reduced by 0.9 SEK/GT for a cargo ship that only carries fuel having sulphur content of less than 1 % or if a ferry has sulphur content in the fuel of less than 0.5 %. The due applied for the first 12 calls per year to a Swedish port for a cargo ship and the first 18 calls per year.

A reduction of the due was also possible to acquire in proportion to the reduction of NO_x the ship could show by using abatement technique and records proving functional NO_x cleaning equipment. The reduction could at maximum be 1.6 SEK/GT giving a total reduction of 50 % of the dues at a maximum reduction of S and NO_x.

Initially[8] the Maritime Administration also gave restitution on investments in NO_x cleaning equipment installed in the vessels over the period. The restitution could be up to 40 % of the

[7] Greece is granted another 2 years for some ferries

[8] Between year 1998 and year 2000

investment. This did not cover for the increased running cost but it helped to reduce the cost of the investment.

As for the exhaust cleaning of NO_x the development has not been that fast. Very few ships (mainly ferries and ships in time charter for the forest industry) have taken measures resulting in a marginal effect on the emissions.

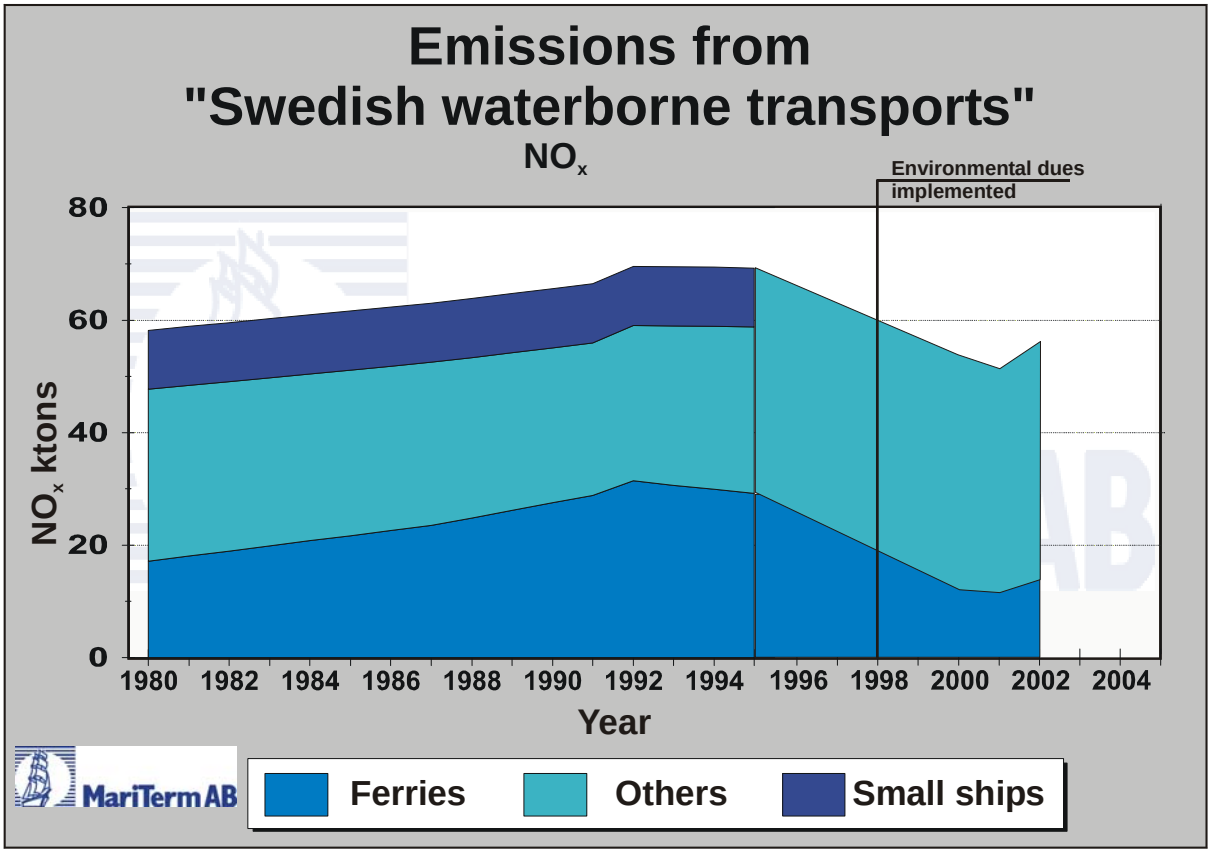


Figure 11; The development of NO_x air emissions for ships' traffic on Sweden

Most of the ports are aiming at a system that encourage incitements but does not affect the economy of the port. This is normally built on a due system that either increases the due with a sum if no measure is taken and decreases the due with the same sum if the ship fulfils the demanded measures. The level of measure coincides with the levels set by the Administration.

There are programs in other ports in Europe that aim at reducing the environmental load from ships. The Green Award in Rotterdam is one of the most well known programs.

4.3 The sulphur abatement program

The sulphur content in the fuel is regarded to be one of the most hazardous emissions as it in contact with the air forms sulphur acid that results in acid rain. North America and North Europe are very sensitive areas for the acids as there is very little lime stone in the soil that can act as a buffer.

There are two major ways to reduce sulphur in the emissions. It is either to limit the sulphur in the fuel or it is to clean the ship's exhaust emissions from sulphur particles, DnV [3].

The option to only use low sulphur fuel where the sulphur is reduced in the refinery is the common way today. This technique is the one used for road traffic where the fuel has a sulphur content of 0.001% of mass. Using refined qualities it is possible to come down to the required sulphur level by mixing low sulphur fuel. Normally a residue quality is used that gives the density required for a

smooth trouble free operation. This can be cst 380 or 180 but the fuel is mixed with qualities that together will give a sulphur content of 1 % or less. The cost for lower sulphur oil has over the past few years been substantial and the ship owners are keeping down costs by using less expensive fuel.

Mixing qualities give a reduction potential of about 70 %. The added cost for this fuel is estimated at € 22 – 48 per ton. Further reduction is very expensive.

The other option is to wash out the sulphur from the emissions and with that get rid of a number of particles and other emissions as well. DME is a leading manufacturer in the marine area of scrubbers and they claim the equipment gives the following performance:

Table 11; The performance of the DME scrubber according to manufacturer DME

Parameter	Performance
Particulate removal	80%
SO2 removal	90%
NOx removal	10%
HCl removal	70%
Noise attenuation	35 dB
Back pressure	7-15 mBar
Plume appearance	Invisible
Diesel smell	Dramatic reduction
Construction	Titanium Gr 2
Engine size	200-400 kW
Fuel type	All fuels

The question is where the residues from the scrubber will go when the circulating water is changed. DME claims that the residues are harmless and can be washed out to the sea. However, running the systems on sea water will by nature imply a number of new particles, not only the soot and sulphur, to be washed out in the water.

The present credits given by the European ports are quite small in comparison to the cost for installing and using the cleaning equipment. By this it is not commercially viable for the ship owner neither to use low sulphur fuel nor to install cleaning equipment unless his client is ready to pay for it. In Sweden it was assumed to be solved by time where it was expected that a number of other countries would start to take the same measures inspired by the Swedish progress. This did not happen. On the other hand some industries[9] agreed to participate in the work of raising the environmental quality of sea transports and they equipped their ships with exhaust cleaning equipment

[9] Especially the forest industry that signed an agreement to have exhaust cleaning equipment installed on all vessels that enter into service after the agreement was made. They have honoured this agreement so far.

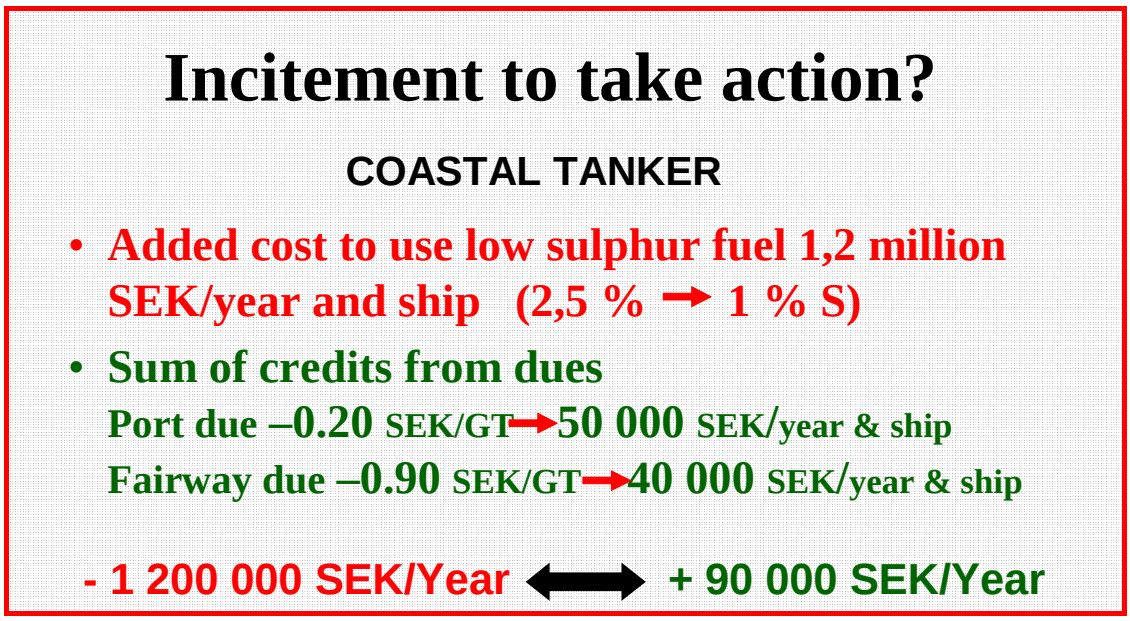


Figure 12; Having only incitement from one country the charters will have to put up with the cost to be environmental friendly

One of the major polluting ship categories are the ferries. Not by the fact that their pollution is more hazardous or dirty but because of the high frequency. The frequent ferry service (which to a very large extent is a part of the road/rail network being virtual bridges connecting road/rail ends) represents the larger part of the emissions in the Baltic Sea. The total share of NO_x emissions from ferries is calculated to be about 60 %. The ferry operators showed early the ambition to reduce the environmental load from ships. In mid 1980:ies the ports started to demand low sulphur fuel in the bunker and enforced the ships to empty the black and grey water holding tanks in the ports instead of at sea. This came with some strain to the ports as the sewage network were not designed to receive the amount of sewage in a short time.

The measures gave a clear result in the statistics and when the environmental dues were introduced in Sweden the main ferry operators had already reduced the sulphur in the fuel. This resulted in a marginal effect 1998 of the sulphur reduction for ferries. It did some good as the contribution from the other types of ships that took measures and some ferries that had turned back to the high sulphur heavy oil came back to better qualities.

The small ships did not give much improvement to the sulphur statistics as the quality of this fuel historically is of low sulphur grade.

It should be noticed that a number of ship owners that are running medium speed engines have proved that the operation on low sulphur fuel (equals to better fuel oil quality) is economically viable for some ships as the maintenance cost of the engine will be much lower. The reduced cost comes from; less exchange of components, less spare parts, increased reliability. All of which makes it possible to reduce the manning in the engine room.

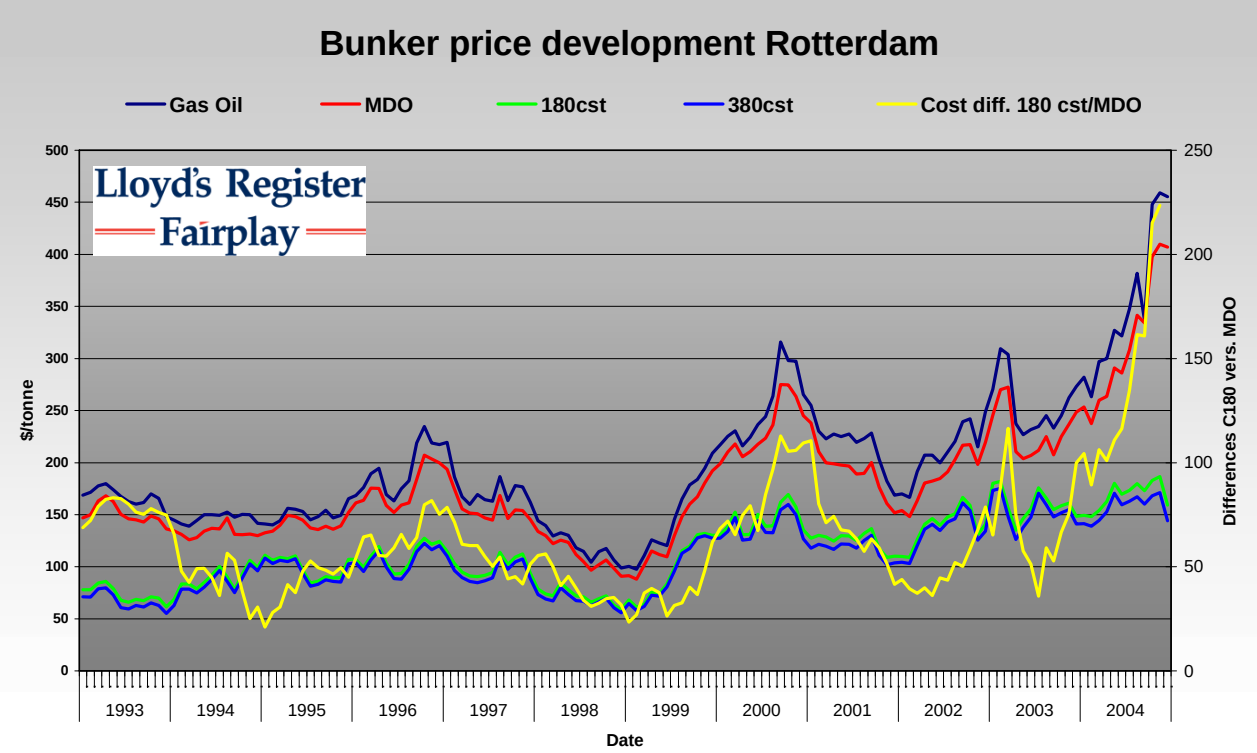


Figure 13; Bunker price development in Rotterdam over the past years

However, it should be noted that this does not apply as a rule of thumb as the price difference varies a lot in the market. The average price cost difference between 180 cst and GO has been about USD 85 per ton in this decade. In the year 2004 it averaged at USD 173 per ton. This is a huge cost to compensate for in a world where the competition is fierce.

In the market the price difference as shown in the beginning of 2000 - 2004 gives a cost increase that can not be absorbed by other cost reductions. An example can be a coaster of about 2,500 DWT that consumes 12 ton/day. The cost increase of 85 USD/ton bunker will give a FIO[10] cost increase of about 6 % for a 1,050 NM roundtrip. A Ro/Ro ship of 10,000 DWT sailing about 1,000 NM will get a FIO cost increase of about 10 %.

It is of course a high cost and a substantial increase of the shipping cost for the companies that take action to reduce environmental loads. However, as time goes by and there are no other operators in Europe that follows, the companies claim that they cannot voluntarily carry this cost by themselves and handicap their products with the extra cost. They demand a political action that makes it compulsory for sea transports to use the lower sulphur fuel in order not to handicap the industries that shows environmental concern. This can only be enforced by a law, in the same way as has been done for road transports.

[10] FIO; Free In & Out, Only the ships cost is included

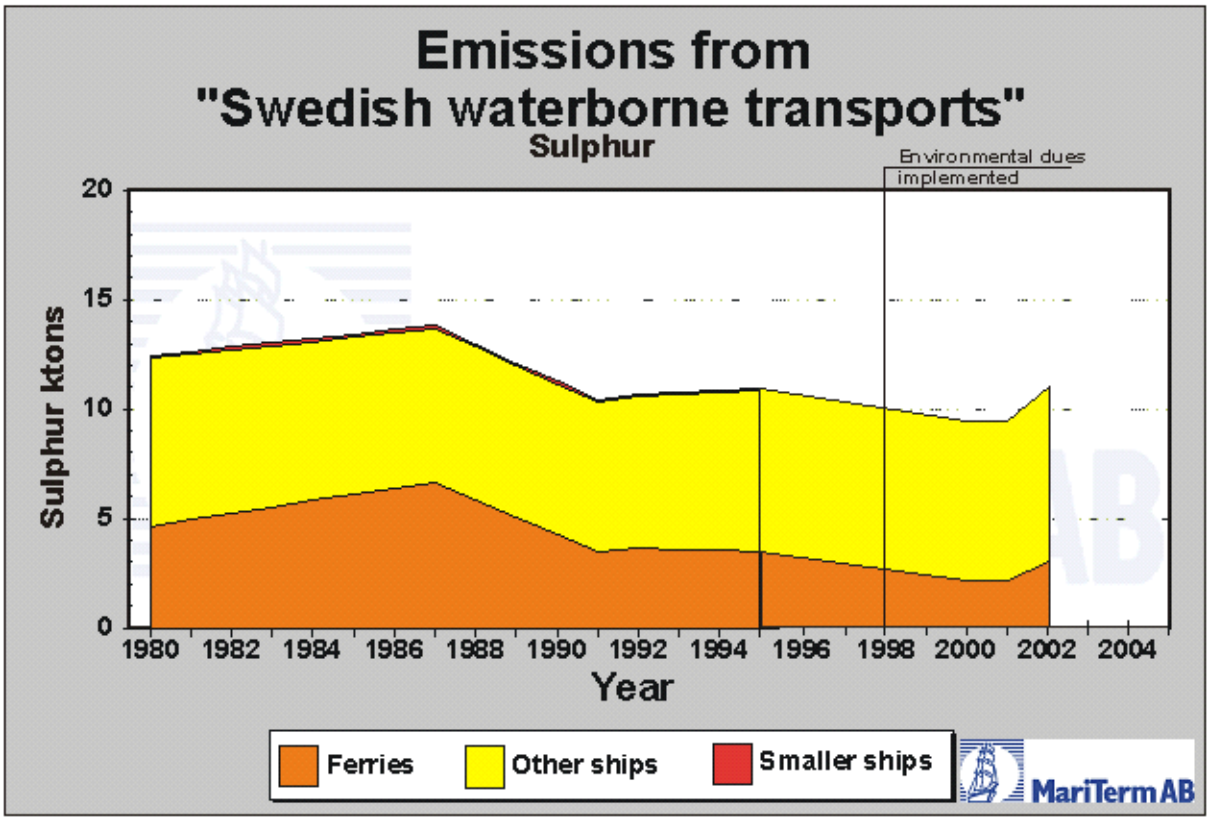


Figure 14; The development of Sulphur emissions in Swedish waters in the 80:ties and 90:ties

The sulphur emission only depends on the sulphur content in the fuel. The sulphur content depends on the type of fuel used by the ship and where the fuel is produced. The quality available is determined by the local market and the type of fuel used on that market.

One major problem in the shipping industry is that the refineries use marine engines to deposit residues from the refineries. For this reason the heavy marine fuel oil is less expensive than crude oil[11]. The rate of the bunker price is normally around half the price of crude oil.

The main contributor to the sulphur emissions is the ships having a GT of over 3,000. This can be seen in Figure 14. The amount of sulphur is very low from smaller ships. The emission figures in Figure 11 and Figure 14 can be compared to the traffic development in the region shown in Figure 11 as the energy consumption. The CO_2 emissions can be put equal to the traffic activity.

The fuel quality used by the ferries has varied over the years which Figure 14 indicates. The drop in ferry activity in the late 1990:ties was followed by an increase in the activities the last few years. A lot of these activities are services to the East Baltic Sea countries.

[11] In Sept. 2004 the bunker price in Rotterdam for IF380 was around 160 USD/ton (www.bunkerworld.com) the crude oil price at the same time was around 40 USD/bbl or 240 USD/ton

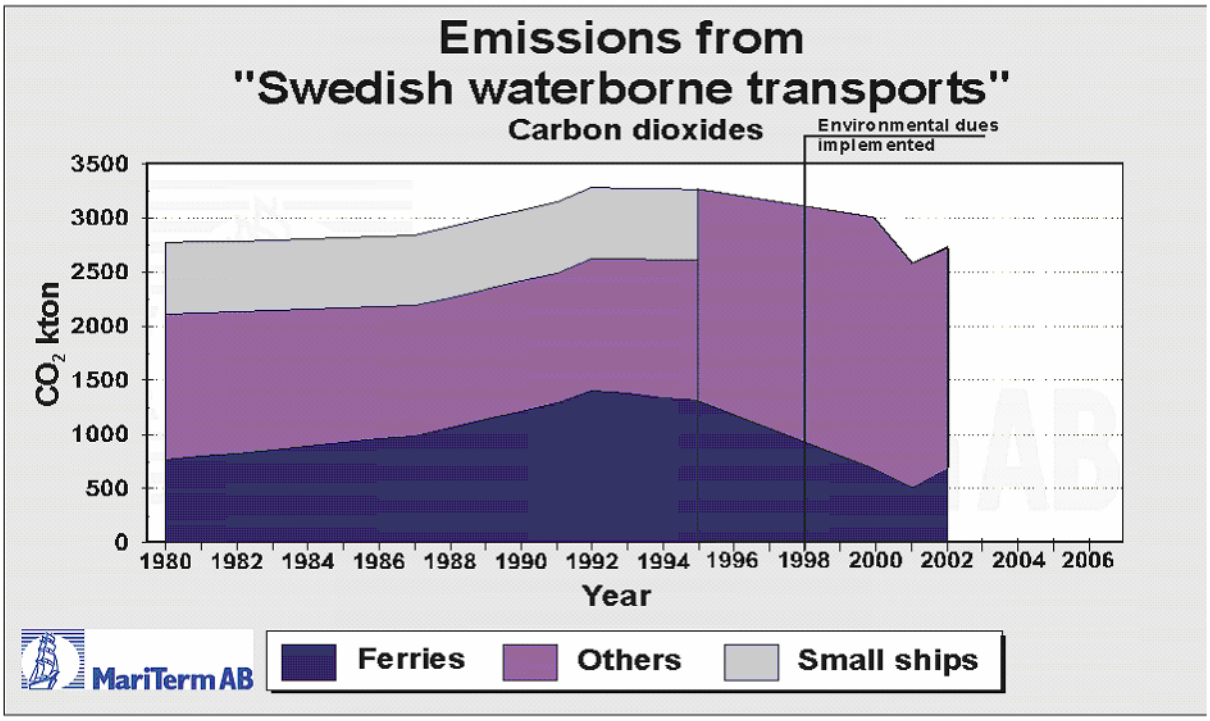


Figure 15; The development of carbon dioxide, which relays the traffic activity

Unfortunately there are larger discrepancies in the records of ships than in the figures of the emissions from them. This brings the attention to another matter as regards the assessment of emissions from sea transports. The quality and validity of the shipping activity and the records of the ships that call the port and the area is very important as it sets the total emissions in the region. Lloyds Maritime Intelligence Unit (LMIU) is often used as a source for the shipping activities. At some times the variation of shipping frequency in an area can change 25 – 40 % from the previous year which is beyond the normal range. The importance of having proper traffic information as well as having proper relation between the ship's identity and the emissions cannot be undervalued. In order to enable a follow up of the development the database must be coherent over the time. It cannot vary in a rage of 25 – 40 % to give a reliable assessment of the development.

Accurate ship movement's data is hard to find. Eurostat tried to build up a ship call database but as the integrity policy did not allow the identification of the ship it was difficult to establish a system that produced useful information. The information produced was too general where only the size and type of ship were known but not where it came from or went to.

Nevertheless the method for the assessment should be functional for all type of ship statistics if only the type of ship, the GT or DWT are recorded and in what relation the ship is moving. In the future the AIS (Automatic Identification System) will record all ships on line and can by this not only produce information about the relations in which the ships are trading but also the enroute information. It also records the exact speed of the ship as this is given from the ship as a part of the reported status of the ship. Having a link to the register and the ship's data, a continuous record of the ships emissions could be obtained. In comparison to road traffic there are a couple of basics that should be noticed:

- Ships are individuals and have to be treated as individuals
- The total activity is not larger than it can be recorded in total

5 The methodology of assessment

The methodology of assessment system differs between the purposes of the assessment. The assessment can be for a local study or cover a spatial study. In a local study the steaming distance is known or modelled. Typical examples are assessments of the traffic along a coast or at the approach to a port.

5.1 The spatial assessment

In a spatial study the ship's steaming distance is between ports in the area or between a border of the area and a port. Even though this sounds reasonable it may differ substantially depending on which route the ship is taking. A good and simple practice is to use distance tables that are made up from ship's operation (in order to follow the fairways and normal routes).

More advanced methods are numerical data applications that optimise the shortest way between two points and calculate the distance. However, as the traffic has increased substantially this has demanded traffic regulation into zones or single lane fairways that must be considered in the assessment. This is also possible to do numerically.

When using a port to port record it is impossible know which way the ship took between two ports if there is an option of two or more routes. It is not generally the shortest route as it normally depends on the cost of taking the different routes and when the ship has a choice of route because of its dimensions. A typical example of this is the entrance to the Baltic Sea. For ships up to a certain size the option is to pass around the Skaw or to go by the Kiel Canal. Having passed the Skaw there is an option to go by the Drogden (Öresund) or the Baelt. In assessment of emissions in the Baltic Sea area the options have been modelled from size of ship and frequency of ships that use the different routes.

There is some information of value when building up the ship traffic information. Information from official sources is normally not enough as they do not register the voyage. The information needed is the port the ship calls and where the ship came from or the next port. Further it is recommended that the ships identity is the only information to be recorded. The identity is preferably the IMO number.

The ship's character is then collected from a register, Lloyds Register-Fairplay or a class register from a Classification society.

Ships' movements can be purchased from LMIU (Lloyds Maritime Intelligence Unit). The information is based on observation from agents in the ports. The information gives the present port, previous port, the next port, date of arrival/departure, the ship's type and size in GT and DWT as well as the IMO number of the ship.

The information has proved to be somewhat unreliable and inconsistent as it depends on the agents and their alertness. LMIU has also a ships register.

The ports and the Maritime Administrations usually collect information such as ships' particulars, present, previous and next port plus information for calculating the proper dues. Normally this is the GT and the DWT but it can also be the length of the ship or the NRT. In this respect there is no harmonisation of the information registered.

The increased use of IT gives new IT port systems where ports cooperate in using ships register and these ports can save and share information collectively. This simplifies the ship registration at calls.

Even though the ports may have complete and clear information regarding a ship and ship calls there is no system today to collect the port information and make it available for research purposes.

Although some sophisticated information systems are in operation today in a number of ports. The European ports do not have a common standard for registration and will not share the information because of pure commercial reasons.

5.2 Ships' simplified data

To facilitate for a simple and reliable calculation of the emissions from the ships, a regression based on the type of ship, the size and the speed of the ship has been made. The regression is based on the registered number of ships of given type and speed. The idea is to enable an assessment where the only parameters known are the ship's type and size. Optional is a better figure if the speed also is known. The speed in this case is the service speed.

It should be noted that the figures are always an average of a spectra. This applies for everything from ship's speed – power diagram to the emission factors. Only when regulating equipment controls are present it is possible to present a fixed value. The emission factors controlled by a regulating system that regulates the exhaust to a fixed value will give a reasonably close value within certain limits at certain conditions.

Emissions and power/speed performance of ships varies substantially and can shift from time to time and is very much dependant on the trimming of the engine, see Figure 16.

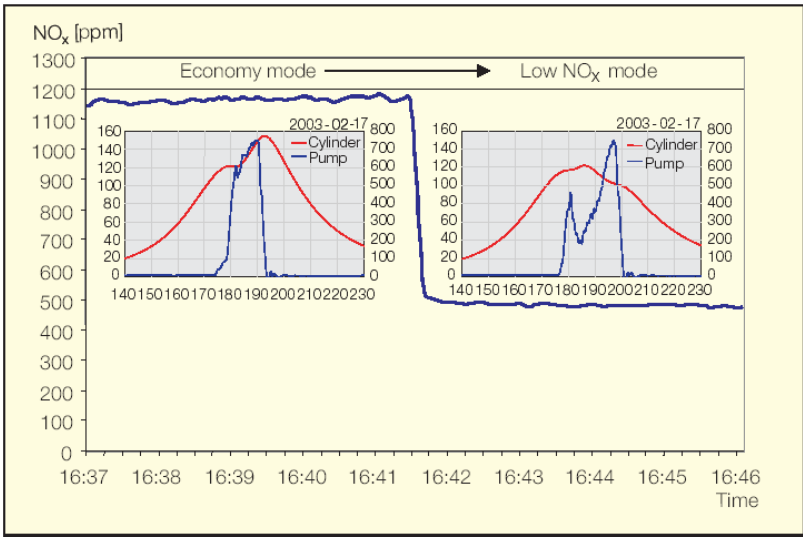


Figure 16; The difference in tuning the engine to a energy efficient burning or NOx minimising burning[12]

The condition of each cylinder, the fuel pumps, the valves etc. is also affecting the performance of the emissions and thus the level of NO_x, HC and particles from each cylinder.

This illustrates the complexity of the data. However, by IMO Annex VI and the regulations regarding the max NO_x and sulphur in the fuel, it can be expected that the shipping society will take actions to follow the regulation which will give a target of more controlled conditions of the marine engines. That is a more accurate level of emissions that can be counted for.

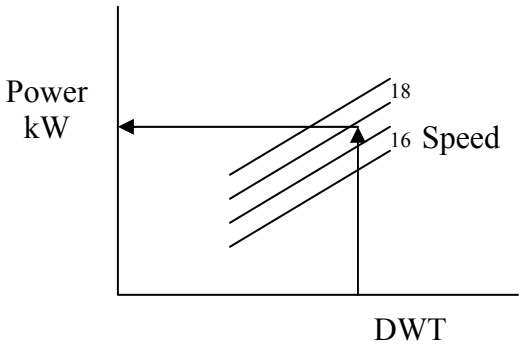
12 Ref: MAN B&W, Two Stroke Engines

6 How to use the information in a SEA[13]

The information built up in the algorithms is based on the Lloyds Register – Fairplay's ships database. The database contains more than 140,000 ships whereof about 58,000 have been used for the analysis. The limitation is set according to the ship categories described in the first chapter and for ships that are built 1980 or later. The reason for this limitation is to look at more modern ships that are in active service. The information used is 63,076 suitable ships build 1980 or later although limited to ships in operation. From these ships 44,669 have all information that suits the study. Further some 100 ships have been omitted of miscellaneous reasons.

For each ship's category information about 47 items have been used for the calculation of ships' energy consumption; at sea and in port.

The data used for the calculation of ships fuel consumption en route is; the ships installed power, the ships speed and the ships size in GT and/or DWT.



The figure illustrate how the algorithm works. The size of the vessel in DWT or GT and its speed will give the demanded power consumption for the category of ship concerned.

The ship's category also determines the power consumption during the ship's stay in port. Some ships are just hotelling while others use the Auxiliary Engines (AE) for the loading/discharging. This has to be modelled for each type of ship.

A non published study for the port authority of Visby regarding cruise vessels' traffic in the Baltic Sea during the summer of 2003 suggests a rough estimate of required output in kW when at quay/anchor to be 0,15*GT for larger cruise vessels (> 10,000 GT) and 0,1*GT for smaller cruise ships.

A report of energy and emission factors for ships in operation [4] concludes the following Auxiliary Engine loads (of total installed auxiliary engine output) when loading/unloading.

*Table 12; Average power output figures for auxiliary engines**

AE load	All vessels	General Cargo	Bulk	Ro/Ro	Tankers	Car Ro/Ro
Loading/unloading	43%	33%	32%	41%	62%	37%
Lay-Time	21%	27%	21%	25%	19%	18%

* Tanker Loading/unloading figure applies for unloading only. Lay-time applies for loading

The overall distribution of ships from size is shown in Figure 17. The vast majority of ships are in the class between 500 – 5,000 DWT. In this class the General Cargo ships are dominating.

[13] SEA Strategic Environmental Assessment

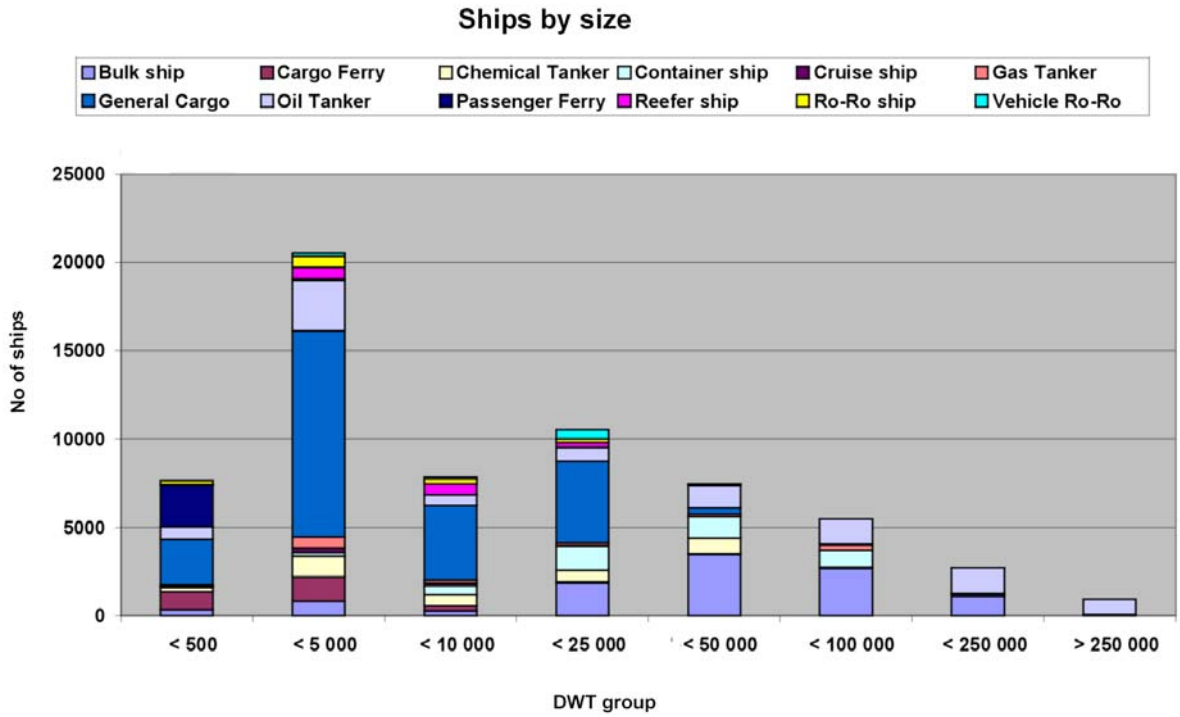


Figure 17; Number of ships by size and type

The average speed of the ships presented in detail as a function of the fuel consumption for each ship type in the following. The general overview of the ships speed in relation to DWT and GT is shown in Table 13 and Table 14 below.

Table 13; The average speed per ship type and DWT group

	Average Speed Knots							
DWT Group	<500	<5 000	<10 000	<25 000	<50 000	<100 000	<250 000	>250 000
Bulk ship	11	12	13	14	15	15	15	14
Cargo Ferry	20	19	22	19	18			
Container		14	16	19	22	24	25	
Cruise Ship	15	18	21	23				
Gas Tanker	17	13	15	16	17	19		
General Cargo	13	13	14	16	15	15		
Passenger Ferry	30	18	19	23				
Reefer Ship		15	19	21	21			
Ro-Ro	14	16	18	18	20			
Tanker	13	13	13	14	15	15	15	15
Vehicle RoRo	14	16	19	19	19	15		

Table 14; The average speed per ship type and GT group

	Average Speed Knots							
GT Group	<500	<5 000	<10 000	<25 000	<50 000	<100 000	<250 000	>250 000
Bulk ship	12	13	14	15	15	15	14	
Cargo Ferry	16	18	20	20	23	22		
Container		14	17	19	22	24	25	
Cruise Ship	19	15	17	19	21	22	22	
Gas Tanker		13	15	16	17	20	20	
General Cargo	12	13	15	17	15	15		
Passenger Ferry	31	26	17	21	23			
Reefer Ship	16	16	19	21	21			
Ro-Ro	13	15	16	18	21	22		
Tanker	10	13	14	15	15	15	15	17
Vehicle RoRo	15	15	16	18	19	20		

The age profile in relation to the emission factors is also analysed. The age profile of the oil tanker fleet[14] is in given in Figure 18 and Figure 19.

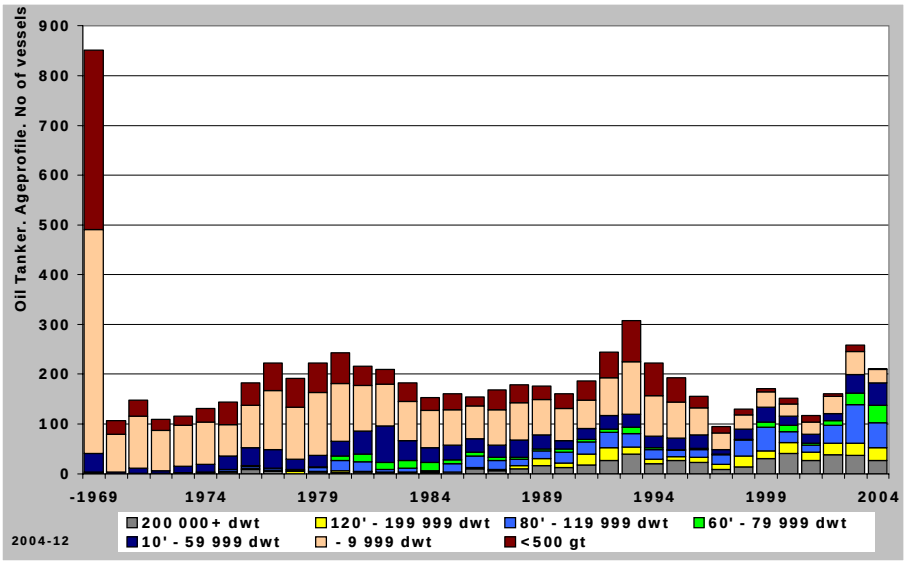


Figure 18; The age profile of tankers

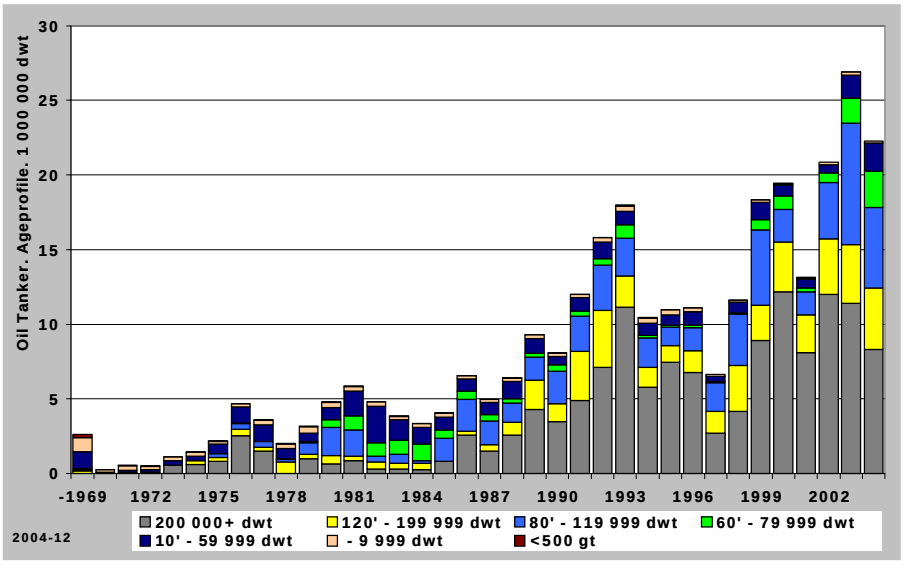


Figure 19; The age profile of oil tankers in relation to transport capacity, DWT

[14] The age of the ship is the registered date of built

All other types of ships are presented in Appendix I.

In the same way it is of interest to see how the demand for speed has developed over the years. In most cases the demand for speed are set by the cost of operation. As the lifetime of the ships are 20 – 30 years and it takes 2 years to build a ship the phase of development is very slow. In the following graphs development of the average speed and fuel consumption over time is shown for General Cargo vessels.

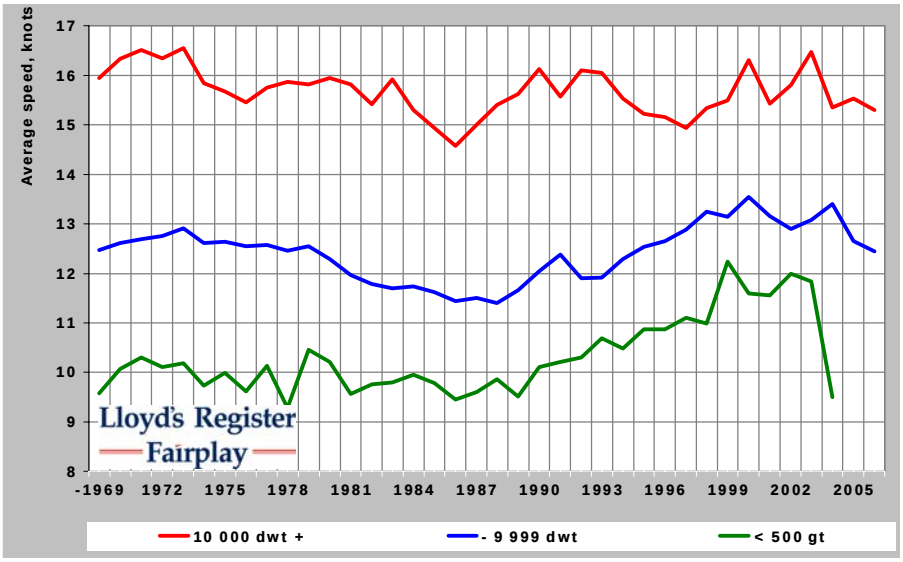


Figure 20; The average speed in relation to age for General Cargo ships

The speed normally gives the fuel consumption although it is known that in times when the fuel is expensive the ship owners try to save as much fuel as possible by slowing down speed. This type of measures is difficult to determine by statistics.

Table 15;The average emission factors per ship's type, size and day

		Average emissions of ships delivered 1990-2006 (incl order)							
		g NOx /dwt/day	g NOx /gt/day	g CO /dwt/day	g CO /gt/day	g HC /dwt/day	g HC /gt/day	g PM /dwt/day	g PM /gt/day
Oil Tanker	200 000 dwt +	31	58	1,4	2,7	0,9	1,6	0,9	1,7
	60' - 199 999	46	82	2,6	4,7	1,5	2,8	1,4	2,5
	E 10' - 59 999 dwt	81	129	3,7	5,9	2,8	4,4	2,4	3,8
	F - 9 999 dwt	131	190	5,0	7,2	5,1	7,4	2,5	3,7
	X < 500 gt	*Records not avilable for ships of this size*							
Chemical Tanker	60 000 dwt +	49	83	3,3	5,6	1,7	2,8	1,7	2,9
	10' - 59 999 dwt	96	150	4,7	7,3	2,9	4,5	2,4	3,6
	- 9 999 dwt	171	249	6,9	10,3	5,4	7,8	2,6	3,7
	< 500 gt	*Records not avilable for ships of this size*							
Gas tankers	LNG	114	69	9,0	5,4	1,8	1,1	0,0	0,0
	LPG 50 000 cbm +	180	217	7,5	9,0	6,1	7,3	3,4	4,3
	LPG - 49 999 cbm	89	105	4,9	5,7	2,7	3,1	2,9	3,5
	< 500 gt	*Records not avilable for ships of this size*							
Bulker	80 000 dwt +	39	75	1,7	3,2	1,3	2,6	1,1	2,1
	55' - 79 999 dwt	48	90	2,9	5,4	1,8	3,4	1,5	2,9
	10'-54 999 dwt	73	121	3,5	5,9	3,1	5,1	2,1	3,4
	- 9 999 dwt	183	260	3,4	4,9	1,3	1,9	2,8	4,0
	< 500 gt	*Records not avilable for ships of this size*							
Container	5 000 teu +	278	298	12,3	13,2	14,7	15,5	8,8	9,1
	3' - 4 999 teu	264	308	9,9	11,6	12,5	14,6	7,8	9,0
	1' - 2 999 teu	243	303	12,1	14,9	10,9	13,4	7,4	9,3
	- 999 teu	240	297	10,1	12,4	3,7	4,6	4,2	5,1
	< 500 gt	*Records not avilable for ships of this size*							
Reefer	7 100 cbm +	412	434	18,2	19,2	18,7	18,9	12,5	12,4
	- 7 099 cbm	334	300	9,2	8,2	6,9	5,3	3,8	4,1
	< 500 gt	*Records not avilable for ships of this size*							
Dry cargo n.e.s.	10 000 dwt +	135	184	6,1	8,3	4,6	6,4	3,9	5,2
	- 9 999 dwt	162	217	6,1	8,2	4,3	5,9	2,5	3,3
	< 500 gt	*Records not avilable for ships of this size*							
Vehicle Ro-Ro	4 000 ceu +	321	105	16,4	5,4	9,6	3,2	9,6	3,2
	- 3 999 ceu	442	162	16,0	6,1	15,7	5,8	7,0	3,0
	< 500 gt	*Records not avilable for ships of this size*							
Ro-Ro n.e.s.	2 200 lm +	439	249	23,9	14,4	12,4	8,0	9,0	5,3
	- 2 199 lm	368	281	13,7	10,6	11,4	9,2	4,7	4,1
	< 500 gt	*Records not avilable for ships of this size*							
Ferry; Cargo	1 300 lm +	1 964	361	89,8	17,3	42,7	7,8	23,0	4,4
	- 1 299 lm	1 806	341	71,4	16,5	44,9	8,8	28,1	5,8
	< 500 gt	*Records not avilable for ships of this size*							
Ferry; Non Cargo	> 500 gt	1 249	273	77,9	17,5	35,1	6,5	15,8	2,5
	< 500 gt	*Records not avilable for ships of this size*							
Cruise	1 000 low berths +	1 904	184	199,2	19,7	25,4	2,4	0,0	0,0
	- 999 low berths	1 860	202	59,7	6,8	64,7	7,4	15,0	2,3
	< 500 gt	*Records not avilable for ships of this size*							
Average all		**188**	**175**	**9,3**	**8,1**	**6,2**	**6,4**	**4,5**	**5,1**

The factors are based on the by the manufacturer[15] reported engine emission factors for each individual type of engine. The information is also used as a base for the following figures. The fact that the more detailed the information is the less will the samples of each figure be. Lack of samples is shown as broken lines in the figures.

[15] The sample represents 60 % of all ships built 1990 or later in the used ship's database

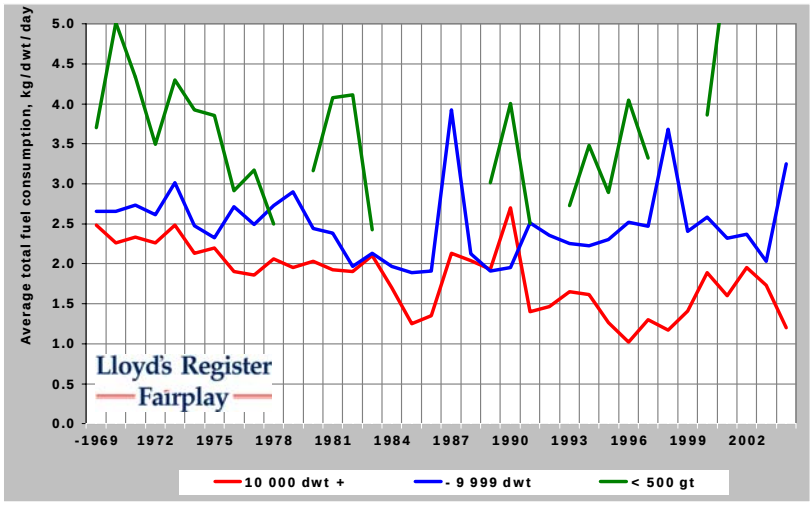


Figure 21; The average fuel consumption per year of built and transport capacity for General Cargo ships

In the statistics of energy efficiency there is a clear trend of increased energy efficiency for most of the ship types. This is explained by the development of the ships engines over time. As for the emission factors the development show a break point at the start of the new century. The demand for environmental measures forced the engine manufacturer to develop ships engines that featured low emissions. This applies especially for ships in urban services.

Figure 22 show the development of NO_x emissions for Cargo Ferries. It should be noted that the characteristics shown in the figures are strongly influenced by the number of ships built each year and the availability of data for these ships. A broken curve indicates insufficient data to set a value.

As there is a contradiction between the reduction of NO_x and fuel efficiency that only can be solved by investments in additional equipment and a more complicated engine the development in an open market is slow. Development in the area is in progress but there is still time before a wider commercial break through can be expected.

The market has to see a commercial added value of the cleaning equipment to invest in it and use it in a wider scale. The only alternative is an enforcement by rules and regulations that can give a faster progress.

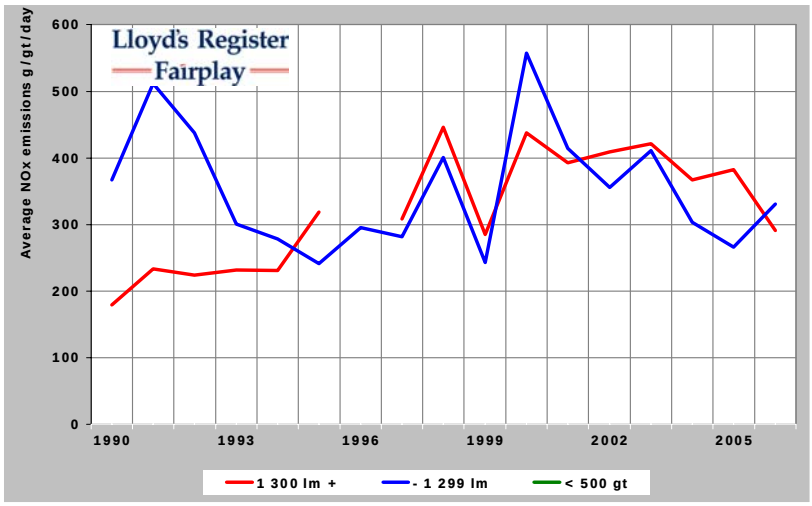


Figure 22; The development of NO_x emissions for Cargo Ferries

Ships over 35,000 DWT are to a large extent engaged in intercontinental traffic, while ships of less than that cover the short sea shipping activities. The emissions are determined by the fuel

consumption per hr which is determined by the installed power and the energy efficiency of the ship's engine. The fuel quality can be estimated from Table 4. Not knowing the type of fuel used can be solved by either to set a quality that is relevant for the trading area (this is preferred) or to use a function of the statistics given in Table 16 and Table 17.

Table 16; Statistics of used fuel for different type of ships

Ship types		Type of Fuel MDO	% of fuel consumption	MGO	% of fuel consumption	RO	% of fuel consumption	Total
Oil Tanker	Percent of type using the quality	64%	44%	1%	0%	35%	56%	**4 598**
	Sum of Fuel Consumption T/Day	92 857		477		119 961		**213 295**
Chemical Tanker	Percent of type using the quality	85%	80%	4%	4%	12%	16%	**1 251**
	Sum of Fuel Consumption T/Day	18 930		1 048		3 785		**23 763**
LNG	Percent of type using the quality	25%	30%	9%	8%	65%	62%	**75**
	Sum of Fuel Consumption T/Day	2 612		702		5 307		**8 620**
LPG	Percent of type using the quality	80%	76%	2%	2%	17%	21%	**539**
	Sum of Fuel Consumption T/Day	7 755		236		2 184		**10 175**
Bulker	Percent of type using the quality	72%	73%	0%	0%	28%	27%	**5 135**
	Sum of Fuel Consumption T/Day	110 589		31		41 083		**151 702**
Combination	Percent of type using the quality	65%	51%			35%	49%	**355**
	Sum of Fuel Consumption T/Day	10 113				9 676		**19 789**
Container	Percent of type using the quality	84%	83%	1%	0%	15%	16%	**1 867**
	Sum of Fuel Consumption T/Day	104 304		615		20 657		**125 576**
Reefer	Percent of type using the quality	81%	80%			19%	20%	**857**
	Sum of Fuel Consumption T/Day	15 622				4 018		**19 640**
General Cargo	Percent of type using the quality	75%	64%	1%	1%	24%	35%	**10 568**
	Sum of Fuel Consumption T/Day	84 482		1 381		45 585		**131 448**
Vehicle Ro-Ro	Percent of type using the quality	85%	80%	0%	0%	14%	19%	**408**
	Sum of Fuel Consumption T/Day	9 000		37		2 178		**11 215**
Cargo Ro-Ro	Percent of type using the quality	82%	75%	3%	3%	15%	22%	**674**
	Sum of Fuel Consumption T/Day	12 715		504		3 674		**16 893**
Cargo Ferry	Percent of type using the quality	85%	77%	3%	6%	12%	18%	**1 275**
	Sum of Fuel Consumption T/Day	32 567		2 472		7 488		**42 528**
Passenger Ferry	Percent of type using the quality	91%	76%	3%	9%	6%	14%	**456**
	Sum of Fuel Consumption T/Day	2 935		348		557		**3 839**
Cruise	Percent of type using the quality	71%	61%	3%	7%	27%	31%	**266**
	Sum of Fuel Consumption T/Day	11 901		1 437		6 095		**19 433**
Total Number of ships		**21 160**		**332**		**6 832**		**28 324**
Total Sum of Fuel Consumption T/Day		**516 382**		**9 288**		**272 246**		**797 916**

Table 17; The average fuel consumption and the relation of consumption between the ship types

Ship types		Type of Fuel MDO	Average	MGO	Average	RO	Average	Total	Average Tons/day
Oil Tanker	Number of ships	2 963	31	24	20	1 611	74	**4 598**	56
	Sum of Fuel Consumption T/Day	92 857		477		119 961		**213 295**	
Chemical Tanker	Number of ships	1 058	18	45	23	148	26	**1 251**	19
	Sum of Fuel Consumption T/Day	18 930		1 048		3 785		**23 763**	
LNG	Number of ships	19	137	7	100	49	108	**75**	116
	Sum of Fuel Consumption T/Day	2 612		702		5 307		**8 620**	
LPG	Number of ships	432	18	13	18	94	23	**539**	19
	Sum of Fuel Consumption T/Day	7 755		236		2 184		**10 175**	
Bulker	Number of ships	3 697	30	3	10	1 435	29	**5 135**	30
	Sum of Fuel Consumption T/Day	110 589		31		41 083		**151 702**	
Combination	Number of ships	232	44			123	79	**355**	61
	Sum of Fuel Consumption T/Day	10 113				9 676		**19 789**	
Container	Number of ships	1 567	67	21	29	279	74	**1 867**	68
	Sum of Fuel Consumption T/Day	104 304		615		20 657		**125 576**	
Reefer	Number of ships	694	23			163	25	**857**	23
	Sum of Fuel Consumption T/Day	15 622				4 018		**19 640**	
General Cargo	Number of ships	7 915	11	132	10	2 521	18	**10 568**	13
	Sum of Fuel Consumption T/Day	84 482		1 381		45 585		**131 448**	
Vehicle Ro-Ro	Number of ships	348	26	2	18	58	38	**408**	28
	Sum of Fuel Consumption T/Day	9 000		37		2 178		**11 215**	
Cargo Ro-Ro	Number of ships	552	23	22	23	100	37	**674**	26
	Sum of Fuel Consumption T/Day	12 715		504		3 674		**16 893**	
Cargo Ferry	Number of ships	1 082	30	41	60	152	49	**1 275**	35
	Sum of Fuel Consumption T/Day	32 567		2 472		7 488		**42 528**	
Passenger Ferry	Number of ships	413	7	15	23	28	20	**456**	10
	Sum of Fuel Consumption T/Day	2 935		348		557		**3 839**	
Cruise	Number of ships	188	63	7	205	71	86	**266**	81
	Sum of Fuel Consumption T/Day	11 901		1 437		6 095		**19 433**	
Total Number of ships		**21 160**		**332**		**6 832**		**28 324**	
Total Sum of Fuel Consumption T/Day		**516 382**		**9 288**		**272 246**		**797 916**	

The power itself gives the fuel consumption to be linked to the type of engine and its Specific Fuel Consumption (SFC) which together with the emission factors depend on the type of engine.

Knowing the type of vessel, size and service speed it is possible to make a reasonable estimation of the installed main engine (ME) output in kW. Based on the stated main engine outputs in Lloyd's Register - Fairplay's database a statistical fit to the relation between the size of the vessels in GT and DWT has produced functions giving the probable ME power output. Each type of vessel is sorted into it operating speed (the integer value). Forming a set of data the group has been plotted and trend lines are retrieved using power regression.

Trends which can be considered to be representative for each ship type, e.g. those that have large populations and good statistical fit (an the value of exact fit to the curve, R^2 value, as close to 1 as possible) are used as basis for the correction of the trend lines for adjacent speeds in accordance of the theoretical distribution of the speed curves. Speed samples that are based on just a few observations are thus calibrated to fit to the theoretical level. The theoretical level is given by using curves having high accuracy as guidelines.

It is not possible to take account for all the dimensions that rules the function between the ship type, its size and the power needed to produce the speed. All the demanded information is not registered why the method is based on the statistics that gives a probability level that can be considered fair. Extreme ships must be noticed separately in an assessment (normally these are high speed ferries etc.) which are added to the total assessment separately.

Figures that associate with each type of ships are shown in the following chapter. Thus the presented equations are combinations between theoretical models and statistical values.

The resulting equations that fit best to a theoretical and statistical curve are:

ME (kW) = k*GT^n for the ships that relates to volume and ***ME (kW) = k*DWT^n*** for ships that relates to the weight of the vessels

The constants k and n are given by tables for each vessel type at a given speed, see tables in chapter 8.

The most likely type of main engine (ME) for each type of ship can be determined using diagrams presented chapters. Generally, small ships have four stroke diesel engines and larger have two stroke diesels, although this is not valid for all ship types. Ships with frequent port calls and/or limited space will normally be equipped with four stroke engines. The two stroke engines require more space although they are more fuel efficient. Some of the largest ships may have Steam Turbines, although it is not common on more modern ships.

Final emissions depend on fuel consumption and data found in Table 19, presented in g/kWh.

In order to operate all electric equipment onboard most vessels have additional engine power, or Auxiliary Engines (AE). A rough approximation of installed AE power can be made using equations in Table 18 and them shown in diagrams associated with each ship type in the following chapters. These relations are based on reliable data from 3,791 ships. The results for Tankers are split in Chemical and Oil and that Cruise AE power depends on whether the ship is equipped with diesel – traditional gear propulsion system or a diesel – electric propulsion system.

AE (kW) = k*(GT/DWT)^n

k and n are constants given per ship type, below.

Table 18; AE power based on vessel size

	k	*DWT/GT*	*n*
Oil Tanker	9,6262	DWT	0,703
Chemical Tanker	5,5294	DWT	0,5863
LNG Tanker	0,0047	DWT	1,2147
LPG Tanker	18,043	DWT	0,5057
Bulker	35,312	DWT	0,3603
Container	0,5504	DWT	0,8637
Reefer	0,4827	DWT	0,9375

	k	*DWT/GT*	*N*
General cargo	0,7476	DWT	0,7796
Vehicle carrier	0,4916	GT	0,8399
Ro/Ro	1,347	GT	0,7512
Cargo ferry	1,655	GT	0,7658
Passenger ferry	1,13	GT	0,8123
Cruise, Mech drive	0,9341	GT	0,9482
Cruise, Elec drive	0,0142	GT	1,0059

Table 19; Main Engine Specific Fuel Consumption and emissions, g/kWh for diesel engines, based on ME type and size

ME_interval	Eng Cyc	SFC g/kWh	NOx g/kWh	CO g/kWh	HC g/kWh	PM g/kWh
< 500 kW	**2**	N/A	16,24	0,84	0,45	-
< 500 kW	**4**	186,71	12,23	1,30	0,61	0,36
500-2 500 kW	**2**	N/A	16,37	0,90	0,43	0,40
500-2 500 kW	**4**	193,43	11,59	0,92	0,55	0,19
2 500-5 000 kW	**2**	210,00	16,05	0,56	0,42	0,50
2 500-5 000 kW	**4**	186,97	11,94	0,51	0,32	0,20
5 000-7 500 kW	**2**	175,00	18,14	0,67	0,52	0,50
5 000-7 500 kW	**4**	183,93	12,86	0,54	0,23	0,19
7 500-10 000 kW	**2**	175,00	16,80	0,87	0,47	0,50
7 500-10 000 kW	**4**	183,49	12,73	0,53	0,24	0,20
10 000-15 000 kW	**2**	170,00	15,56	0,91	0,47	0,50
10 000-15 000 kW	**4**	181,28	13,15	0,59	0,30	0,20
15 000-25 000 kW	**2**	170,00	16,71	0,80	0,44	0,50
15 000-25 000 kW	**4**	181,30	12,94	0,61	0,26	0,20
> 25 000 kW	**2**	167,00	15,24	0,60	0,22	0,50
> 25 000 kW	**4**	178,66	12,80	0,93	0,23	0,22

6.1 Comparison with other emission assessment methods

TRENDS report by DTU uses a relationship between GT and fuel oil consumption per distance travelled in order to account for the significant influence of speed [1]. The proposed relationships are based on 2,300 vessels from DTU's own database. The report state that the TRENDS database is built on the London Conventon 1969 GT, although the stated Gross Tonnage definition is that of the Olso Convention, GRT.

TRENDS curve fitting and the linear curve fitting proposed by the MEET report [6] are applied on the information in the underlying ship population from this study using the assumptions of ME (Main Engine) load and SFC (Specific Fuel Consumption) from TRENDS[16]. The information is compared in a GT – Fuel Consumption (kg/km) diagram, see Figure 23. The following diagrams show the fuel oil consumption per travelled distance for selected ship types, the actual values are data from LRF (Lloyd's Register – Fairplay). The values are compared to the proposed relations from DTU (as presented in TRENDS) and from MEET. The resulting trend lines indicate that the TRENDS relationships generally overestimate the fuel oil consumption, except for Ro/Ro, container and Reefer ships for which they are more accurate. MEET's straight line function is not valid for smaller vessels. The functions do not consider the low fuel consumption for smaller engines and slow speed ships. It tends heavily to overestimate the consumption of Tankers and General Cargo, especially for larger vessels.

For Reefers the relationship corresponds well with those of General Cargo, but Vehicle Carriers differs from other Ro/Ro vessels (Figure 27 vs. Figure 26).

[16] Based on 85% MCR output and 205 g/kWh in Specific Fuel Consumption

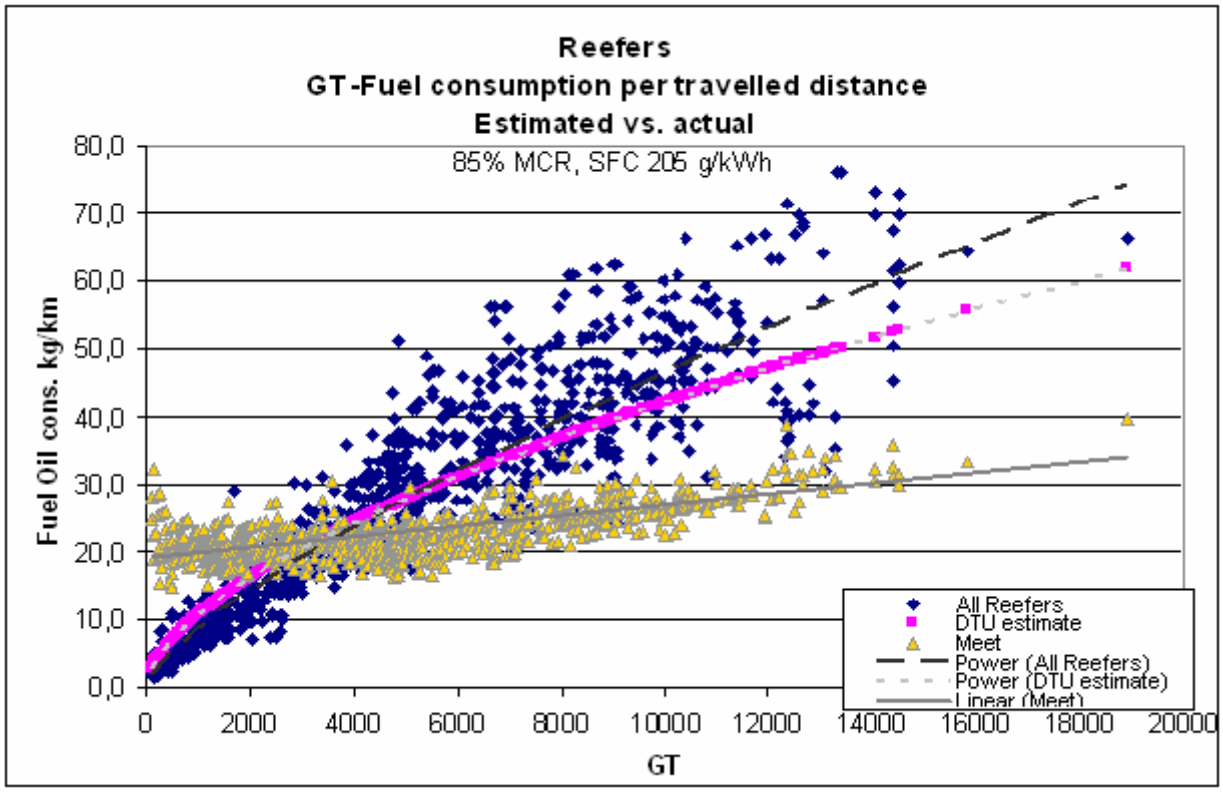


Figure 25; Comparison of methods for estimation of Reefer ships fuel oil consumption per travelled distance

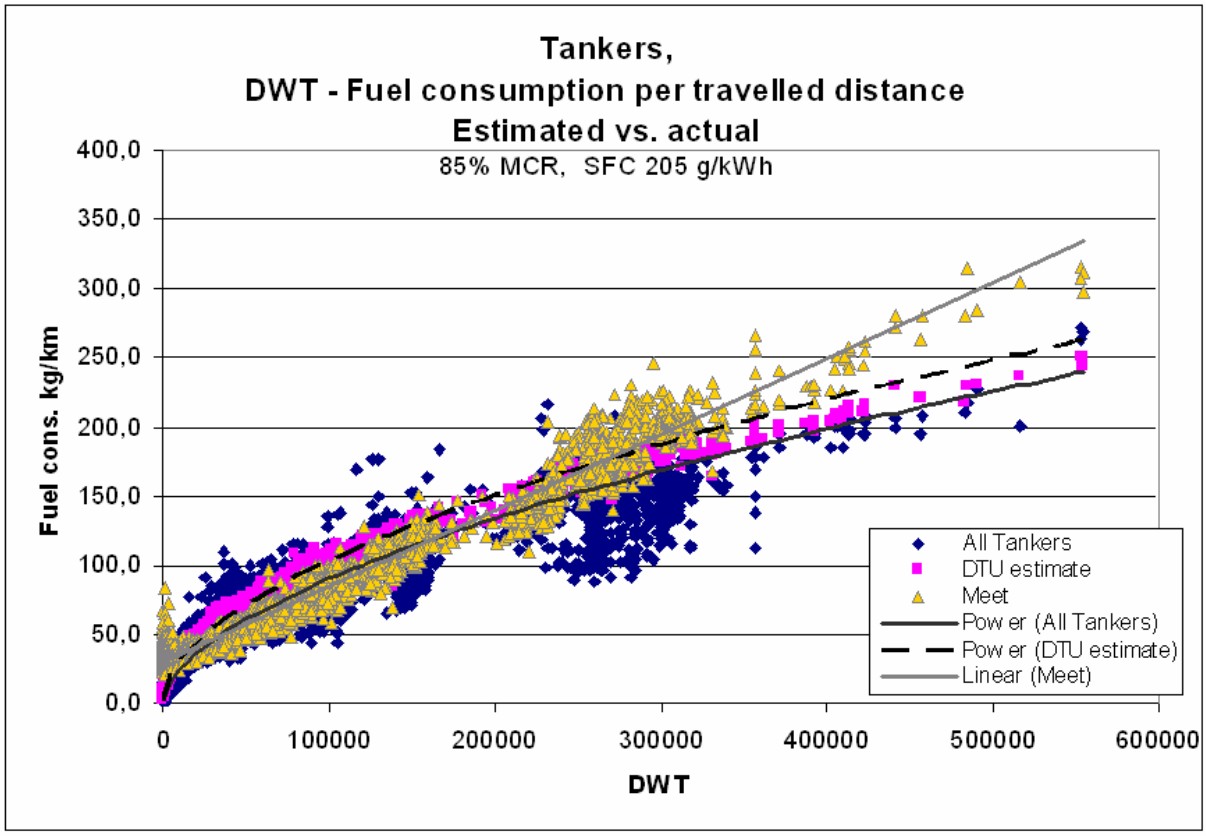


Figure 23; Comparison of methods for estimation of Tankers fuel oil consumption/distance

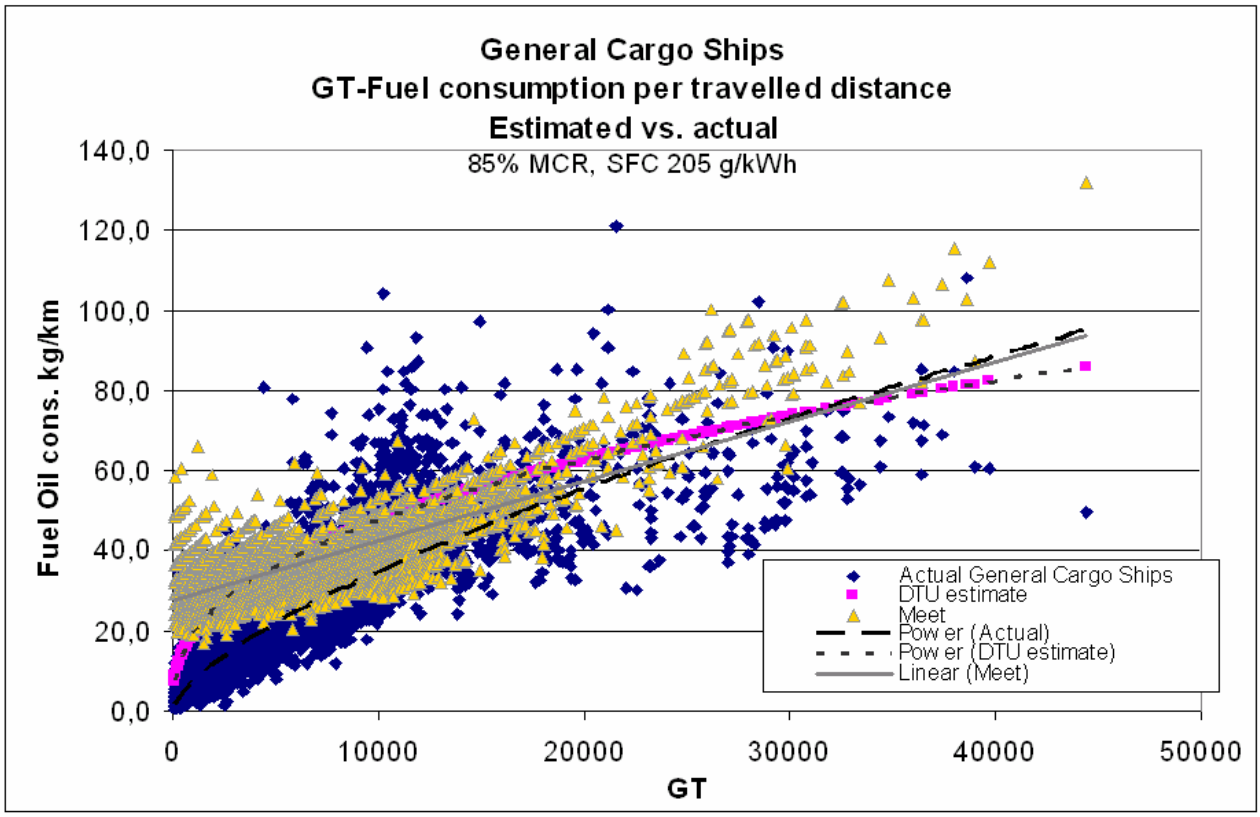


Figure 24; Comparison of methods for estimation of General Cargo ships fuel oil consumption/distance

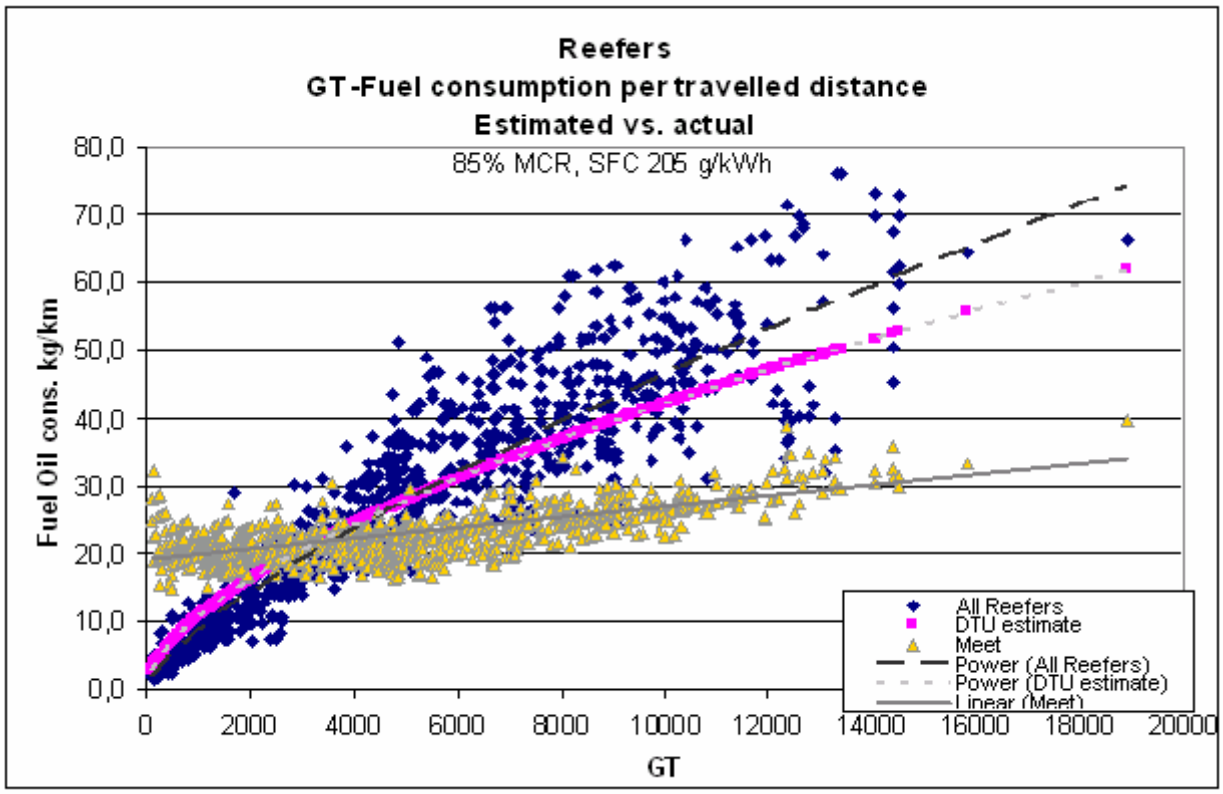


Figure 25; Comparison of methods for estimation of Reefer ships fuel oil consumption per travelled distance

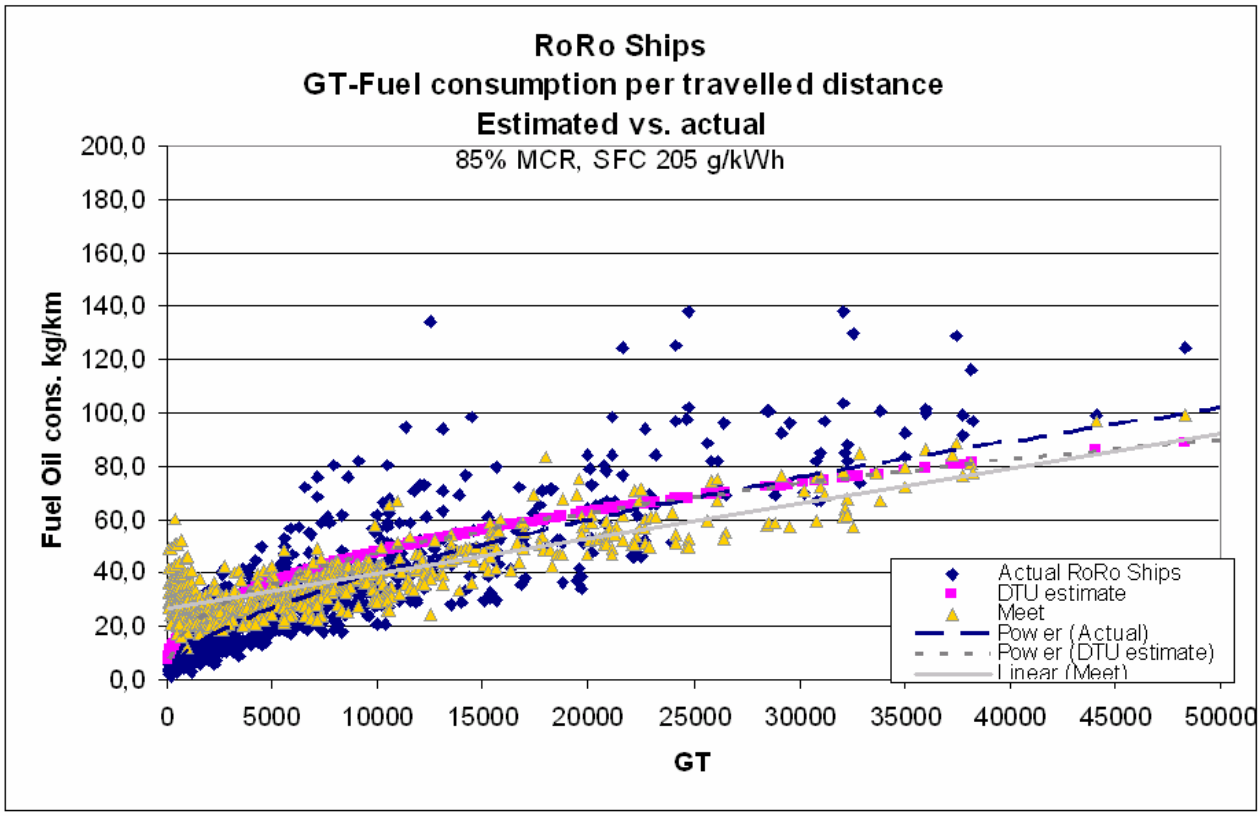


Figure 26; Comparison of methods for estimation of Ro/Ro ships fuel oil consumption/distance

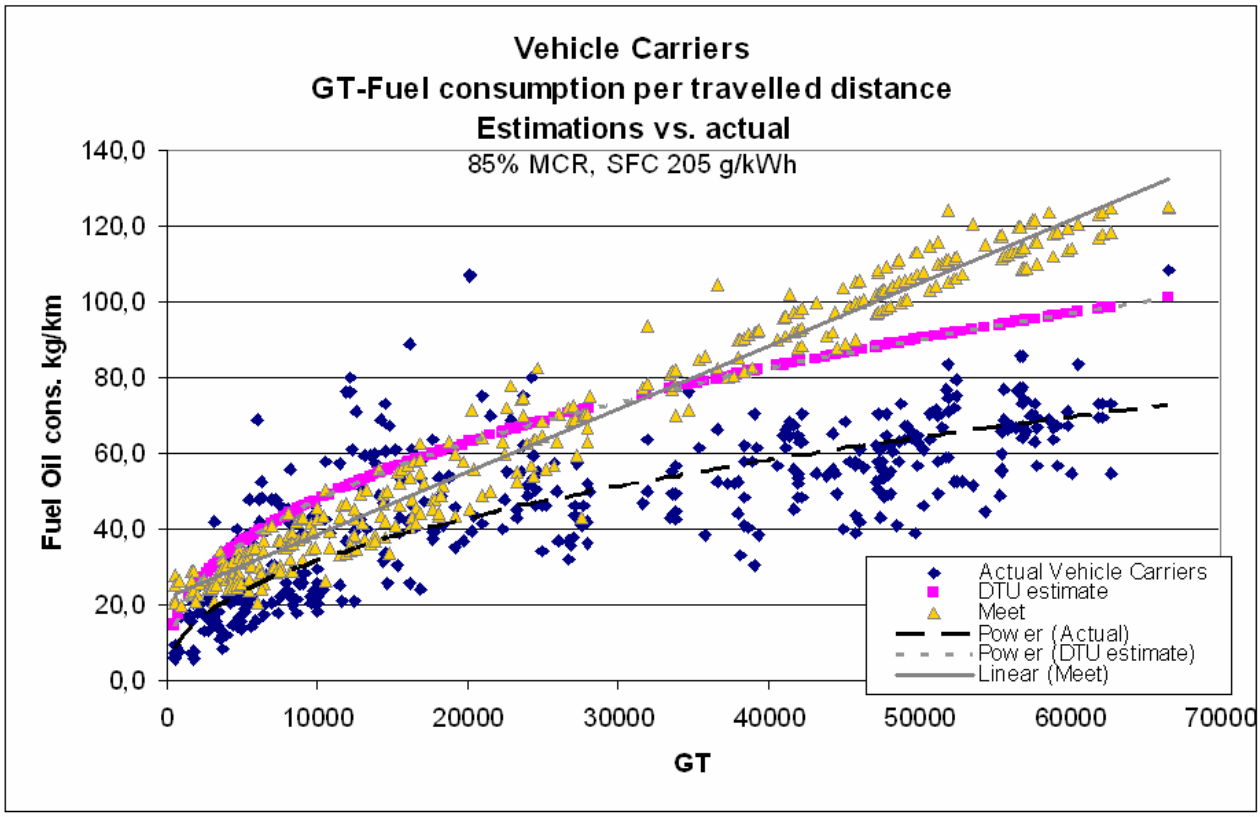


Figure 27 Comparison of methods for estimation of Vehicle Carriers fuel oil consumption/distance

6.2 The relation between energy consumption and size by speed

Bulkers

The Bulk ships are normally of size 20,000 ton and larger. Vessels up to 55,000 DWT are called Handysize or Hadymax, 55,000 up to 80,000 DWT are of Panmax size. The Bulkers are found in these groups which can be seen in the following Figure 28.

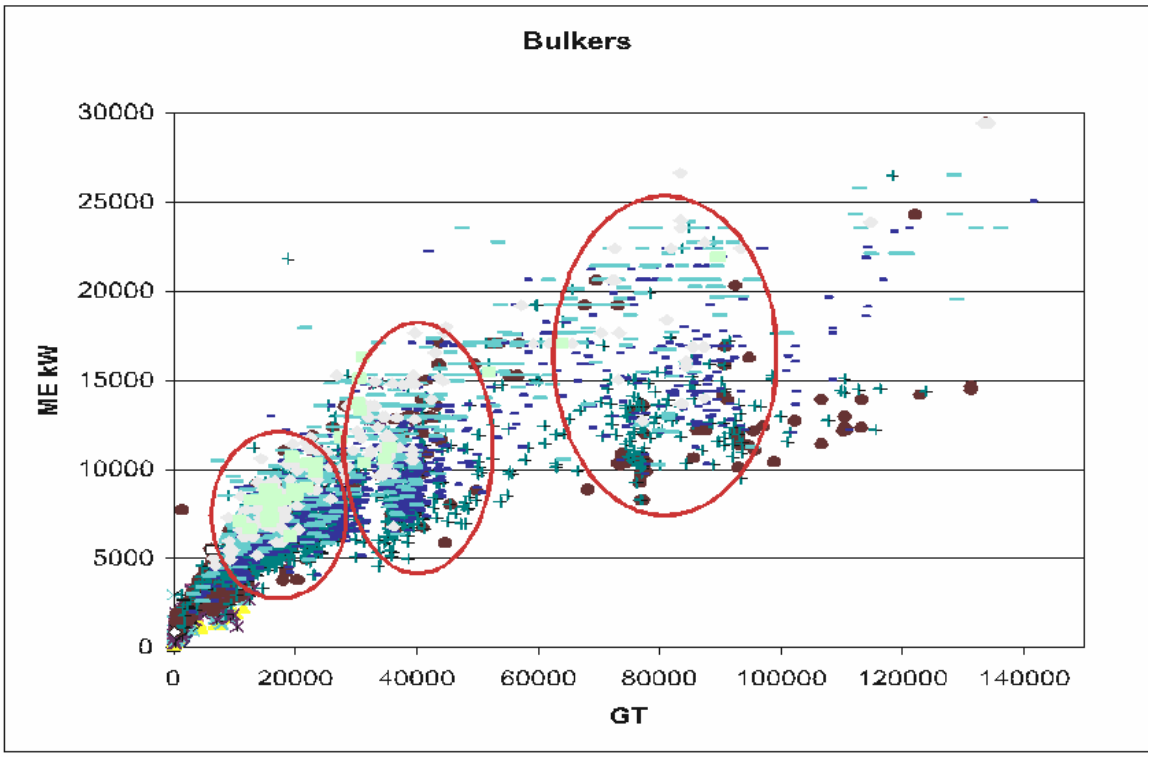


Figure 28; The Bulk ships' intalled power as a function of the Gross Tonnage

The speed is fairly low and the ship type is by this normally an energy efficient vehicle, Figure 29.

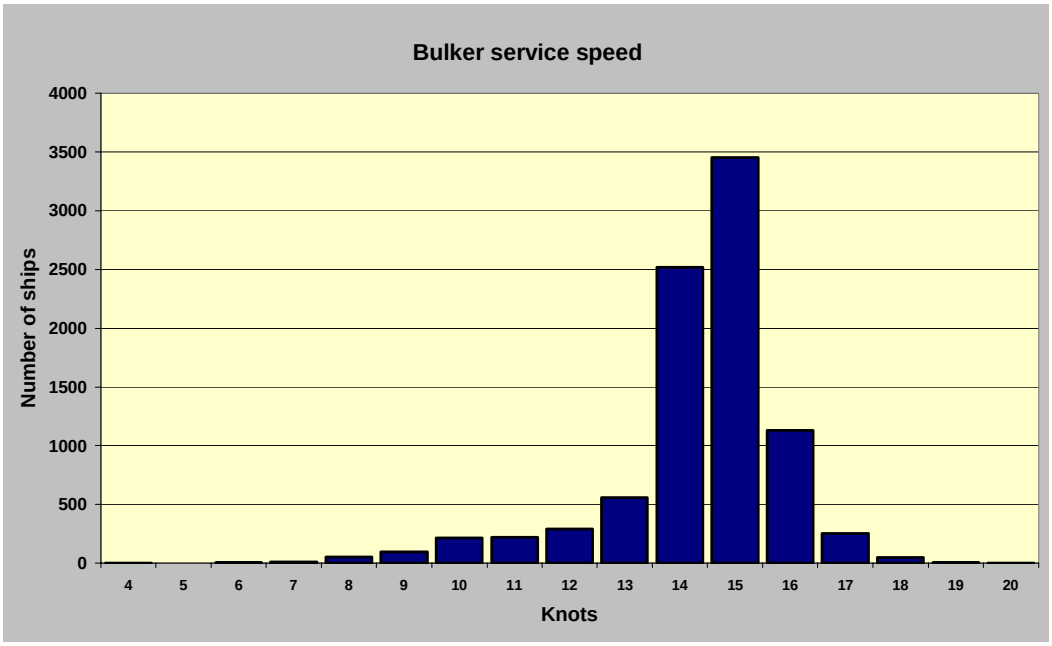


Figure 29; The sample of different speeds of bulk ships show a clear concentration of service speed around 14-15 knots

Some Bulk carriers are equipped with handling gear. This is manly for discharging while the loading of the ship most of times is carried out with equipment in the port.

The speed of the ships built follows the market closely. When the demand is low and the fuel price is high the speed goes down. In good times, as over the past few years, the ship owners can afford to install more power although the fuel cost is high. The speed is still quite moderate which gives one of the best ship types in way of energy efficiency. Most of the smaller ships are burning Marine Diesel Oil while larger ones are burning Residue Diesel Oil. The ship type is the largest dry cargo consumer of fuels. See Table 17.

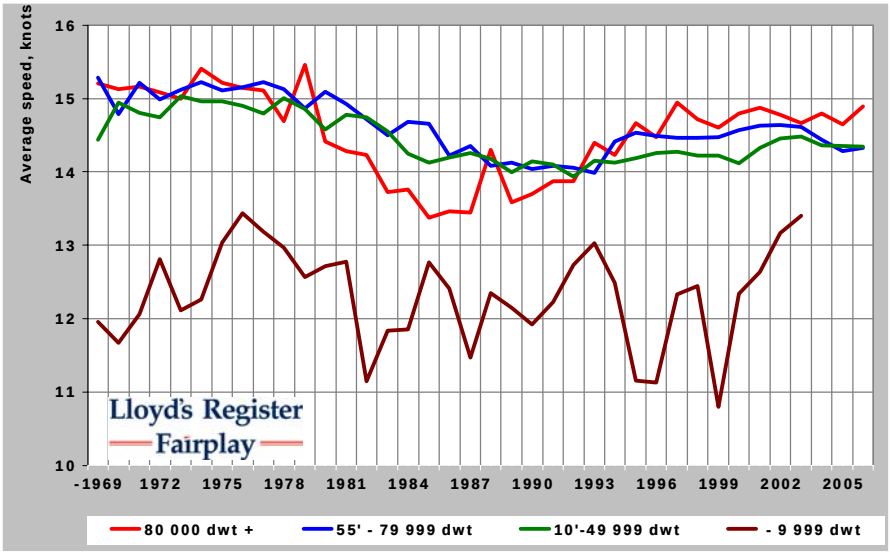


Figure 30; In the last few years the market has been good which shows in increasing speed capability.

The average emission from the ships shown in gives as low as 40 g NO_x per day and DWT.

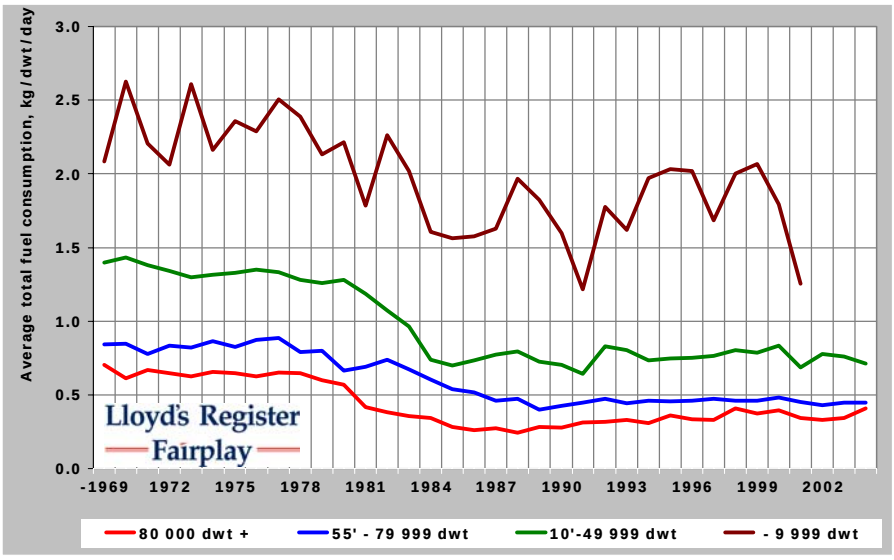


Figure 31; The energy efficiency development for the Bulk ships

The energy efficiency shows a typical development of the two stroke engine. The choice of engine focused on reducing the energy consumption during the oil crises in the 70:ties. This type of engine has the best energy performance of all kinds today. Up to the beginning of the 90:ties there was a development of the fuel efficiency as can be seen for several of the ship types. From this time and on the level is quite stable.

Bulk carriers equipped with own handling gear have a higher fuel consumption during port stops. This is because they use the own handling gear instead of being unloaded by the port's handling equipment. The variation in the relation between size and installed auxiliary engine power can be studied in .

The relations between GT or DWT and ME output for Bulk ships are based on data from about 8,000 vessels with satisfactory information on size, service speed and main engine output (ME). Due to the large span in size of Bulkers, varying from 200 DWT to 200,000 DWT, the data is split into two DWT-groups; Smaller bulkers < 20,000 DWT and Large bulkers 20,000 DWT and up. The equations are guided by the information from the statistics given at 15 knots and adjusted to fit the underlying trends. The equations between GT-ME are also based on the relation at 15 knots, and split in to smaller and larger, but are presented as one equation per speed or speed group.

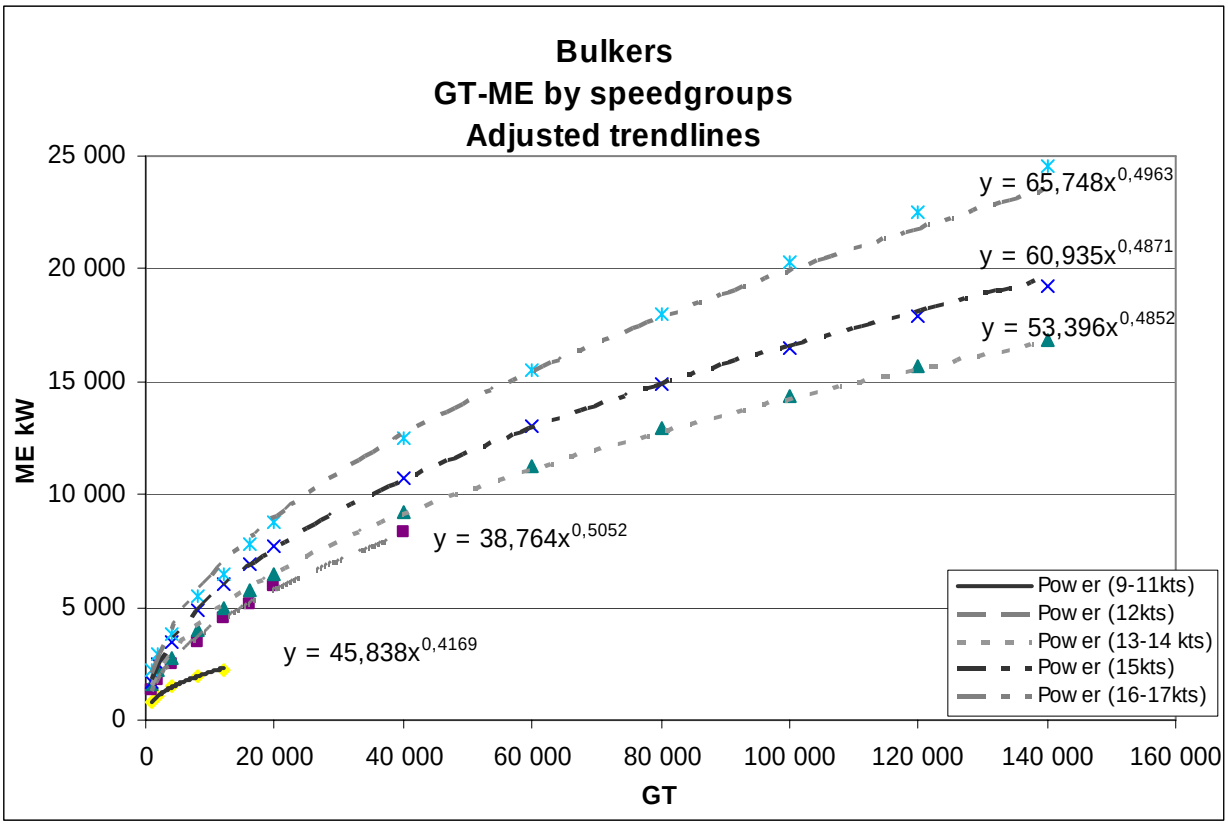


Figure 32; Bulk ships use of ME power in relation to size GT for each speed group

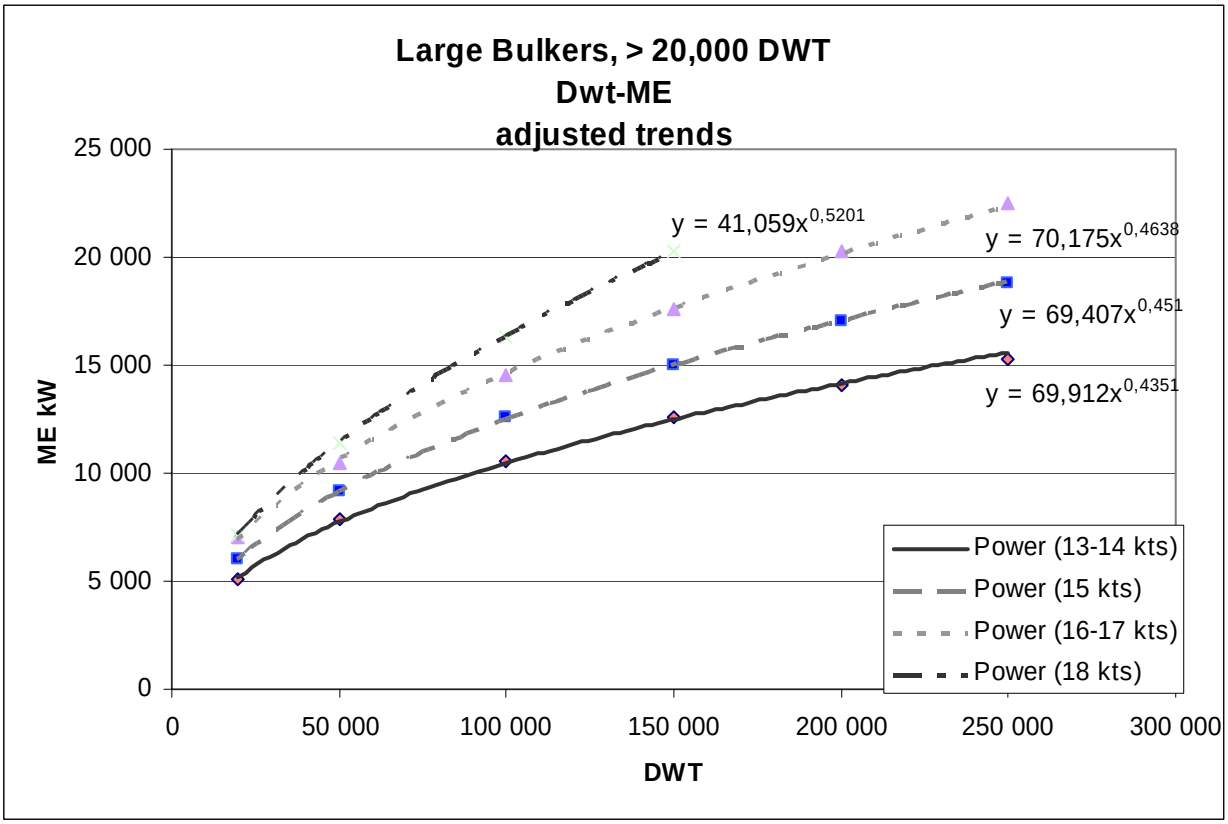


Figure 33; Functions for larger vessels, ≥20,000 DWT

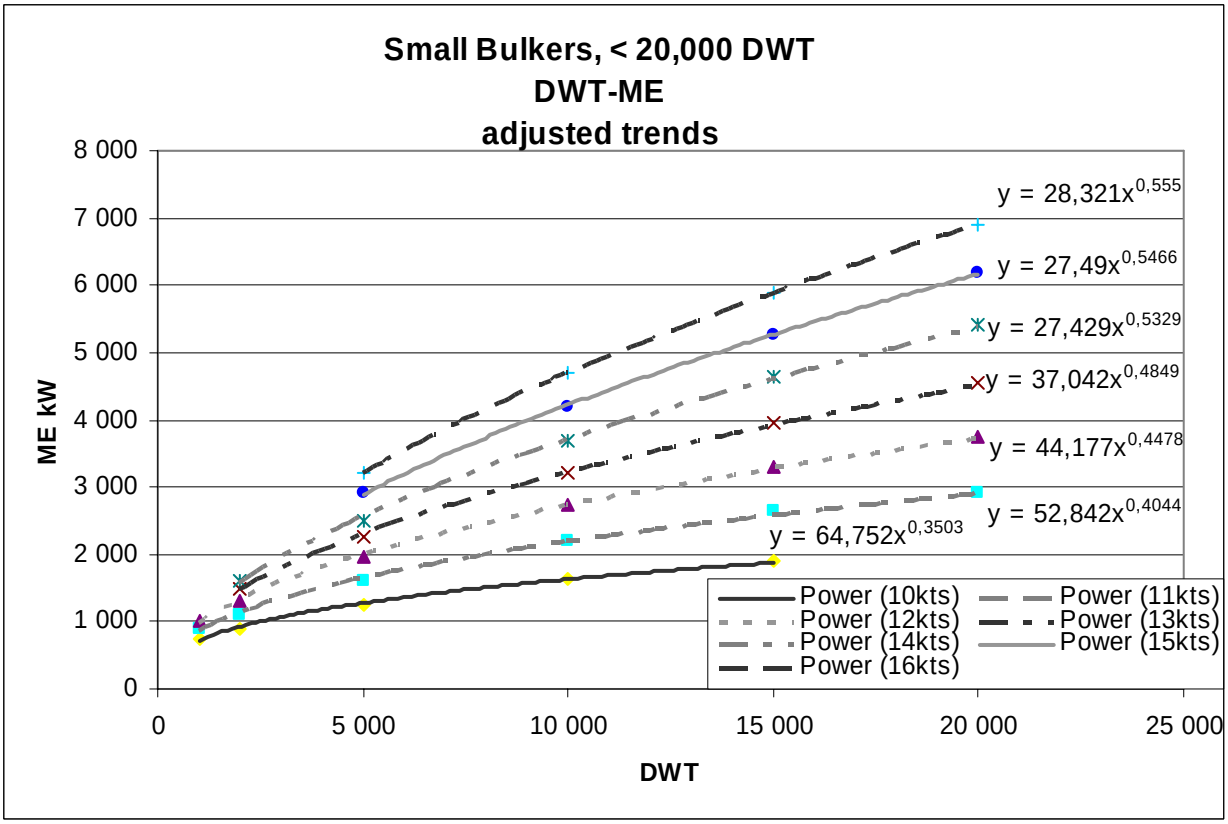
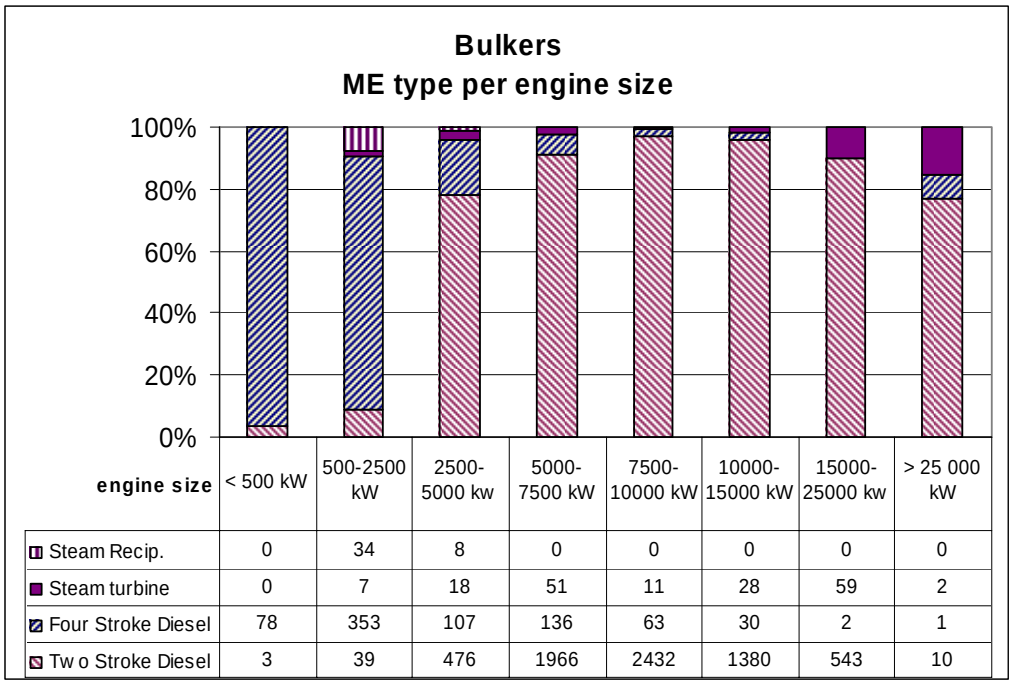


Figure 34; Bulk ships size (DWT) – ME by speed. Funtions for smaller vessels, < 20,000 DWT

When the probable size of the main engine has been determined it is possible to asses what type of engine the ship has using the following table/diagram. This gives the distribution of different engine types per ship type, Figure 35. As can be noted the vast majority of Bulk ships' engines are of two stroke diesel type, except for some of the less powerful ones which are of the four stroke type. Steam reciprocating engines can also be found on smaller vessels, but rarely on vessels built in the last 15 years. Some larger, predominately older, engines are of steam turbine type; however it is also used on newer vessels.



engine size	< 500 kW	500-2500 kW	2500-5000 kw	5000-7500 kW	7500-10000 kW	10000-15000 kW	15000-25000 kw	> 25 000 kW
Steam Recip.	0	34	8	0	0	0	0	0
Steam turbine	0	7	18	51	11	28	59	2
Four Stroke Diesel	78	353	107	136	63	30	2	1
Tw o Stroke Diesel	3	39	476	1966	2432	1380	543	10

Figure 35; Bulk ships main engine type based on ME output

The relation between the size (DWT) and total installed auxiliary engine power is shown in . As can be seen the installed power can vary considerably, largely due to possibly installed handling equipment.

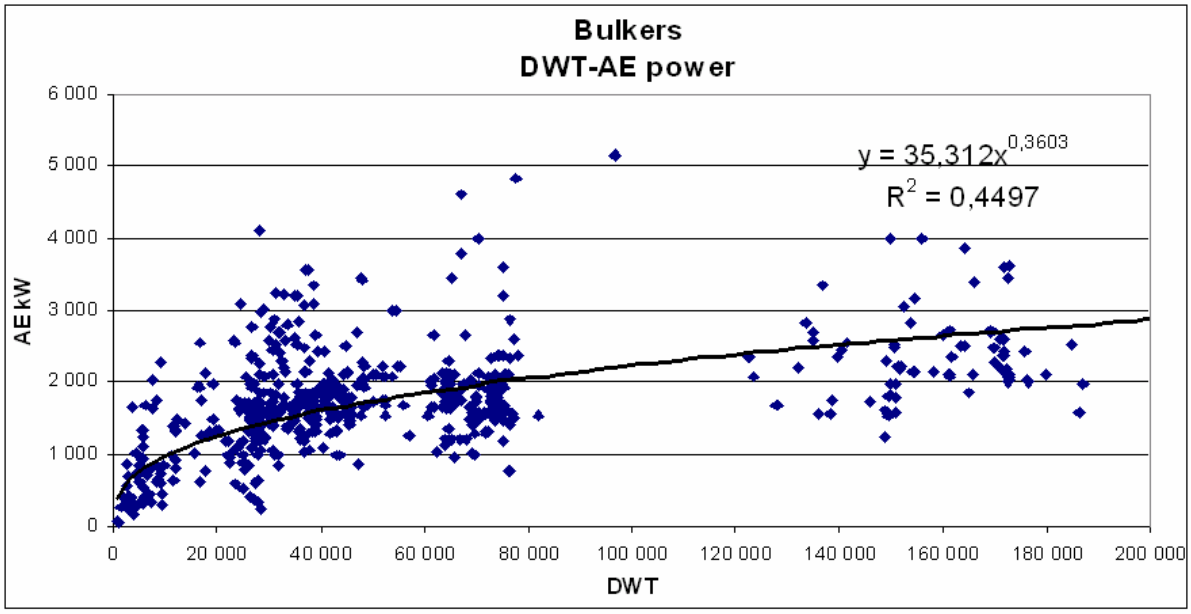


Figure 36; Bulk ships size (DWT) – AE power output. 850 Bulk and Combination ships

Dry Cargo (General Cargo)

The General Cargo ships are the true multipurpose ships trading in the Short Sea Shipping service. In the Baltic the average size of vessel is of 3,500 DWT. Up to 55,000 DWT are called Handysize of Handymax, 55,000 up to 80,000 DWT is of Panmax size.

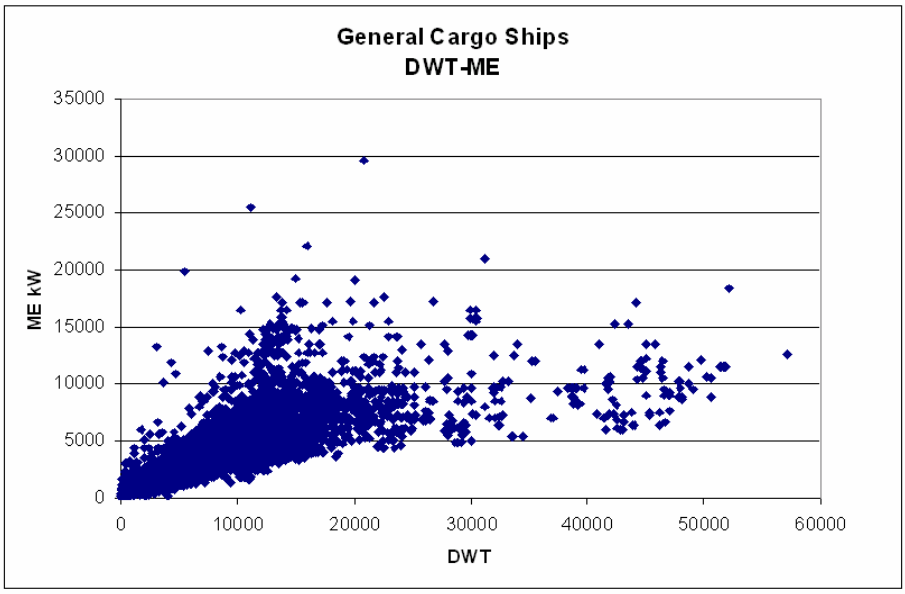


Figure 37; The 16,250 General Cargo ships forms a homogeneous mass in the chart

The General Cargo ships show a quite simple pattern when distributed on a size as a function of propulsion power graph.

The speed is quite low thus giving good energy efficiency. The ship represents the most flexible type, a true multipurpose ship, which carries anything from containers and project cargo to dry bulk. It is normally a tramp activity why the traffic pattern varies extremely.

The ships can be geared or gearless why the fuel consumption in port varies to a large extent.

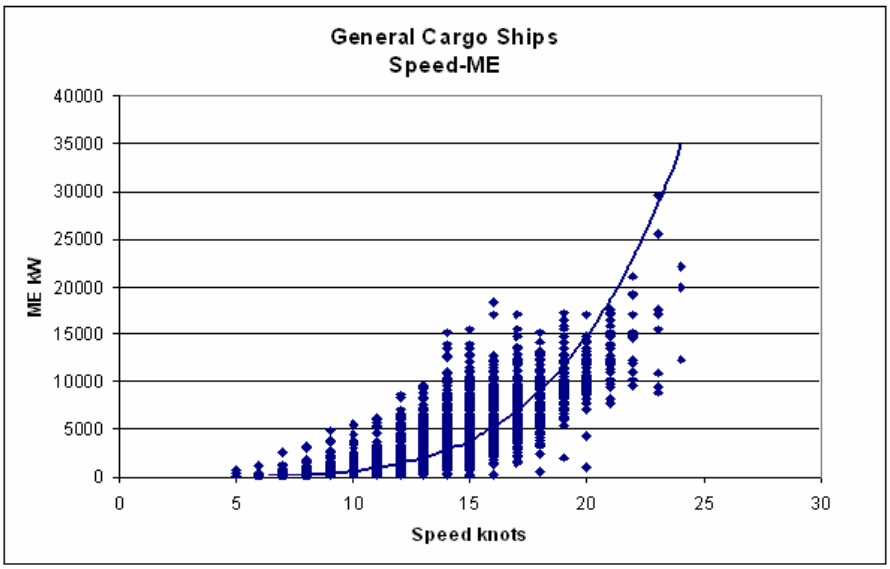


Figure 38; Speed/power relation for General Cargo ships

The speed is low and the deadweight of the ships is normally used at a high extent. The idea of the tramp activities is to increase the utilisation of the ships, just like a trailer on the road. The ship in the best position for taking the next shipment of cargo has naturally an advantage to take the order.

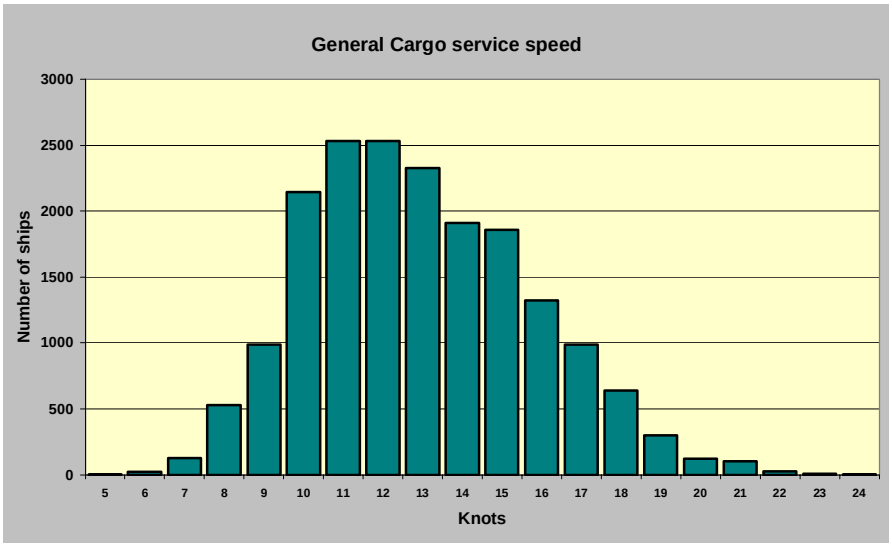
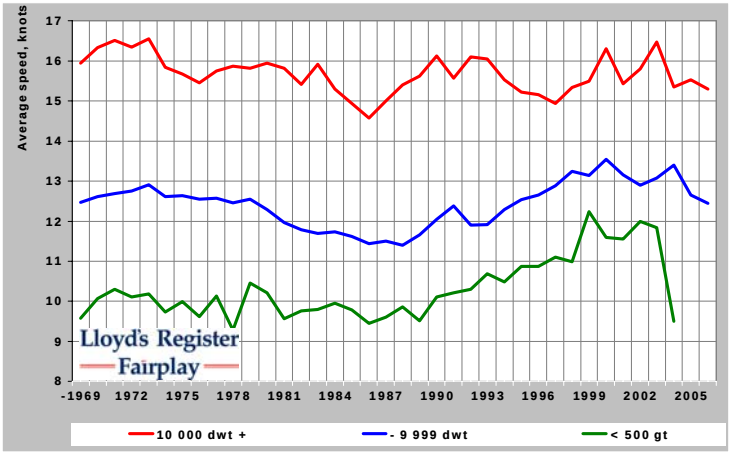


Figure 39; The distribution of speed on the General Cargo ship fleet



Because of the relatively small size and the use of 4-stroke engines, for this type of ships fuel consumption is higher than for the bulk ships. This shows in the energy efficiency diagram, Figure 40.

Figure 40; The speed development over the past decades

The figures give the same impression as regards the fuel consumption development.

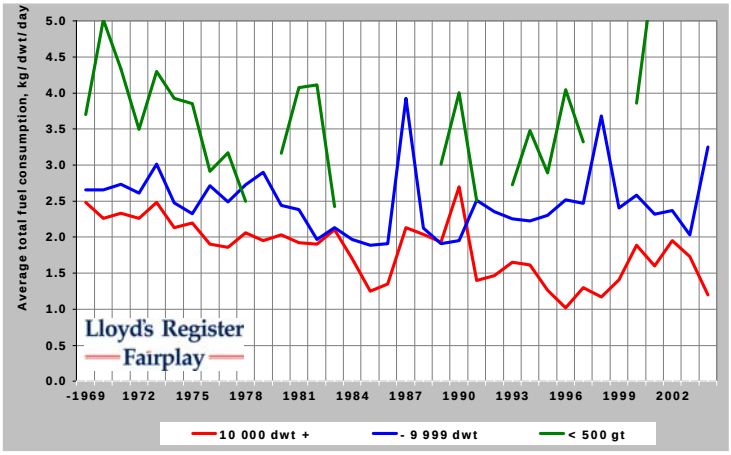


Figure 41; The fuel consumption development for General Cargo vessels

It shall be noted that the speed data cover also future deliveries of ships as the speed normally is known when the contract is made. The fuel consumption is on the other hand an operational figure given by the operator when ship is in service.

There is no way to follow the trends between the information in the diagrams as the final outcome of the fuel efficiency depends on how large the ship is and how much power (speed) that is installed in relation to size. However, the general trend is a decline of consumption for larger ships which may be the effect of a growth in size.

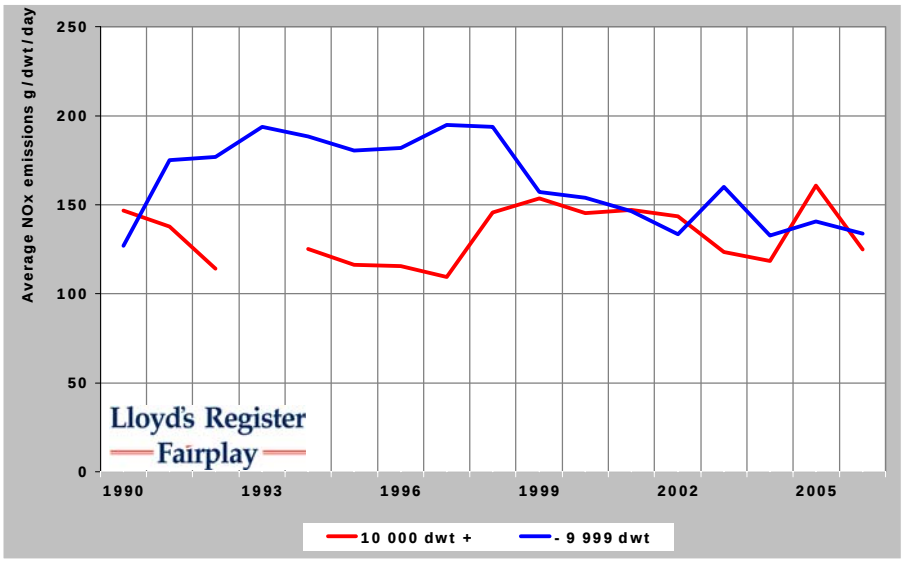


Figure 42; NOx emissions development from General Cargo ships

The Nitrogen Oxides development shows a relatively stable level.

The established relations between size and ME for General Cargo ships are based on data from 16,250 vessels, with credible notations for size, service speed and ME output. The vessel type is very diverse with considerable variations of size, shape and ME within each speed level. However, the overall trends are fairly clear and should be useful for general estimations. The trends for GT-ME at 12 knots have been used for ships < 5,000 GT and 14 knots for larger ships, and the DWT-ME equations are based on the relations at 10 knots for ships <1,000 DWT and 15 knots for larger ships. The final equations are presented per speed level regardless of size.

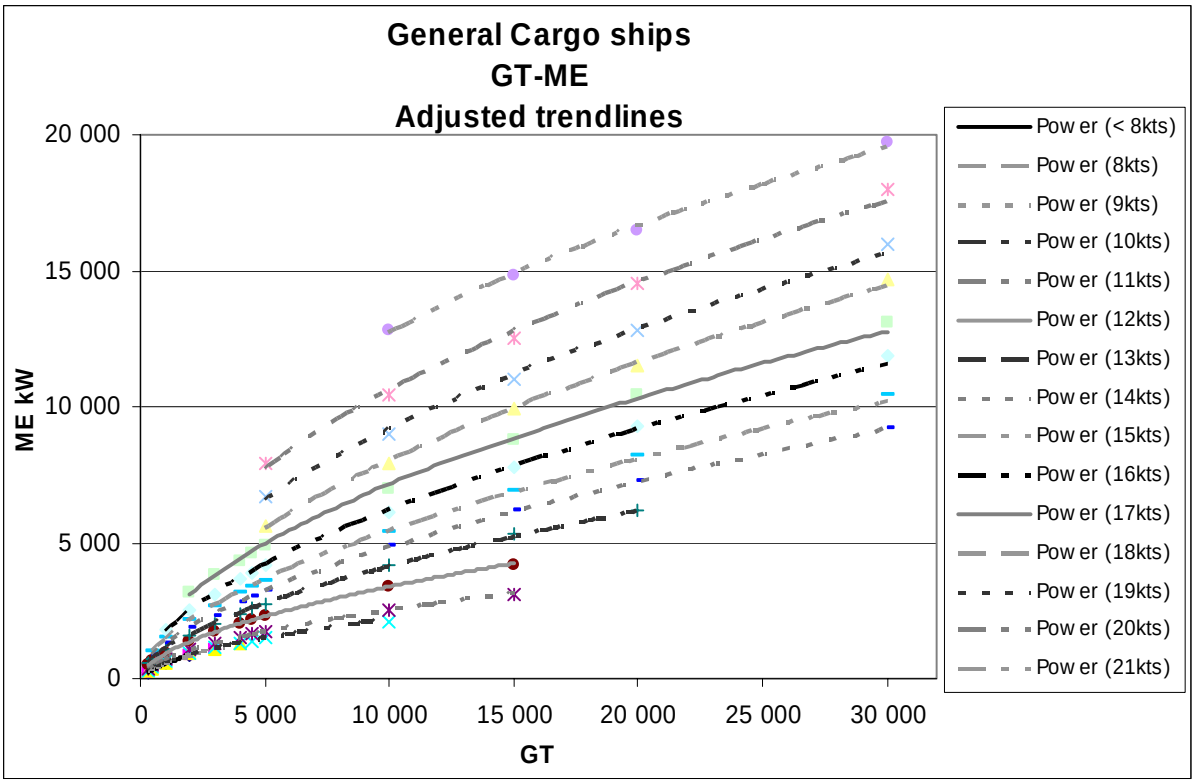


Figure 43; General Cargo ships size (GT) – ME by speed level

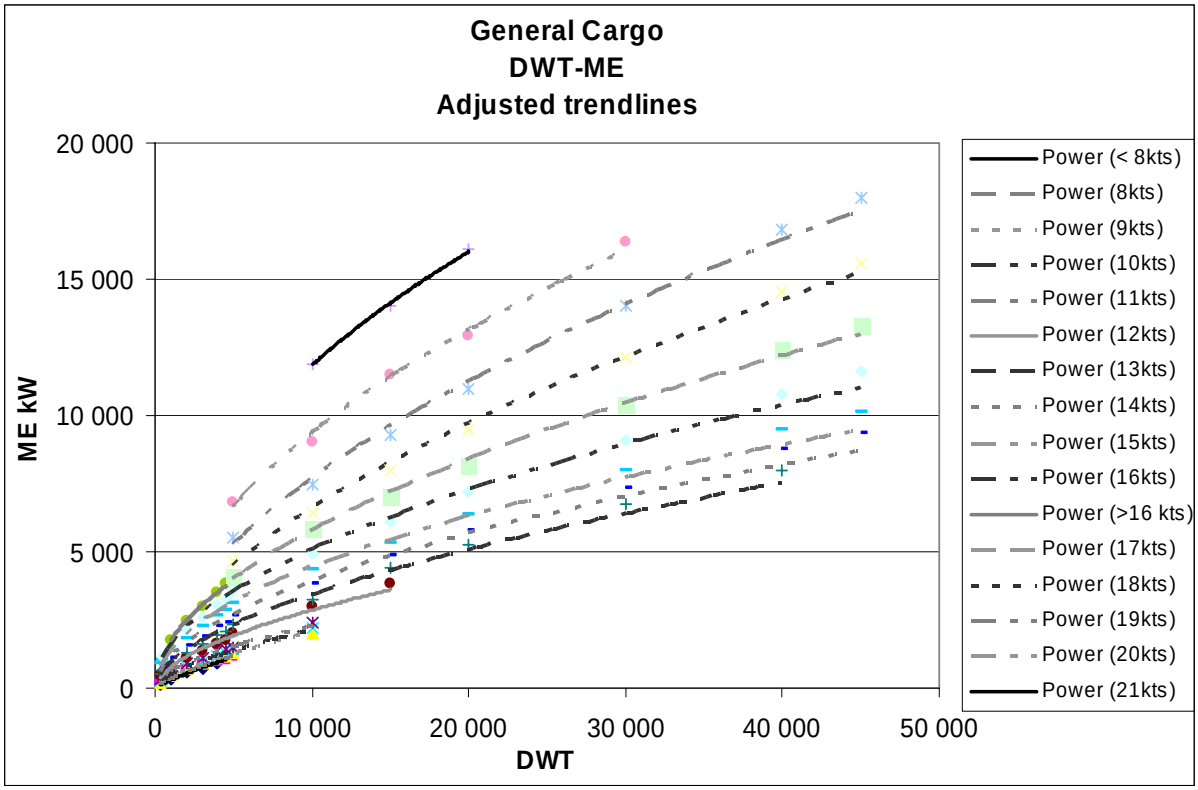
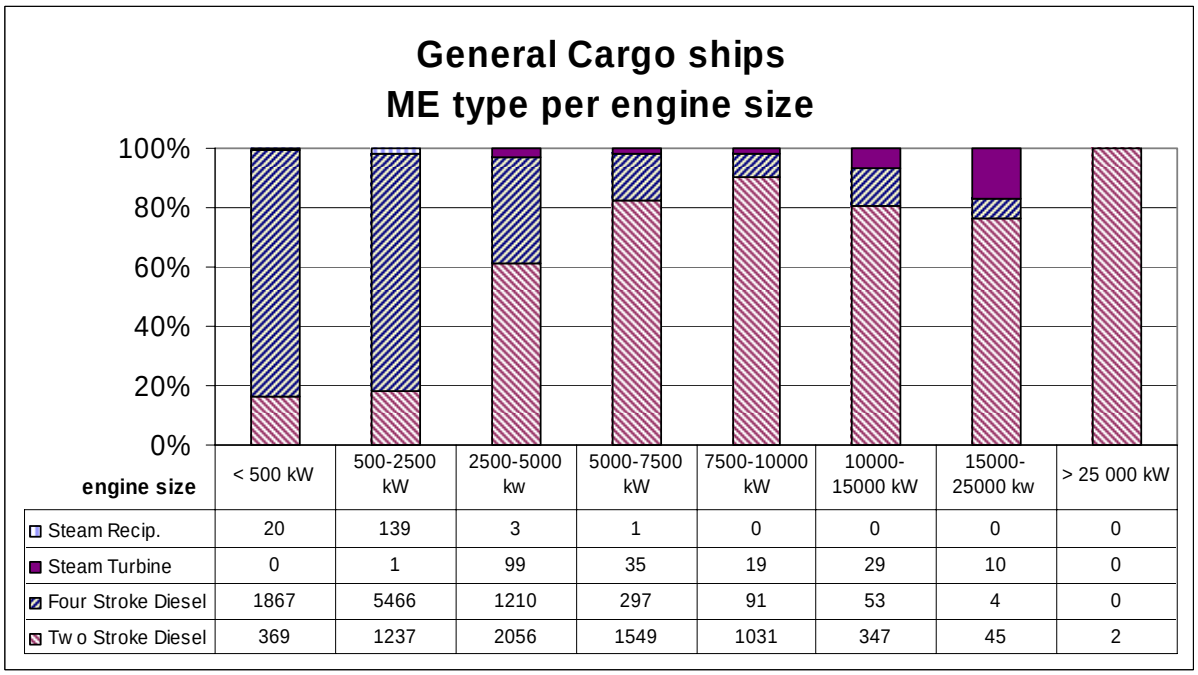


Figure 44; General Cargo ships size (DWT) – ME by speed level

The following table gives the probability of what type of engine used in the General Cargo ship. As General Cargo ships are usually small vessels the most common type of engine is the four stroke diesel engine; the two stroke diesel is more predominate in larger vessels demanding more powerful engines. Steam engines are rare, especially in more modern ships.



engine size	< 500 kW	500-2500 kW	2500-5000 kw	5000-7500 kW	7500-10000 kW	10000-15000 kW	15000-25000 kw	> 25 000 kW
Steam Recip.	20	139	3	1	0	0	0	0
Steam Turbine	0	1	99	35	19	29	10	0
Four Stroke Diesel	1867	5466	1210	297	91	53	4	0
Tw o Stroke Diesel	369	1237	2056	1549	1031	347	45	2

Figure 45; General Cargo ships main engine type per ME output

The total installed auxiliary engine (AE) power can vary depending on installed cargo handling equipment such as cranes, Figure 46.

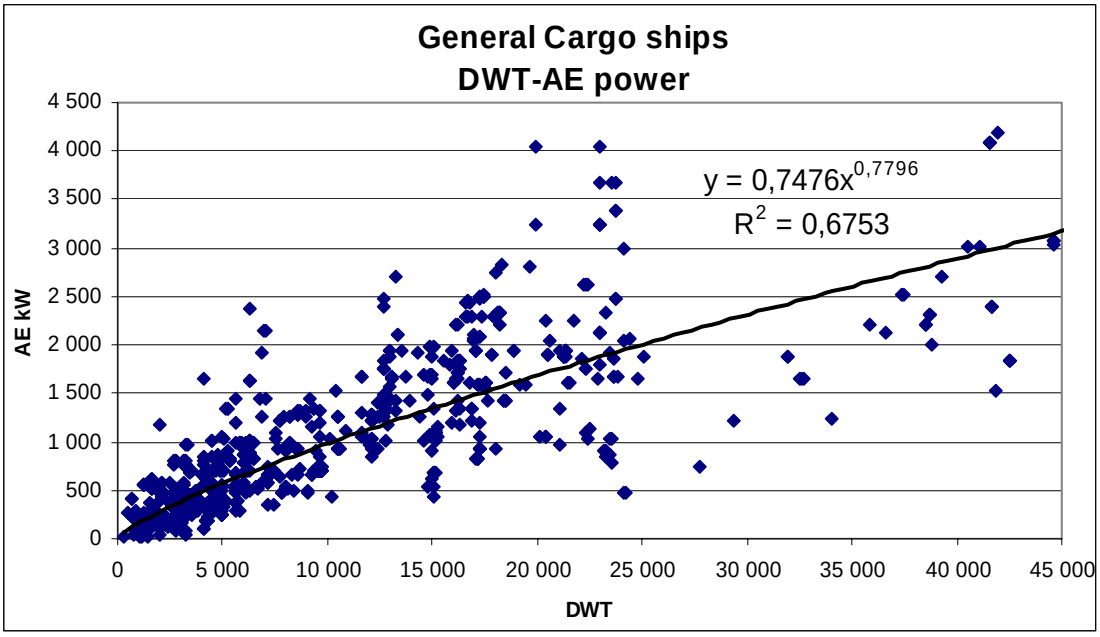


Figure 46; General Cargo ships size (DWT) – AE power output. 743 ships.

Container ships

A dominating character of the Container ships is the direct proportional relation between the number of TEU in capacity and the engine power of the ship. The reason for this is that the ships are in a fixed schedule having a main transport relation between the Far East and America or Europe. Large ships demand more time in port which must be compensated by a faster voyage, hence higher speed and more power. This relation is clear in the diagrams.

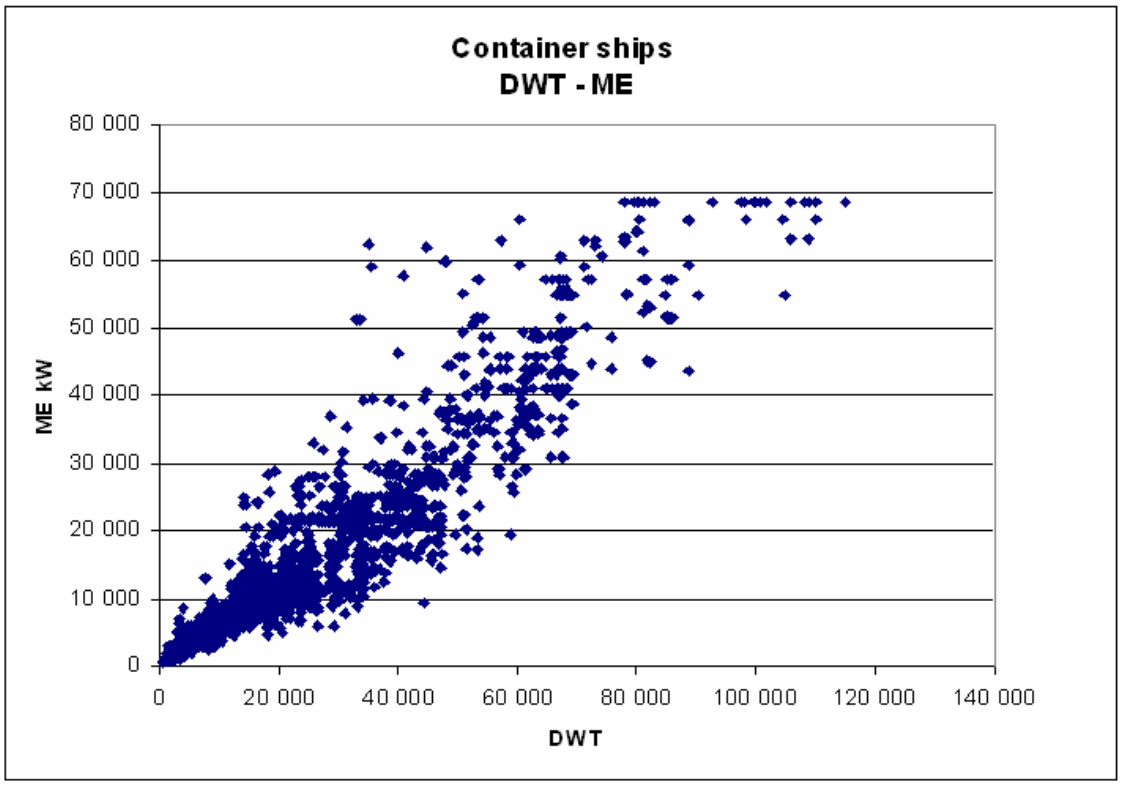


Figure 47; The sample of 3,640 container ships shows a direct relation between the size of the ship and installed power

The character of the container ships is also clearly demonstrated in the diagram of the speed as a function of the size of the ships. As can be noticed there is a sharp power max level just below 70,000 kW. The reason for this is that there was no heavy 2-stroke slow speed direct driven engine available until mid first decade of the first 2000 century. If the ships in order had been added to the statistics we had seen a larger engine to come into the ships. In late 2004 the Samsung shipyard is presented a project of a 12,000 TEU container ship equipped with an 80,080 kW two stroke MAN B&W 14K98ME engine.

This type of engine is supposed to meet the future demand of heavy single 2-stroke engines in the ever growing container ships.

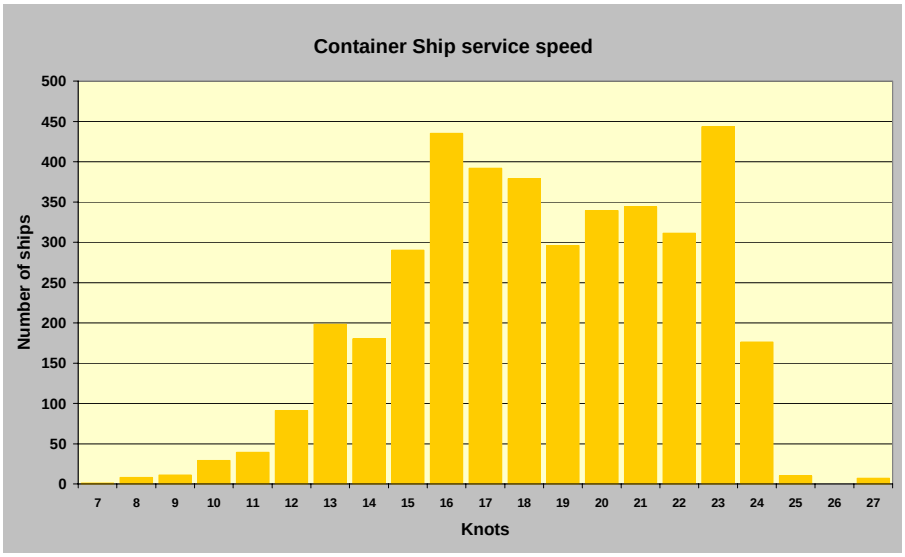


Figure 48; The speed profile of the Container Ships

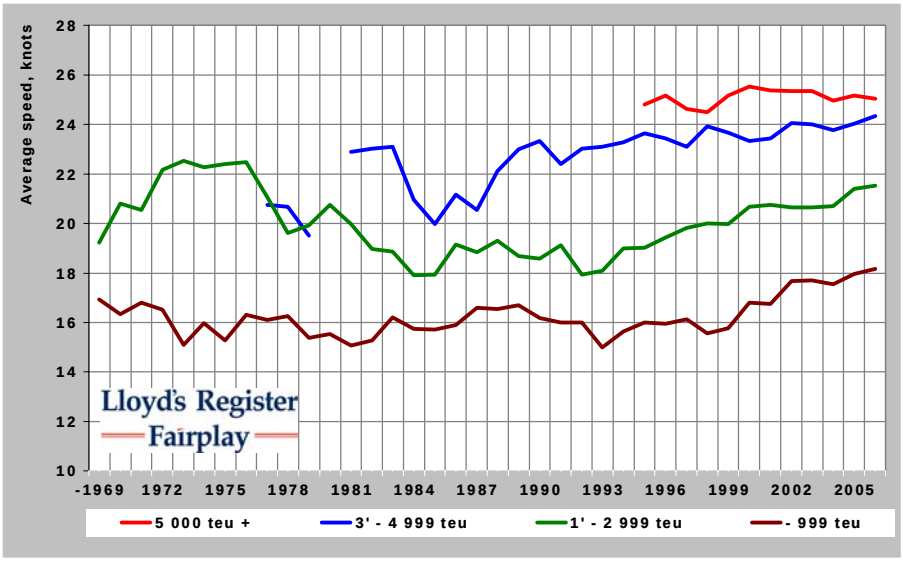


Figure 49; The average speed in relation to size of built Container ships are fairly constant over the years. The speed increase by ships size

The relatively high speed and the use of efficient 2-stroke engine shows in the emissions per the DWT.

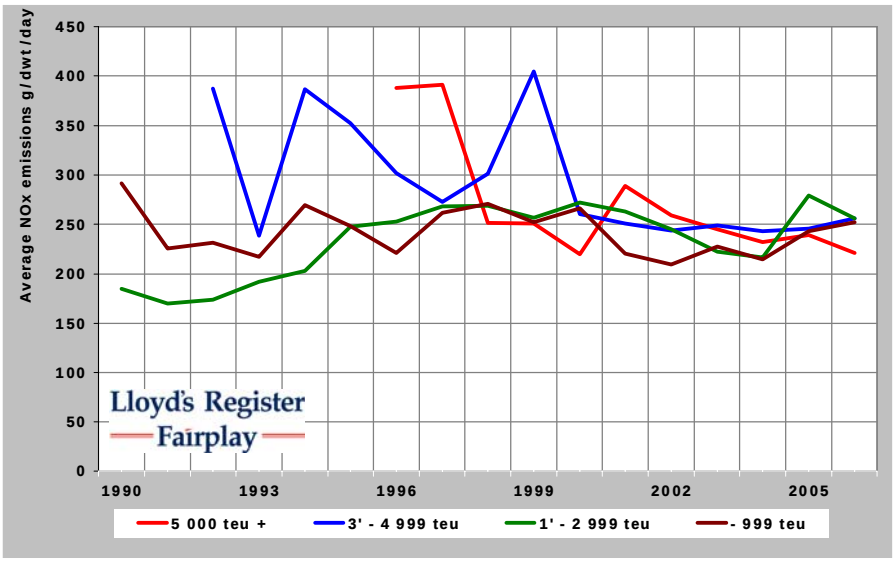


Figure 50; The developement of Nitrogen Oxide emissions from Container ships

Figure 50 shows that there is no "economy of scale" on the emission side as the power and speed increase by size for Container ships.

Based on data from all Container Ships with stated ME power output and design speed, in total 3,646 ships, equations for ME power (in kW) as a function of GT are established for each speed level between 16 and 26 knots. The trends for 17 knots and 25 knots are used for guiding trend lines of the other speed levels, as they both have large populations and high accuracy. The final equations are then presented per speed level.

The procedure is repeated for the DWT-ME power relationship, with the exception that the adjusted trend lines instead are based on 17 and 23 knots. As mentioned earlier the there is an almost linear relation between the increase in size and the increase in engine output. The stated equations can be considered as good approximations.

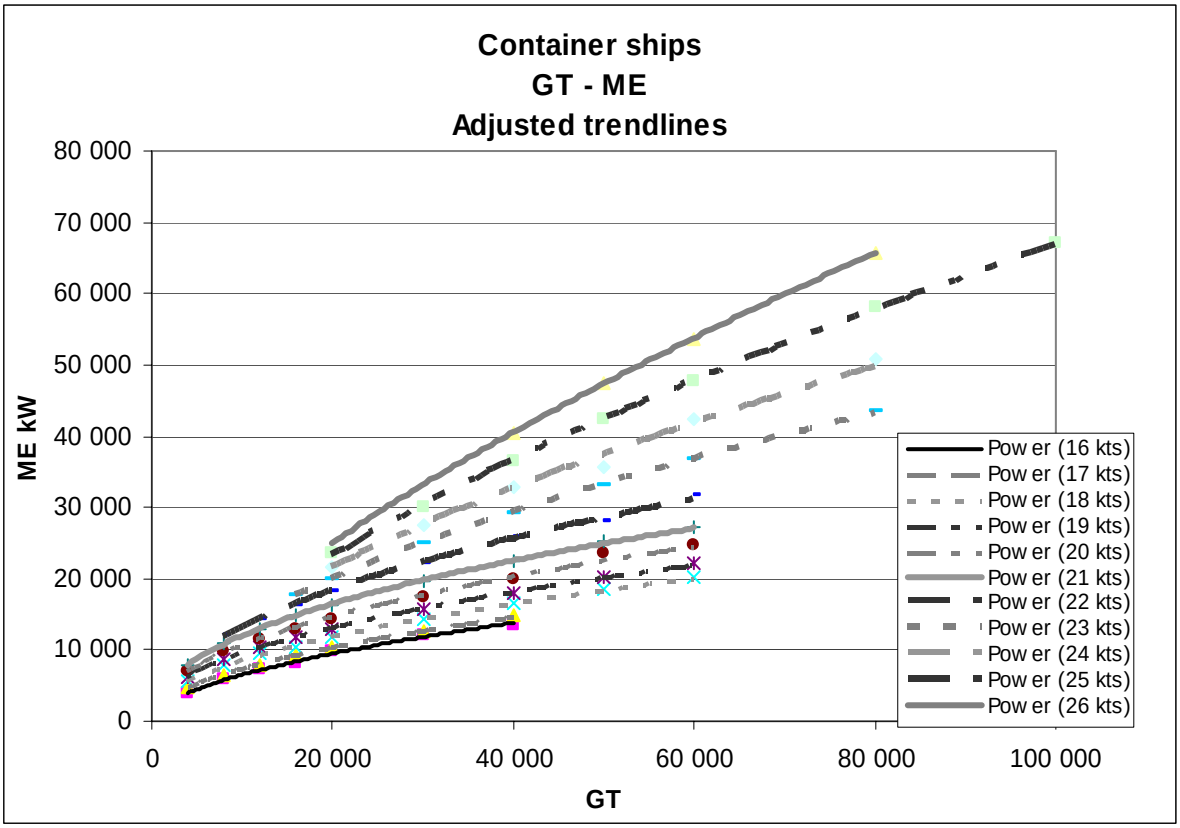


Figure 51; Container ships size (GT) – ME power by speed level

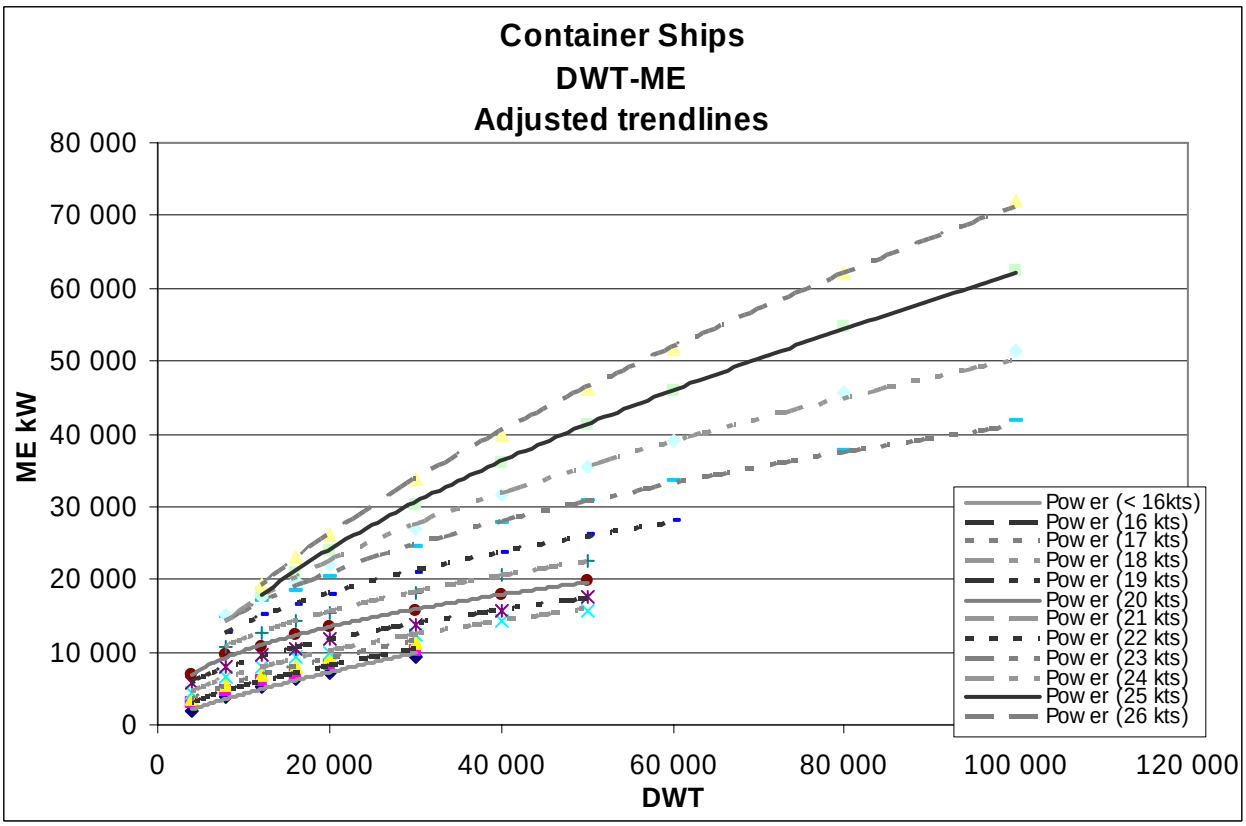
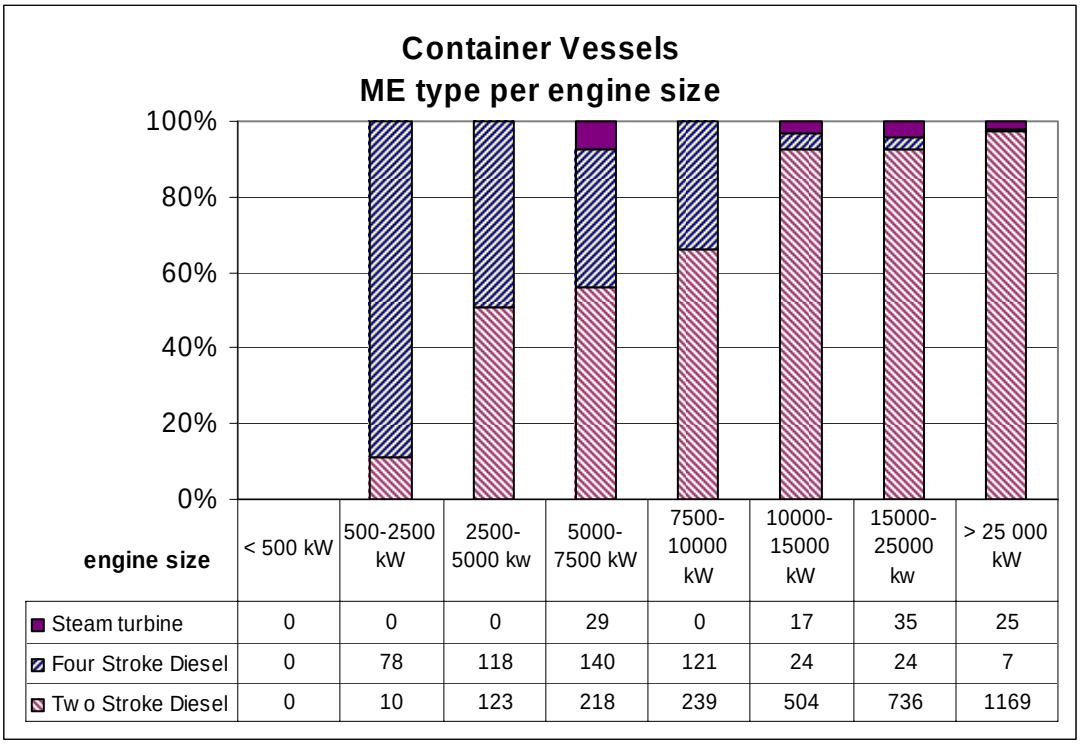


Figure 52; Container ships size (DWT) – ME power by speed level

The following table/diagram shows the distribution of different engine types per ship type that relate to the power of the ME. Larger vessels are more likely to have two stroke diesel engines than smaller ones, however four stroke engines are more common in the span between 5,000 and 10,000 kW compared to Bulk and General Cargo ships.



engine size	< 500 kW	500-2500 kW	2500-5000 kw	5000-7500 kW	7500-10000 kW	10000-15000 kW	15000-25000 kw	> 25 000 kW
Steam turbine	0	0	0	29	0	17	35	25
Four Stroke Diesel	0	78	118	140	121	24	24	7
Tw o Stroke Diesel	0	10	123	218	239	504	736	1169

Figure 53; Container vessels main engine type based on ME power output

The need for auxiliary power seems fairly similar for all sizes of container vessels.

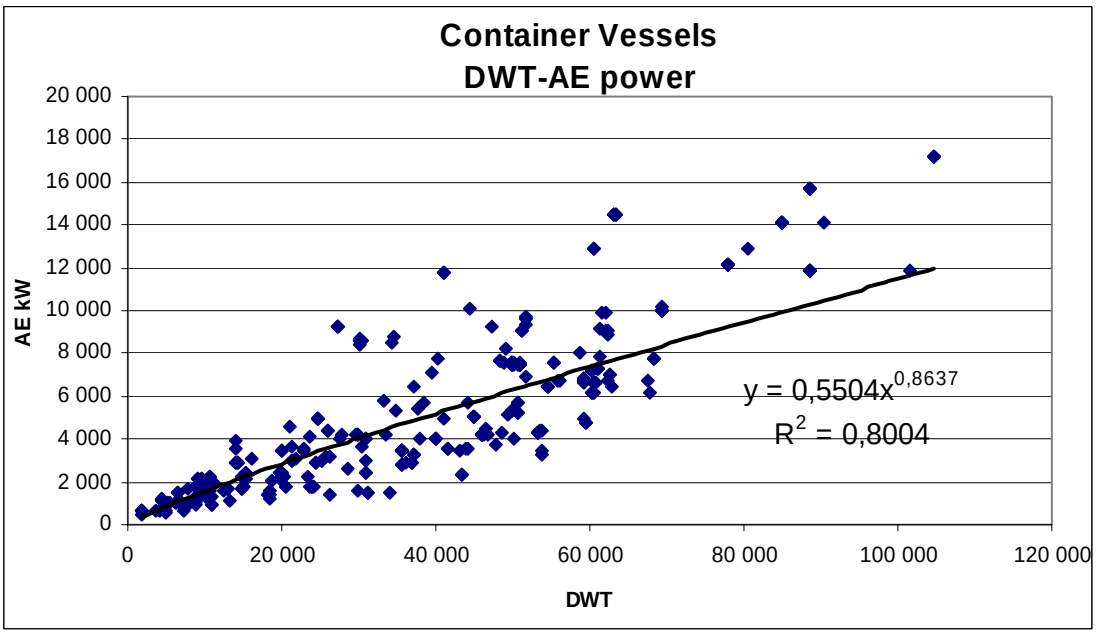


Figure 54; Container vessels size (DWT) - AE power output. Based on 377 vessels.

Ro/Ro

Ro/Ro ships are mainly used in two kinds of service, as industrial operation for break bulk cargo or in Short Sea service carrying everything from break bulk, trailers to containers.

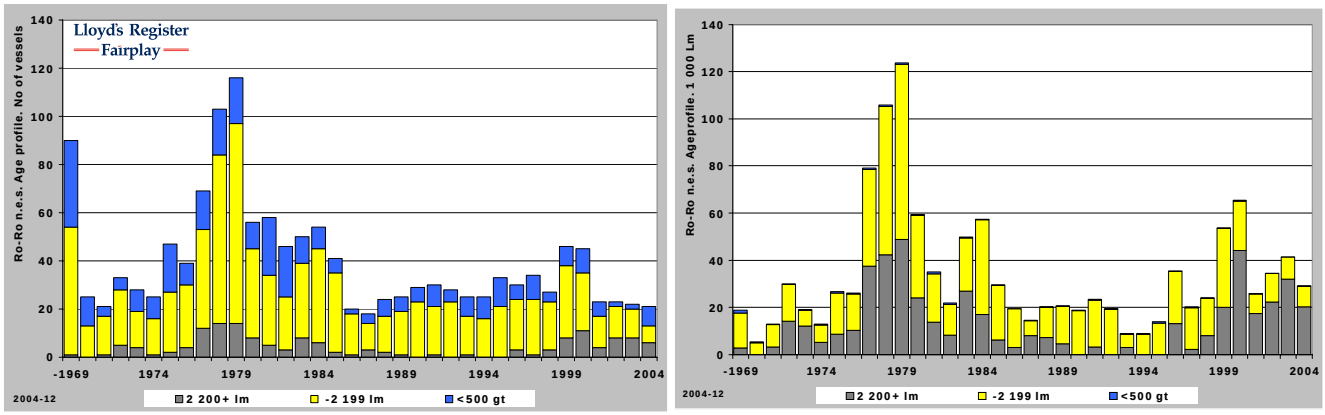


Figure 55; The age profile in number of vessels to the left and in lane metre capacity to the right

The speed performance is varying but stays within reasonable limits. Often the ships have more powerful machinery than is utilised in normal service operation.

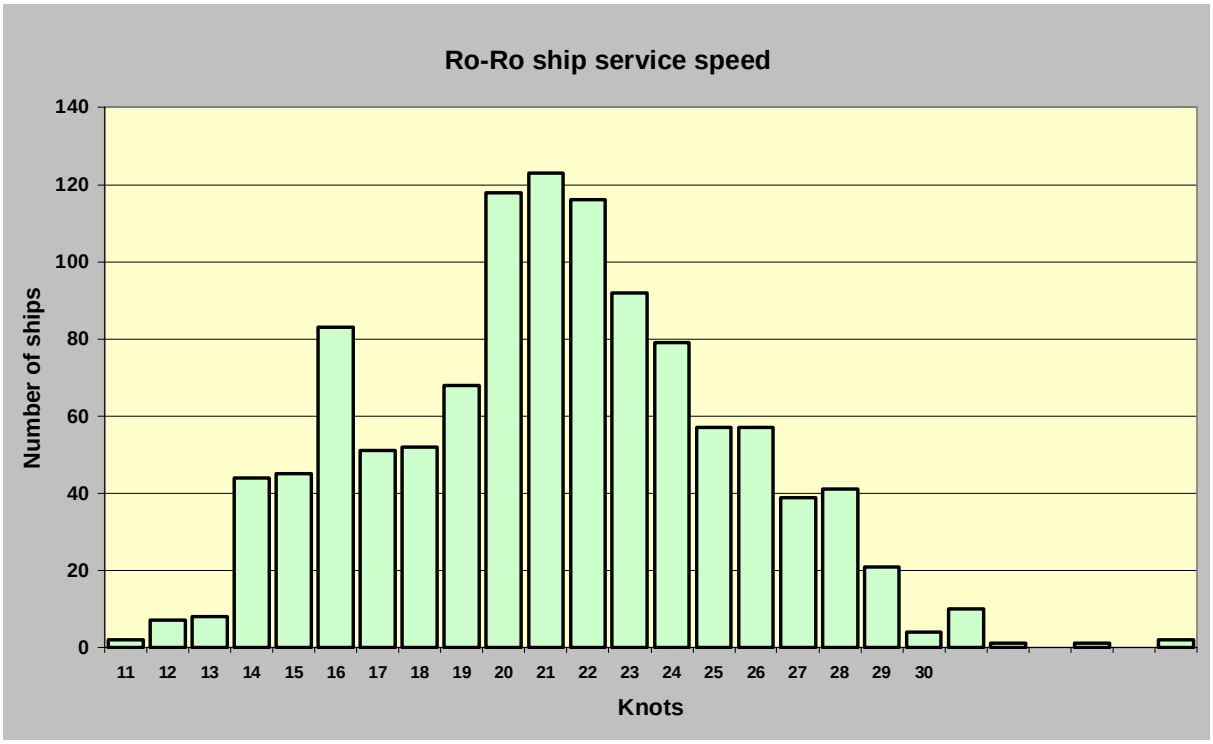


Figure 56; The speed range of is vast for Ro/Ro ships

The environmental performance of a Ro/Ro ship is very much depending on how the ship is used. If the ship is used as a ferry that only ship trailer units the utilisation of the ships carrying capacity is very low the environmental/energy load per ton transported goods will be high and the emissions per ton cargo are higher than for a direct transport on the road. While if the ship is used in industrial transport systems utilising the full carrying capacity in DWT the performance is much better and in accordance with the following information.

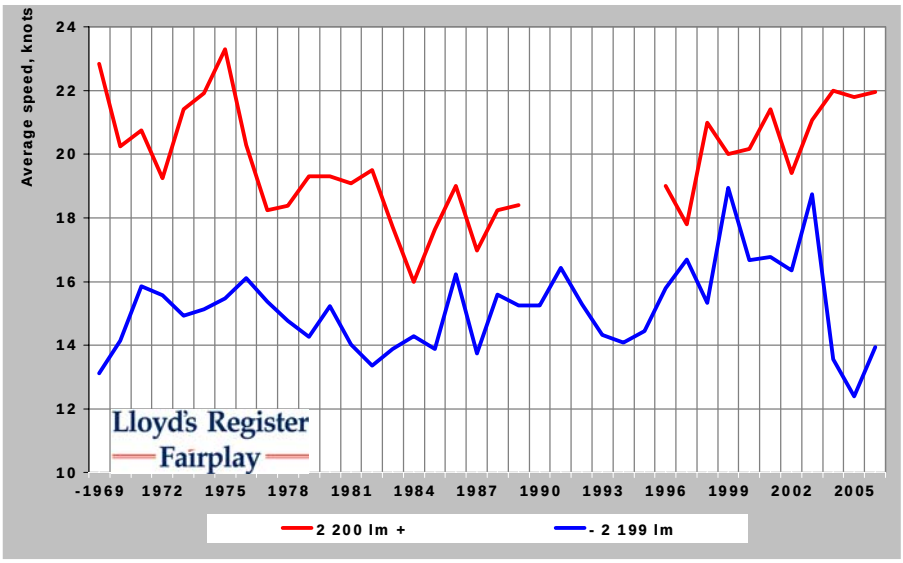


Figure 57; Development of speed performance of Ro/Ro ships

In the mid 90:ies the speed suddenly began to increase as the Scandinavian ship owners started to ordering new ships of higher speed. The idea was to equip the ship with a speed capacity that allowed a weekly schedule between the Baltic Sea and the Continental North Sea ports. A number of these ships were built late 90:ies and start of 2000. These ships contributed to the speed curve.

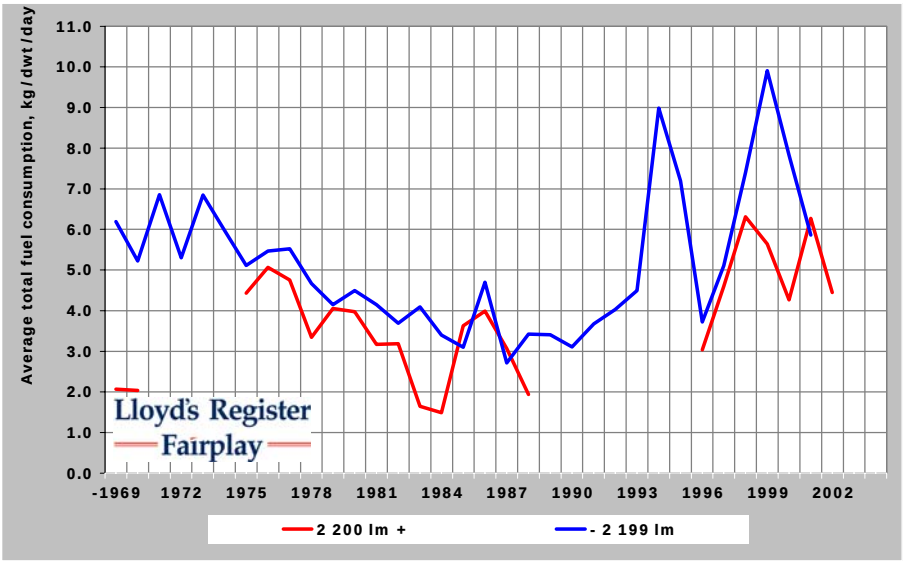


Figure 58; The development of fuel consumption for Ro/Ro ships

Coming from a relatively low level of fuel consumption it tripled for the ships being built during these years.

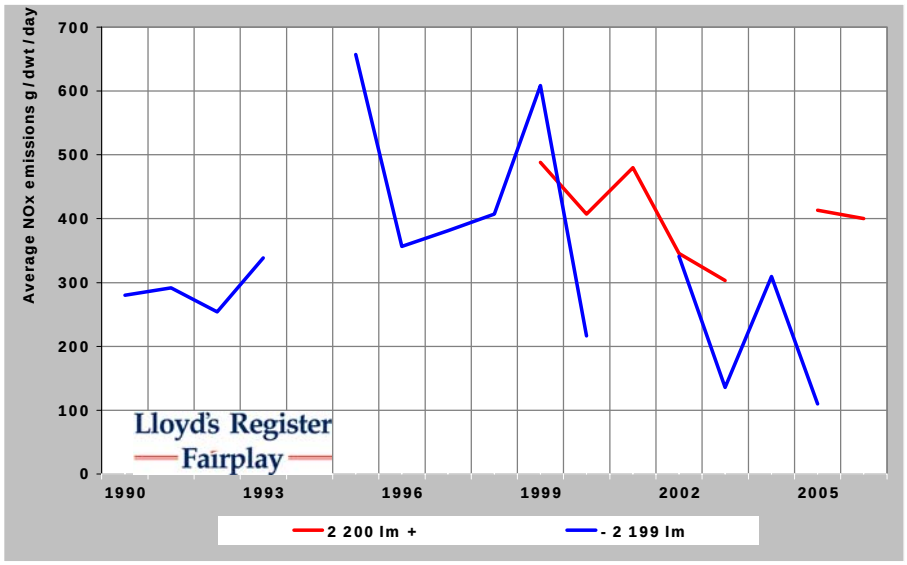


Figure 59; The development of emissions gives an impression of a strong reduction in late and coming years

The development of High speed Ro/Ro ships has slowly returned to a more reasonable level after a few years of intense deliveries of higher speed vessels.

A total of 1,000 Ro/Ro ships are used for the GT-ME power and DWT-ME power relations. The GT-ME power equations are based on trends for 10 knots for smaller Ro/Ro's <5,000 GT while 15 and 19 knots are used for larger. The DWT-ME power equations are based on trends for 10 knots <5,000 DWT, and 16 knots and 19 knots. The presented equations can be considered to be good estimations.

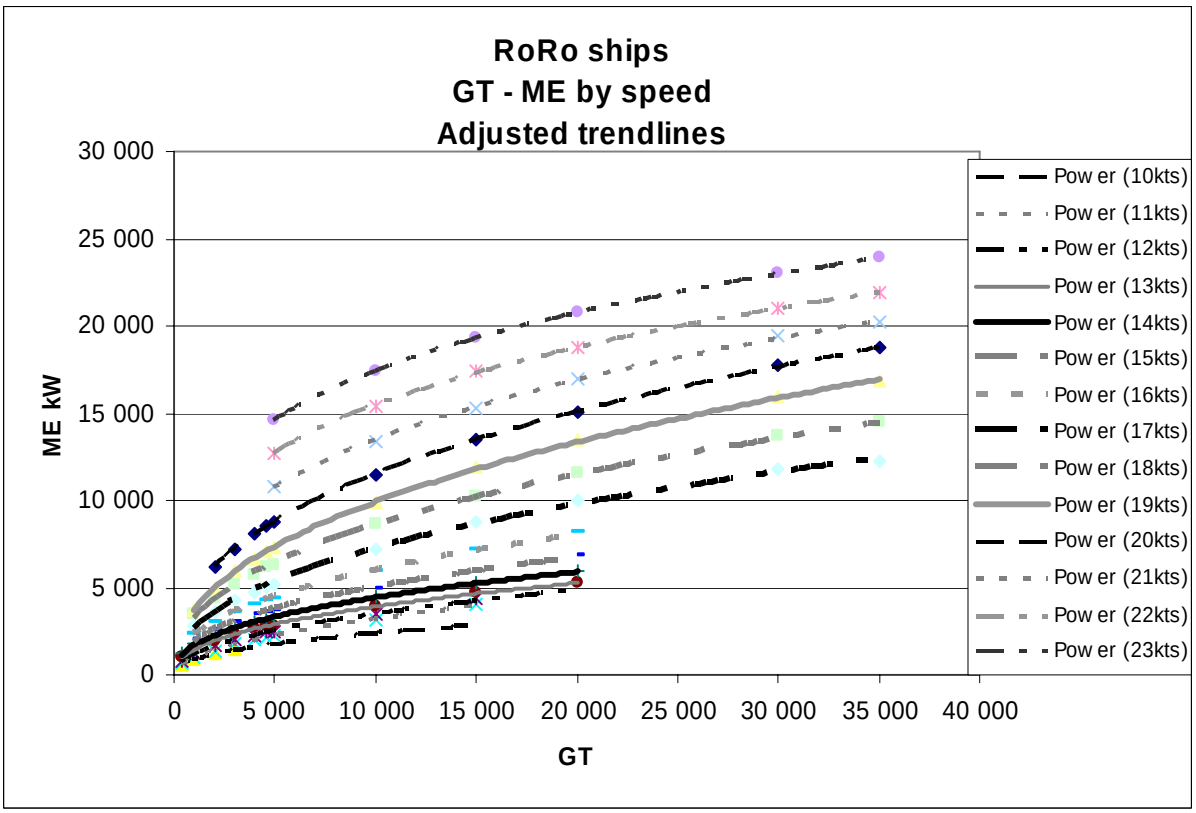


Figure 60; Ro/Ro ships relations size (GT) – ME power output by speed level

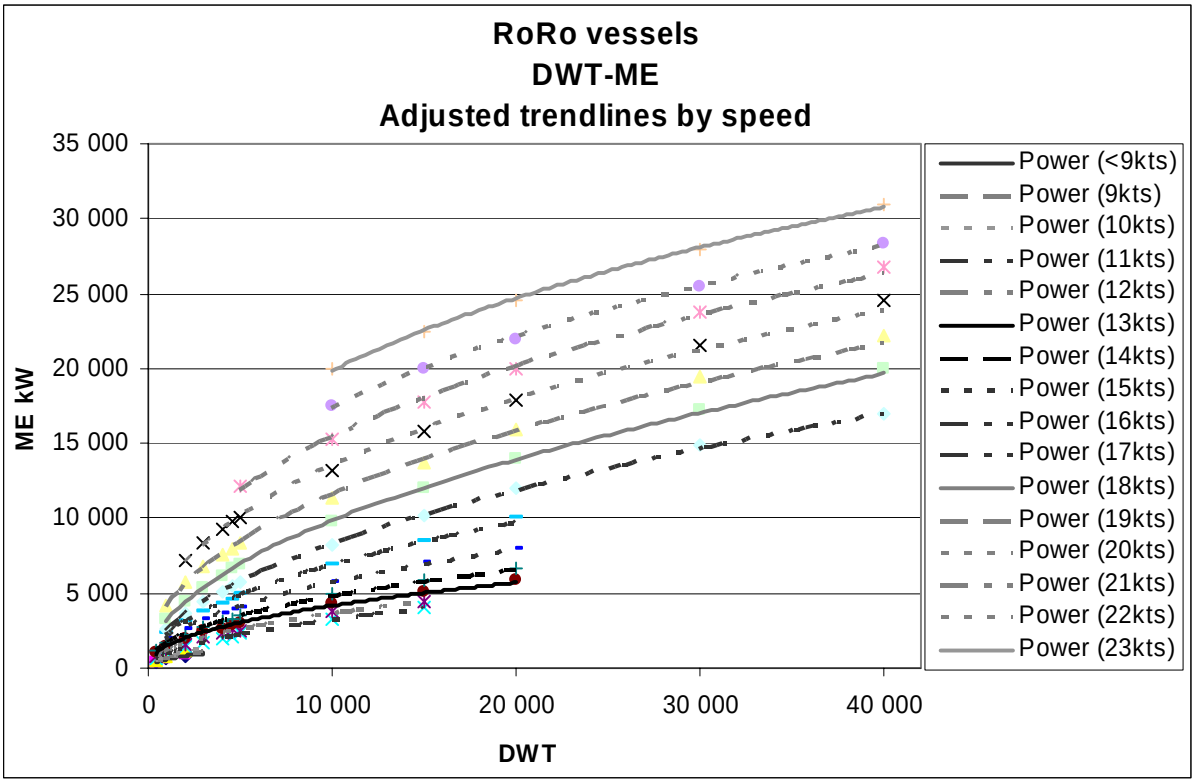
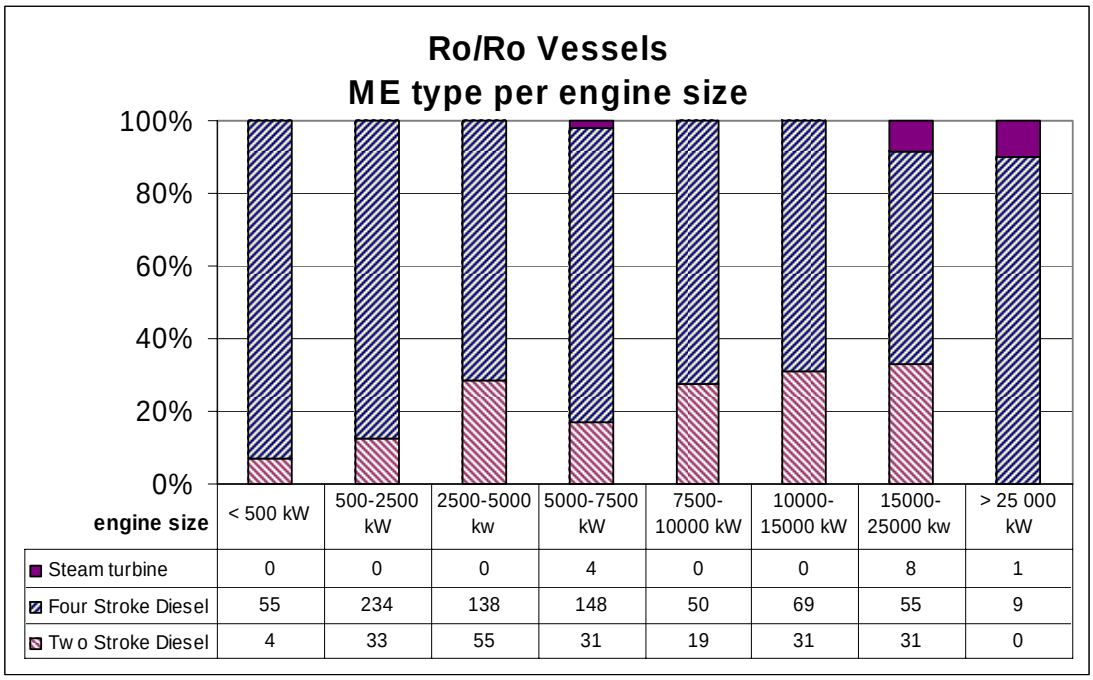


Figure 61; Ro/Ro ships relations size (DWT) – ME power output by speed level

The vast majority of Ro/Ro vessels are equipped with four stroke diesels, also for larger ships with more powerful engine needs. This can to some part be attributed to the restrictions on engine room height and space in the aft part of the ship due to ramp arrangements. It is by this common to use several four stroke diesel engines instead of one large two stroke diesel engine. This allows for greater flexibility in operation and as well as higher redundancy. The need for higher manoeuvrability due to frequent port calls makes Ro/Ro ships to have more commonly twin screws compared with other vessels.



engine size	< 500 kW	500-2500 kW	2500-5000 kw	5000-7500 kW	7500-10000 kW	10000-15000 kW	15000-25000 kw	> 25 000 kW
Steam turbine	0	0	0	4	0	0	8	1
Four Stroke Diesel	55	234	138	148	50	69	55	9
Two Stroke Diesel	4	33	55	31	19	31	31	0

Figure 62; Ro/Ro vessels main engine type based on ME power output

Based on complete data from 137 Ro/Ro vessels a relation can be established between size (GT) and total installed auxiliary engine (AE) power.

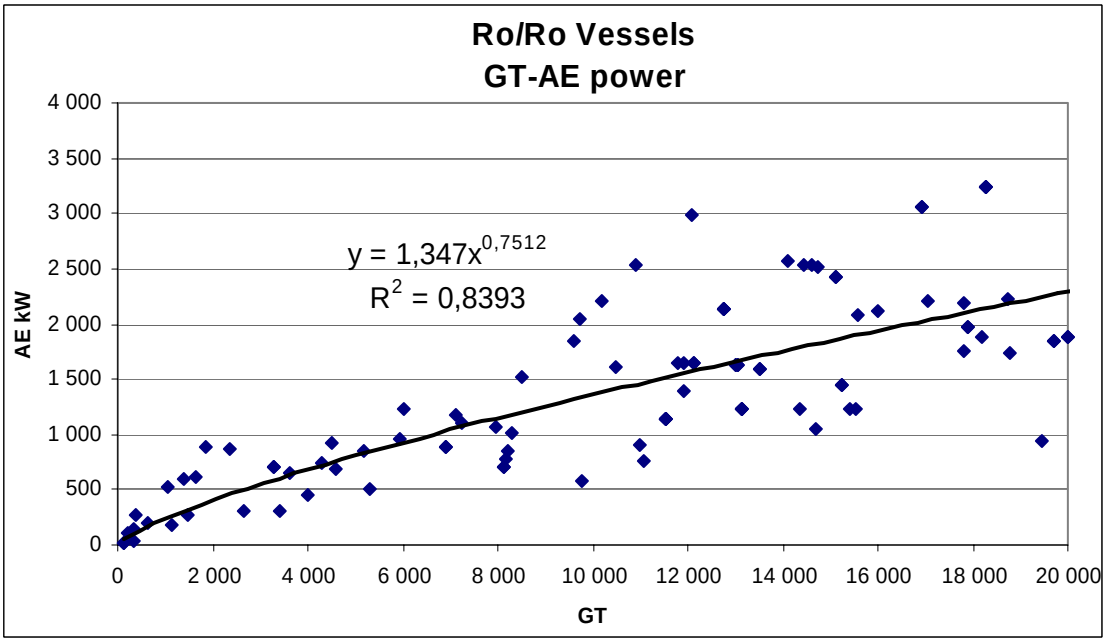


Figure 63; Ro/Ro vessels size (GT) – AE power output. Based on 137 ships.

Reefer

Reefer ships are undergoing a development driven by a hard competition from the container services shipping reefer containers.

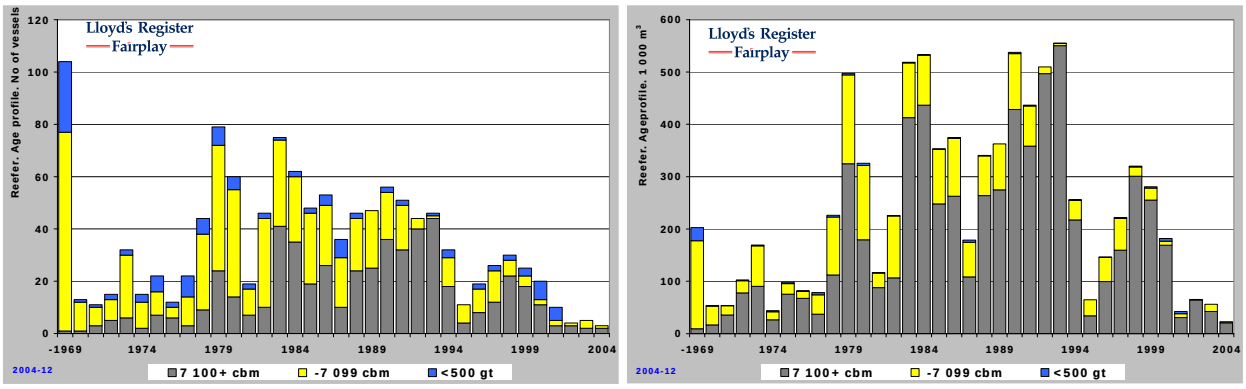


Figure 64; The age profile of Reefer ships by number and capacity

New concepts of reefer ships are on the way. However, this will mainly be an adaptation to higher flexibility as concerns both palletised cargo and containers.

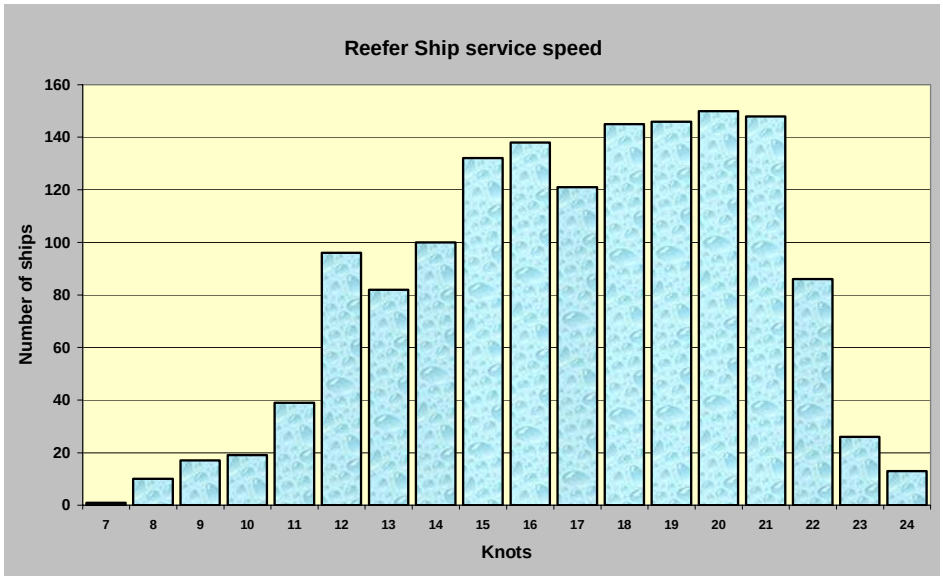


Figure 65; The speed profile of Reefer Ships

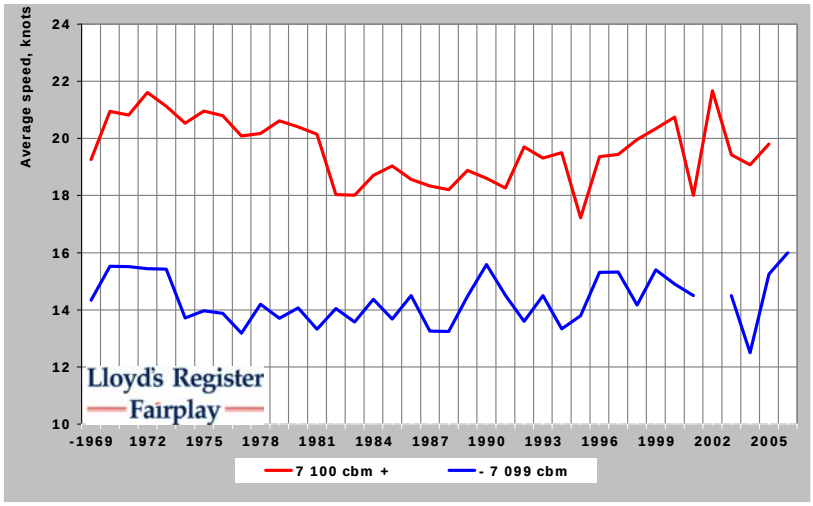


Figure 66; The development of the Reefer ships shows a relatively stable speed level

The speed of the Reefer ships is very much based on the traditional way of shipping and the established schedules.

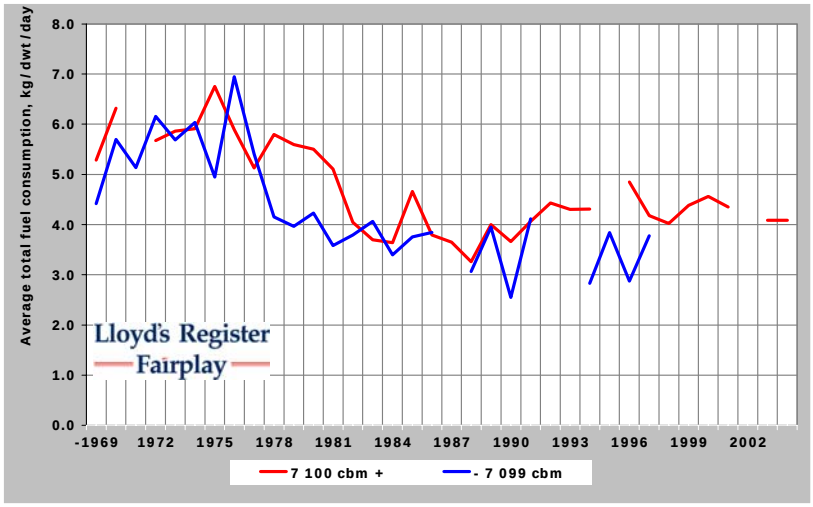


Figure 67; The development of fuel consumption

As for the fuel consumption this reflects the growth of ship size giving a higher carrying capacity at the same speed. Also these figures indicate a stabilisation over the last few years.

The emission data is too poor to comment on.

Data on some 1,250 reefers is used to establish the relations between vessel size in GT/DWT and ME power output. Reefers have historically been slender ships optimised for high speeds, and as a group seem to be rather homogeneous in design, thus follow similar size – ME power patterns for most sizes and speeds. For vessels >5,000 GT the GT-ME equations are based on the 18 knots trend and presented per speed level, however due to more diverged relations for smaller reefers these are grouped in speed groups of two and based on the 14-15 knots trend. The DWT – ME power equations are based on the trends for 12 knots and 18 knots. They are presented as one equation per speed level.

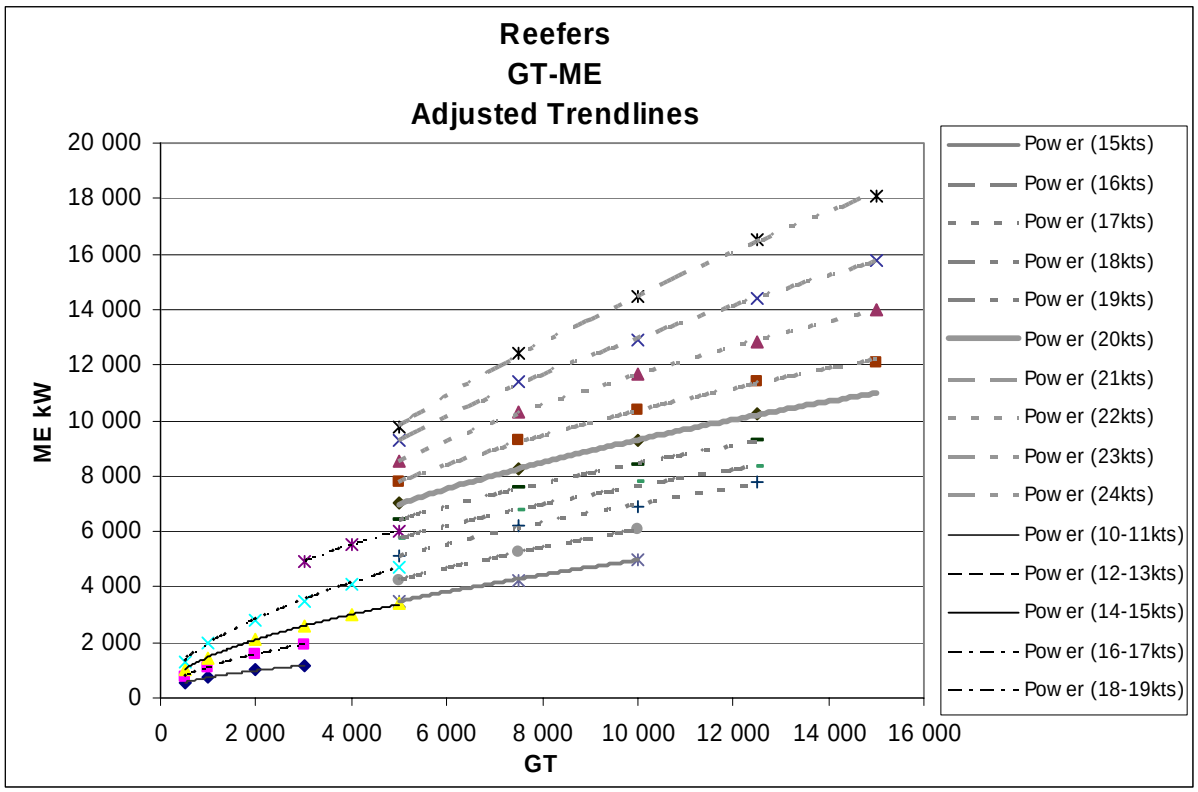


Figure 68; Reefer vessels size (GT) – ME power output by speed level

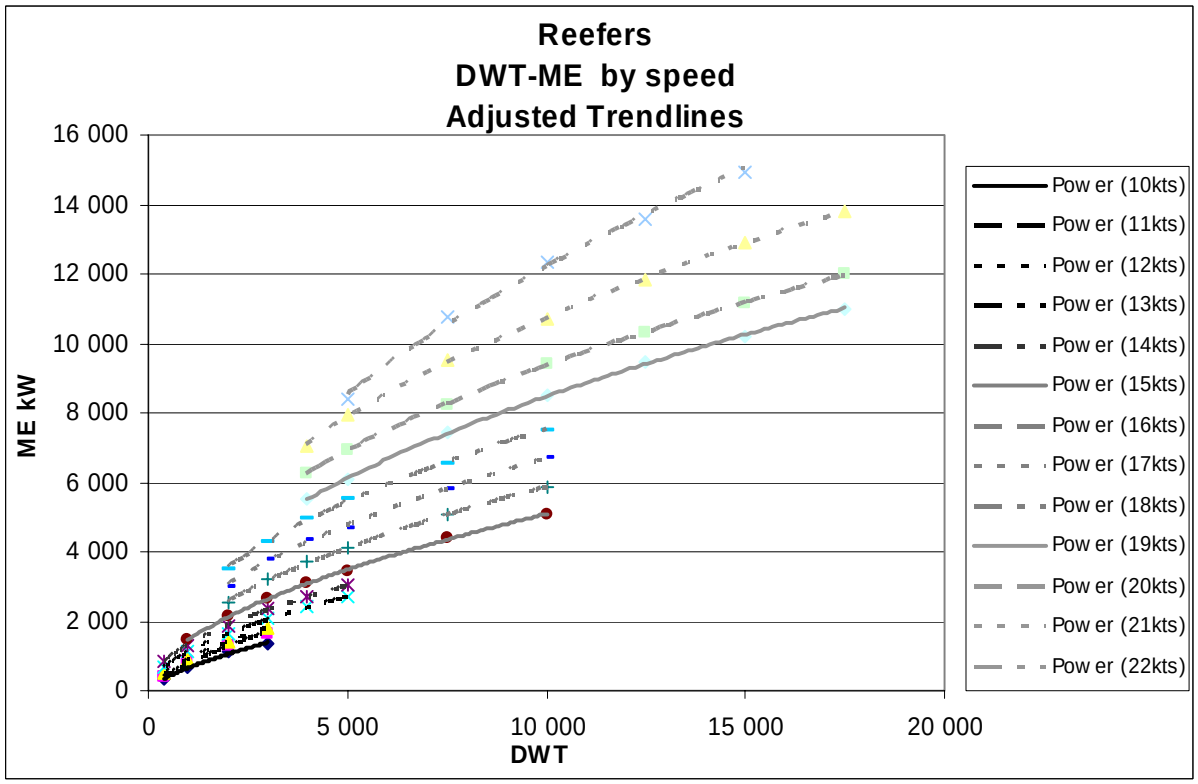


Figure 69; Reefer vessels size (DWT) – ME power output by speed level

As for other type of vessels, larger ones are more likely to have two stroke diesel engines than smaller ones.

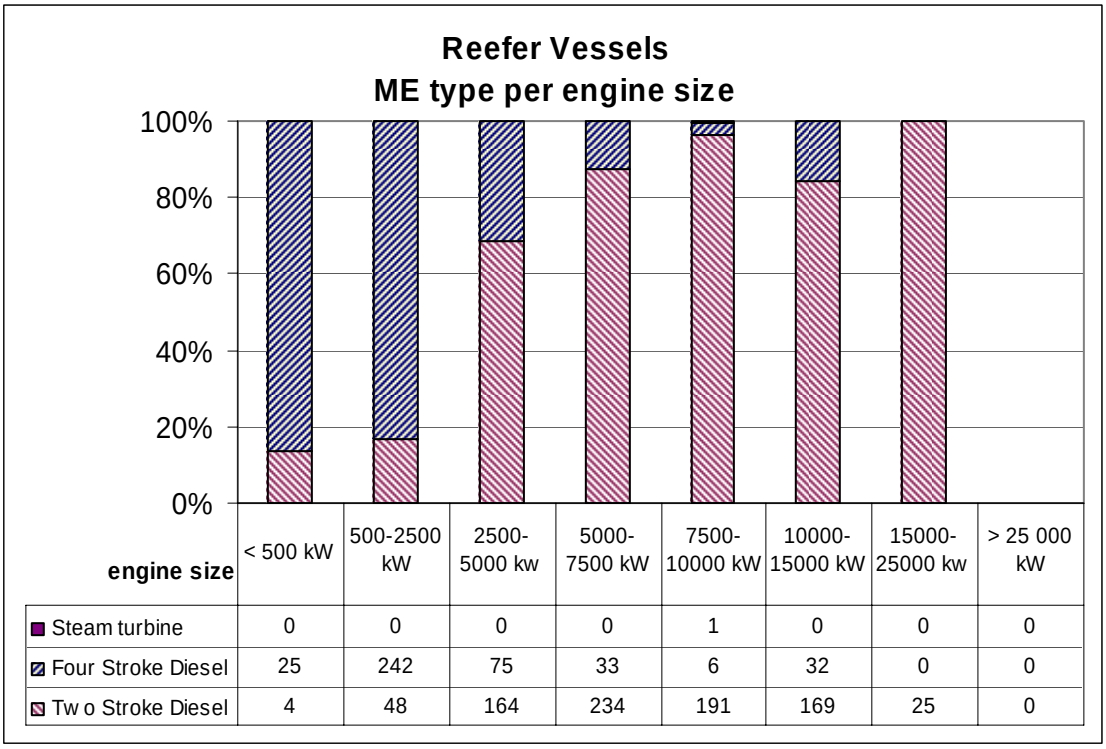


Figure 70; Reefer vessels main engine type based on ME power output

There is a clear relation between size (GT) and total installed auxiliary engine power for Reefers, Figure 71.

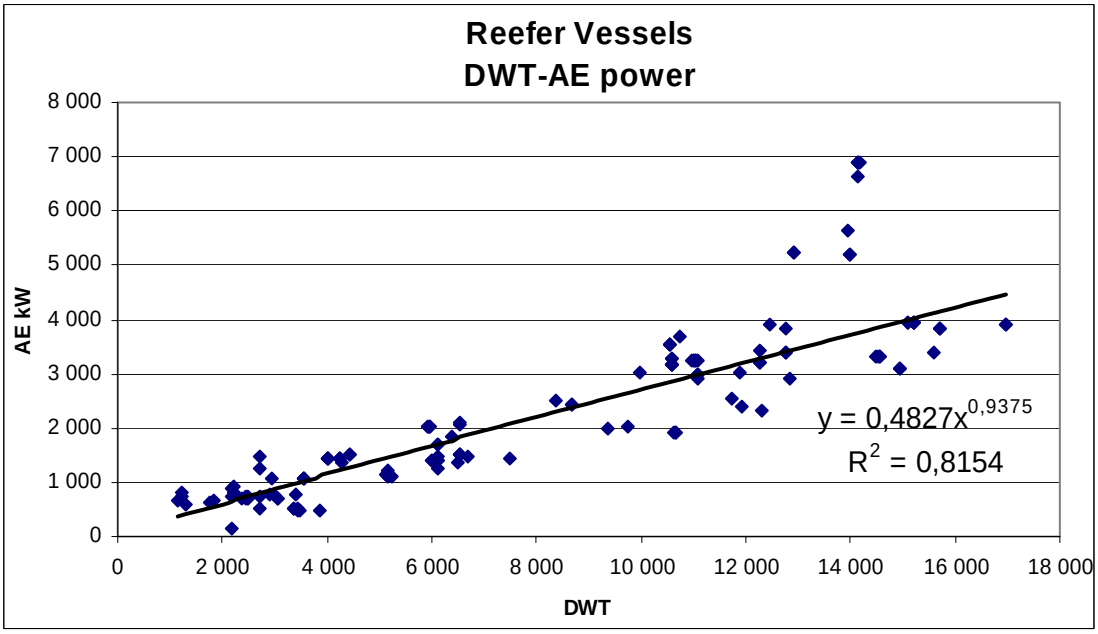


Figure 71; Reefer vessels size (DWT) – AE power output. Based on 140 ships.

Cargo Ferries

The Cargo Ferry is normally a Ro/Ro ship having passenger capacity. The ship trades in regular service, usually between two ports only.

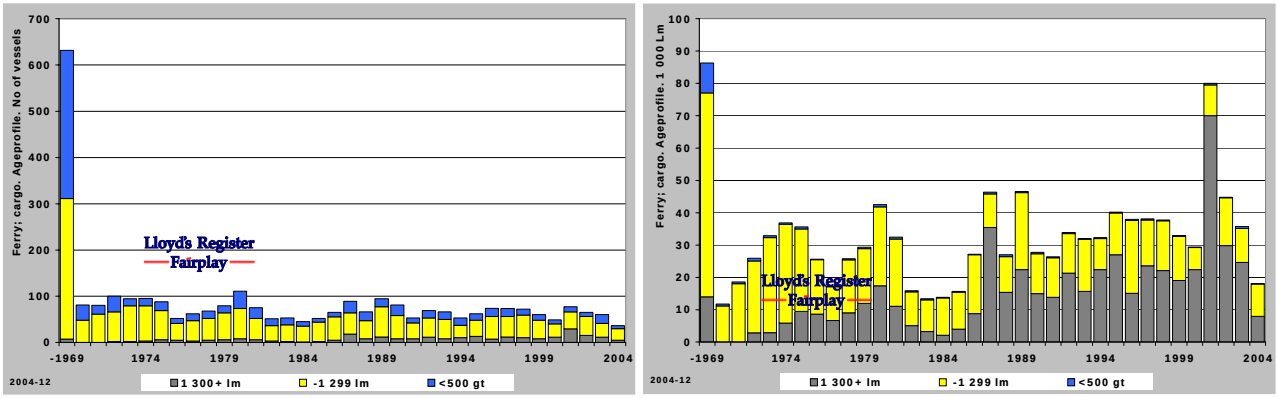


Figure 72; The Cargo Ferry in age per number of ships and in fleet capacity

Trend wise, new ships are getting larger by year. This may relate to that the ferries are replaced by Ro-pax ships to compensate for the increased demand of freight cargo and declining demand for passenger service.

In this part the ferries having a service speed of up to 30 knots is considered. Ferries having a speed of 30 knots or more are presented in the High Speed Chapter that follows.

Most of the ships in this sector are built for a regular service at a fixed speed. It is normal that the ship has a higher speed capacity than the service speed given, but use as much speed as is needed to keep the time schedule on the service that is operated.

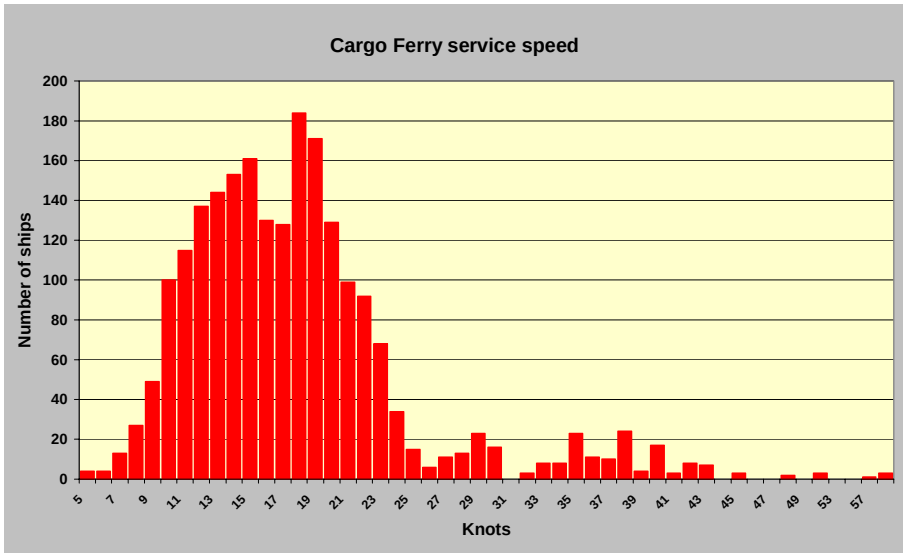


Figure 73; The speed profile of the Cargo Ferries shows a wide spread distribution

The environmental performance is difficult to model since the passenger space onboard vary in size. The emissions should preferably be related to the ship's GT which relates the volume of the vessel.

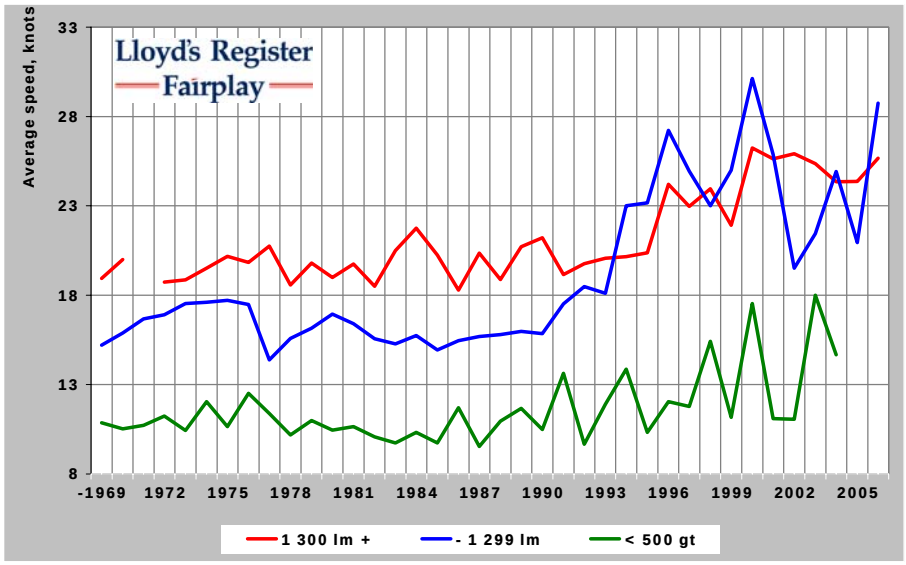


Figure 74; The Cargo Ferry speed development

The cargo ferries show a trend in increased speed that is evident for the class of middle sized ships but is visible for all sizes. This is a clear demand from the passengers that has influenced the building of ships.

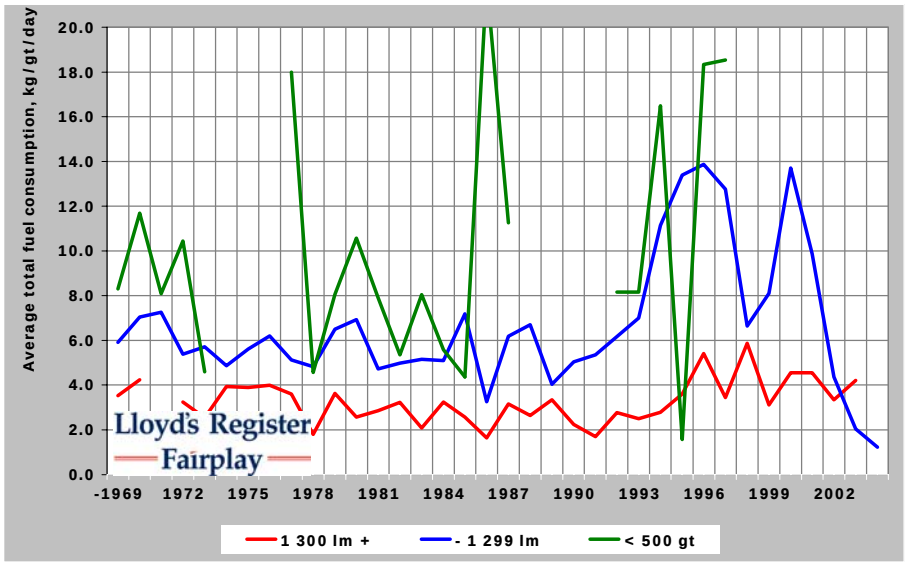


Figure 75; The development of fuel consumption for Cargo Ferries

The fuel consumption per GT and day indicates an increase a few years in the late 90:ties where the delivered ships' consumption more than doubled in comparison to previous years. In mid 2000 the discussion concerned Ferries and high speed crafts is considered as a market that only stayed at a vision for most of the projects, especially the yards. There came a backlash in the beginning of 2000 when the market dropped. Although there are some services that benefit from a high speed to attract traffic. This concerns road linking services. The environmental friendliness can be questioned of these from emission and energy consumption point of view, but they may have other environmental qualities. In mid of the first 2000 decade the fuel prices do not encourage investments in High Speed ships. The majority of the High Speed vessels built today are small and light ships.

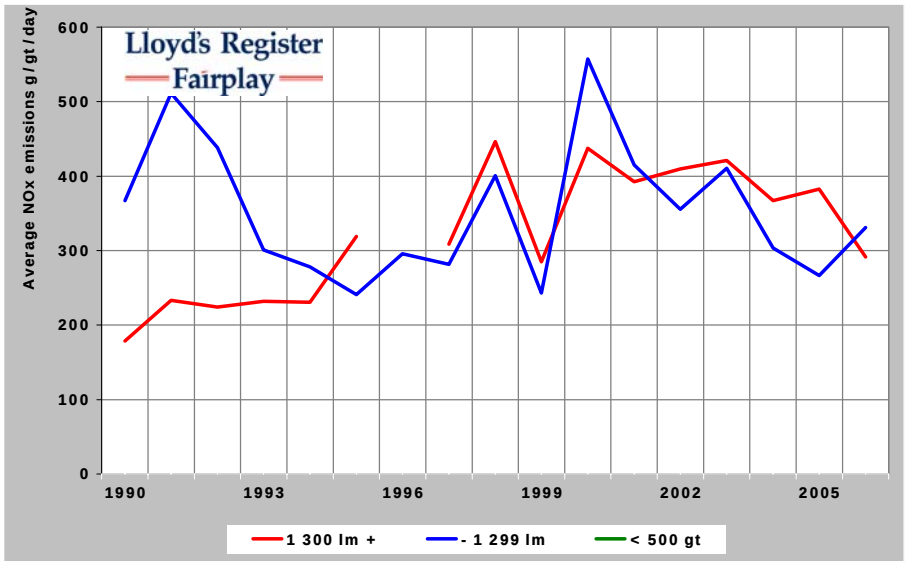


Figure 76; The development of NO_x emissions for Cargo Ferries

The emission factors follow roughly the same pattern as the fuel consumption, although the changes are not all that dramatic. The trend shifts after the year 2000.

Size-ME power output relations for Cargo Ferries with a stated service speed less than 30 knots, are based on data from almost 2,600 ships. However, only about 1,800 of them have reliable information regarding size, speed and ME power. Ferries vary much in size, type and performance. There are many individual hull types as well as different machinery and propulsion sets depending on the field of operation that they have been designed for. This makes it difficult to find reliable relations.

However, there are quite clear relations in larger speed groups, much more than for other type vessels. Thus the equations are presented in four speed groups, together with the corresponding statistical variance R^2-value. These equations are not adjusted to fit theoretical curves. Instead the actual result from the statistical curve fitting is used. Generally it seams to be more appropriate to use GT to determine ME power output instead of DWT. As ferries shows such a variety in design and are generally quite low carrying capacity (low DWT) it is not a suitable parameter to use for the characterisation.

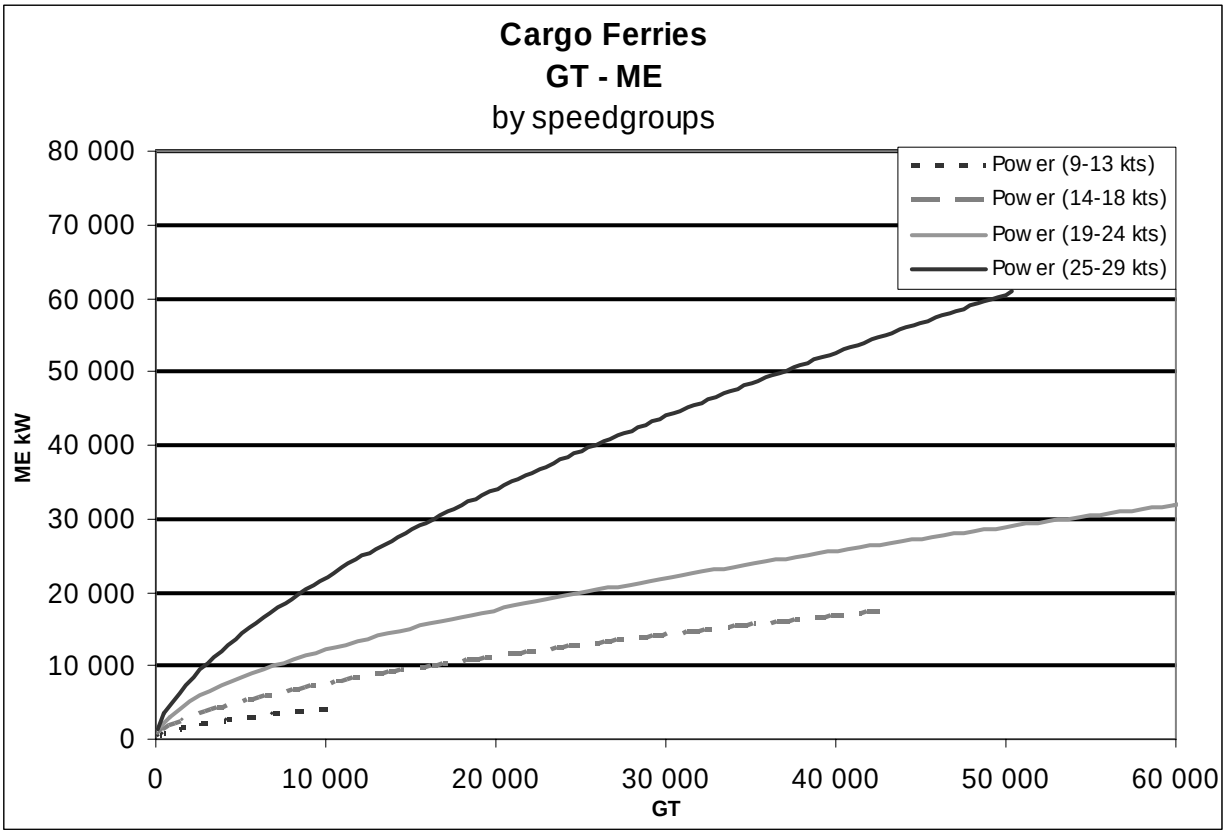


Figure 77; The relation between ME power output and GT for Cargo Ferries

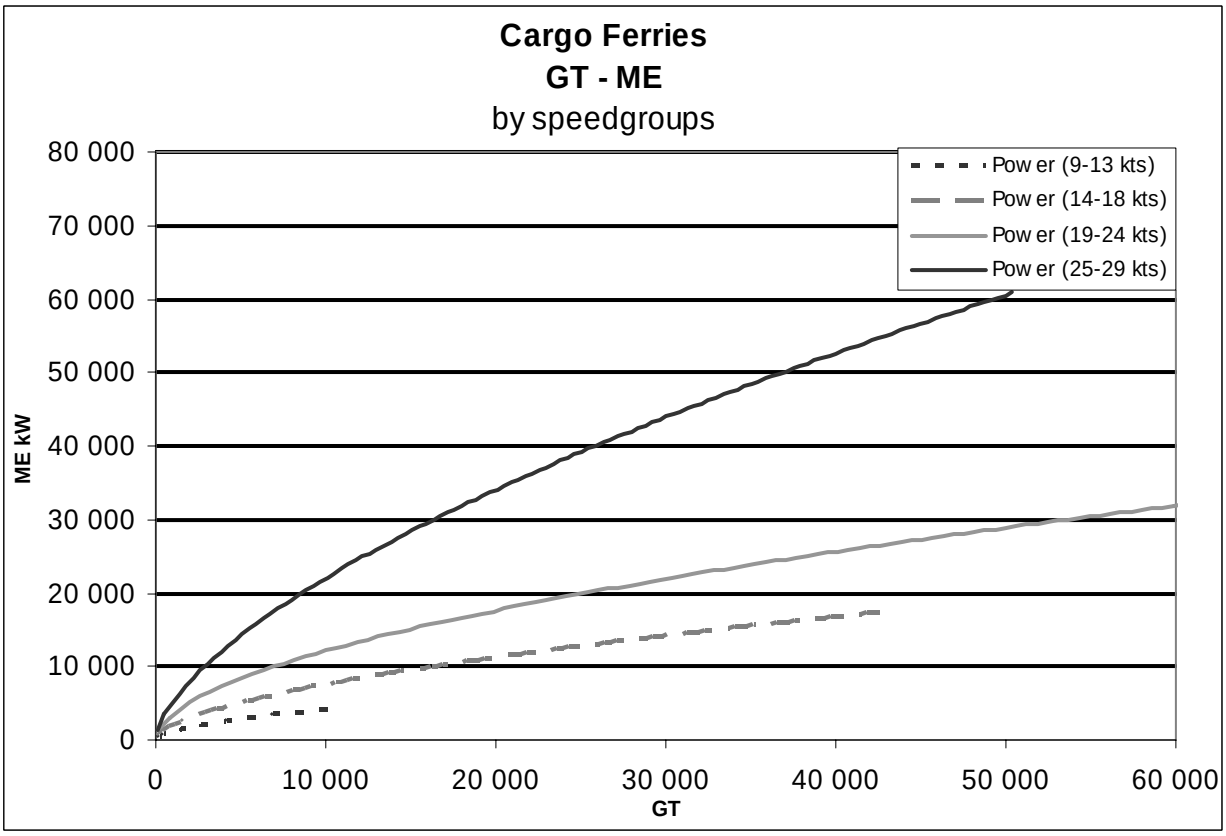
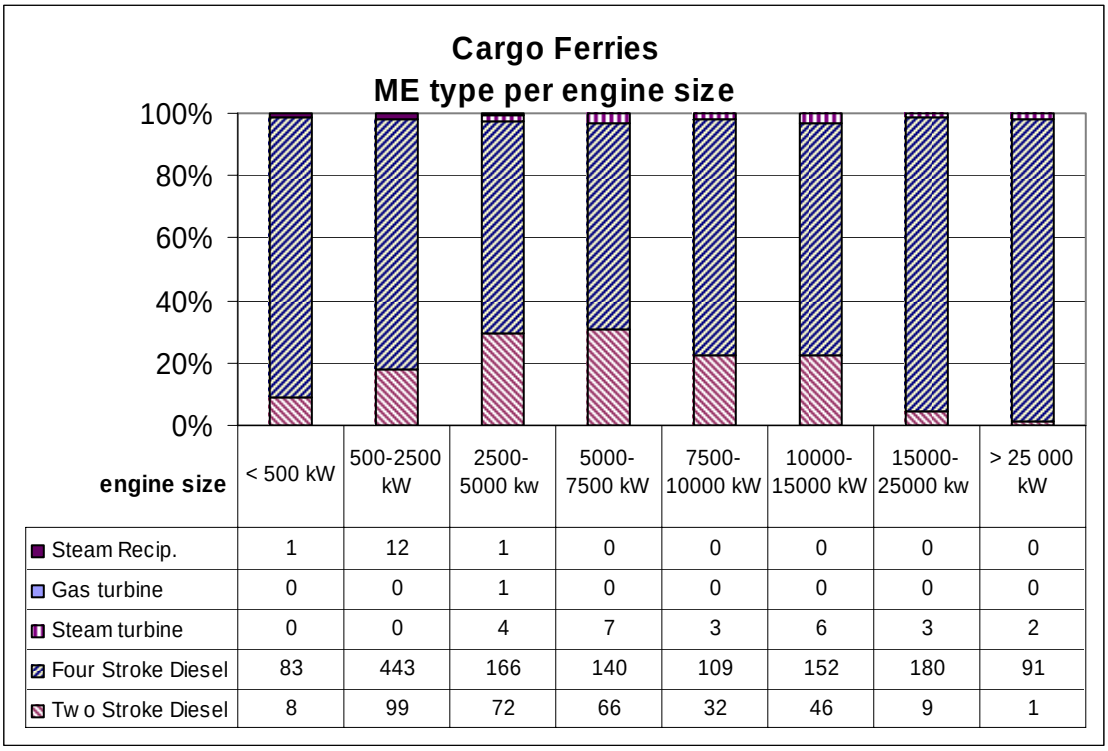


Figure 78; The relation between ME power output and DWT for Cargo Ferries

The vast majority of Cargo ferries have four stroke diesel engines also in vessels with high demand of ME power output. The reason is very much the same as for Ro/Ro vessels. Frequent departures, manoeuvring in ports, varying modes and conditions of operation call for flexibility with several main engines to optimise the power output.



engine size	< 500 kW	500-2500 kW	2500-5000 kw	5000-7500 kW	7500-10000 kW	10000-15000 kW	15000-25000 kw	> 25 000 kW
Steam Recip.	1	12	1	0	0	0	0	0
Gas turbine	0	0	1	0	0	0	0	0
Steam turbine	0	0	4	7	3	6	3	2
Four Stroke Diesel	83	443	166	140	109	152	180	91
Tw o Stroke Diesel	8	99	72	66	32	46	9	1

Figure 79; Cargo ferries main engine type based on ME output

The relation between ferry size and installed auxiliary engine power is fairly stable.

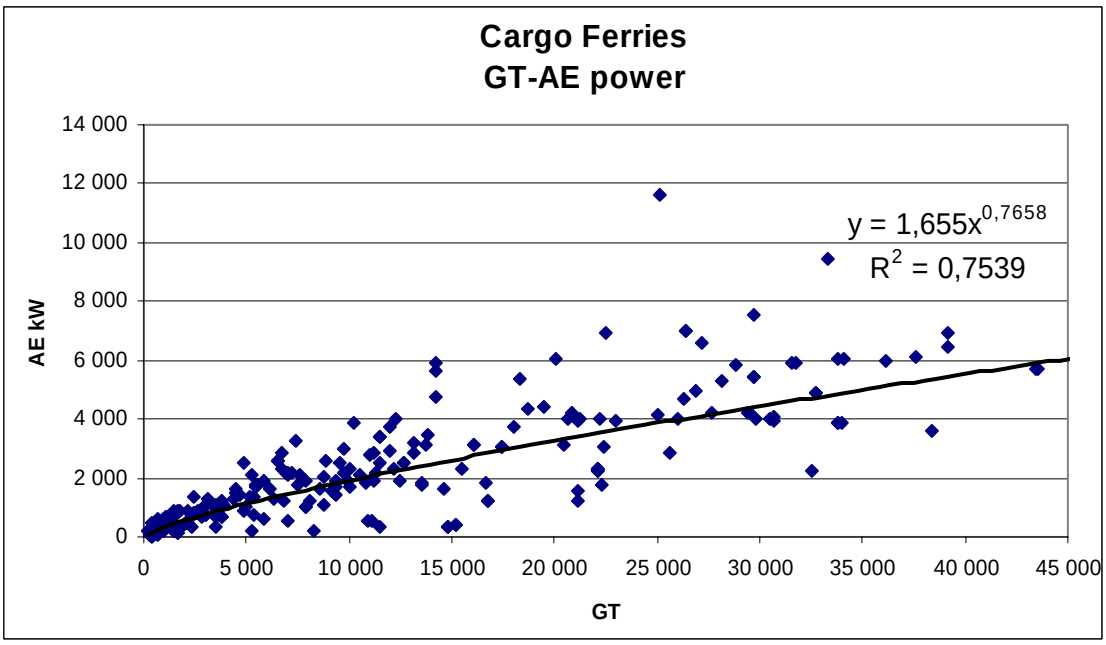


Figure 80; Cargo ferries size (GT) – AE power output. Based on 226 ships (including High speed).

Passenger Ferry

The passenger ferries or "Non Cargo Ferries" are of a smaller type of ships servicing islands or cross river connections etc. In this respect the pattern of the number of vessels and the capacity do not differ.

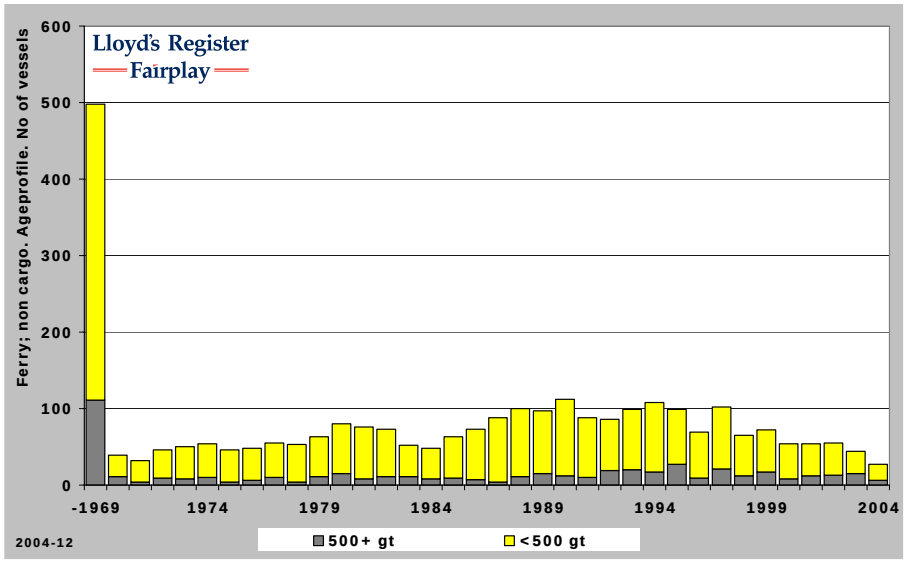


Figure 81; The age profile of the passenger vessels

The speed profile of the vessels show two concentrations of speed levels; around 10 – 15 knots and around 30 – 35 knots, all of which are quite small vessels, see Figure 81.

The small and light vessels allows for higher speed. Figure 82 shows the very wide speed profile of the ship type. This is quite natural seen from an operational point of view. The ship type operates in all conditions from harbour commuter to sea buses and commuters in the Norwegian, Mediterranean, Japanese or Caribbean archipelagos.

The ship type includes ships with capacity to carry cars and a small amount or buses or trucks.

In this part the ferries having a service speed of up to 30 knots is considered. Ferries having a speed of 30 knots or more are presented in the Chapter of High Speed that follows.

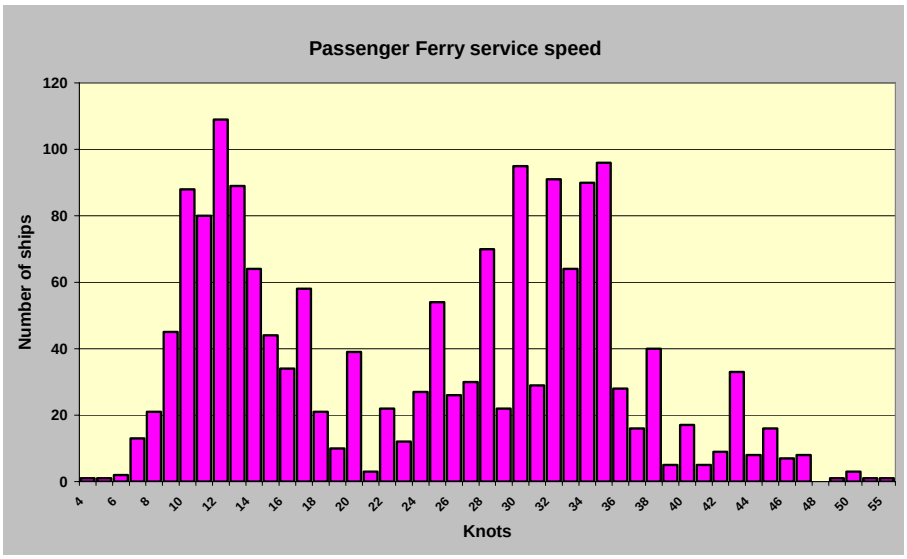


Figure 82; The speed profile of the Passenger Ships

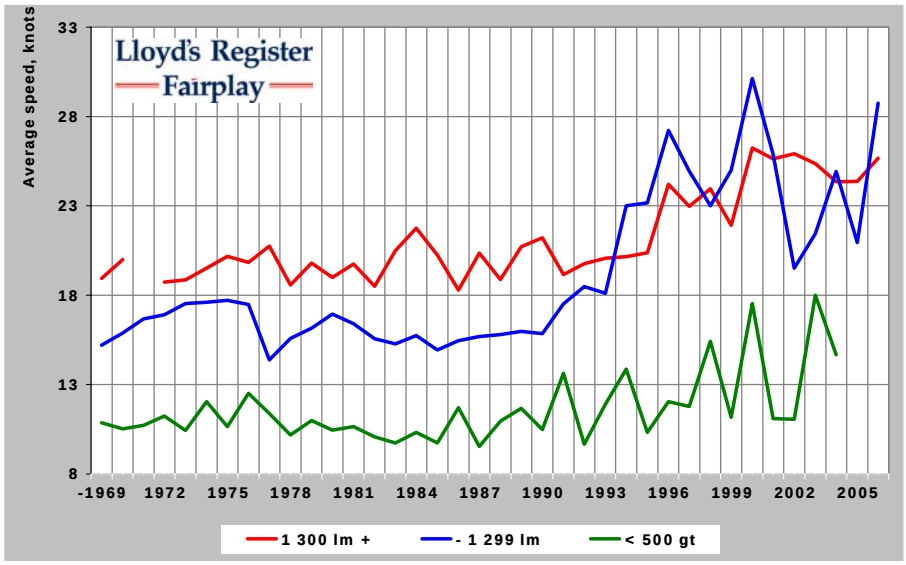


Figure 83; The speed development of the Passenger Ferries

The speed development follows the general trend in the society of increased speed. The passengers are willing to pay for faster transit for all types of transports. Several new ship concepts have been produced that try to use lighter materials and more efficient engines to increase speed at as low additional cost as possible.

The development will also influence the fuel consumption. The year of operation should be noticed when comparing Figure 83 and Figure 84. As the consumption depends on the size and capacity of the ship the result of the graphs will depend on the type of ship built in the years concerned.

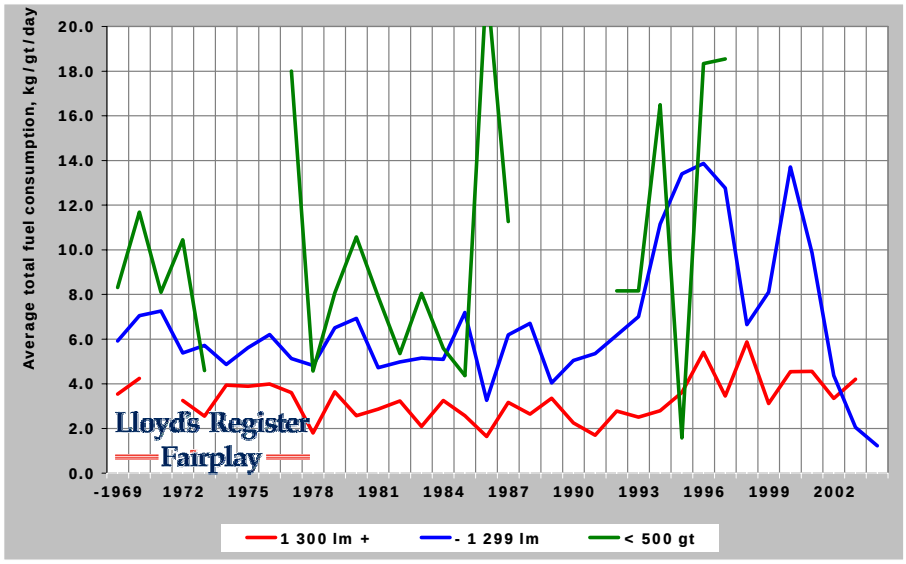


Figure 84; The fuel consumption development of Passenger Ferries

The NO_x emission development indicates two things; the increased speed increase the emissions and that the diesel engine is preferred.

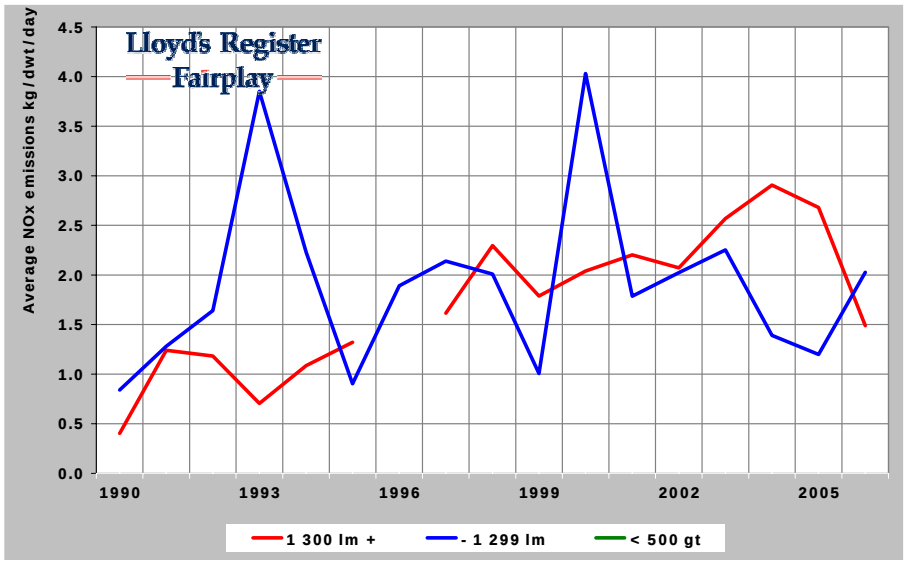


Figure 85; The NO_x emission development for Passenger Ferries

The relation between ship's size – ME power output for Passenger ferries with stated service speeds less than 30 knots are based on data from almost 1,800 ships. However, only about 850 of them have reliable information regarding size, speed and ME power output. The Ferries vary much in size and type. Many individual hull types are found in the market as well as different machinery and propulsion sets. These are optimised to field of operation that they have been designed to fit. The base of statistics becomes poor, even more than for cargo ferries. However, higher speed groups show more clear relations. The equations are presented in four speed groups. The equations are not adjusted but the actual curve fit results. Generally it seems to be more appropriate to use GT to determine ME instead of DWT. As ferries vary much in design and generally have low DWT, this is not a suitable character, which is demonstrated for the higher speeds in the DWT-ME power output, see Figure 87.

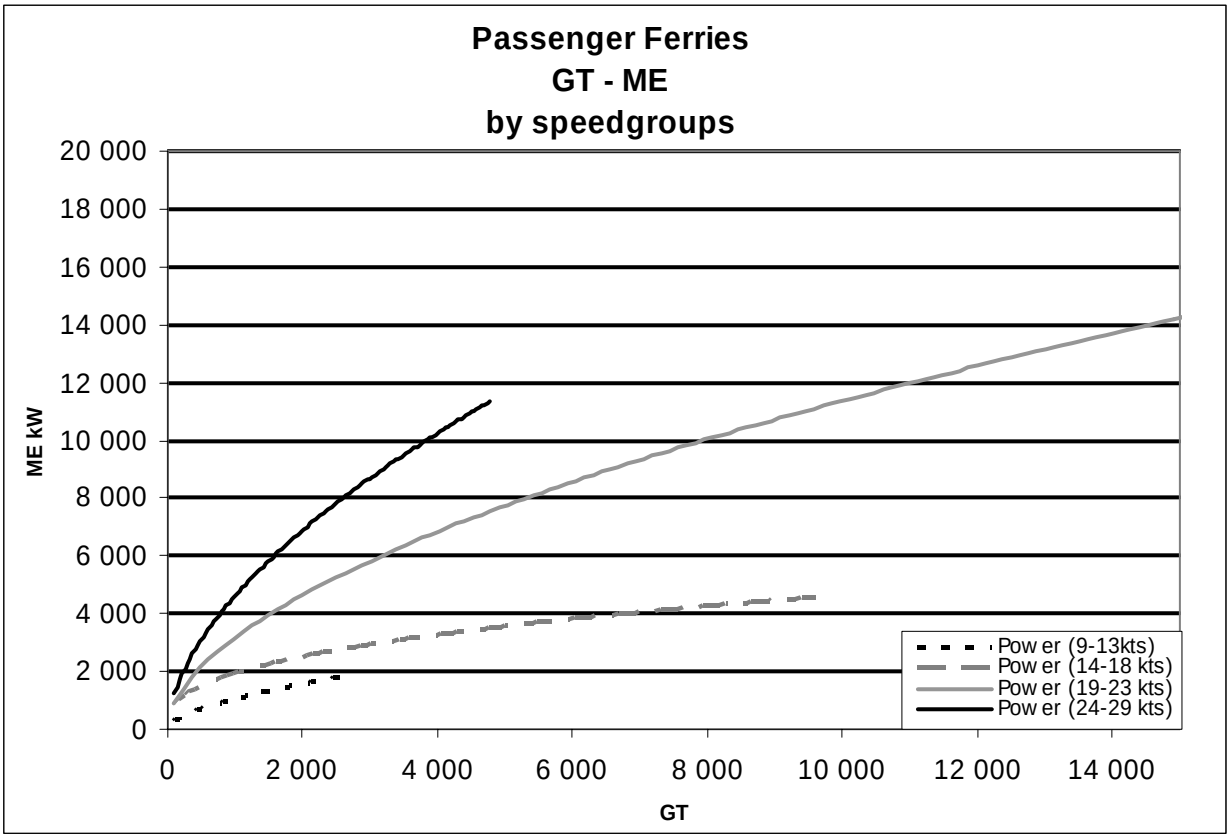


Figure 86; The relation between GT and ME power output for Passenger Ferries

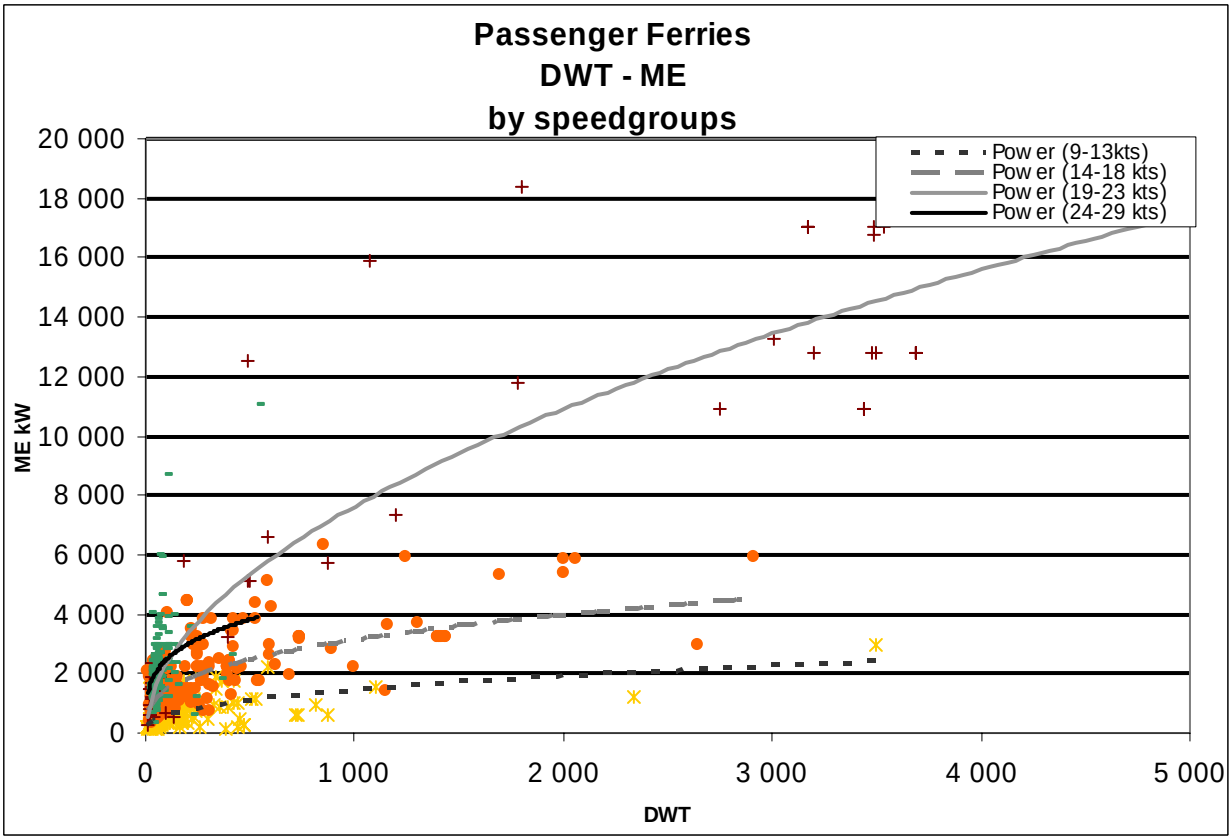
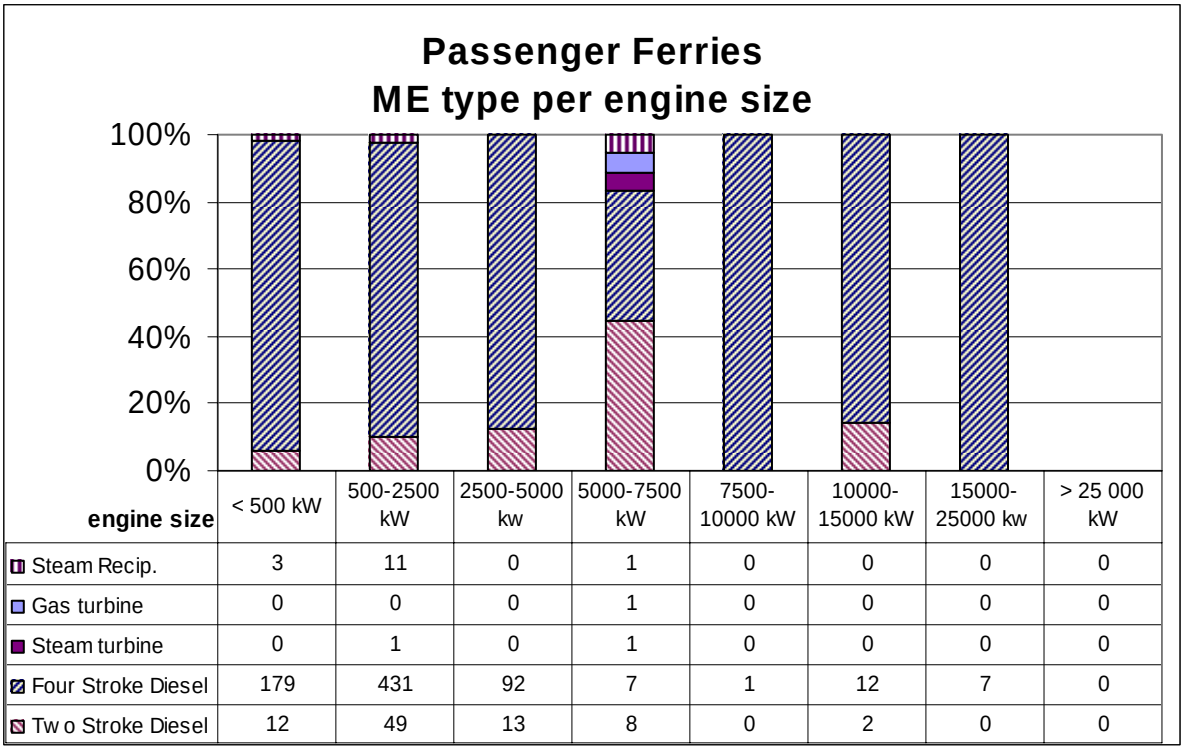


Figure 87; The relation between DWT and ME power output for Passenger Ferries

The following diagram shows the distribution of different engine types for Passenger Ferries, Figure 88. The vast majority of ferries have four stroke diesel engines, even in vessels that demands high ME power output. The reasons are the same as for Ro/Ro vessels and Ferries. Also Passenger ferries are dependant on good manoeuvring in ports, varying modes and conditions of operation why these vessels several normally have 2 or more main engines and often double propulsion systems. For ships with ME power output higher than 5,000 kW the data is to be used with care when applied as there are few ferries with such high power demand. For example there is only one registered vessel with an output between 7,500 and 10,000 kW.



engine size	< 500 kW	500-2500 kW	2500-5000 kw	5000-7500 kW	7500-10000 kW	10000-15000 kW	15000-25000 kw	> 25 000 kW
Steam Recip.	3	11	0	1	0	0	0	0
Gas turbine	0	0	0	1	0	0	0	0
Steam turbine	0	1	0	1	0	0	0	0
Four Stroke Diesel	179	431	92	7	1	12	7	0
Tw o Stroke Diesel	12	49	13	8	0	2	0	0

Figure 88; Passenger ferries main engine type based on ME power output

With reliable data on installed auxiliary engine power from only 38 passenger ferries available, including High speed, it is difficult to conclude any definite relations between size and AE power.

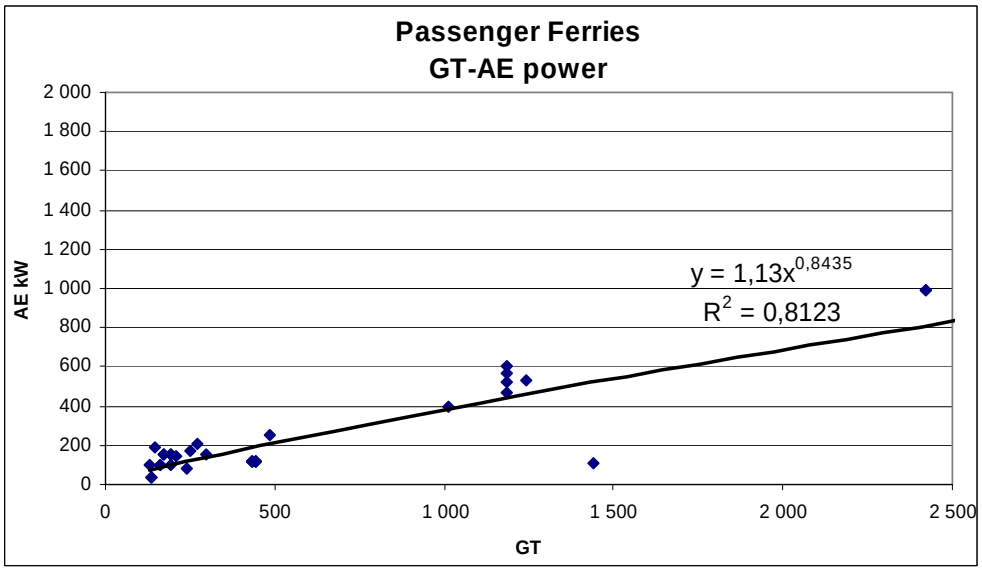


Figure 89 Passenger ferries size (GT) – AE power output. Based on 38 ships (including High speed).

High Speed Ferries

The High Speed or Fast Ferry section is fragmented and it consists of a number of vessels with different configuration in size, propulsion, hulls, speed performance etc. This is illustrated by the result of plotting the ships in a diagram, Figure 93.

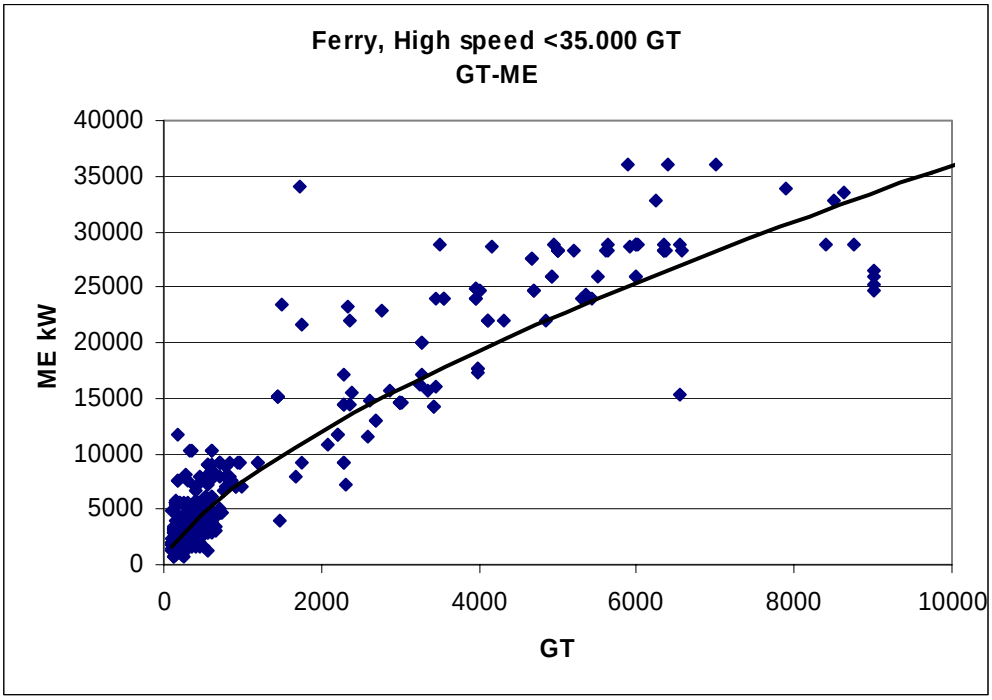


Figure 90; The relation between GT and the ME power output for High speed ferries

The number of vessels in each speed group is also small why the statistics become fragmented. For this reason the speed groups are covering a wider range.

In an assessment it is recommended to identify the ships and their route individually. This is mainly because they are fairly few, the service of the ships is almost always public and that the service represents normally high energy consumption and high emissions.

Size – ME power output relations for High speed Ferries, both cargo and passenger ferries with stated service speeds of 30 knots or more, are based on data of about 700 ships, whereof 140 cargo and 570 passenger ferries. However, as ferries vary much in size, there are very many individual hull types as well as different machinery and propulsion sets selected for the field of operation it gives a variety of ship performances. This makes it difficult to present reliable simple functions. Attempts to distinguish between single and multi hull vessels, as wells as air-cushion crafts like hover-crafts have not improved the trends. As a result there are no such sorting made in the presented relations in order to favour the use of larger populations.

The relations are more distinct when ignoring vessels smaller than 300 GT and the few that are larger than 10,000 GT. The best found relations are, as with other ferries, in speed groups of a bit wider range. Thus the equations based on GT are presented in five speed groups.

The DWT-ME power output equations are similarly based on ferries of more than 40 DWT and presented in three speed groups, together with the corresponding statistical variance, the R^2-value. These DWT-equations are not adjusted to fit theoretical curves. The actual curve fit functions are

presented. Generally it seams to be more appropriate to use GT to determine ME power output instead of DWT as ferries vary much in design and generally have a low DWT.

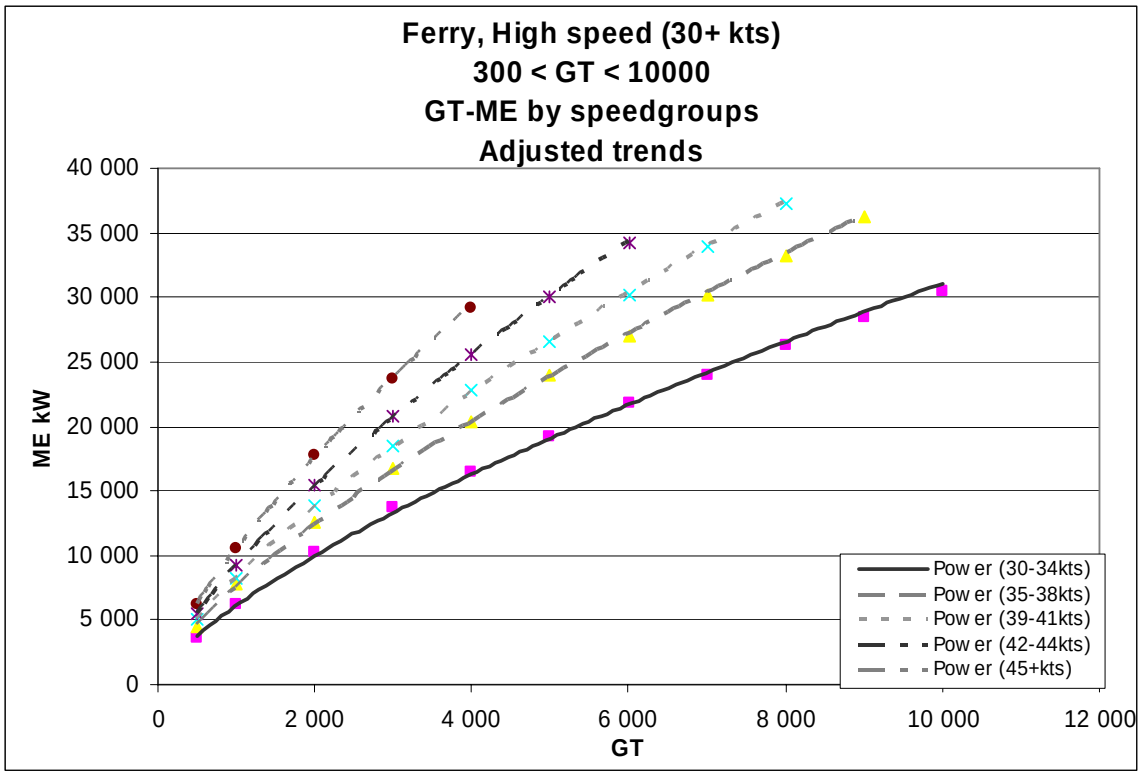


Figure 91; The Relation between Main Engine power output and GT for High speed ferries

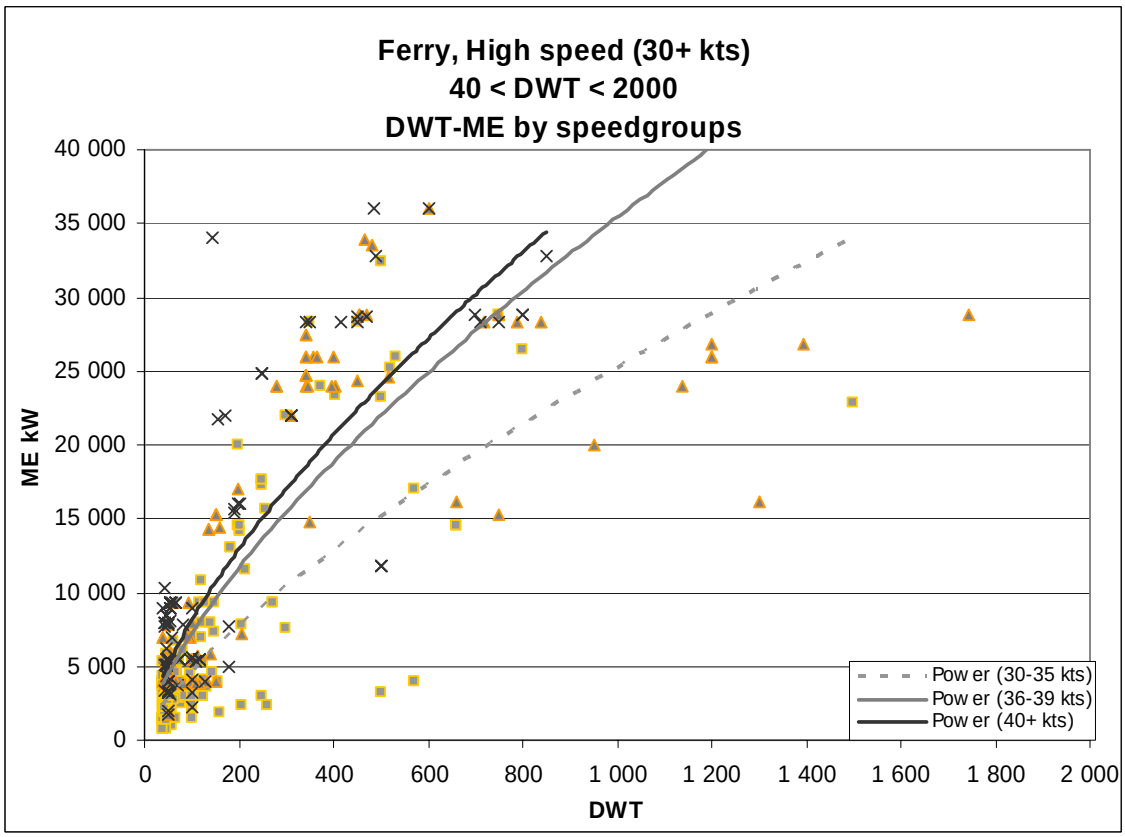
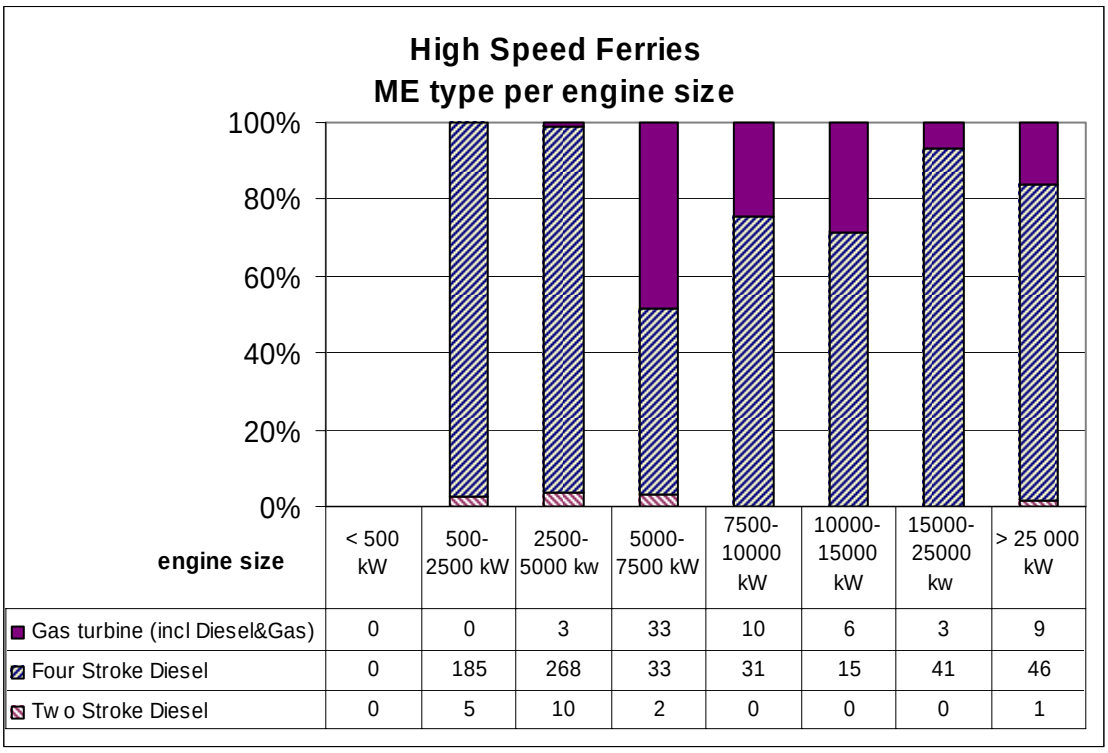


Figure 92; The Relation between Main Engine power output and DWT for High speed ferries

The majority of High speed Ferries have four stroke diesel engines, especially smaller ferries. Larger ferries and ferries with high service speed can be equipped with gas turbines or a combination of gas turbines and four stroke diesel engines. One reason for not using two stroke engines is weight of the machinery which is not suitable for high speed ships. Four stroke engines have a higher output per weight and demands less space. Frequent departures, manoeuvring in ports and different conditions of operation call for flexibility. A number of engines and good propulsion systems help to optimise the power output in comparison to an operation in open sea with few stops that can be performed by one heavy single engine and a fixed straight propulsion system.



engine size	< 500 kW	500-2500 kW	2500-5000 kw	5000-7500 kW	7500-10000 kW	10000-15000 kW	15000-25000 kw	> 25 000 kW
Gas turbine (incl Diesel&Gas)	0	0	3	33	10	6	3	9
Four Stroke Diesel	0	185	268	33	31	15	41	46
Tw o Stroke Diesel	0	5	10	2	0	0	0	1

Figure 93; High speed ferries main engine type based on ME power output. Gas turbine includes vessels with both turbine and diesel engines.

The Size – AE relation for High speed ferries can be based on the relations for Cargo and Passenger ferries, Figure 80 and Figure 89.

Tanker

The Tanker type of ships has a wide market. The number of ships gives a solid statistical base. New safety aspects give a turnover of old ships to new ones featuring a more safe design. This development started when a demand came on the tankers to have a ballast capacity that allowed approaching the port of loading and leaving the port of discharge using ballast tanks that are segregated and never used as tanks for cargo. The development started already in the 70:ies and it affected the rules how to measure the tonnage of the ships. For this reason some fairway dues and port dues are still based on the GRT (Oslo convention) or there is a general discount on the GT (London convention) for tankers.

The development can be seen in Figure 94 displaying the age of the ships.

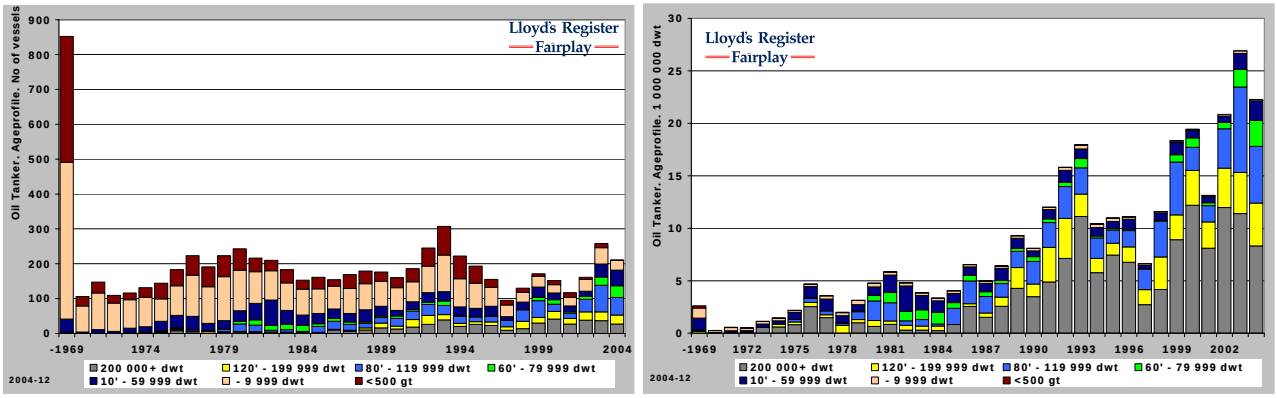


Figure 94; The age profile of oil tankers in number of ships to the left and in relation to capacity to the right

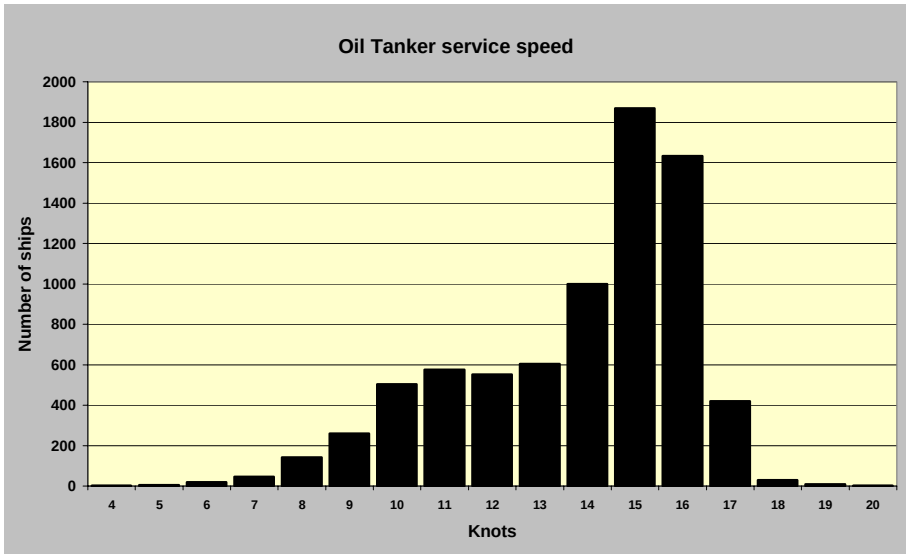


Figure 95; The speed profile for Tankers

The speed profile of Tankers shows a concentration to the 15 knot area. Tankers are normally a slow type of ships where the running cost is important. This results in a good environmental performance from emissions and freight point of view.

The speed development shows minor variation over time. The same applies to the Chemical Tankers why all tankers are integrated in the Tanker type of ships. The major difference is the arrangement of tanks, pumps and pipes in the ship and a slightly higher displacement for the Chemical tankers of the same DWT.

The development of speed is very similar for both type of ships, see Figure 96 and Figure 97.

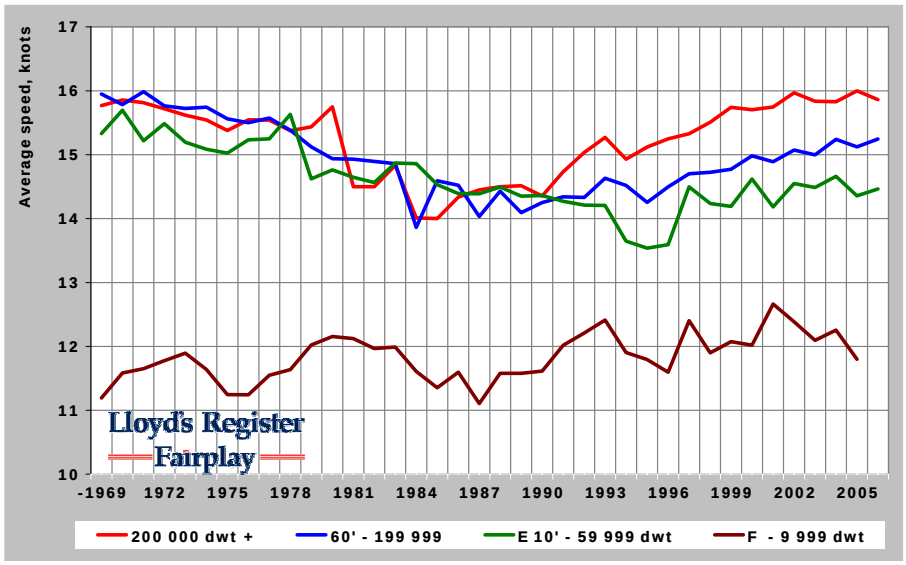


Figure 96; The speed development for Oil Tankers

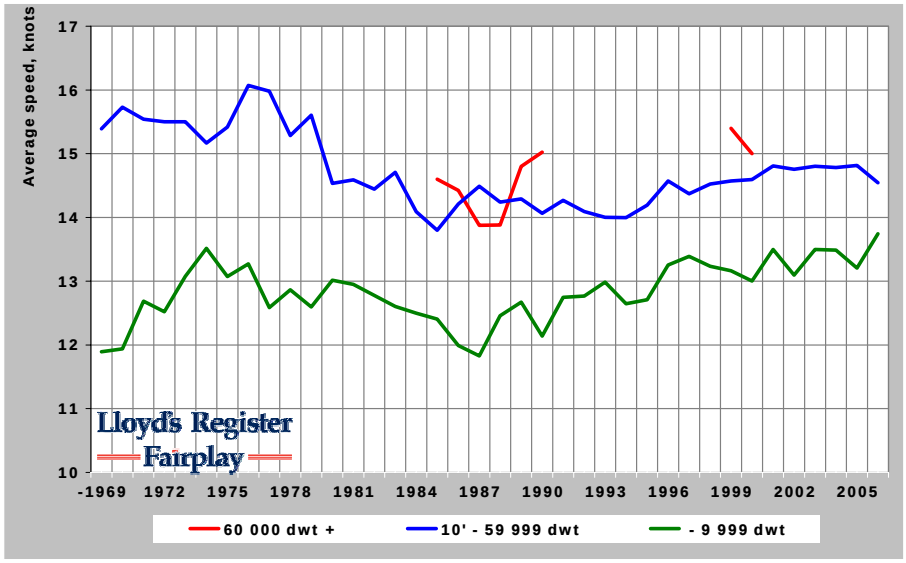


Figure 97; The speed development for the Chemical Tankers

The environmental performance of the ships is good since large quantities are shipped at low speed, which results in a low fuel consumption per carrying capacity (DWT) and day.

Figure 98 demonstrates the continuous increase of fuel efficiency and the effect of "economy of scale" on fuel consumption when the size of the ships increases.

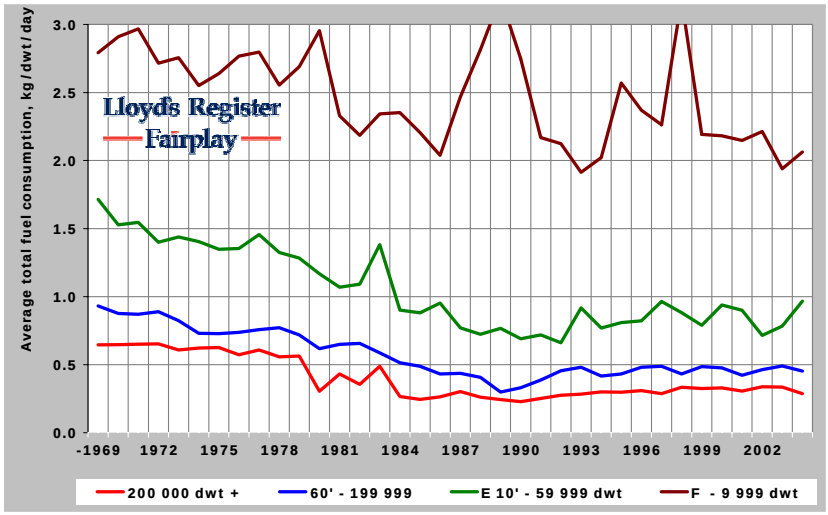


Figure 98; The development of fuel efficiency for Tankers

The low fuel consumption also gives lower emissions per freight unit, see Figure 99.

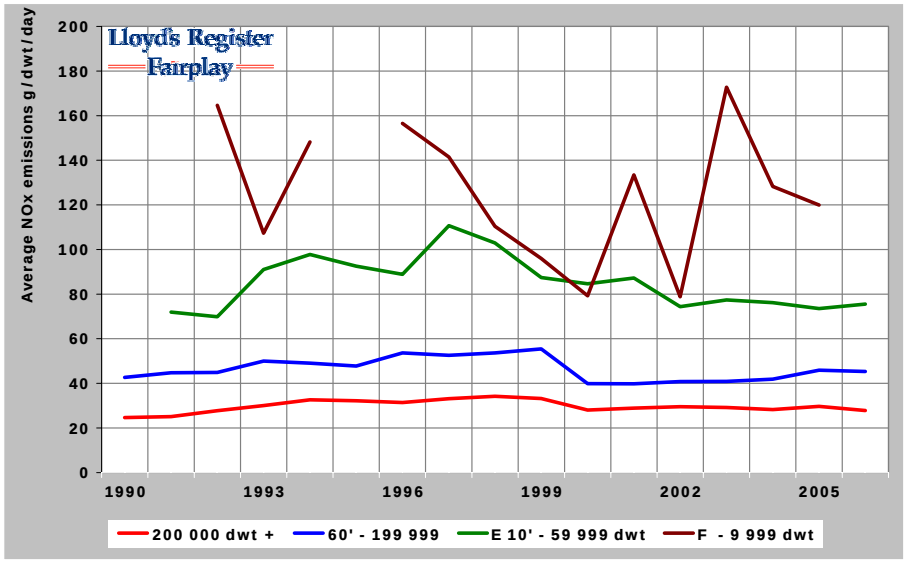


Figure 99; The development of NO_x emissions for Tankers

Figure 99 shows a stable and very low level of NO_x emissions for Tankers in operation and to be delivered over the years.

The Size – ME power output relations for tankers are based on data from some 13,600 Oil and Chemical Tankers, of which about 9,100 have satisfactory notations regarding size, service speed and installed ME power output. In order to better account for the considerable span in size for tankers, ranging from small bunker tankers of 50 DWT to VLCC/ULCC tankers of 500,000 DWT, they are split in to three groups; Small <10,000 DWT; Handysize 10,000 – 60,000 DWT and Large Tankers >60,000 DWT.

The functions are determined for each group but are adjusted to fit as a continuous curve. The equations are based on the relations at 12 knots for small tankers and those of 15 and 16 knots for larger. A similar procedure is made for GT – ME power output relations, but different groups are combined to one final equation for each speed level. It is suggested to use the DWT-based relations if possible, they are more representative and DWT is a common size denomination for tankers.

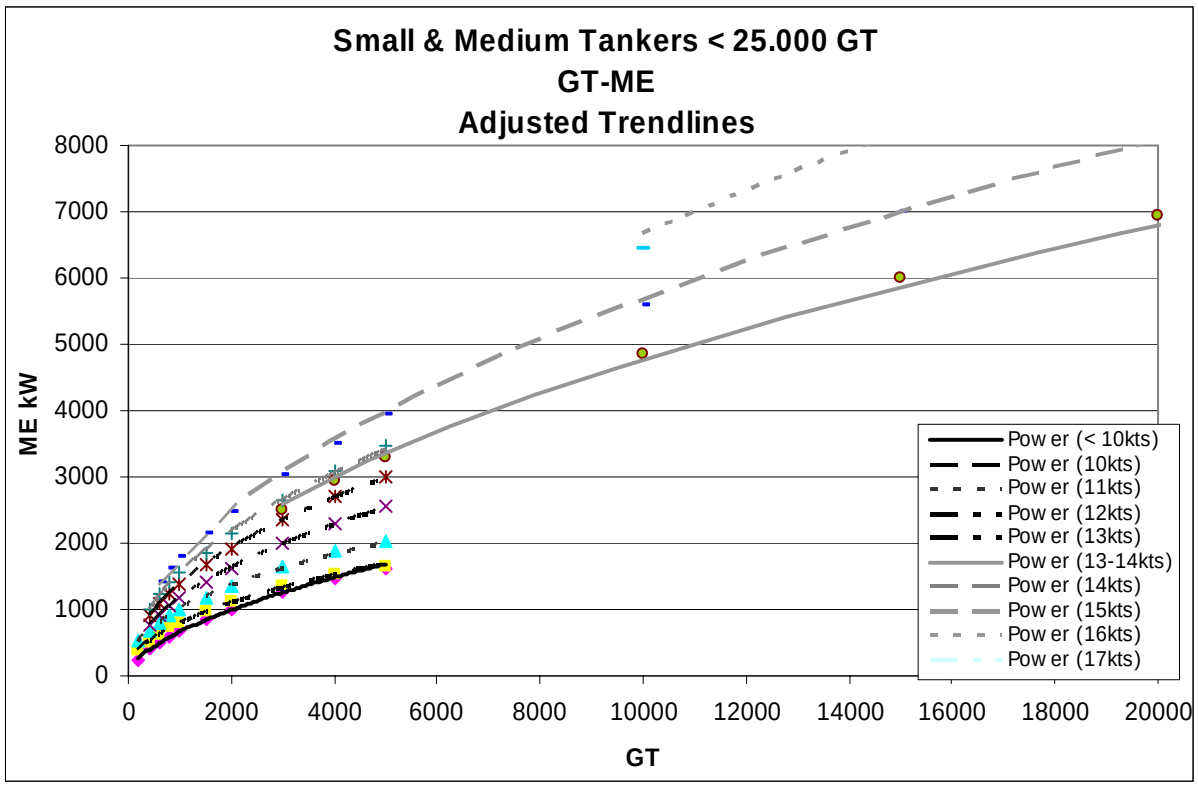


Figure 100; Oil and chemical tankers size GT – ME power output relations by speed. Tankers <25,000 GT

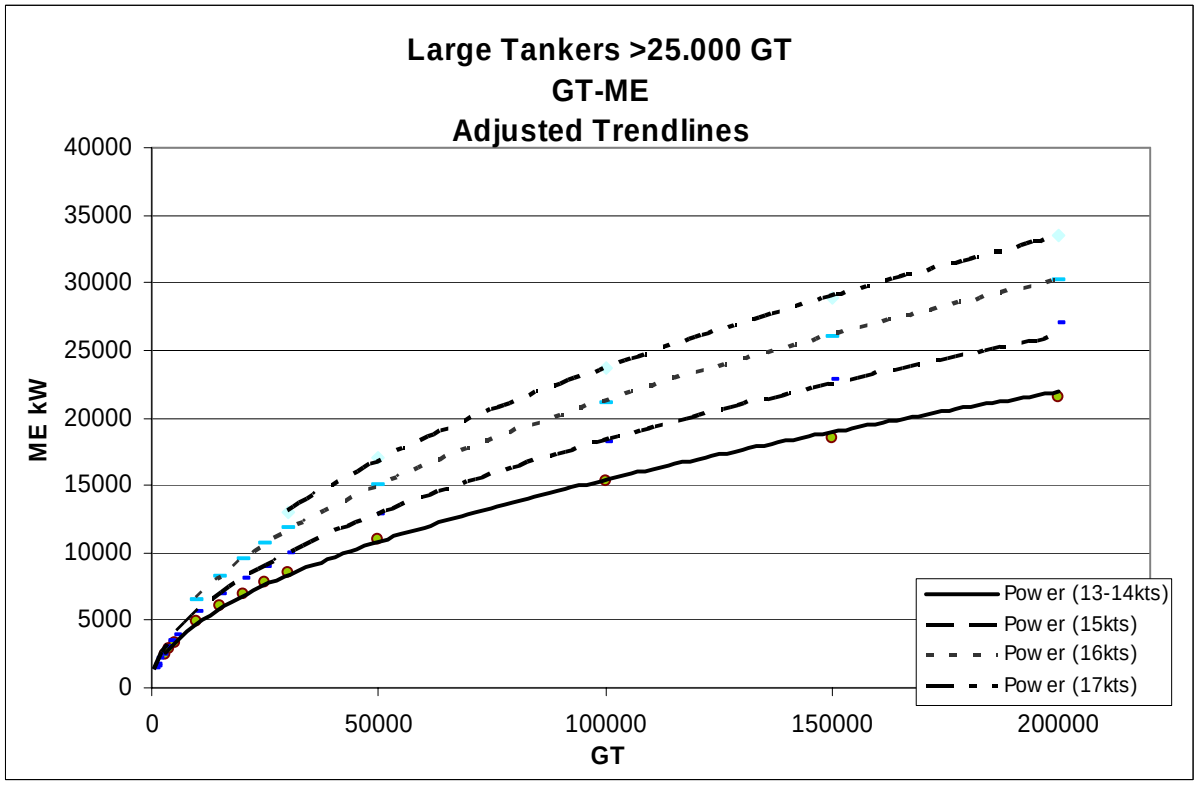


Figure 101; Oil and chemical tankers size GT – ME power output relations by speed. Tankers >25,000 GT

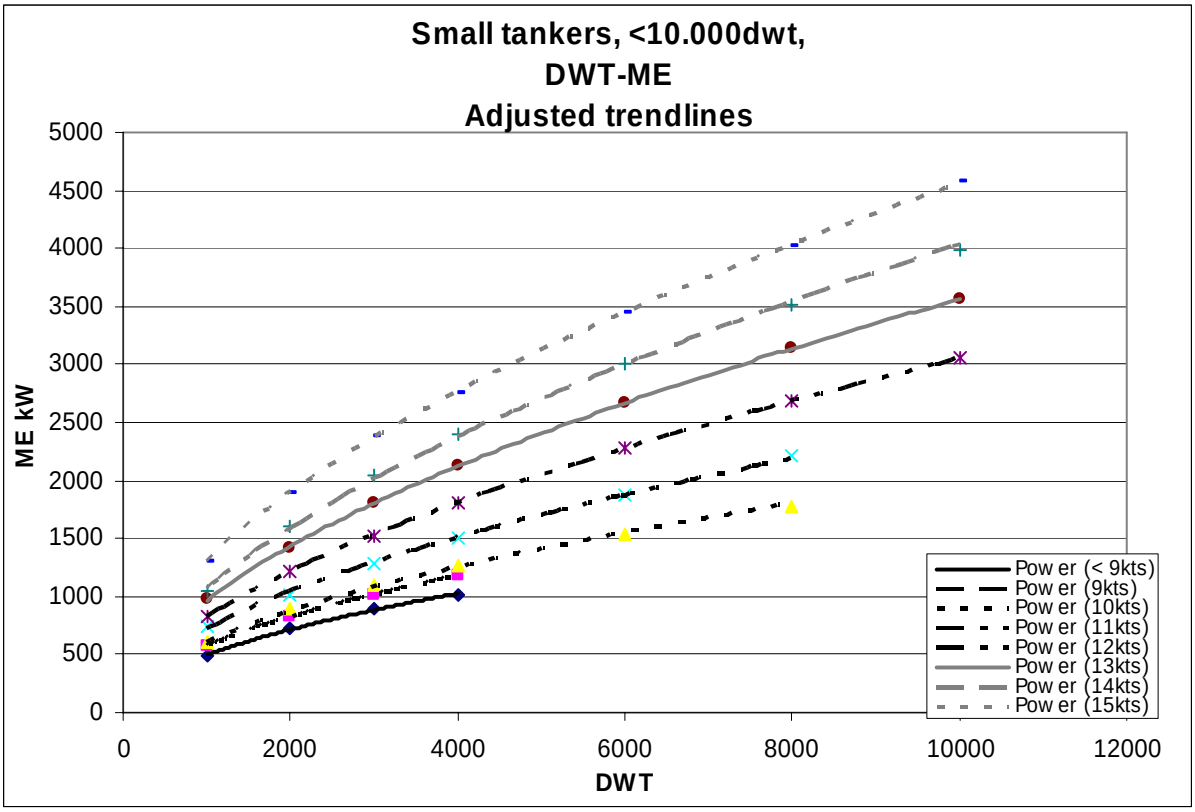


Figure 102; Oil and chemical tankers size DWT – ME power output relations by speed. Small tankers <10,000 DWT

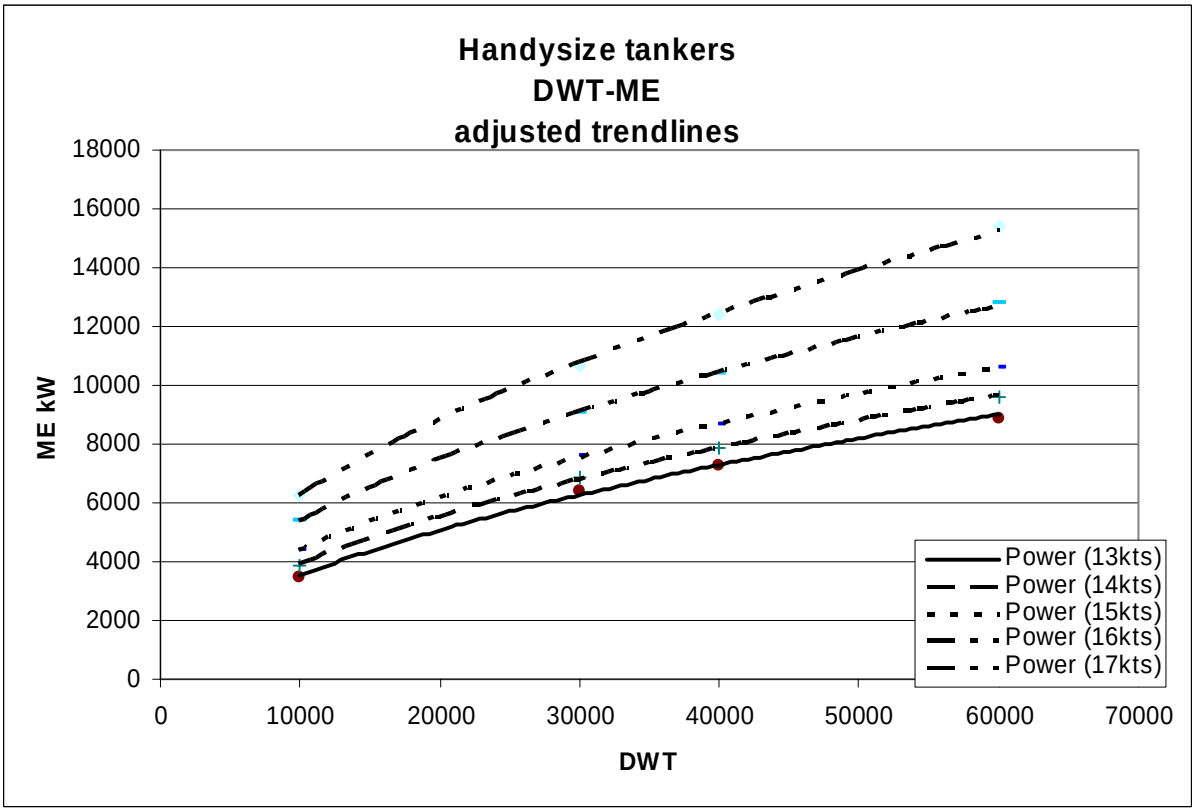


Figure 103; Oil and chemical tankers, DWT – ME power output relations by speed. Handysize tankers 10 – 60,000 DWT

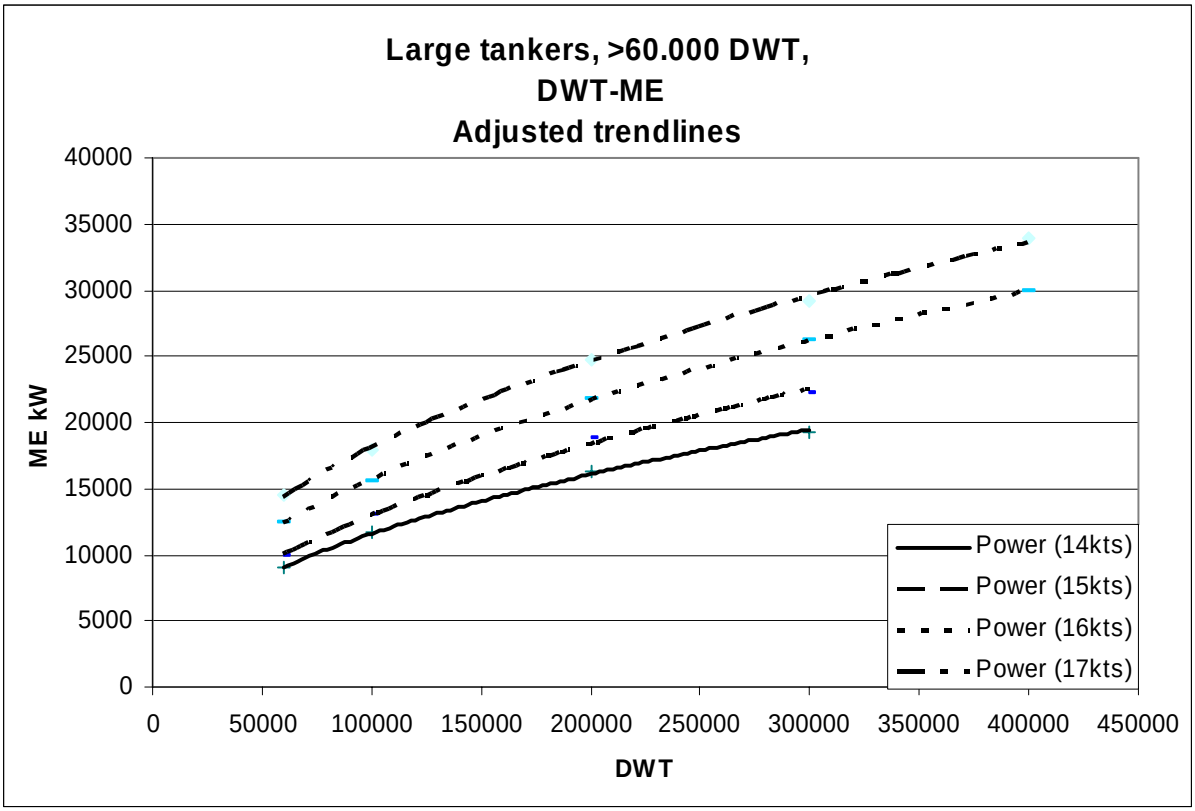
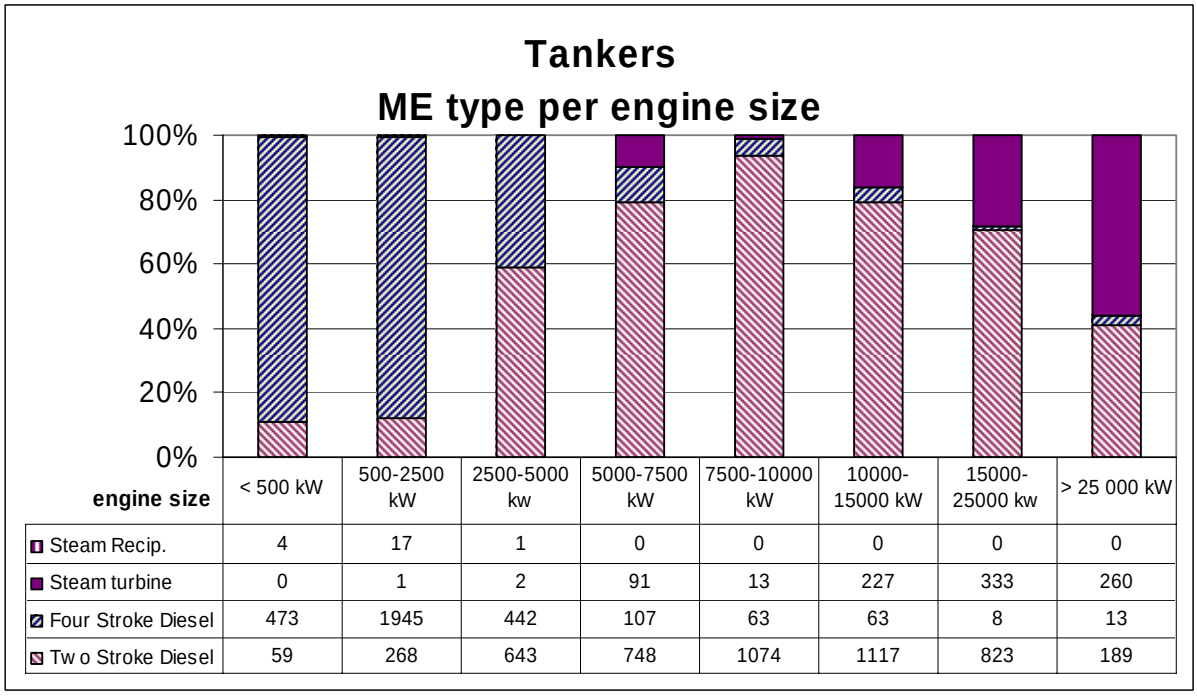


Figure 104; Oil and chemical tankers size (DWT) – ME power output relations by speed. Large tankers >60,000 DWT

Generally small tankers are equipped with four stroke diesel engines and larger with two stroke diesel engines. The majority of the largest mostly older ships are equipped with steam turbine engines.



engine size	< 500 kW	500-2500 kW	2500-5000 kw	5000-7500 kW	7500-10000 kW	10000-15000 kW	15000-25000 kw	> 25 000 kW
Steam Recip.	4	17	1	0	0	0	0	0
Steam turbine	0	1	2	91	13	227	333	260
Four Stroke Diesel	473	1945	442	107	63	63	8	13
Tw o Stroke Diesel	59	268	643	748	1074	1117	823	189

Figure 105; Oil and Chemical Tankers main engine type based on assumed ME power output

The relation between size (DWT) and installed auxiliary engine power for Tankers depends on the type of tanker, if it has several small tanks, which is common for Chemical and Product tankers or if it has fewer and larger tanks, as the number of tanks corresponds with the power needed to operate the pumps. In the Figure 106 below it is not possible to distinguish between Product and Crude oil tankers, only between Chemical and Oil.

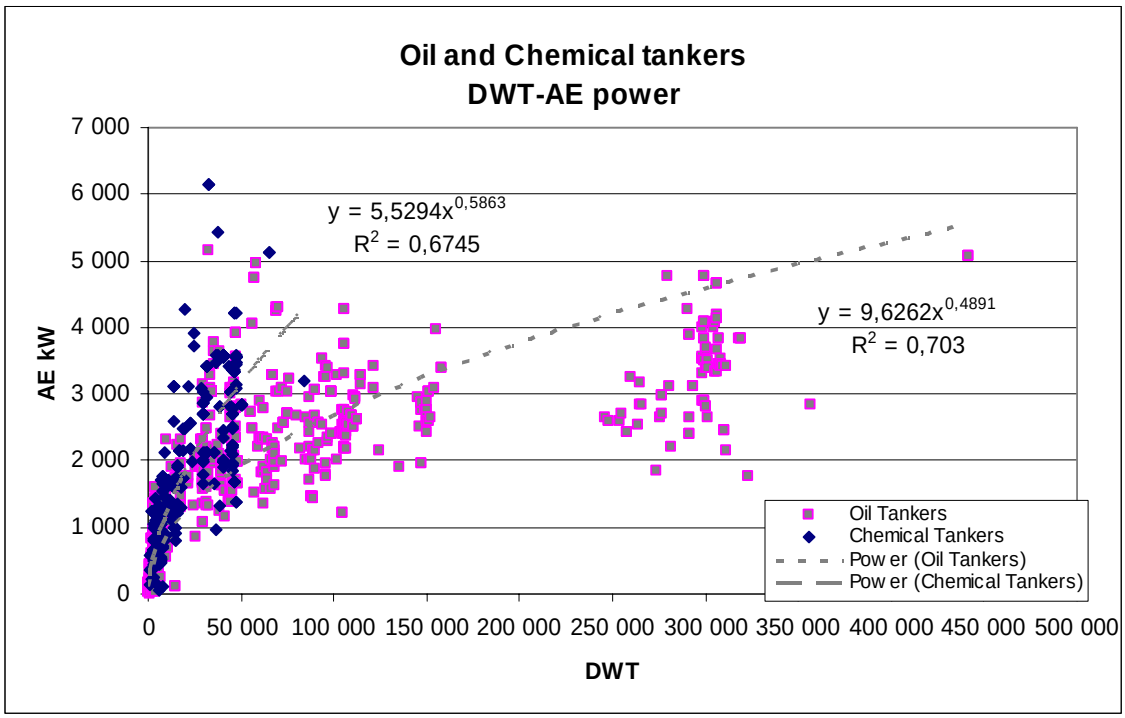


Figure 106; The relations between ships carrying capacity in DWT and installed Auxiliary Engine power for 729 Oil tankers and 278 Chemical Tankers.

Gas Tanker

Gas Tankers are represented by the LPG and LNG type of ships where LNG normally is a Turbine Tanker that uses the gas (the cargo) as fuel for the engines. The number of LNG ships is still very low and of a very special size why it makes no reason to separate the two types.

Especially the LNG tankers are predicted to grow in number in future. They are predicted to participate in the distribution system for the supply of clean energy in Europe and over the world.

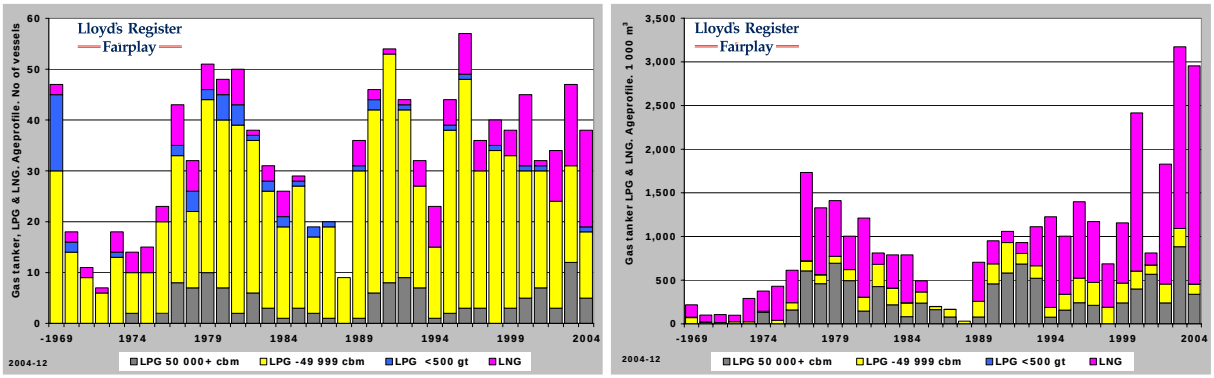


Figure 107; The age profile of Gas Tankers in number of ships to the left and in capacity to the right

The speed characteristics of the ship type show a higher speed than for the Tankers. The LNG (Liquid Natural Gas) ship is very complicated with a system to liquefy the gas and to keep it

liquefied during the transport. The ship uses the gas as fuel for the engines. The LPG (Liquid Petrol Gas) ship is simpler.

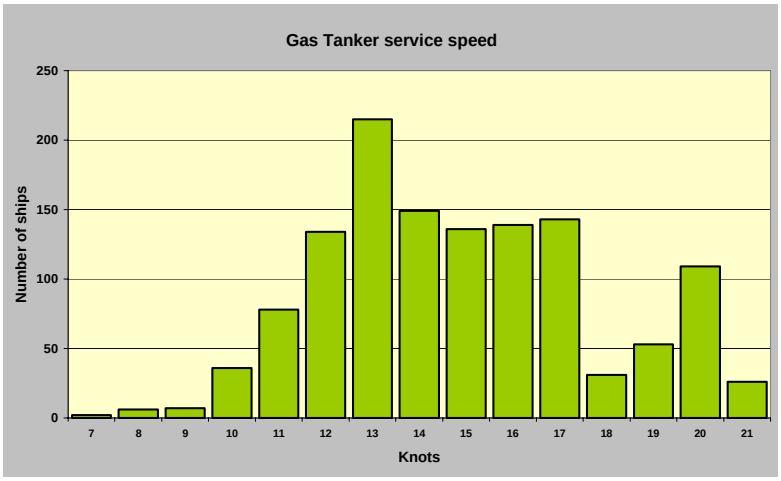


Figure 108; The profile of speed for Gas Tankers

The profile of speed shows two levels whereof the LNG is the one between 18 – 21 Knots.

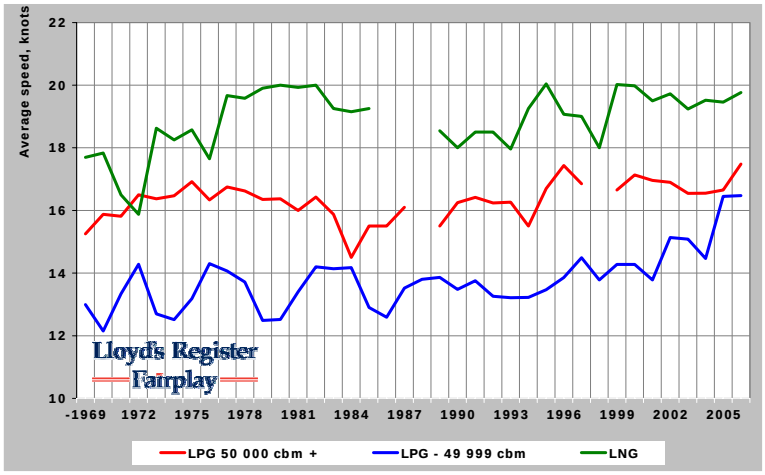


Figure 109; The development of speed for the Gas Tankers

Figure 109 shows the development of speed for the different ship types and sizes. The LNG and the larger LPG ships seem to be relatively constant while small LPG ships are built for higher speed.

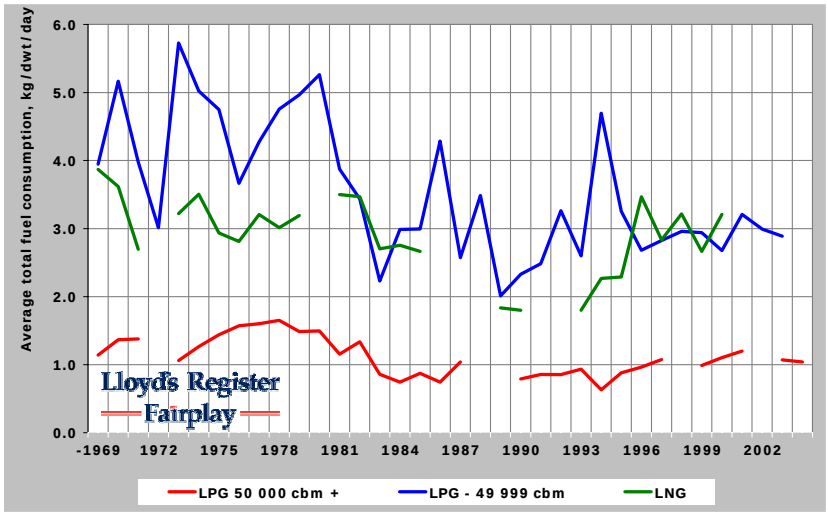


Figure 110; Gas tanker, fuel consumption development

The fuel consumption displays a rather declining consumption for all types and categories. Once a gain it should be noted that the LNG ships are very few and that they are running on the cargo that gives low NO_x and good environmental performance.

The relation of ships' size – ME power output for Gas tankers are based on data from some 1,000 LPG tankers and 160 LNG tankers that have satisfactory data regarding size, service speed and installed ME power output. Initially the intention was to present relations valid for all gas tankers, however as LNG tankers generally are much larger than LPG tankers, the type was instead split in to three size groups, small LPG <5,000 GT, large LPG and LNG tankers. The final equations are presented for LPG and LNG. The equations are based at 13 knots for small LPG tankers and for 14 and 16 knots for larger LPG, while the equations for LNG tankers are based on the relations at 20 knots. The small populations make especially the relations for LNG very uncertain; as this is a fast growing segment with a predicted rise in demand, there will probably be a considerable development in hull types and machinery.

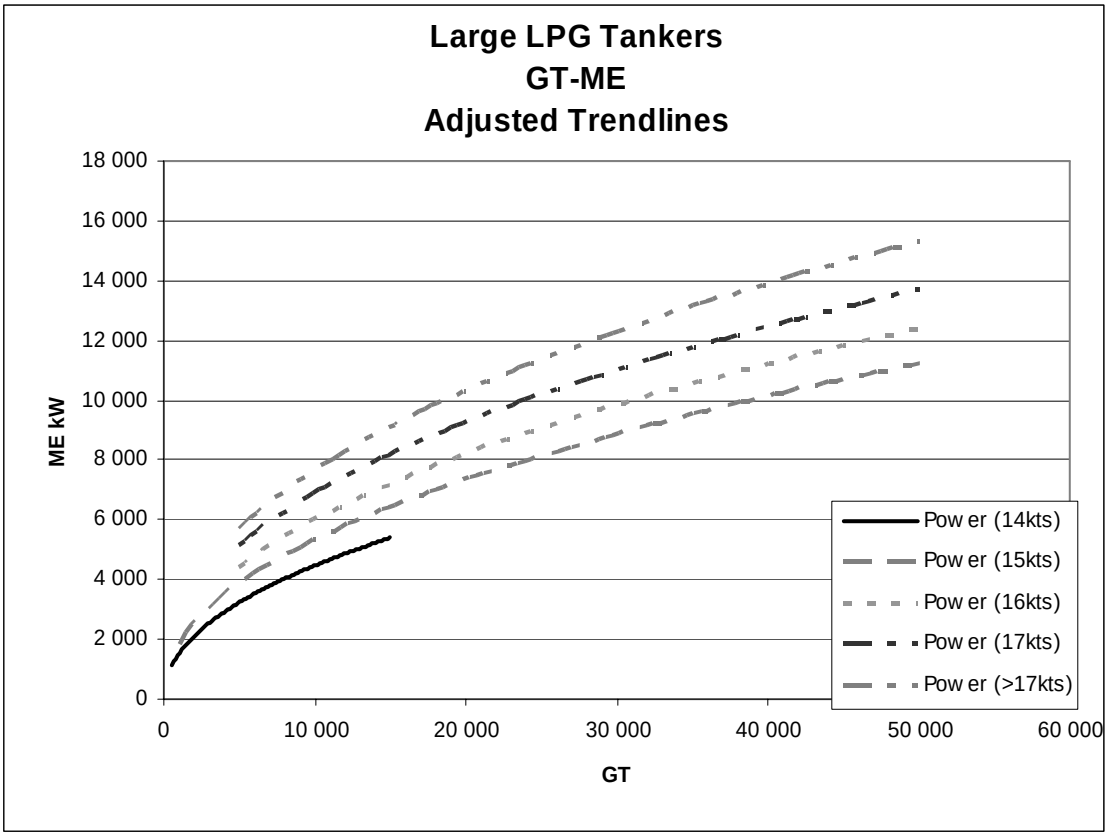


Figure 111; LPG tankers size GT – ME power output relations by speed level

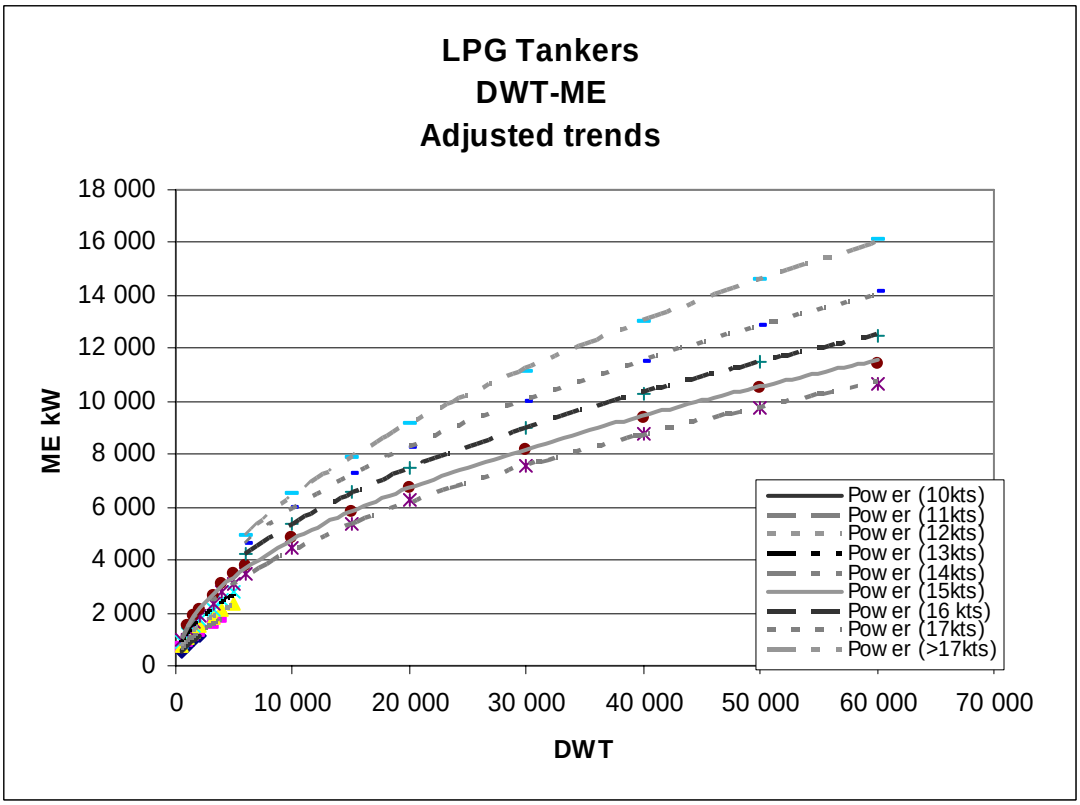


Figure 112; LPG tankers size DWT – ME power output relations by speed level

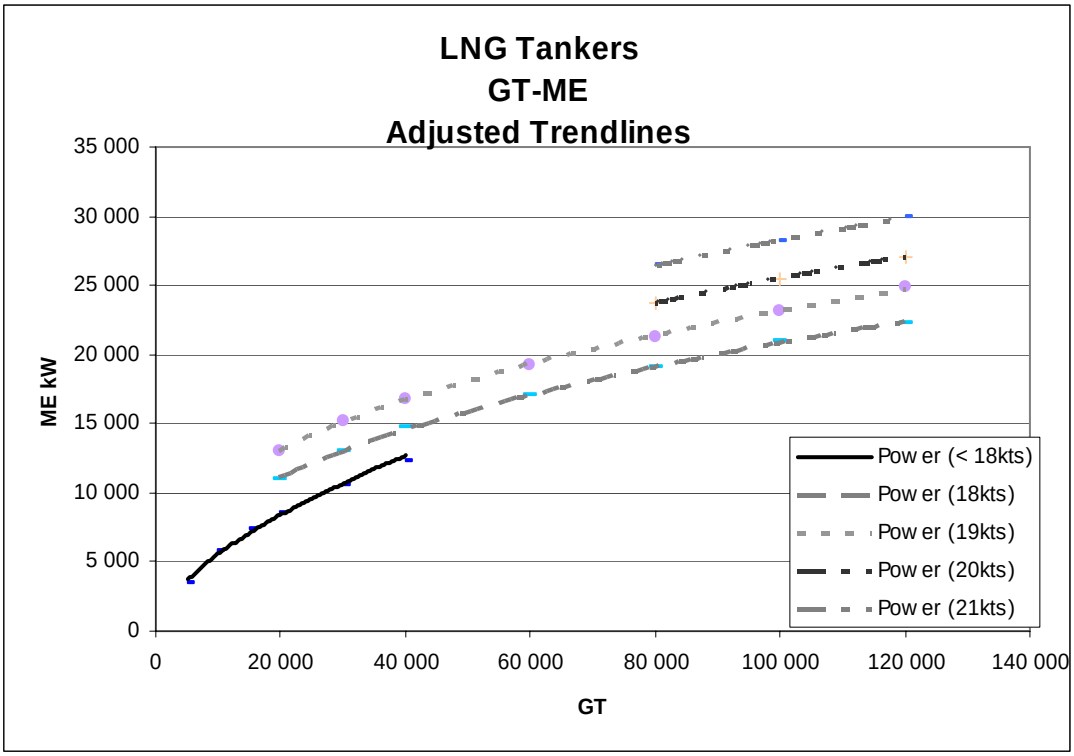


Figure 113; LNG tankers size GT – ME power output relations by speed level

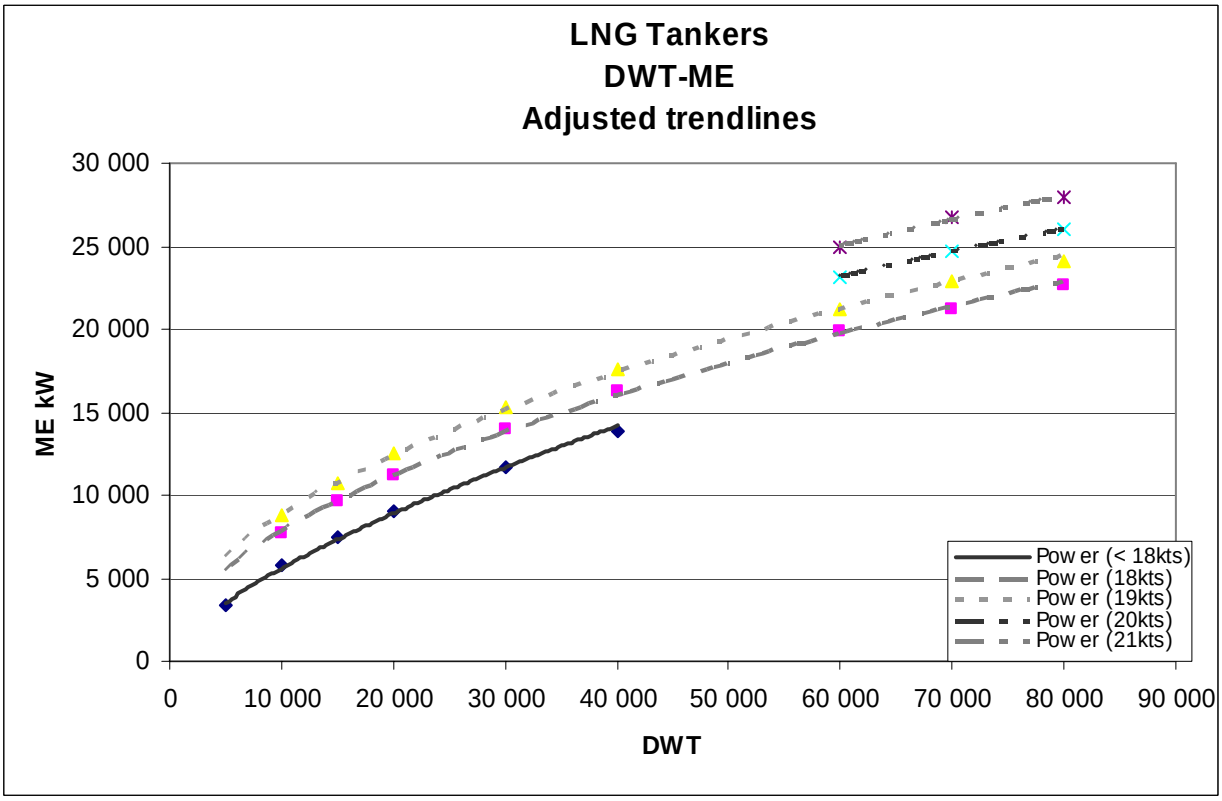
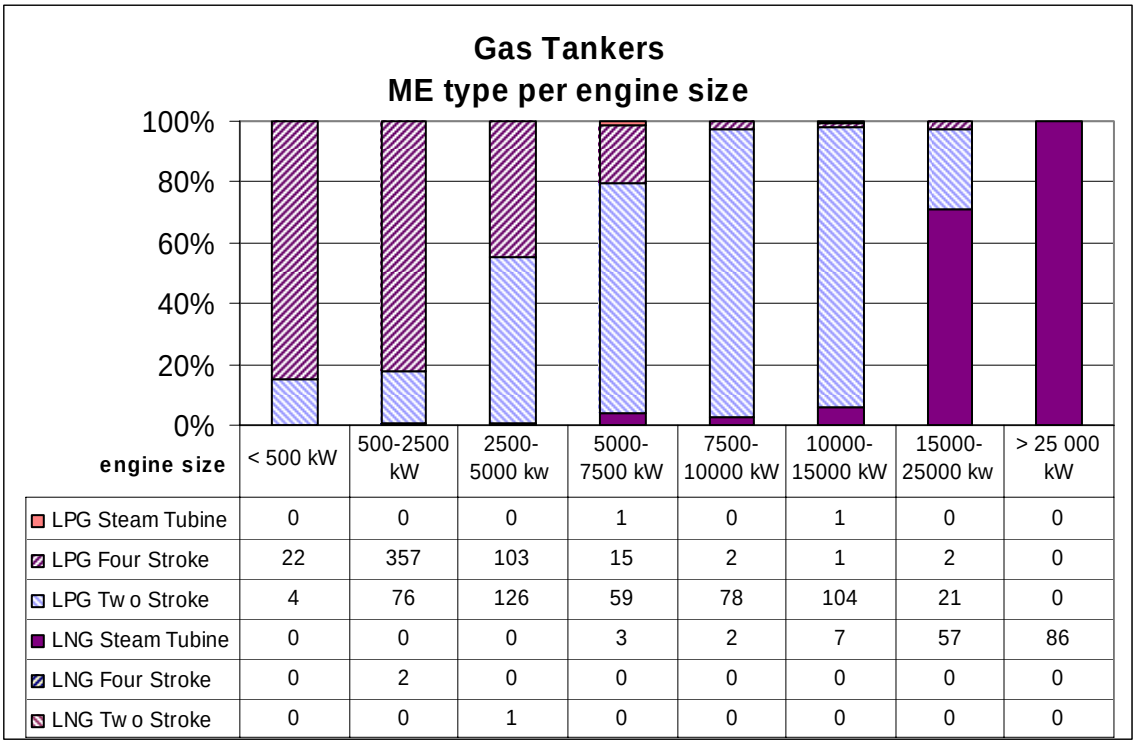


Figure 114; LNG tankers size in DWT – ME power output relations by speed level



engine size	< 500 kW	500-2500 kW	2500-5000 kw	5000-7500 kW	7500-10000 kW	10000-15000 kW	15000-25000 kw	> 25 000 kW
LPG Steam Tubine	0	0	0	1	0	1	0	0
LPG Four Stroke	22	357	103	15	2	1	2	0
LPG Tw o Stroke	4	76	126	59	78	104	21	0
LNG Steam Tubine	0	0	0	3	2	7	57	86
LNG Four Stroke	0	2	0	0	0	0	0	0
LNG Tw o Stroke	0	0	1	0	0	0	0	0

Figure 115; Gas Tankers Main Engine type based on ME power output

The set up of engines in Figure 115 shows a very typical distribution of how the different types of engines are used as a relation to ships needed ME power.

The installed auxiliary engine power is presented in Figure 116 and Figure 117. The relation for LNG Tankers should be used with caution, as the data is of a quite wide range.

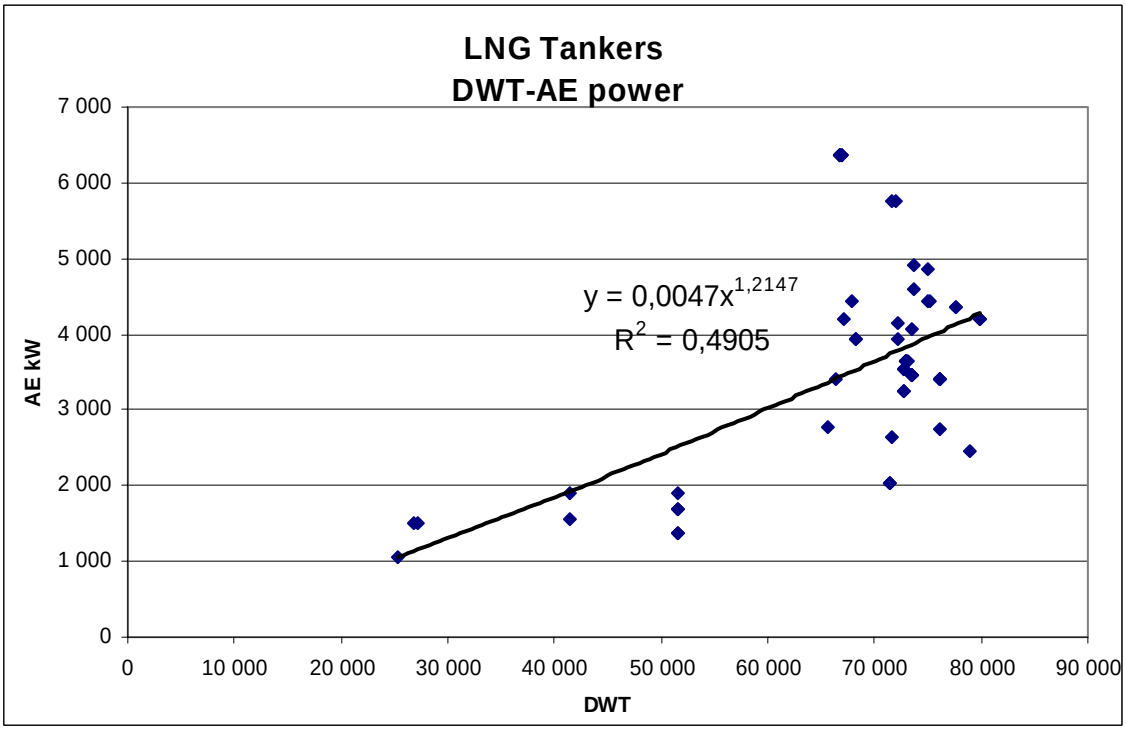


Figure 116 LNG Tankers size (DWT) – AE power output. 57 vessels.

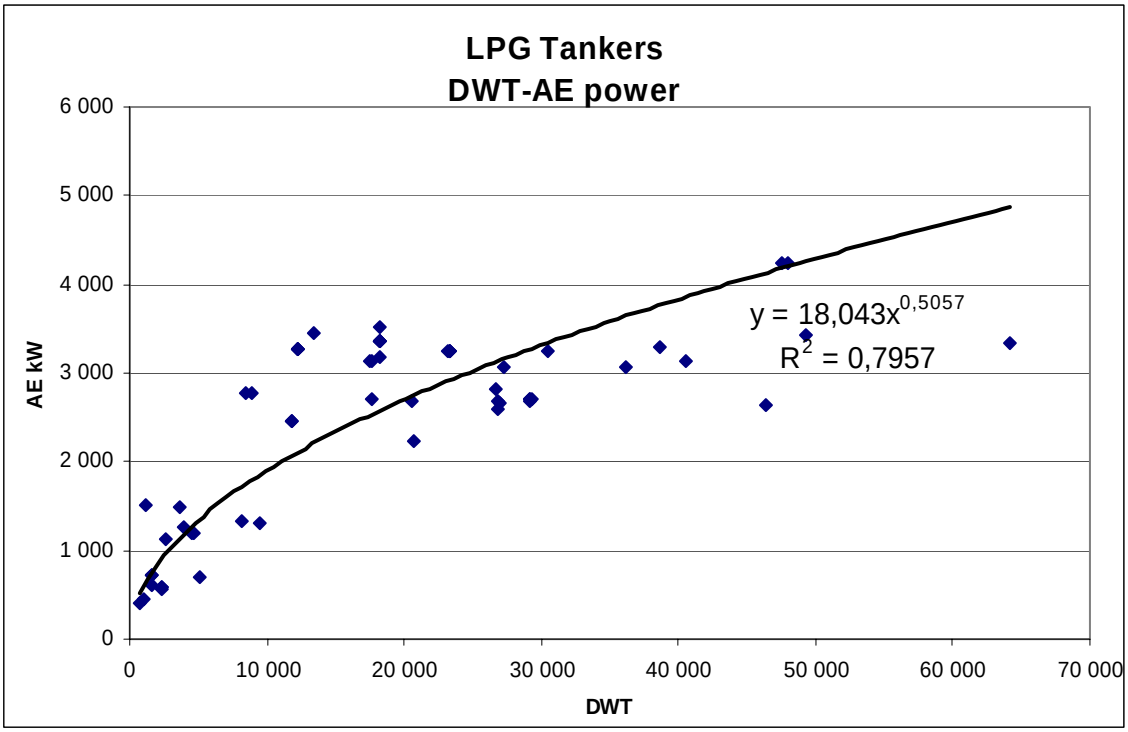


Figure 117 LPG Tankers size (DWT) – AE power output. 60 vessels.

Cruise vessels

Cruise vessels are defined as pure passenger ships with berths, e.g. over-night capacity for all passengers. They are generally designed for longer voyages although the type also includes larger yachts, sailing yachts and certain river vessels. Most of the latter vessels are not included in this study. Cruise vessels are generally larger in volume than ferries, and have excess engine capacity to handle the considerable need of ventilation and air-conditioning. Typically a cruise vessel will travel during the night and lay still during day-time when the need for electricity is high. There has been a considerable increase in size in newer cruise ships and an introduction of diesel-electric engine sets. The electric generation is often combined with poded propulsion (special swivelling propeller arrangement).

The relation of size in GT – ME power output for Cruise ships are based on data from some 500 vessels of which about 400 have satisfactory data regarding size, service speed and installed ME power output. Much like ferries, cruise ships can vary much in size and design, however by ignoring some 30 vessels with unrepresentative relation of GT/DWT especially for small ships (<2,000 GT) the relationship become more clear. As with ferries it is appropriate to present the equations by grouping the speed levels.

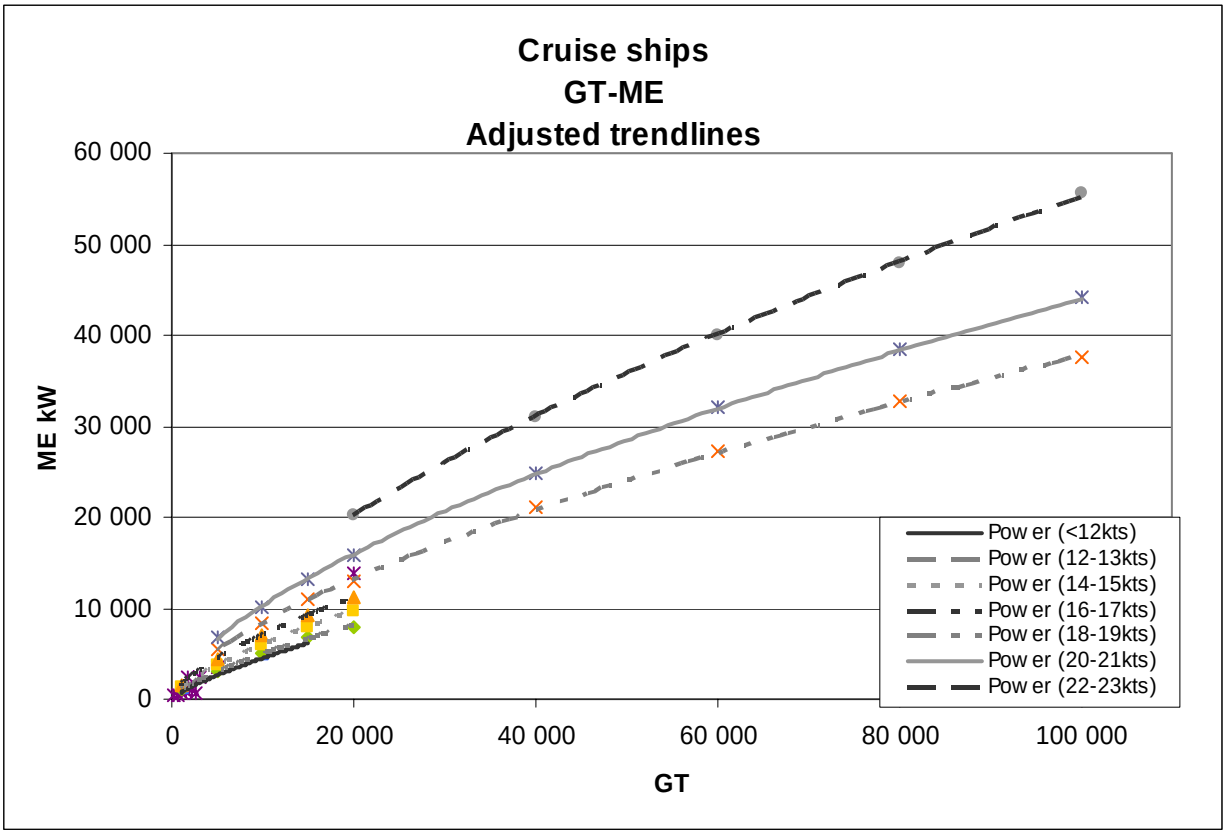


Figure 118; Cruise vessels size in GT – ME power output relations by speed levels

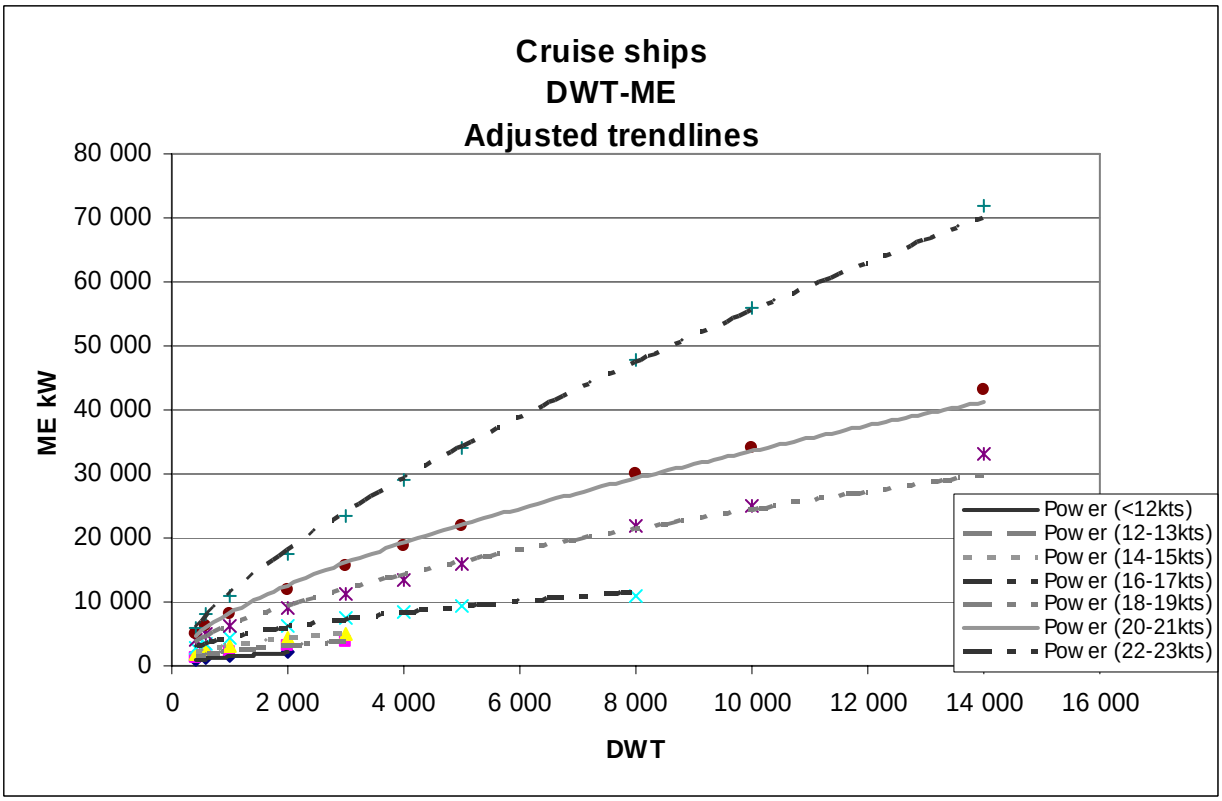
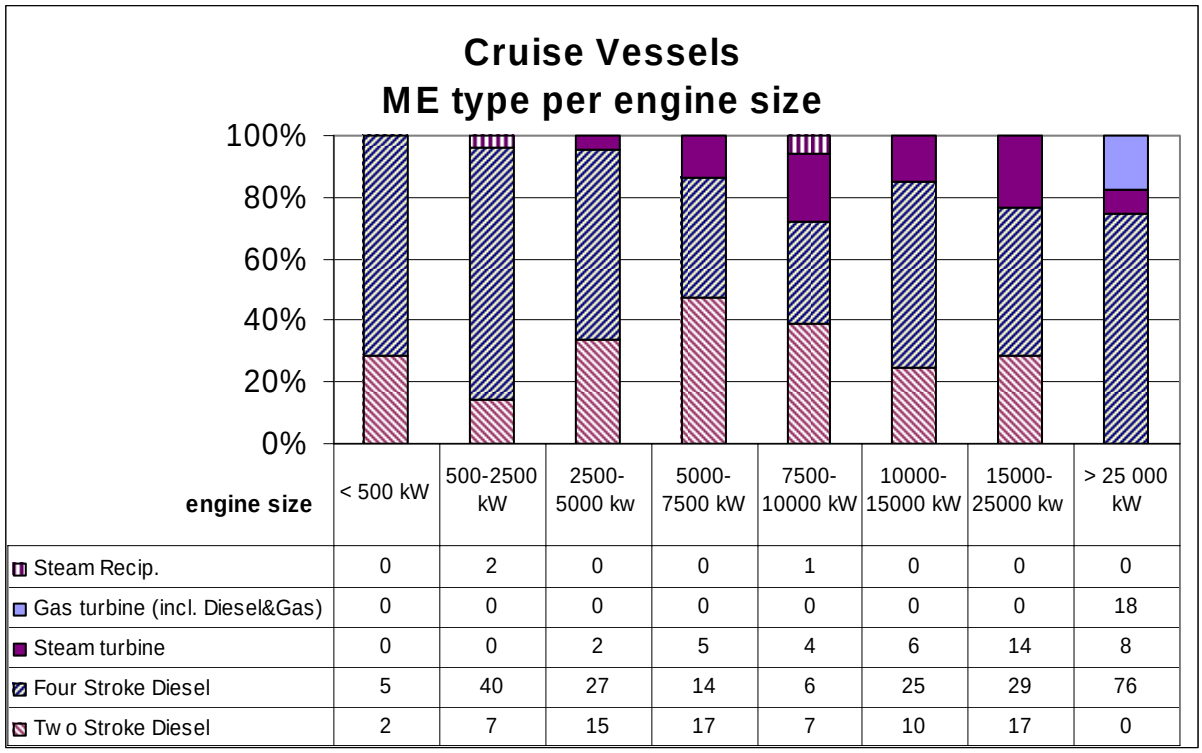


Figure 119; Cruise vessels size in DWT – ME power output relations by speed groupings

Most cruise vessels are equipped with four stroke diesels but there are no clear relations between total installed ME output and engine type, except that the only gas turbine engine sets are found in vessels with a ME output of 25,000 kW or more.



engine size	< 500 kW	500-2500 kW	2500-5000 kw	5000-7500 kW	7500-10000 kW	10000-15000 kW	15000-25000 kw	> 25 000 kW
Steam Recip.	0	2	0	0	1	0	0	0
Gas turbine (incl. Diesel&Gas)	0	0	0	0	0	0	0	18
Steam turbine	0	0	2	5	4	6	14	8
Four Stroke Diesel	5	40	27	14	6	25	29	76
Tw o Stroke Diesel	2	7	15	17	7	10	17	0

Figure 120; Cruise vessels main engine type based on ME output. Gas turbine includes ships with a combination of diesel and gas engines. Two and four stroke includes vessels with sail and diesel engines as auxiliary.

The relations between size in GT and total installed AE power output is clearly divided in two groups depending on if the ships are equipped with electric drives or not, Figure 121. Ships with diesel electric or similar type of Main Engine do not need additional engine power for generation of electricity. Generally this applies to larger cruise vessels.

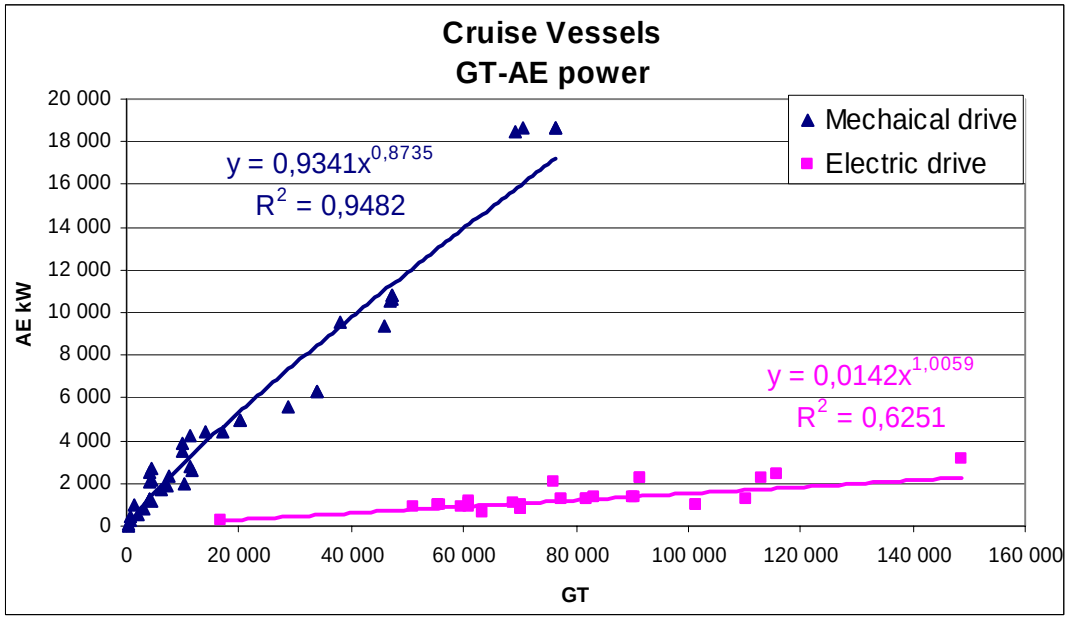


Figure 121; Cruise ships size (GT) – AE power output. 87 ships.

Vehicle Carriers

Vehicle Carriers are ships primarily intended to carry new and non loaded vehicles. Large Vehicle Carriers generally operate on linear round-the-world services at a fixed moderate high speed. The speed distribution show a strong concentration around 19 – 20 knots.

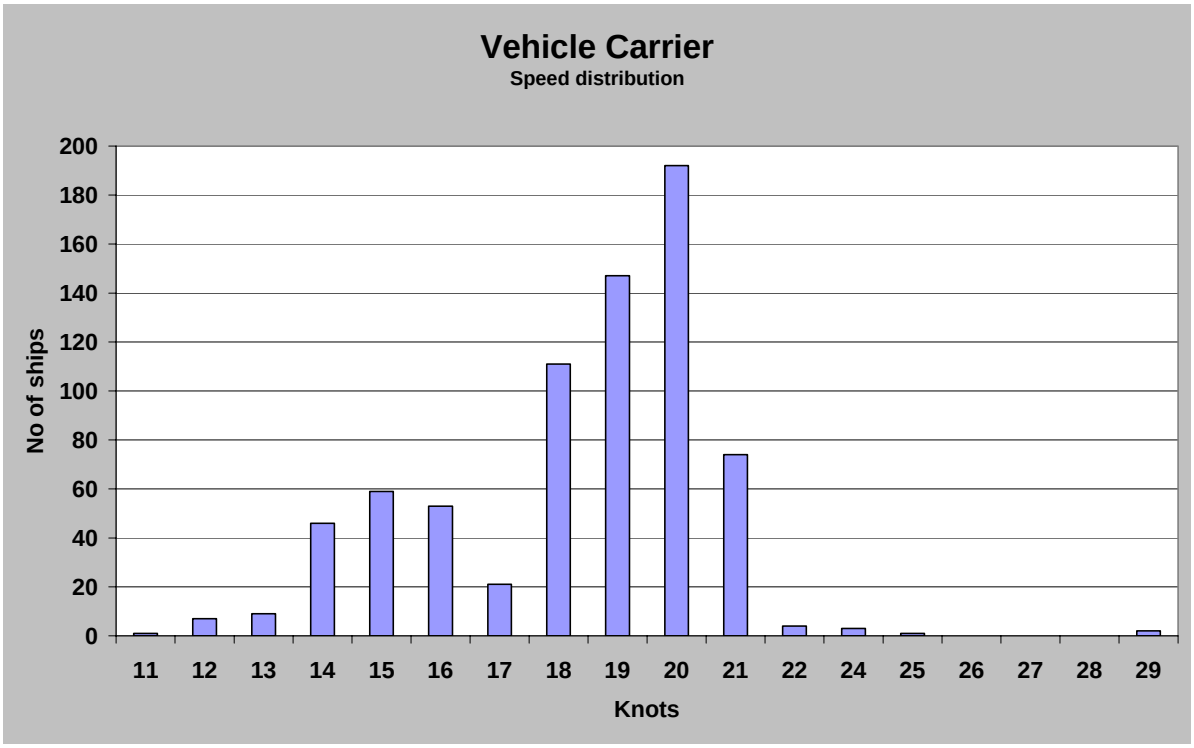


Figure 122; Distribution of speed for Vehicle Carriers

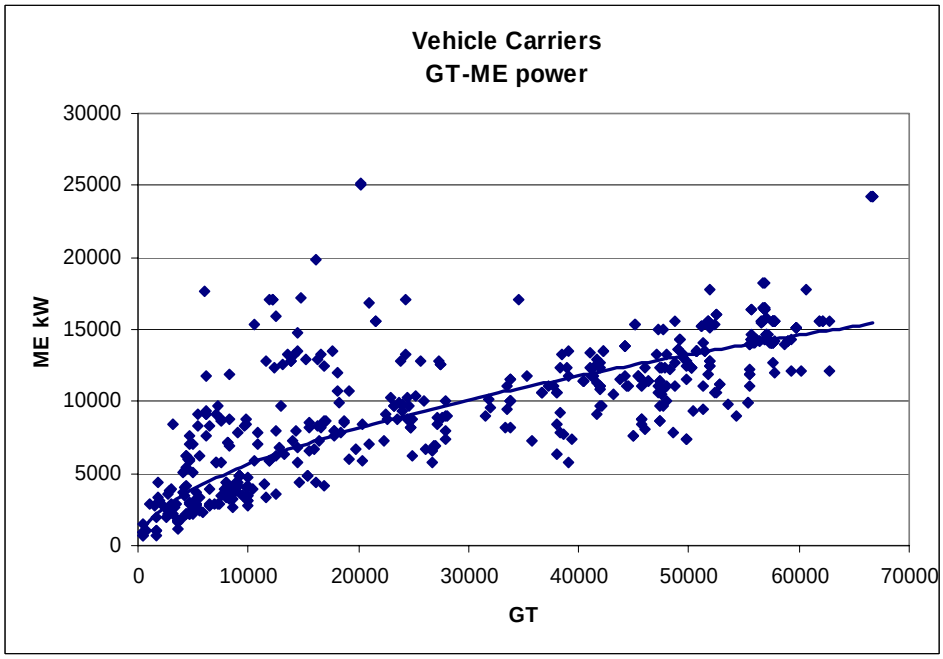


Figure 123; ME power output based on vessel size in GT for Vehicle Carriers

The ships' size in GT – ME power output relations for Vehicle Carriers are based on data from 850 vessels, of which 500 have satisfactory data regarding size, service speed and installed ME power output. The equations use the 19 knots relation as a guide. The final trends differ from other

vessels, most notably from other Ro/Ro ships, as the trends are more level. A large increase in size does not necessarily result in a large increase in needed ME power output, this can be addressed to the fact that cars are "volume goods", in the sense that the capacity is limited by the available cargo space, not by weight. Increase in capacity without an equal increase in weight will give a very limited need for additional ME power output.

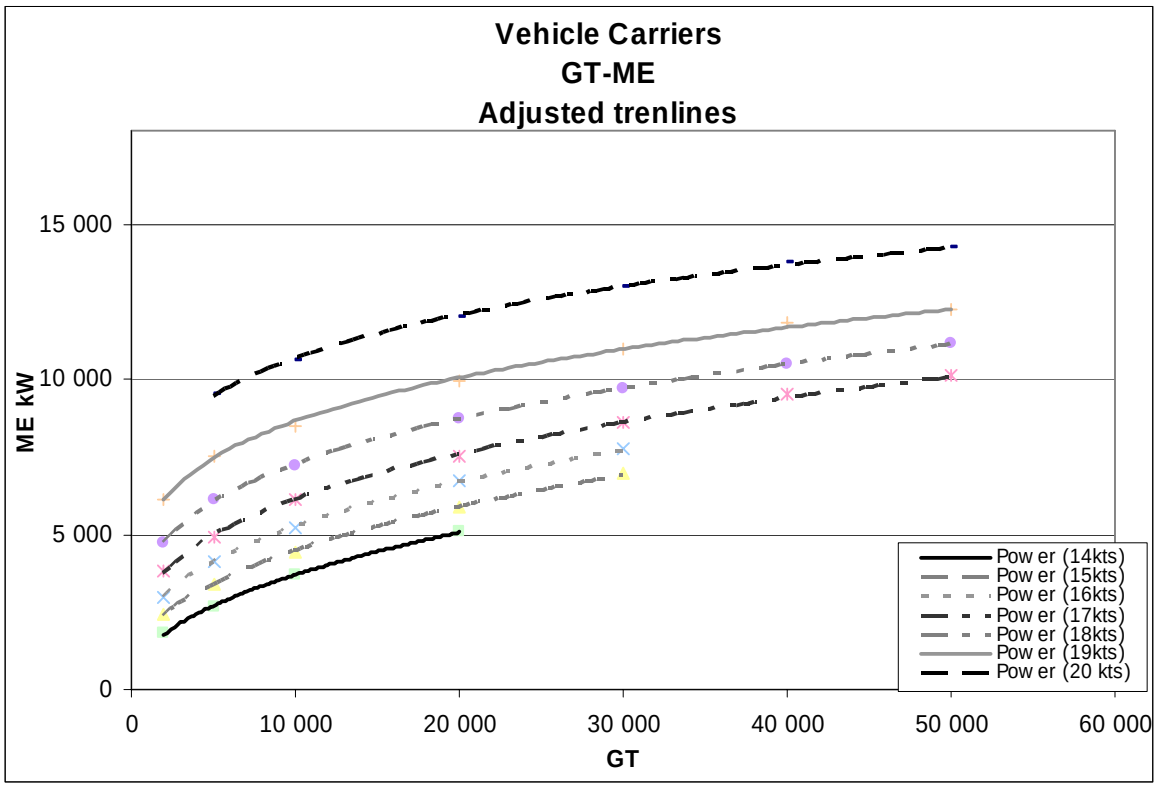


Figure 124; Vehicle carriers size in GT – ME power output relations at speed levels

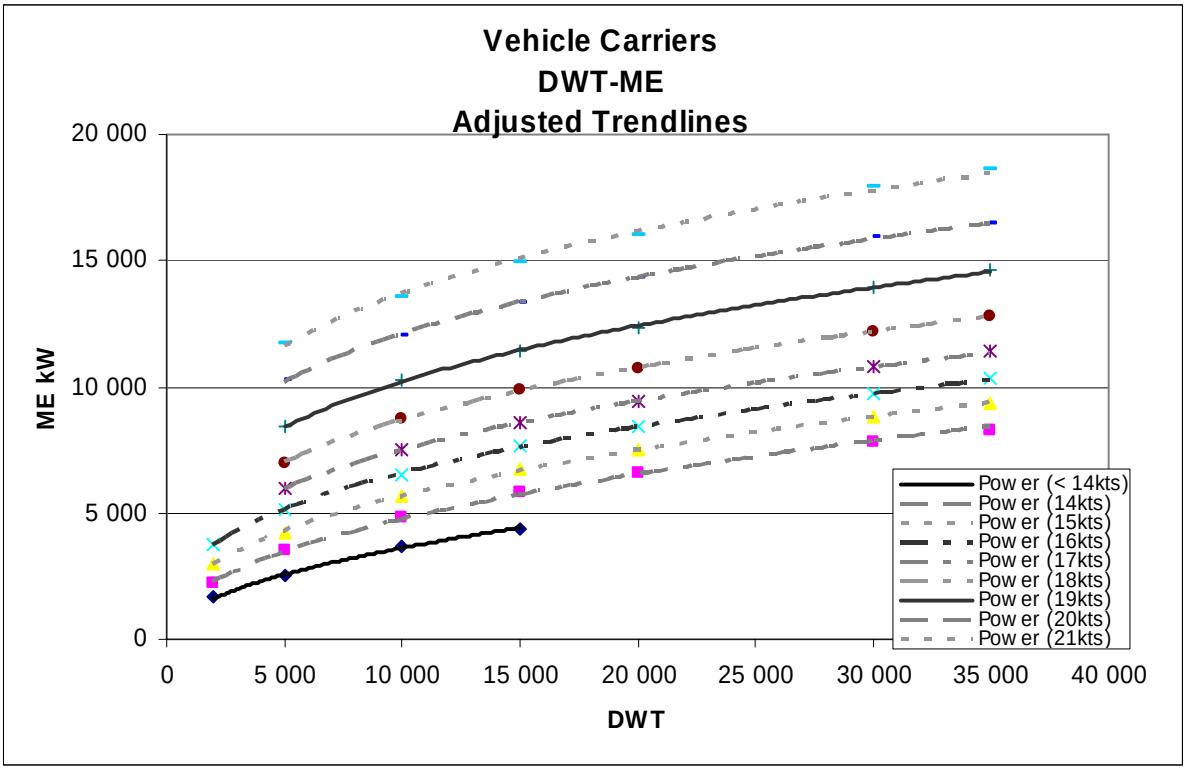
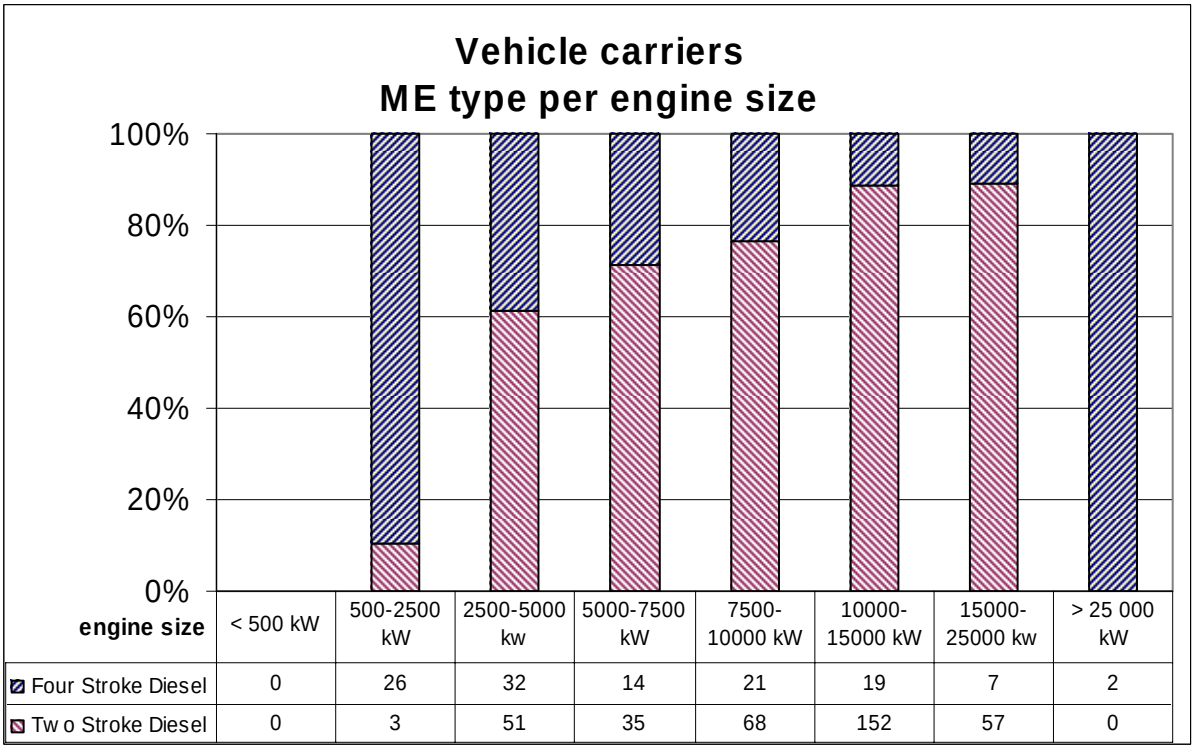


Figure 125 Vehicle carriers size in DWT – ME power output relations by speed levels

Most Vehicle carriers are equipped with two stroke diesel engines, except the smaller vessels. The largest engine group, ME power output > 25,000 should be ignored as there are only data for two ships.



engine size	< 500 kW	500-2500 kW	2500-5000 kw	5000-7500 kW	7500-10000 kW	10000-15000 kW	15000-25000 kw	> 25 000 kW
Four Stroke Diesel	0	26	32	14	21	19	7	2
Tw o Stroke Diesel	0	3	51	35	68	152	57	0

Figure 126 Vehicle Carriers main engine type based on ME output.

Based on reliable data from 70 Vehicle Carriers a relation can be established between size in GT and the total installed Auxiliary Engine power output, Figure 127. The relation seems clear especially for smaller vessels.

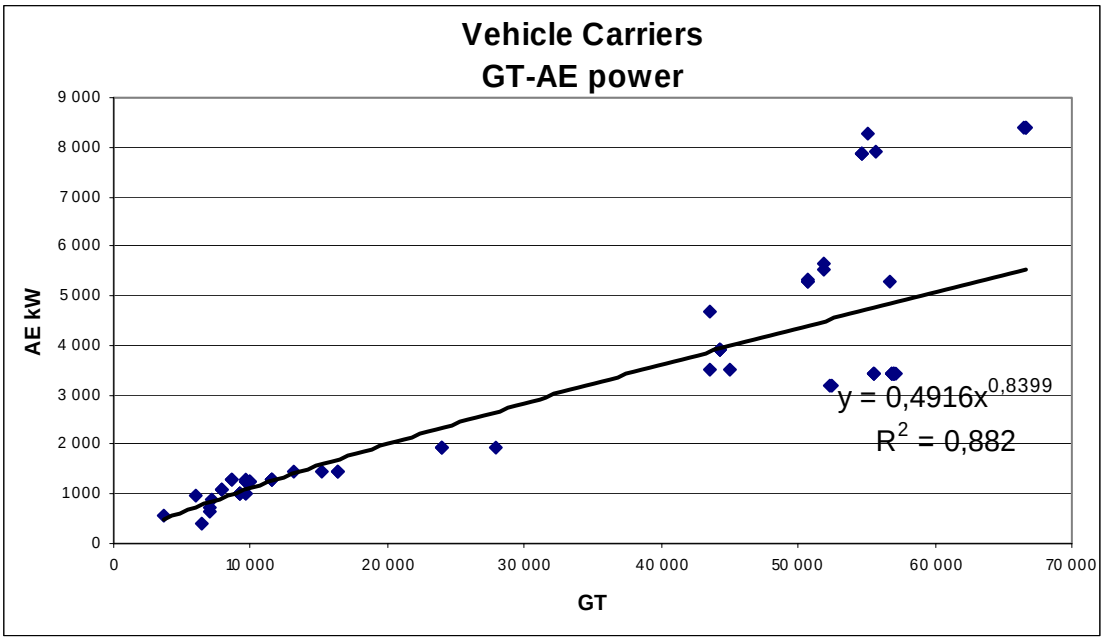


Figure 127; Vehicle carriers size (GT) – AE power output for 70 ships.

7 Example of emission estimation

This is an example of how to calculate the emissions from an existing vessel having the following basic identity:

3,309 DWT, General Cargo ship

A quick estimation of the emissions can be made using which sets the emissions to:

NO_x	536	kg/day,
CO	20	kg/day
HC	19	kg/day
PM	8,3	kg/day

A more detailed estimation requires also the speed and ME power.

- From Table 13; *The average speed per ship type and DWT* sets the typical speed for a General Cargo ship between 500 and 5,000 DWT at 13 Knots.
- The tables for General Cargo ships in Chapter 8 sets the probable needed ME power output to 1,845 kW (=18.997*3309^0,5646),
- Figure 45; *General Cargo ships main engine type per ME output* indicates that the Main Engine probably is of the four stroke diesel type when the needed ME output is between 500-2,500 kW
- The fuel consumption depends on the engine's specific fuel consumption, SFC (g/kWh), which can be obtained with Table 19; *Main Engine Specific Fuel Consumption and emissions, g/kWh for diesel engines, based on ME type and size*, which also gives the estimated emissions. For the above vessel, with a four stroke engine of 1,845 kW, the following data is obtained;

	g/kWh	*kg/h*	*kg/24h*
SFC	193.43	356.9	8,600
NOX	11.59	21.4	500
CO	0.92	1.7	40.7
HC	0.55	1.0	24.5
PM	0.19	0.35	8.39

- Sulphur emissions are based on fuel type, which can be in found in Table 47.

The above example shows how emissions can be approximated using only limited vessel data.

Table 16 can be used to estimate the most probable type of fuel used by the ships.

8 Tables and formulas for the calculation of ships' emissions

ME (kW) = k*GT^n k and n are constants given by tables for each vessel type at a given speed.

ME (kW) = k*DWT^n k and n are constants given by tables for each vessel type at a given speed.

Table 20; Bulkers ME functions

Bulkers **ME as function of GT, by speed** *ME (kW) = k*GT^n*			**Bulkers** **ME as function of DWT, by speed** *ME (kW) = k*DWT^n*					
			< 20.000 DWT			*> 20.000 DWT*		
Speed	*k*	*n*	*Speed*	*k*	*n*	*Speed*	*k*	*n*
9-11 kts	45,838	0,4169	10 kts	64,752	0,3503			
			11 kts	52,842	0,4044			
12 kts	38,764	0,5052	12 kts	44,177	0,4478			
13-14 kts	53,396	0,4852	13 kts	37,042	0,4849			
			14 kts	27,429	0,5329	13-14 kts	69,921	0,4351
15 kts	60,935	0,4871	15 kts	27,49	0,5466	15 kts	69,407	0,451
16-17 kts	65,748	0,4963	16 kts	28,321	0,555	16-17kts	70,175	0,4638
						18 kts	41,059	0,5201

Table 21; General Cargo ME functions

General Cargo ships **ME as function of GT, by speed**			**General Cargo ships** **ME as function of DWT, by speed**		
Speed	*k*	*n*	*Speed*	*k*	*n*
< 8 kts	4,3879	0,6985	< 8 kts	0,9607	0,8323
8 kts	7,3138	0,6266	8 kts	2,3159	0,7323
9 kts	9,6173	0,5931	9 kts	3,5786	0,6902
10 kts	13,34	0,5544	10 kts	6,6358	0,6276
11 kts	17,355	0,5408	11 kts	12,425	0,5663
12 kts	19,414	0,5602	12 kts	15,351	0,5678
13 kts	20,299	0,5773	13 kts	18,997	0,5646
14 kts	22,556	0,5828	14 kts	29,68	0,5305
15 kts	27,881	0,5725	15 kts	44,083	0,5012
16 kts	34,534	0,5638	16 kts	44,297	0,5151
17 kts	55,548	0,5275	17 kts	41,548	0,5362
18 kts	57,296	0,5364	18 kts	39,941	0,5548
19 kts	105,58	0,4849	19 kts	39,405	0,5727
20 kts	156,55	0,4578	20 kts	102,31	0,4903
21 kts	344,98	0,3915	21 kts	218,13	0,4338

Table 22; Container vessel ME functions

Container vessels ME as function of GT, by speed			**Container vessels** ME as function of DWT, by speed		
Speed	*k*	*n*	*Speed*	*k*	*n*
			< 16 kts	3,8556	0,7612
16 kts	44,842	0,5408	16 kts	19,536	0,6089
17 kts	77,312	0,4946	17 kts	29,4	0,5796
18 kts	104,78	0,4774	18 kts	76,086	0,4941
19 kts	132,25	0,4644	19 kts	160,65	0,433
20 kts	142,72	0,4679	20 kts	239,5	0,4071
21 kts	186,03	0,4528	21 kts	295,93	0,4001
22 kts	155,96	0,4813	22 kts	384,24	0,3892
23 kts	82,339	0,5546	23 kts	321,78	0,4214
24 kts	53,756	0,605	24 kts	164,05	0,4972
25 kts	34,97	0,6562	25 kts	72,141	0,5869
26 kts	25,002	0,6975	26 kts	55,869	0,6212

Table 23; Ro/Ro ME functions

Ro/Ro vessels ME as function of GT, by speed			ME as function of DWT, by speed		
Speed	*k*	*n*	*Speed*	*k*	*n*
< 9 kts	25,384	0,4838	< 9 kts	27,029	0,4494
9 kts	27,919	0,4832	9 kts	21,336	0,497
10 kts	46,212	0,4286	10 kts	24,417	0,5043
11 kts	30,412	0,5068	11 kts	27,07	0,5192
12 kts	47,933	0,4667	12 kts	41,59	0,4861
13 kts	75,99	0,4279	13 kts	63,995	0,4536
14 kts	99,983	0,4118	14 kts	74,333	0,4527
15 kts	115,36	0,41	15 kts	75,937	0,4693
16 kts	130,25	0,4159	16 kts	72,454	0,4949
17 kts	140,2	0,4283	17 kts	71,11	0,5169
18 kts	189,44	0,4142	18 kts	101,46	0,497
19 kts	192,26	0,4281	19 kts	182,05	0,4512
20 kts	316,94	0,3901	20 kts	308,55	0,4106
21 kts	664,6	0,3268	21 kts	449,88	0,3841
22 kts	1179,4	0,2794	22 kts	697,02	0,3493
23 kts	1687,9	0,2534	23 kts	1084,2	0,3157

Table 24; Reefer ME functions

Reefer ships ***ME as function of GT, by speed***						**Reefer ships** ***ME as function of DWT, by speed***		
	< 5000 GT			*> 5000 GT*				
Speed	*k*	*n*	*Speed*	*k*	*n*	*Speed*	*k*	*n*
10-11 kts	42,397	0,4141				10 kts	5,8621	0,6831
						11 kts	6,3304	0,6986
12-13 kts	30,491	0,5169				12 kts	10,961	0,6392
						13 kts	24,182	0,5546
14-15 kts	42,751	0,5128				14 kts	38,529	0,5122
			15 kts	44,425	0,5122	15 kts	34,009	0,5437
16-17 kts	44,127	0,5472	16 kts	55,156	0,5102	16 kts	50,839	0,5157
			17 kts	111,88	0,4488	17 kts	72,331	0,4917
18-19 kts	204,64	0,3967	18 kts	175,92	0,4094	18 kts	98,164	0,4714
			19 kts	217,46	0,3974	19 kts	112,03	0,4697
			20 kts	206,93	0,4132	20 kts	166,41	0,4376
			21 kts	239,9	0,4087	21 kts	172,15	0,4488
			22 kts	185,23	0,4497	22 kts	104,09	0,5174
			23 kts	155,77	0,48			
			24 kts	80,229	0,5642			

Table 25; Cargo Ferries ME functions

Cargo Ferries **ME as function of GT, by speed**			**ME as function of DWT, by speed**		
Speed	*k*	*n*	*Speed*	*k*	*n*
9-13 kts	28,624	0,5405	9-13 kts	150,56	0,3227
14-18 kts	38,518	0,5738	14-18 kts	166,08	0,454
19-24 kts	84,472	0,5393	19-24 kts	290,14	0,4739
25-29 kts	67,39	0,6286	25-29 kts	275,13	0,577

Table 26; Passenger Ferries ME functions

Passenger Ferries **ME as function of GT, by speed**			**ME as function of DWT, by speed**		
Speed	*k*	*n*	*Speed*	*k*	*n*
9-13 kts	19,208	0,5796	9-13 kts	93,195	0,3982
14-18 kts	140,32	0,3801	14-18 kts	299,51	0,3402
19-23 kts	69,114	0,554	19-23 kts	215,61	0,5162
24-29 kts	87,564	0,5742	24-29 kts	715,1	0,2699

Table 27; High Speed Ferries ME functions

High speed ferries					
ME as function of GT, by speed			**ME as function of DWT, by speed**		
Speed	*k*	*n*	*Speed*	*k*	*n*
30-34 kts	47,013	0,7052	30-35 kts	152,9	0,7392
35-38 kts	54,705	0,7139	36-39 kts	304,49	0,6886
39-41 kts	55,564	0,7247	40+ kts	363,55	0,6746
42-44 kts	57,507	0,735			
45+ kts	61,422	0,7442			

Table 28, Tankers ME functions DWT

Tankers						
ME as function of DWT, by speed						
	< 10.000 DWT		*10.000-60.000 DWT*		*> 60.000 DWT*	
Speed	*k*	*n*	*k*	*n*	*k*	*n*
< 9 kts	13,547	0,5219				
9 kts	16,156	0,5175				
10 kts	16,872	0,5198				
11 kts	17,966	0,5344				
12 kts	15,864	0,571				
13 kts	19,463	0,5656	28,353	0,5237		
14 kts	19,535	0,5787	37,544	0,5046	50,322	0,4725
15 kts	30,294	0,5443	47,845	0,4911	39,921	0,5025
16 kts			65,161	0,4793	73,777	0,4657
17 kts			65,057	0,496	105,71	0,4468

Table 29; Tankers ME functions GT

Tankers				
ME as function of GT, by speed				
	< 5.000 GT		*> 5.000 GT*	
Speed	*k*	*n*	*k*	*n*
< 10 kts	12,273	0,5781		
10 kts	30,878	0,4703		
11 kts	51,849	0,4298		
12 kts	44,005	0,4762		
13 kts	51,742	0,4763	43,715	0,5095
14 kts	53,269	0,4885	43,715	0,5095
15 kts	52,8	0,5082	52,8	0,5082
16 kts			64,108	0,5044
17 kts			79,34	0,4952

Table 30; LNG Tankers ME functions

LNG Tankers ME as function of GT, by speed			**LNG Tankers** ME as function of DWT, by speed		
Speed	*k*	*n*	*Speed*	*k*	*n*
< 18 kts	23,375	0,5946	< 18 kts	11,608	0,6707
18 kts	227,47	0,3925	18 kts	67,328	0,5164
19 kts	386,21	0,3556	19 kts	96,644	0,4902
20 kts	604,05	0,3252	20 kts	271,12	0,4043
21 kts	825,44	0,3069	21 kts	325,32	0,3948

Table 31; LPG Tankers ME functions

LPG Tankers					
ME as function of GT, by speed			**ME as function of DWT, by speed**		
Speed	*k*	*n*	*Speed*	*k*	*n*
10 kts	48,024	0,391	10 kts	20,591	0,5253
11 kts	78,635	0,3614	11 kts	32,046	0,4856
12 kts	71,16	0,4028	12 kts	37,728	0,48$6
13 kts	60,473	0,4472	13 kts	41,119	0,4929
04 kts	62,701	0,4632	14 kts	43,697	0,5003
15 kts	74,578	0,4636	15 kts	52,035	0,4911
16 kts	95,104	0,4501	16 kts	70,171	0,4712
17 kts	135,15	0,4269	17 kts	70,335	0,4815
> 17 kts	144,75	0,4308	> 17 kts	57,889	0,5111

Table 32; Cruise vessels ME functions

Cruise vessels					
ME as function of GT, by speed			**ME as function of DWT, by speed**		
Speed	*k*	*n*	*Speed*	*k*	*n*
< 12 kts	3,5852	0,7752	< 12 kts	41,305	0,5141
12-13 kts	8,0077	0,6995	12-13 kts	75,18	0,4892
14-15 jts	10,974	0,6852	14-15 kts	134,28	0,4553
16-17 kts	17,658	0,6516	16-17 kts	175,73	0,4661
18-19 kts	20,572	0,6528	18-19 kts	111,4	0,5854
20-21 kts	30,969	0,6306	20-21 kts	123,02	0,6091
22-23 kts	41,075	0,6257	22-23 kts	91,224	0,696

Table 33; Vehicle Carriers ME functions

Vehicle Carriers					
ME(kW) based on GT, by speed			**ME (kW) based on DWT, by speed**		
Speed	*k*	*n*	*Speed*	*k*	*n*
			< 14 kts	38,059	0,4945
14 kts	56,46	0,454	14 kts	71,328	0,4563
15 kts	118,43	0,3946	15 kts	141,91	0,4007
16 kts	210,96	0,3492	16 kts	251,55	0,3546
17 kts	361,19	0,3076	17 kts	362,08	0,3293
18 kts	629,84	0,2654	18 kts	507,01	0,3086
19 kts	1187,5	0,2156	19 kts	756,85	0,2826
20 kts	2058,7	0,1787	20 kts	1250,2	0,246
			21 kts	1528,4	0,2381

Table 34; Validation of used speed curves for the relations between size of ship and Main Engine

Validation chart Speed curves used for Size-ME relations

		Speed curve	pop-%	R^2 (GT)	R^2 (DWT)	
Bulkers	large	15 knots	44,9%	0,7122	0,6645	
	small	15 knos	19,2%	0,5762	0,5605	
General Cargo	all	14 knots	10,1%	0,7766		
	all	15 knots	10,2%		0,7103	
	small	12 knots	20,1%	0,6272		
		10 knots	19,2%		0,6474	
Container vessels	all	18 knots	10,8%	0,6558	0,733	
	all	25 knots	11,0%	0,7879	0,7324	
Ro/Ro		15 knots	11,0%	0,5581		
		16 knots	10,6%		0,5527	
		19 knots	5,5%	0,8019	0,866	
	small	11 knots	8,2%	0,5869	0,5284	
Reefers	all	18 knots	9,8%	0,4398		
	all	17 knots	7,7%		0,539	
	small	14-15 knots	30,2%	0,7301		
	small	12 knots	15,1%		0,7359	
Cargo ferries	all	9-13 knots		0,5983	0,2179	Trendline not adjusted
	all	14-18 knots		0,7493	0,5087	Trendline not adjusted
	all	19-24 jnots		0,7216	0,$683	Trendline not adjusted
	all	25-29 knots		0,9575	0,8972	Trendline not adjusted
Passenger ferries	all	9-13 knots		0,4555	0,3832	Trendline not adjusted
	all	14-18 knots		0,5627	0,5058	Trendline nnt adjusted
	all	19-23 knots		0,8424	0,8673	Trendline not adjusted
	all	24-29 knots		0,5245	0,1347	Trendline not adjusted
High Speed ferries		35-38 knots	37,6%	0,9001		
		30-35 knods			0,5725	Trenline not adjusted
		36-39 knots			0,7655	Trenline not adjusted
		40+ knots			0,6296	Trenline not adjusted
Tankers	large	15 knots	35,4%	0,7948	0,7212	
		16 knots	41,7%	0,844	0,8442	
	Handysize	15 knots	45,2%	0,5802	0,4952	
		16 knots	19,7%	0,6848	0,6524	
	small	12 knots	18,4%	0,6433	0,7228	
Gas Tankers	LPG, large	14 knots	4,4%	0,5354	0,5221	
		16 knots	31,3%	0,7988	,8148	
	LPG, small	13 knots	31,7%	0,6021	0,6761	
Cruire	all	20-21 knots	24,1%	0,8476	0,6196	
		22-23 knots	14,5%	0,8697	0,7833	
	small	16-17 knots	22,2%	0,8393	0,4894	
Vehicle Carrier	all	19 knots	19,9%	0,3624	0,545	

Table 35; Statistics of type of engine in Bulk ships

Bulk ships ME type per engine size

Tot ME power	Two Stroke Diesel	Four Stroke Diesel	Steam turbine	Steam Recip.	Pop	Other/ Unknown
< 500 kW	3	78	0	0	134	53
500-2500 kW	39	353	7	34	465	32
2500-5000 kw	476	107	18	8	609	0
5000-7500 kW	1966	136	51	0	2157	4
7500-10000 kW	2432	63	11	0	2514	8
10000-15000 kW	1380	30	28	0	1443	5
15000-25000 kw	543	2	59	0	609	5
> 25 000 kW	10	1	2	0	13	0
	6849	770	176	42	7944	107

Table 36; Statistics of type of engine in General Cargo ships

General Cargo ships ME type per ME output

Tot ME power	Two Stroke Diesel	Four Stroke Diesel	Steam Turbine	Steam Recip.	pop	Other/ Unknown
< 500 kW	369	1867	0	20	2421	185
500-2500 kW	1237	5466	1	139	6932	228
2500-5000 kw	2056	1210	99	3	3375	10
5000-7500 kW	1549	297	35	1	1886	5
7500-10000 kW	1031	91	19	0	1141	0
10000-15000 kW	347	53	29	0	429	0
15000-25000 kw	45	4	10	0	59	0
> 25 000 kW	2	0	0	0	2	0
	6636	8988	193	163	16245	428

Table 37; Statistics of type of engine in Container ships

Container vessels ME type per engine size

Tot ME power	Two Stroke Diesel	Four Stroke Diesel	Steam turbine	Pop	Other/Unknown
< 500 kW	0	0	0	0	0
500-2500 kW	10	78	0	88	0
2500-5000 kw	123	118	0	241	0
5000-7500 kW	218	140	29	387	0
7500-10000 kW	239	121	0	378	18
10000-15000 kW	504	24	17	549	4
15000-25000 kw	736	24	35	795	0
> 25 000 kW	1169	7	25	1205	4
	2999	512	106	3643	26

Table 38; Statistics of type of engine in Ro/Ro ships

Ro/Ro vessels ME type per engine size

Tot ME power	Two Stroke Diesel	Four Stroke Diesel	Steam turbine	Pop	Other/Unknown
< 500 kW	4	55	0	60	1
500-2500 kW	33	234	0	278	11
2500-5000 kw	55	138	0	195	2
5000-7500 kW	31	148	4	183	0
7500-10000 kW	19	50	0	69	0
10000-15000 kW	31	69	0	101	1
15000-25000 kw	31	55	8	102	8
> 25 000 kW	0	9	1	13	3
	204	758	13	1001	26

Table 39; Statistics of type of engine in Reefer ships

Reefer Vessels ME type per engine size

Tot ME power	Two Stroke Diesel	Four Stroke Diesel	Steam turbine	Pop	Other/Unknown
< 500 kW	4	25	0	30	1
500-2500 kW	48	242	0	290	0
2500-5000 kw	164	75	0	239	0
5000-7500 kW	234	33	0	267	0
7500-10000 kW	191	6	1	198	0
10000-15000 kW	169	32	0	204	3
15000-25000 kw	25	0	0	25	0
> 25 000 kW	0	0	0	0	0
	835	413	1	1253	4

Table 40; Statistics of type of engine in Cargo Ferries

Cargo ferries ME type per engine size

Tot ME power	Two Stroke Diesel	Four Stroke Diesel	Steam turbine	Gas turbine	Steam Recip.	Pop	Other/Unknown
< 500 kW	8	83	0	0	1	100	8
500-2500 kW	99	443	0	0	12	568	14
2500-5000 kw	72	166	4	1	1	248	4
5000-7500 kW	66	140	7	0	0	217	4
7500-10000 kW	32	109	3	0	0	144	0
10000-15000 kW	46	152	6	0	0	204	0
15000-25000 kw	9	180	3	0	0	197	5
> 25 000 kW	1	91	2	0	0	95	1
	333	1364	25	1	14	1773	36

Table 41; Statistics of type of engine in Passenger Ferries

Passenger ferries ME type per engine size

Tot ME power	Two Stroke Diesel	Four Stroke Diesel	Steam turbine	Gas turbine	Steam Recip.	Pop	Other/Unknown
< 500 kW	12	179	0	0	3	203	9
500-2500 kW	49	431	1	0	11	504	12
2500-5000 kw	13	92	0	0	0	108	3
5000-7500 kW	8	7	1	1	1	18	0
7500-10000 kW	0	1	0	0	0	1	0
10000-15000 kW	2	12	0	0	0	14	0
15000-25000 kw	0	7	0	0	0	7	0
> 25 000 kW	0	0	0	0	0	0	0
	84	729	2	1	15	855	24

Table 42; Statistics of type of engine in High Speed Ferries

High speed ferries ME type per engine size

Tot ME power	Two Stroke Diesel	Four Stroke Diesel	Gas turbine (incl Diesel&Gas)	Pop	Other/Unknown
< 500 kW	0	0	0	0	0
500-2500 kW	5	185	0	193	3
2500-5000 kw	10	268	3	284	3
5000-7500 kW	2	33	33	69	1
7500-10000 kW	0	31	10	41	0
10000-15000 kW	0	15	6	22	1
15000-25000 kw	0	41	3	44	0
> 25 000 kW	1	46	9	57	1
	18	619	64	710	9

Table 43; Statistics of type of engine in Tankers

Tankers ME type per engine size

Tot ME power	Two Stroke Diesel	Four Stroke Diesel	Steam turbine	Steam Recip.	Pop	Other/Unknown
< 500 kW	59	473	0	4	591	55
500-2500 kW	268	1945	1	17	2269	38
2500-5000 kw	643	442	2	1	1101	13
5000-7500 kW	748	107	91	0	953	7
7500-10000 kW	1074	63	13	0	1155	5
10000-15000 kW	1117	63	227	0	1417	10
15000-25000 kw	823	8	333	0	1169	5
> 25 000 kW	189	13	260	0	462	0
	4921	3114	927	22	9117	133

Table 44; Statistics of type of engine in Gas Tankers

Gas Tankers ME type per engine size

Tot ME power	LNG Two Stroke	LNG Four Stroke	LNG Steam Tubine	LPG Two Stroke	LPG Four Stroke	LPG Steam Tubine	pop	Other/ Unknown
< 500 kW	0	0	0	4	22	0	30	4
500-2500 kW	0	2	0	76	357	0	436	1
2500-5000 kw	1	0	0	126	103	0	231	1
5000-7500 kW	0	0	3	59	15	1	78	0
7500-10000 kW	0	0	2	78	2	0	83	1
10000-15000 kW	0	0	7	104	1	1	117	4
15000-25000 kw	0	0	57	21	2	0	82	2
> 25 000 kW	0	0	86	0	0	0	89	3
	1	2	155	468	502	2	1146	16

Table 45; Statistics of type of engine in Cruise Vessels

Cruise vessels ME type per engine size

Tot ME power	Two Stroke Diesel	Four Stroke Diesel	Steam turbine	Gas turbine (incl. Diesel&Gas)	Steam Recip.	Pop	Other/ Unknown
< 500 kW	2	5	0	0	0	8	1
500-2500 kW	7	40	0	0	2	53	4
2500-5000 kw	15	27	2	0	0	44	0
5000-7500 kW	17	14	5	0	0	36	0
7500-10000 kW	7	6	4	0	1	19	1
10000-15000 kW	10	25	6	0	0	44	3
15000-25000 kw	17	29	14	0	0	61	1
> 25 000 kW	0	76	8	18	0	108	6
	73	222	39	18	3	373	18

Table 46; Statistics of type of engine in Vehicle Carriers

Vehicle Carriers ME type per engine size

Tot ME power	Two Stroke Diesel	Four Stroke Diesel	Pop	Other/Unknown
< 500 kW	0	0	0	0
500-2500 kW	3	26	29	0
2500-5000 kw	51	32	83	0
5000-7500 kW	35	14	49	0
7500-10000 kW	68	21	89	0
10000-15000 kW	152	19	173	2
15000-25000 kw	57	7	67	3
> 25 000 kW	0	2	2	0
	366	121	492	5

Table 47; Sulphur content in fuel

Sulphur content in fuels	
	%
MGO	0,2
MDO	1
RO	2

Ref [10]

Note: These values will vary in the market

Table 48; Reduction factors for exhaust cleaning equipment

Type of equipment	NOx	HC	CO	PM	SOx	NH_3	Noise	Additives	Fuel quality	Comments	
SCR* ex. Oxi	95%		+ 50%	0 - 20%		+ 0,1 g/kWh				Proved technique Does not affect engine	
SCR* with oxidiser	95%	80%**	70%**	1 - 20%		+ 0,1 g/kWh	30dB	Urea 40% solution 1,5 lit/kg NOx	MGO - HFO	Proved technique Does not affect engine	
HAM	70%		+ 20%				20dB	Water/Sea water	MGO - HFO	Technique under develop Affects engine	Use of water amounts to 10 times the fuel
DWI	60%								MGO - HFO	Technique under develop Affects engine	Fuel increase
Scrubber				80%	90%		35%	Sea water	MGO - HFO	Small engines Under development	

*The techniques are affected by the level of Sulphur, however SCR demands higher exhaust gas temperatures by increased Sulphur
**Oxidiser
Factors noted with + gives the value in added emissions

9 Ships' statistics

		Average emissions of ships delivered 1990-1999							
		g NOx/DWT/day	g NOx/GT/day	g CO/DWT/day	g CO/GT/day	g HC/DWT/day	g HC/GT/day	g PM/DWT/day	g PM/GT/day
Oil Tanker	**200 000 DWT +**	31	57	1,8	3,3	1,9	3,6	0,7	1,3
	60' - 199 999	48	87	2,1	3,8	2,2	4,0	1,3	2,4
	E 10' - 59 999 DWT	86	136	3,1	4,9	3,6	5,7	2,4	3,9
	F - 9 999 DWT	128	191	3,9	5,7	2,4	3,6	2,2	3,1
	X < 500 GT	*Not applicable in the study*							
Chemical Tanker	**60 000 DWT +**	54	100	2,8	5,1	2,3	4,2	1,6	3,0
	10' - 59 999 DWT	109	171	4,1	6,3	3,6	5,7	2,5	3,9
	- 9 999 DWT	206	307	8,8	13,5	6,2	9,1	2,9	4,1
	< 500 GT	*Not applicable in the study*							
Gas tankers	**LPG 50 000 cbm +**	193	233	7,7	9,3	8,0	9,6	3,8	4,6
	LPG - 49 999 cbm	90	113	4,3	5,3	4,1	5,1	2,5	3,3
	< 500 GT	*Not applicable in the study*							
Bulker	**80 000 DWT +**	40	77	1,8	3,5	1,9	3,7	1,0	1,9
	55' - 79 999 DWT	51	96	2,3	4,3	2,6	5,0	1,5	2,9
	10'-54 999 DWT	78	129	3,1	5,1	3,7	6,1	2,0	3,3
	- 9 999 DWT	183	260	3,4	4,9	1,3	1,9	2,8	4,0
	< 500 GT	*Not applicable in the study*							
Container	**5 000 teu +**	310	316	12,0	12,2	20,0	20,0	8,4	8,4
	3' - 4 999 teu	263	301	10,4	12,0	15,8	18,0	7,3	8,4
	1' - 2 999 teu	235	297	10,7	13,4	11,1	13,8	7,0	8,9
	- 999 teu	253	316	13,1	16,1	8,4	10,5	5,4	6,9
	< 500 GT	*Not applicable in the study*							
Reefer	**7 100 cbm +**	412	438	17,8	19,0	19,4	19,8	12,2	12,3
	- 7 099 cbm	253	276	6,9	7,6	3,5	3,9	3,8	4,1
	< 500 GT	*Not applicable in the study*							
Dry cargo n.e.s.	**10 000 DWT +**	135	189	5,7	7,9	6,0	8,4	4,5	6,1
	- 9 999 DWT	178	242	6,6	8,9	3,4	4,8	2,5	3,4
	< 500 GT	*Not applicable in the study*		0,0	0,0	0,0	0,0	0,0	0,0
Vehicle Ro-Ro	**4 000 ceu +**	365	115	14,6	4,6	12,8	4,1	9,6	3,0
	- 3 999 ceu	376	166	14,6	6,4	15,5	6,7	7,0	3,0
	< 500 GT	*Not applicable in the study*							
Ro-Ro n.e.s.	**2 200 lm +**	458	256	23,4	13,2	18,3	11,6	9,8	6,6
	- 2 199 lm	383	294	12,3	9,7	12,3	10,0	4,9	4,2
	< 500 GT	*Not applicable in the study*		0,0	0,0	0,0	0,0	0,0	0,0
Ferry; Cargo	**1 300 lm +**	1 324	277	110,3	22,9	28,1	6,1	22,7	5,0
	- 1 299 lm	1 761	325	84,1	21,6	36,4	7,8	22,8	4,4
	< 500 GT	*Not applicable in the study*							
Ferry; Non Cargo	**> 500 GT**	1 133	249	65,1	14,9	32,4	5,9	15,8	2,5
	< 500 GT	*Not applicable in the study*		0,0	0,0	0,0	0,0	0,0	0,0
Cruise	**1 000 low berths +**	1 915	198	250,0	26,1	19,0	1,9	0,0	0,0
	- 999 low berths	2 054	208	61,1	6,3	59,9	5,4	17,1	2,6
	< 500 GT	*Not applicable in the study*							
Average all		**183**	**186**	**9,2**	**8,1**	**6,9**	**8,0**	**4,3**	**5,1**

		Average emissions of ships delivered 2000-2006 (incl order)							
		g NOx/DWT/day	g NOx/GT/day	g CO/DWT/day	g CO/GT/day	g HC/DWT/day	g HC/GT/day	g PM/DWT/day	g PM/GT/day
Oil Tanker	200 000 DWT +	31	59	1,0	1,9	0,8	1,5	1,1	2,0
	60' - 199 999	44	79	2,9	5,3	1,2	2,1	1,5	2,7
	E 10' - 59 999 DWT	77	123	4,1	6,6	2,2	3,5	2,4	3,6
	F - 9 999 DWT	133	190	5,4	7,8	6,1	8,9	2,6	3,9
	X < 500 GT	*Not applicable in the study*							
Chemical Tanker	60 000 DWT +	48	78	3,5	5,7	1,4	2,3	1,8	2,7
	10' - 59 999 DWT	92	143	4,9	7,6	2,7	4,2	2,3	3,6
	- 9 999 DWT	145	207	5,6	8,0	5,0	7,3	2,6	3,7
	< 500 GT	*Not applicable in the study*							
Gas tankers	LNG	114	69	9,0	5,4	1,8	1,1	0,0	0,0
	LPG 50 000 cbm +	159	189	7,3	8,6	4,1	4,9	2,9	3,8
	LPG - 49 999 cbm	89	101	5,1	5,9	2,1	2,4	3,5	3,9
	< 500 GT	*Not applicable in the study*							
Bulker	80 000 DWT +	38	74	1,5	2,9	0,8	1,5	1,3	2,4
	55' - 79 999 DWT	45	84	3,4	6,3	1,5	2,7	1,5	2,9
	10'-54 999 DWT	67	114	3,9	6,6	2,5	4,2	2,1	3,6
	- 9 999 DWT	0	0	0,0	0,0	0,0	0,0	0,0	0,0
	< 500 GT	*Not applicable in the study*							
Container	5 000 teu +	272	295	12,4	13,4	14,1	15,0	8,8	9,3
	3' - 4 999 teu	265	315	9,4	11,2	9,9	11,8	8,7	10,4
	1' - 2 999 teu	258	313	14,7	17,6	10,5	12,8	8,0	9,9
	- 999 teu	230	282	7,8	9,6	1,3	1,7	3,8	4,7
	< 500 GT	*Not applicable in the study*							
Reefer	7 100 cbm +	409	396	21,5	20,8	14,5	13,9	14,0	12,7
	- 7 099 cbm	1 071	515	29,5	14,2	36,9	17,8	0,0	0,0
	< 500 GT	*Not applicable in the study*							
Dry cargo n.e.s.	10 000 DWT +	134	178	6,6	8,8	3,3	4,4	3,1	4,2
	- 9 999 DWT	145	192	5,7	7,4	4,8	6,5	2,5	3,3
	< 500 GT	*Not applicable in the study*							
Vehicle Ro-Ro	4 000 ceu +	281	97	18,0	6,2	8,6	3,0	9,7	3,4
	- 3 999 ceu	482	159	16,9	6,0	15,9	5,3	7,1	3,0
	< 500 GT	*Not applicable in the study*							
Ro-Ro n.e.s.	2 200 lm +	434	247	24,0	14,7	11,1	7,3	8,9	5,1
	- 2 199 lm	327	245	17,7	13,2	9,2	7,3	4,3	3,7
	< 500 GT	*Not applicable in the study*							
Ferry; Cargo	1 300 lm +	2 207	393	82,0	15,2	47,8	8,3	23,4	3,7
	- 1 299 lm	1 847	356	60,2	11,9	50,5	9,4	32,9	7,0
	< 500 GT	*Not applicable in the study*							
Ferry; Non Cargo	> 500 GT	1 799	388	138,8	30,3	68,3	14,1	0,0	0,0
	< 500 GT	*Not applicable in the study*							
Cruise	1 000 low berths +	1 897	175	168,4	15,8	29,3	2,7	0,0	0,0
	- 999 low berths	1 744	198	58,9	7,1	67,2	8,4	14,5	2,2
	< 500 GT	*Not applicable in the study*							
Average all		**192**	**166**	**9,4**	**8,2**	**5,6**	**5,4**	**4,7**	**5,1**

Conversion table		Size group approximate equal to					
Type	Size	DWT			GT		
Oil Tanker	200 000 DWT +	200 000	+		105 000		
	60' - 199 999	60 000	-	199 999	37 000	-	105 000
	E 10' - 59 999 DWT	10 000	-	59 999	6 700	-	37 000
	F - 9 999 DWT	1 400	-	9 999	500	-	6 700
	X < 500 GT	100	-	1 399	100	-	499
Chemical Tanker	60 000 DWT +	60 000	+		33 000	+	
	10' - 59 999 DWT	10 000	-	59 000	6 700	-	33 000
	- 9 999 DWT	1 400	-	9 999	500	-	6 700
	< 500 GT	100	-	1 399	100	-	499
Gas tankers	LNG	All			All		
	LPG 50 000 cbm +	36 000	+		25 000	+	
	LPG - 49 999 cbm	600	-	36 000	500	-	25 000
	< 500 GT	150	-	599	100	-	499
Bulker	80 000 DWT +	80 000	+		43 000	+	
	55' - 79 999 DWT	55 000	-	79 999	31 000	-	43 000
	10'-54 999 DWT	10 000	-	54 999	6 000	-	30 999
	- 9 999 DWT	1 000	-	9 999	499	-	5 999
	< 500 GT	150	-	999	100	-	499
Container	5 000 teu +	65 000	+		55 000	+	
	3' - 4 999 teu	45 000	-	64 999	40 000	-	54 999
	1' - 2 999 teu	15 000	-	44 999	10 000	-	39 999
	- 999 teu	1 500	-	14 999	500	-	9 999
	< 500 GT	500	-	1 499	100	-	499
Reefer	7 100 cbm +	8 000	+		6 000	+	
	- 7 099 cbm	800	-	7 999	500	-	5 999
	< 500 GT	150	-	799	100	-	499
Dry cargo n.e.s.	10 000 DWT +	10 000	+		6 000	+	
	- 9 999 DWT	600	-	9 999	500	-	5 999
	< 500 GT	100	-	599	100	-	499
Vehicle Ro-Ro	4 000 ceu +	15 000	+		40 000	+	
	- 3 999 ceu	900	-	14 999	500	-	39 999
	< 500 GT	100	-	899	100	-	499
Ro-Ro n.e.s.	2 200 lm +	15 000	+		20 000	+	
	- 2 199 lm	800	-	14 999	500	-	19 999
	< 500 GT	100	-	799	100	-	499
Ferry; Cargo	1 300 lm +	2 000	+		10 000	+	
	- 1 299 lm	500	-	1 999	500	-	9 999
	< 500 GT	50	-	499	100	-	499
Ferry; Non Cargo	> 500 GT	150	+		500	+	
	< 500 GT	20	-	149	100	-	499
Cruise	1 000 low berths +	5 000	+		30 000	+	
	- 999 low berths	500	-	4 999	500	-	29 999
	< 500 GT	30	-	499	100	-	499

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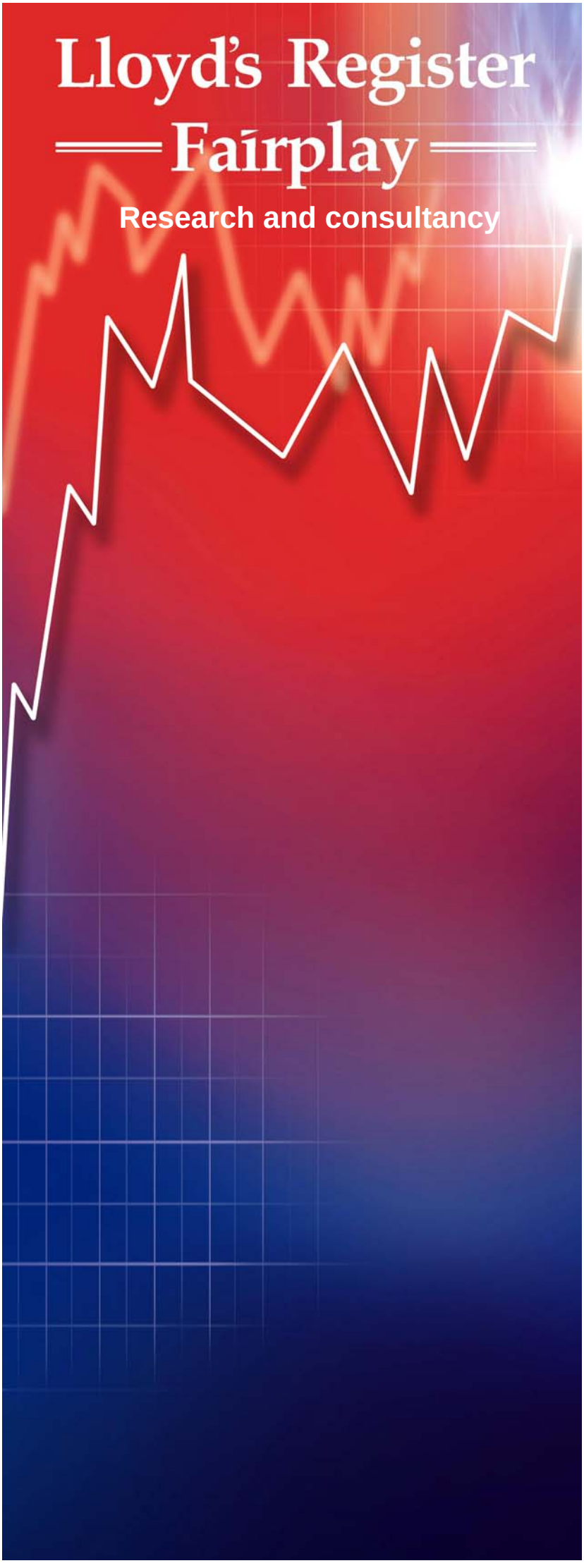
Appendix 1

EMISSION DATA

EMISSIONS FROM MARINE ENGINES

—Fleet structure and emission development



Content

Content and structure of the report ii
1 The world fleet 1
2 Oil tanker 4
2.1 Age profile of the fleet 4
2.2 Speed profile & development 5
2.3 Fuel consumption development 6
2.4 Emission profile of the fleet 6
3 Chemical tanker 8
3.1 Age profile of the fleet 8
3.2 Speed profile & development 9
3.3 Fuel consumption development 10
3.4 Emission profile of the fleet 10
4 Gas tanker 12
4.1 Age profile of the fleet 12
4.2 Speed profile & development 13
4.3 Fuel consumption development 14
4.4 Emission profile of the fleet 14
5 Bulker 16
5.1 Age profile of the fleet 17
5.2 Speed profile & development 17
5.3 Fuel consumption development 18
5.4 Emission profile of the fleet 18
6 Container 20
6.1 Age profile of the fleet 21
6.2 Speed profile & development 21
6.3 Fuel consumption development 22
6.4 Emission profile of the fleet 22
7 Dry cargo n.e.s. 24
7.1 Age profile of the fleet 24
7.2 Speed profile & development 25
7.3 Fuel consumption development 26
7.4 Emission profile of the fleet 26
8 Reefer 28
8.1 Age profile of the fleet 28
8.2 Speed profile & development 29
8.3 Fuel consumption development 30
8.4 Emission profile of the fleet 30
9 Vehicle ro-ro 32
9.1 Age profile of the fleet 32
9.2 Speed profile & development 33
9.3 Fuel consumption development 34
9.4 Emission profile of the fleet 35
10 Ro-ro n.e.s 38
10.1 Age profile of the fleet 39
10.2 Speed profile & development 39
10.3 Fuel consumption development 40
10.4 Emission profile of the fleet 41
11 Ferry cargo 44
11.1 Age profile of the fleet 45
11.2 Speed profile & development 45
11.3 Fuel consumption development 46
11.4 Emission profile of the fleet 47
12 Ferry non cargo 50
12.1 Age profile of the fleet 50
12.2 Speed profile & development 51
12.3 Fuel consumption development 52
12.4 Emission profile of the fleet 53
13 Cruise 55
13.1 Age profile of the fleet 55
13.2 Speed profile & development 56
13.3 Fuel consumption development 57
13.4 Emission profile of the fleet 58
14 Summary table 61
15 Approach 62

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Figures and tables

Figure 1: Type of engines in ships built 1980 and onwards 3
Figure 2: The speed profile of ships built 1980 and onwards 3
Figure 3: Oil tanker age profile, numbers 4
Figure 4: Oil tanker age profile, dwt capacity 5
Figure 5: Oil tanker, fleet service speed 5
Figure 6: Oil tanker, avg. speed development 5
Figure 7: Oil tanker, fuel consumption development 6
Figure 8: Oil tankers, avg. NOx emissions 1990-2006 (incl order) 6
Figure 9: Oil tankers, avg. CO emissions 1990-2006 (incl order) 7
Figure 10: Oil tankers, avg. HC emissions 1990-2006 (incl order) 7
Figure 11: Oil tankers, avg. PM emissions 1990-2006 (incl order) 7
Figure 12: Chemical tanker age profile, numbers 8
Figure 13: Chemical tanker age profile, dwt capacity 9
Figure 14: Chemical tanker, fleet service speed 9
Figure 15: Chemical tanker, avg. speed development 9
Figure 16: Chemical tanker, fuel consumption development 10
Figure 17: Chemical tankers, avg. NOx emissions 1990-2006 (incl order) 10
Figure 18: Chemical tankers, avg. CO emissions 1990-2006 (incl order) 11
Figure 19: Chemical tankers, avg. HC emissions 1990-2006 (incl order) 11
Figure 20: Chemical tankers, avg. PM emissions 1990-2006 (incl order) 11
Figure 21: Gas tanker age profile, numbers 12
Figure 22: Gas tanker age profile, cubic meter capacity 13
Figure 23: Gas tanker, fleet service speed 13
Figure 24: Gas tanker, average speed development 13
Figure 25: Gas tanker, fuel consumption development 14
Figure 26: Gas tankers, average NOx emissions 1990-2006 (incl order) 14
Figure 27: Gas tankers, avg. CO emissions 1990-2006 (incl order) 15
Figure 28: Gas tankers, avg. HC emissions 1990-2006 (incl order) 15
Figure 29: Gas tankers, avg. PM emissions 1990-2006 (incl order) 15
Figure 30: Bulker age profile, numbers 17
Figure 31: Bulker age profile, dwt capacity 17
Figure 32: Bulker, fleet service speed 17
Figure 33: Bulker, avg. speed development 18
Figure 34: Bulker, fuel consumption development 18
Figure 35: Bulkers, avg. NOx emissions 1990-2006 (incl order) 18
Figure 36: Bulkers, avg. CO emissions 1990-2006 (incl order) 19
Figure 37: Bulkers, avg. HC emissions 1990-2006 (incl order) 19
Figure 38: Bulkers, avg. PM emissions 1990-2006 (incl order) 19
Figure 39: Container age profile, numbers 21
Figure 40: Container age profile, TEU capacity 21
Figure 41: Container, service speed 21
Figure 42: Container, avg. speed development 22
Figure 43: Container, fuel consumption development 22
Figure 44: Container, avg. NOx emissions 1990-2006 (incl order) 22

Figure 45: Container, avg. CO emissions 1990-2006 (incl order) ... 23
Figure 46: Container, avg. HC emissions 1990-2006 (incl order) ... 23
Figure 47: Container, avg. PM emissions 1990-2006 (incl order).... 23
Figure 48: Dry cargo n.e.s. age profile, numbers..... 24
Figure 49: Dry cargo n.e.s. age profile, dwt capacity 25
Figure 50: General cargo, fleet service speed 25
Figure 51: Dry cargo n.e.s., avg. speed development..... 25
Figure 52: Dry cargo, fuel consumption development..... 26
Figure 53: Dry Cargo, avg. NOx emissions 1990-2006 (incl order) . 26
Figure 54: Dry Cargo, avg. CO emissions 1990-2006 (incl order)... 27
Figure 55: Dry Cargo, avg. HC emissions 1990-2006 (incl order)... 27
Figure 56: Dry Cargo, avg. PM emissions 1990-2006 (incl order)... 27
Figure 57: Reefer age profile, numbers..... 28
Figure 58: Reefer age profile, cubic meter capacity..... 29
Figure 59: Reefer, fleet service speed..... 29
Figure 60: Reefer, avg. speed development..... 29
Figure 61: Reefer, fuel consumption development 30
Figure 62: Reefer, avg. NOx emissions 1990-2006 (incl order) 30
Figure 63: Reefer, avg. CO emissions 1990-2006 (incl order)..... 31
Figure 64: Reefer, avg. HC emissions 1990-2006 (incl order)..... 31
Figure 65: Reefer, avg. PM emissions 1990-2006 (incl order)..... 31
Figure 66: Vehicle roro age profile, numbers 32
Figure 67: Vehicle roro age profile, car eqv. units capacity..... 33
Figure 68: Vehicle ro-ro, fleet service speed 33
Figure 69: Vehicle ro-ro, avg. speed development 33
Figure 70: Vehicle ro-ro, fuel consumption development 34
Figure 71: Vehicle ro-ro, fuel consumption development 34
Figure 72: Vehicle ro-ro, avg. NOx emissions (dwt) 1990-2006 (incl order)..... 35
Figure 73: Vehicle ro-ro, avg. NOx emissions (gt) 1990-2006 (incl order)..... 35
Figure 74: Vehicle ro-ro, avg. CO emissions (dwt) 1990-2006 (incl order)..... 35
Figure 75: Vehicle ro-ro, avg. NOx emissions (gt) 1990-2006 (incl order)..... 36
Figure 76: Vehicle ro-ro, avg. HC emissions (dwt) 1990-2006 (incl order)..... 36
Figure 77: Vehicle ro-ro, avg. HC emissions (gt) 1990-2006 (incl order)..... 36
Figure 78: Vehicle ro-ro, avg. PM emissions (dwt) 1990-2006 (incl order)..... 37
Figure 79: Vehicle ro-ro, avg. PM emissions (gt) 1990-2006 (incl order)..... 37
Figure 80: Ro-ro n.e.s. age profile, numbers 39
Figure 81: Ro-ro n.e.s. age profile, lanemeter capacity 39
Figure 82: Ro-ro, fleet service speed 39
Figure 83: Ro-ro n.e.s., avg. speed development DWT 40
Figure 84: Ro-ro n.e.s., avg. speed development GT..... 40
Figure 85: Ro-ro n.e.s, fuel consumption development..... 40
Figure 86: Ro-ro n.e.s, avg. NOx emissions (dwt) 1990-2006 (incl order)..... 41
Figure 87: Ro-ro n.e.s, avg. NOx emissions (gt) 1990-2006 (incl order)..... 41
Figure 88: Ro-ro n.e.s, avg. CO emissions (dwt) 1990-2006 (incl order)..... 41
Figure 89: Ro-ro n.e.s, avg. CO emissions (gt) 1990-2006 (incl order) 42
Figure 90: Ro-ro n.e.s, avg. HC emissions (dwt) 1990-2006 (incl order)..... 42
Figure 91: Ro-ro n.e.s, avg. HC emissions (gt) 1990-2006 (incl order) 42
Figure 92: Ro-ro n.e.s, avg. PM emissions (dwt) 1990-2006 (incl order) 43
Figure 93: Ro-ro n.e.s, avg. PM emissions (gt) 1990-2006 (incl order) 43
Figure 94: Ferry cargo age profile, numbers 45
Figure 95: Ferry cargo age profile, lanemeter capacity 45
Figure 96: Cargo ferry, fleet service speed 45
Figure 97: Ferry cargo, avg. speed development 46
Figure 98: Ferry cargo, fuel consumption development (gt)..... 46
Figure 99: Ferry cargo, fuel consumption development (dwt) 46
Figure 100: Ferry cargo, avg. NOx emissions (dwt) 1990-2006 (incl order) 47
Figure 101: Ferry cargo, avg. NOx emissions (gt) 1990-2006 (incl order) 47
Figure 102: Ferry cargo, avg. CO emissions (dwt) 1990-2006 (incl order) 47
Figure 103: Ferry cargo, avg. CO emissions (gt) 1990-2006 (incl order) 48
Figure 104: Ferry cargo, avg. HC emissions (dwt) 1990-2006 (incl order) 48
Figure 105: Ferry cargo, avg. HC emissions (gt) 1990-2006 (incl order) 48
Figure 106: Ferry cargo, avg. PM emissions (dwt) 1990-2006 (incl order) 49
Figure 107: Ferry cargo, avg. PM emissions (gt) 1990-2006 (incl order) 49
Figure 108: Ferry non cargo age profile, numbers..... 50
Figure 109: Ferry non age profile, passenger capacity 50
Figure 110: Ferry non cargo, fleet service speed..... 51
Figure 111: Ferry non cargo, avg. speed development..... 51
Figure 112: Ferry non cargo, fuel consumption development DWT.. 52
Figure 113: Ferry non cargo, fuel consumption development GT 52
Figure 114: Ferry non cargo, avg. NOx emissions (dwt) 1990-2006 (incl order) 53
Figure 115: Ferry non cargo, avg. NOx emissions (gt) 1990-2006 (incl order) 53
Figure 116: Ferry non cargo, avg. CO emissions (dwt) 1990-2006 (incl order) 53
Figure 117: Ferry non cargo, avg. CO emissions (gt) 1990-2006 (incl order) 54
Figure 118: Ferry non cargo, avg. HC emissions (gt) 1990-2006 (incl order) 54
Figure 119: Ferry non cargo, avg. HC emissions (gt) 1990-2006 (incl order) 54
Figure 120: Cruise age profile, numbers..... 55
Figure 121: Cruise age profile, Lower berth capacity 56
Figure 122: Cruise, fleet service speed..... 56
Figure 123: Cruise, avg. speed development..... 56
Figure 124: Cruise, fuel consumption development DWT..... 57
Figure 125: Cruise, fuel consumption development GT 57
Figure 126: Cruise, avg. NOx emissions (dwt) 1990-2006 (incl order) 58
Figure 127: Cruise, avg. NOx emissions (gt) 1990-2006 (incl order)58
Figure 128: Cruise, avg. CO emissions (dwt) 1990-2006 (incl order) 58
Figure 129: Cruise, avg. CO emissions (gt) 1990-2006 (incl order) 59
Figure 130: Cruise, avg. HC emissions (dwt) 1990-2006 (incl order) 59
Figure 131: Cruise, avg. HC emissions (gt) 1990-2006 (incl order). 59
Figure 132: Cruise, avg. PM emissions (dwt) 1990-2006 (incl order) 60
Figure 133: Cruise, avg. PM emissions (gt) 1990-2006 (incl order). 60

Table 1: Help table for the size groups featured in the report 1
Table 2: The world fleet and deliveries from 1990 2
Table 3: Average emission values, ships delivered 1990-2006 (incl order) 61

Content and structure of the report

This report contains 15 chapters, whereof the first is an introduction and the last is a general description of the Lloyd's Register – Fairplay Research approach.

In the first chapter – "the world fleet" we present a general overview of the 46,791 ships in the world passenger and cargo carrying fleet. We also present the number of ships in each sector delivered from 1990 up to and including scheduled deliveries 2005 and 2006.

The information presented in this report is based on data held in Lloyd's Register-Fairplay's ships register. The specific engine related data has been counter checked with the major engine designers.

Emission data has been collected from the major engine designers. The scope has been limited to all cargo and/or passenger carrying vehicles delivered to the world fleet from 1990 and onwards, including ships on order for delivery up to and including 2006. The information obtained from engine manufacturers has been applied to the corresponding vessels in the world fleet.

The engine types in the world fleet are presented as well as which speed ranges different ship types generally operate in.

The following 13 chapters highlight certain characteristics of the different sectors of the merchant fleet. Oil tankers, Chemical tankers, Gas tankers, Bulkers, Container ships, Reefers, Dry cargo n.e.s. (not elsewhere specified), Vehicle roro, Ferry; cargo, Ferry; non cargo and finally the cruise ships.

For each segment the age profile of the fleet is presented both in number of ships and in relevant capacity, i.e. dwt for oil tankers and TEU for containerships etc. The age profile graphs presents the current fleet by size and year of built.

Thereafter the profile of the ships speed and the average speed development from 1969 and onwards are presented.

This is followed by a graph that presents the fuel consumption development for ships built in every year from 1969 and onwards, i.e. the x-axis displays the year of delivery. In both this and the previous section the ships built before 1969 but still present in respective fleet are lumped together in the 1969 numbers. The fuel consumption is given per dwt (gt in some cases) and day, so that changes in sizes within a segment over time not will affect the data.

Finally the emissions for Nitrogen oxides (NOx), Carbon monoxide (CO), Hydro carbon (HC) and Particles (PM) are presented in g/dwt/day (gt where appropriate). The years on the x-axis are the year of delivery. The graphs thus present the averages for vessels delivered to the world fleet each year.

In some cases, data coverage has been insufficient. This is indicated in the graphs by gaps in the lines.

In chapter 14 the averages for each individual ship category and ship segment are presented in a table.

In addition to this report, a confidential database containing detailed information on vessel characteristics and engine specifics has been supplied to MariTerm AB for further processing.

1 The world fleet

The world fleet ships are divided in to size groups according to their market importance, ie their relevant capacity, in this report. Table 1 gives approximate size groups in dwt and gt as well.

Table 1: Help table for the size groups

Conversion table		Size group approximate equal to					
Type	Size	dwt			gt		
Oil Tanker	200 000 dwt +	200,000	+		105,000		
	60' - 199 999	60,000	-	199,999	37,000	-	105,000
	E 10' - 59 999 dwt	10,000	-	59,999	6,700	-	37,000
	F - 9 999 dwt	1,400	-	9,999	500	-	6,700
	X < 500 gt	100	-	1,399	100	-	499
Chemical Tanker	60 000 dwt +	60,000	+		33,000	+	
	10' - 59 999 dwt	10,000	-	59,000	6,700	-	33,000
	- 9 999 dwt	1,400	-	9,999	500	-	6,700
	< 500 gt	100	-	1,399	100	-	499
Gas tankers	LNG	All			All		
	LPG 50 000 cbm +	36,000	+		25,000	+	
	LPG - 49 999 cbm	600	-	36,000	500	-	25,000
	< 500 gt	150	-	599	100	-	499
Bulker	80 000 dwt +	80,000	+		43,000	+	
	55' - 79 999 dwt	55,000	-	79,999	31,000	-	43,000
	10'-54 999 dwt	10,000	-	54,999	6,000	-	30,999
	- 9 999 dwt	1,000	-	9,999	499	-	5,999
	< 500 gt	150	-	999	100	-	499
Container	5 000 teu +	65,000	+		55,000	+	
	3' - 4 999 teu	45,000	-	64,999	40,000	-	54,999
	1' - 2 999 teu	15,000	-	44,999	10,000	-	39,999
	- 999 teu	1,500	-	14,999	500	-	9,999
	< 500 gt	500	-	1,499	100	-	499
Reefer	7 100 cbm +	8,000	+		6,000	+	
	- 7 099 cbm	800	-	7,999	500	-	5,999
	< 500 gt	150	-	799	100	-	499
Dry cargo n.e.s.	10 000 dwt +	10,000	+		6,000	+	
	- 9 999 dwt	600	-	9,999	500	-	5,999
	< 500 gt	100	-	599	100	-	499
Vehicle Ro-Ro	4 000 ceu +	15,000	+		40,000	+	
	- 3 999 ceu	900	-	14,999	500	-	39,999
	< 500 gt	100	-	899	100	-	499
Ro-Ro n.e.s.	2 200 lm +	15,000	+		20,000	+	
	- 2 199 lm	800	-	14,999	500	-	19,999
	< 500 gt	100	-	799	100	-	499
Ferry; Cargo	1 300 lm +	2,000	+		10,000	+	
	- 1 299 lm	500	-	1,999	500	-	9,999
	< 500 gt	50	-	499	100	-	499
Ferry; Non Cargo	> 500 gt	150	+		500	+	
	< 500 gt	20	-	149	100	-	499
Cruise	1 000 low berths +	5,000	+		30,000	+	
	- 999 low berths	500	-	4,999	500	-	29,999
	< 500 gt	30	-	499	100	-	499

Table 2: The world fleet and deliveries from 1990

		World fleet in december 2004			Deliveries 1990-2006 (incl. Order)			Number of ships with known emissions delivered 1990-2006 (incl. Order)							
		No	1.000 DWT	1.000 GT	No	1.000 DWT	1.000 GT	NOx	NOx %	CO	CO %	HC	HC %	PM	PM %
Oil Tanker	200 000 dwt +	464	135,419	71,808	437	129,550	68,746	264	60%	264	60%	121	28%	66	15%
	60' - 199 999	1,169	124,615	68,808	1,101	121,743	66,757	909	83%	909	83%	815	74%	222	20%
	E 10' - 59 999 dwt	951	31,567	19,352	469	18,060	11,183	342	73%	340	72%	321	68%	41	9%
	F - 9 999 dwt	2,936	9,160	5,720	860	3,561	2,255	70	8%	70	8%	69	8%	40	5%
	X < 500 gt	1,514	940	474	420	279	127	0	0%	0	0%	0	0%	0	0%
Chemical Tanke	60 000 dwt +	26	2,123	1,146	10	940	536	8	80%	8	80%	8	80%	4	40%
	10' - 59 999 dwt	1,088	31,795	19,868	1,071	32,156	20,341	656	61%	656	61%	631	59%	85	8%
	- 9 999 dwt	1,244	5,852	3,709	734	3,831	2,487	134	18%	134	18%	109	15%	55	7%
	< 500 gt	581	452	205	258	224	97	0	0%	0	0%	0	0%	0	0%
Gas tankers	LNG	129	6,558	5,612	87	4,418	3,858	2	2%	2	2%	2	2%	0	0%
	LPG 50 000 cbm +	173	11,114	15,111	158	10,896	15,282	117	74%	117	74%	88	56%	31	20%
	LPG - 49 999 cbm	839	4,683	3,959	439	3,108	2,605	48	11%	48	11%	48	11%	15	3%
	< 500 gt	55	25	20	8	4	3	0	0%	0	0%	0	0%	0	0%
Bulker	80 000 dwt +	669	106,810	55,163	600	94,238	48,425	542	90%	542	90%	508	85%	64	11%
	55' - 79 999 dwt	1,265	91,733	49,911	1,008	73,712	39,499	945	94%	945	94%	714	71%	188	19%
	10'-54 999 dwt	3,617	119,623	73,005	1,708	64,645	39,263	895	52%	895	52%	894	52%	232	14%
	- 9 999 dwt	626	2,772	1,832	176	770	494	4	2%	4	2%	4	2%	2	1%
	< 500 gt	470	372	179	164	156	69	0	0%	0	0%	0	0%	0	0%
Container	5 000 teu +	310	23,728	6,118	486	39,208	36,179	336	69%	319	66%	303	62%	158	33%
	3' - 4 999 teu	531	27,993	22,134	527	28,076	24,148	366	69%	360	68%	326	62%	205	39%
	1' - 2 999 teu	1,470	39,193	24,597	1,296	33,020	26,112	729	56%	729	56%	633	49%	323	25%
	- 999 teu	895	7,618	32,404	641	5,387	4,326	263	41%	263	41%	222	35%	150	23%
	< 500 gt	2	4	1	0	3	0	0							
Reefer	7 100 cbm +	533	5,062	4,724	259	2,534	2,366	108	42%	108	42%	71	27%	29	11%
	- 7 099 cbm	589	1,681	1,520	101	368	349	10	10%	10	10%	10	10%	7	7%
	< 500 gt	121	53	39	28	12	8	1	4%	1	4%	1	4%	0	0%
Dry cargo n.e.s.	10 000 dwt +	1,855	37,311	26,507	600	13,793	9,800	377	63%	377	63%	350	58%	144	24%
	- 9 999 dwt	9,315	33,938	24,815	2,769	12,540	9,296	683	25%	683	25%	552	20%	399	14%
	< 500 gt	4,904	3,304	1,556	1,316	1,160	458	1	0%	1	0%	1	0%	1	0%
Vehicle Ro-Ro	4 000 ceu +	305	5,368	14,999	232	4,138	12,424	113	49%	113	49%	77	33%	24	10%
	- 3 999 ceu	325	2,806	6,372	130	1,147	2,649	50	38%	50	38%	50	38%	19	15%
	< 500 gt	6	3	3	1	1	1	0	0%	0	0%	0	0%	0	0%
Ro-Ro n.e.s.	2 200 lm +	151	2,852	4,088	69	1,009	1,973	44	64%	44	64%	41	59%	32	46%
	- 2 199 lm	914	4,326	5,811	303	1,619	2,052	79	26%	79	26%	69	23%	12	4%
	< 500 gt	364	162	108	109	56	36	0	0%	0	0%	0	0%	0	0%
Ferry; Cargo	1 300 lm +	270	1,689	6,867	181	1,174	5,065	87	48%	87	48%	85	47%	13	7%
	- 1 299 lm	1,908	2,525	8,689	649	872	3,371	78	12%	78	12%	70	11%	33	5%
	< 500 gt	904	238	261	215	47	62	2	1%	2	1%	2	1%	2	1%
Ferry; Non Carg	> 500 gt	505	227	921	238	88	410	23	10%	23	10%	13	5%	3	1%
	< 500 gt	2,363	146	561	953	59	245	6	1%	6	1%	6	1%	6	1%
Cruise	1 000 low berths +	130	993	9,165	112	907	9,191	71	63%	71	63%	71	63%	0	0%
	- 999 low berths	220	437	2,182	92	144	1,058	20	22%	20	22%	19	21%	7	8%
	< 500 gt	85	81	21	36	39	9	0	0%	0	0%	0	0%	0	0%
Total		46,791	887,350	600,348	21,051	709,688	473,619	8,383	40 %	8,358	40 %	7,304	35 %	2,612	12 %

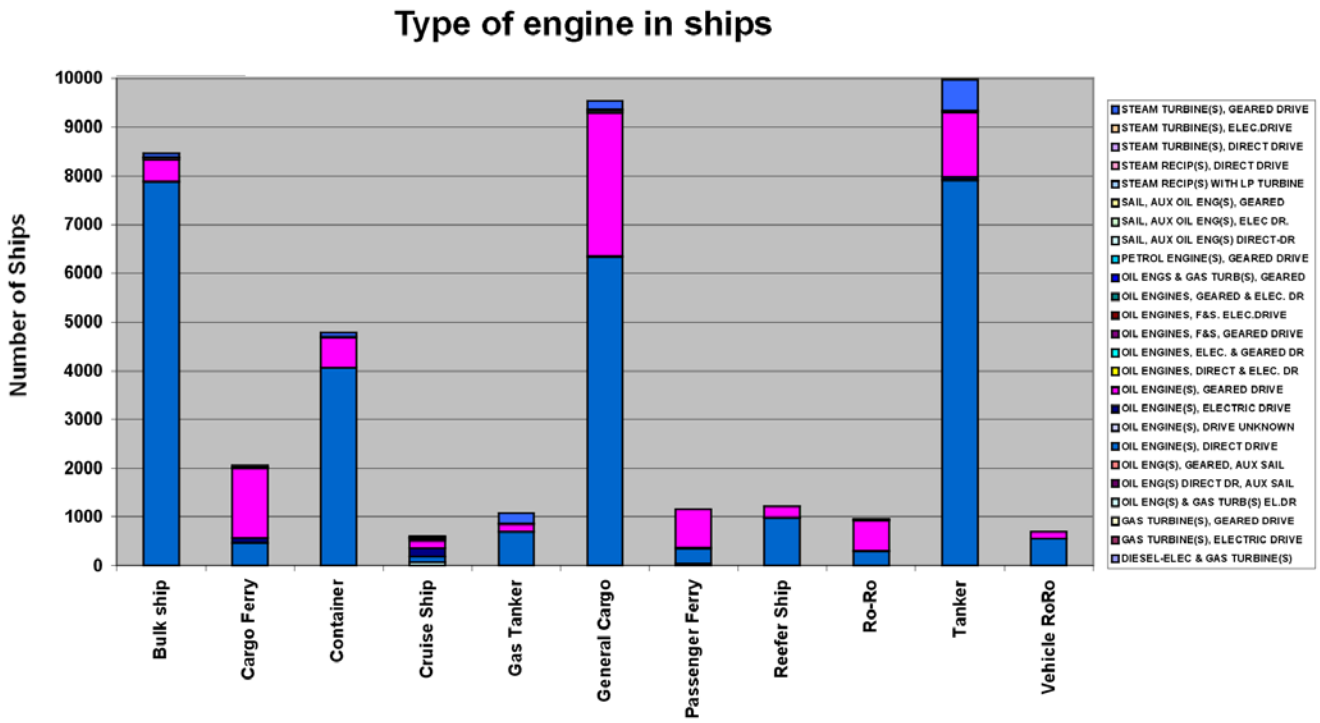


Figure 1: Type of engines in ships built 1980 and onwards

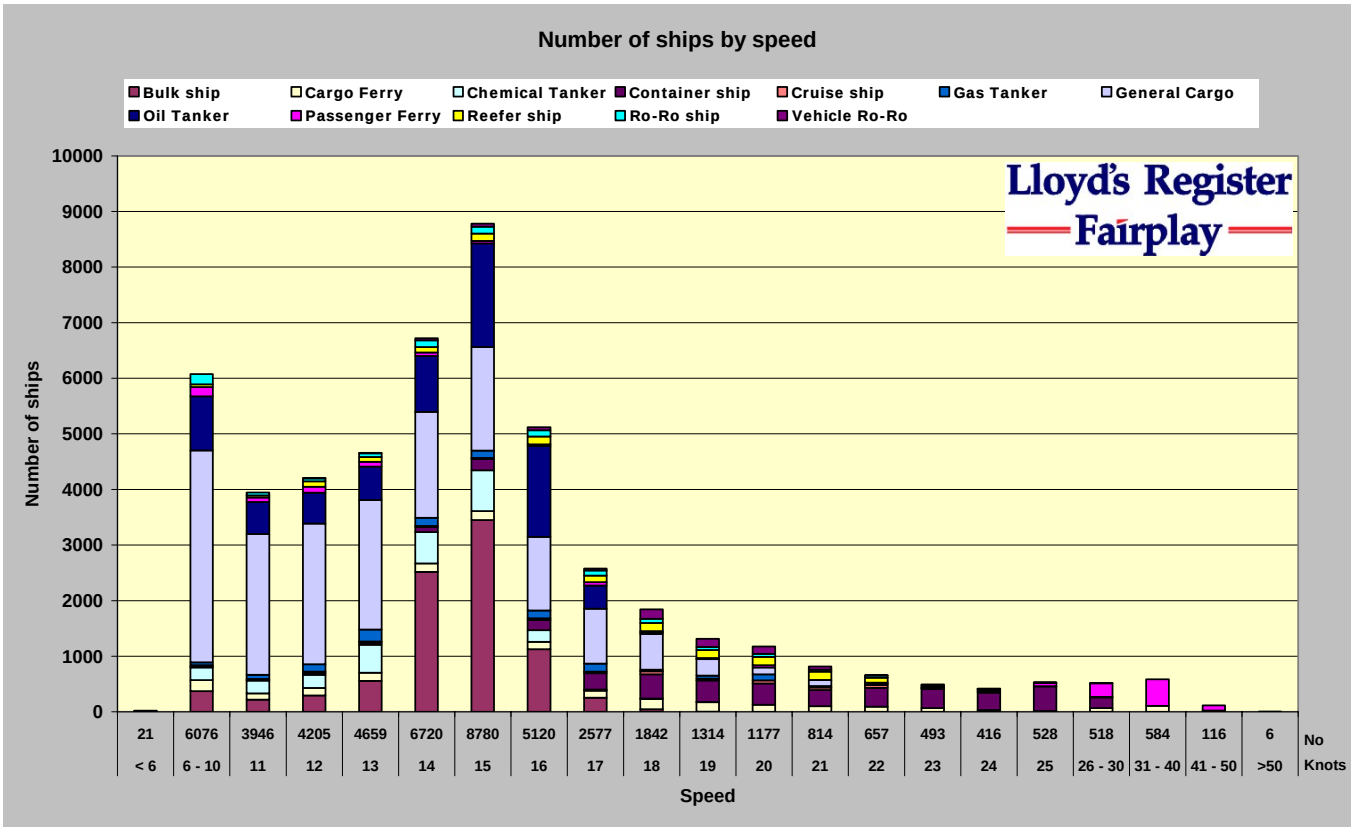


Figure 2: The speed profile of ships built 1980 and onwards

2 Oil tanker

Put simply, oil tanker market basics are about the transport of crude oil to refineries (Crude Oil Tankers) and of refined products to storage or other refineries (Product, Chemical or combined product/chemical Tankers).

The tanker market has gone through a consolidation process on both the demand and the supply side. The charterers are a handful oil companies and some traders. Examples could be Exxon/Mobil, Total/Fina/Elf, Chevron/Texaco and BP/Amoco.

To match this, players on the supply side have formed larger operating entities such as Frontline, World-Wide and Teekay. Some "smaller" operators have started pooling their capacities by the creation of Tankers International VLCC (Very Large Crude Carriers), the Alliance pool (Suezmax) and the Torm pool (Product tankers).

Crude transport is carried out by VLCCs (200,000 DWT-plus) mainly on long-haul trades, Suezmaxes (120-200,000 DWT) mainly on medium-haul trades and Aframax tankers (80-120,000 DWT) mainly on short- to medium-haul trades. The latter trades are covered by the smaller Panamax (60-80,000 DWT) segment as well. Products are mainly carried by vessels smaller than Aframax size. The different products range from "light" products such as MTBE, naphtha, jet fuel, kerosene, gasoline, diesel/gasoil to the "heavy" ones like heavy fuel oils and bitumen.

The smallest oil tankers are also the oldest. Quite a few of these ships are bunker tankers that service other ships. The vast majority of the bunker ships are rarely double hulled, and a regulation that prohibits them from trading will concern all shipping markets in the world.

2.1 Age profile of the fleet

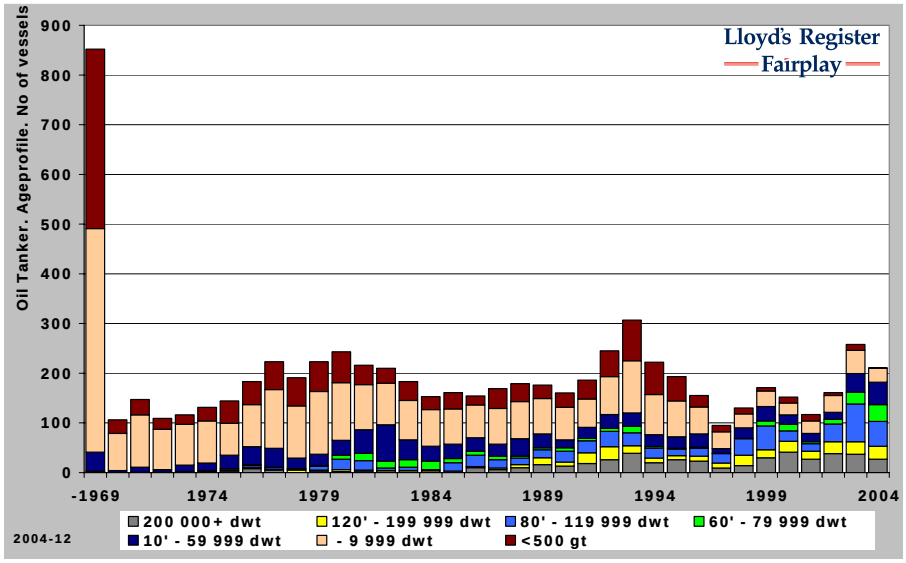


Figure 3: Oil tanker age profile, numbers

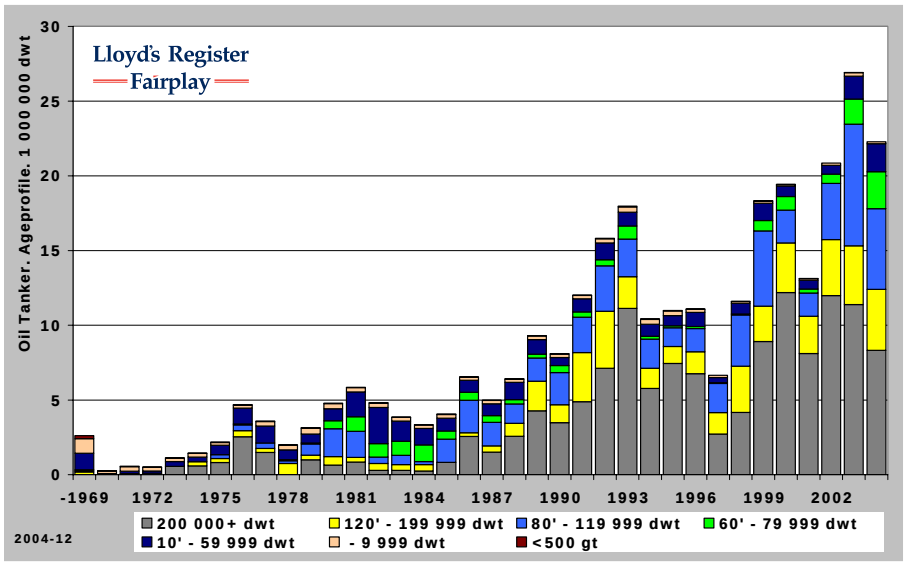


Figure 4: Oil tanker age profile, dwt capacity

2.2 Speed profile & development

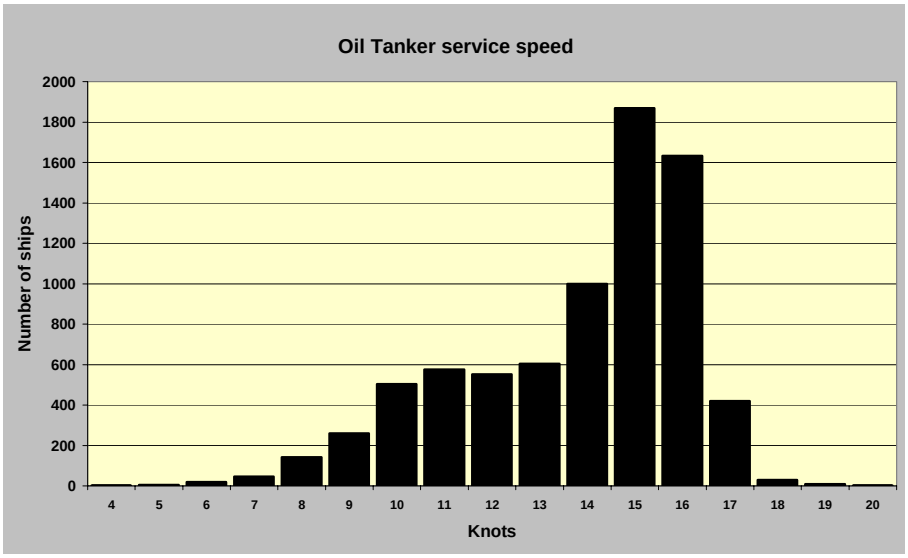


Figure 5: Oil tanker, fleet service speed

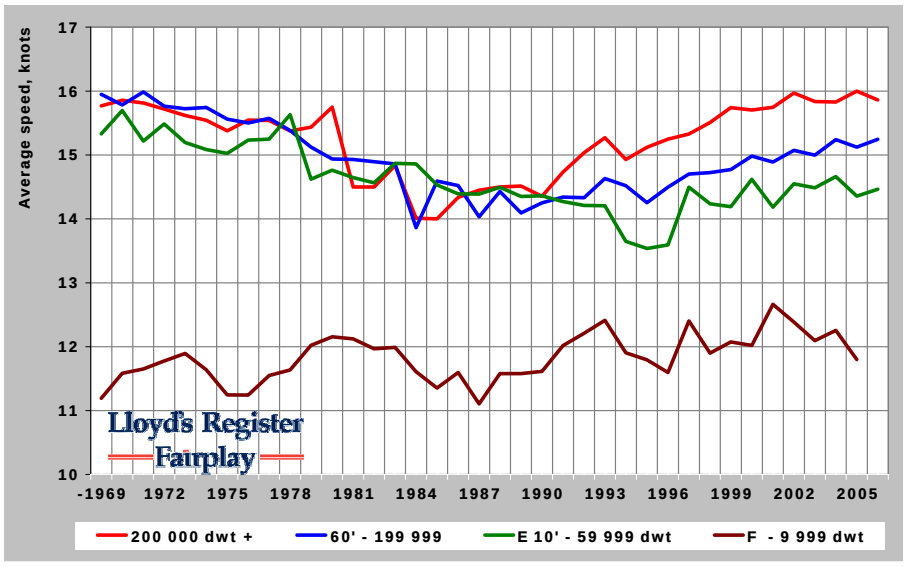


Figure 6: Oil tanker, avg. speed development

2.3 Fuel consumption development

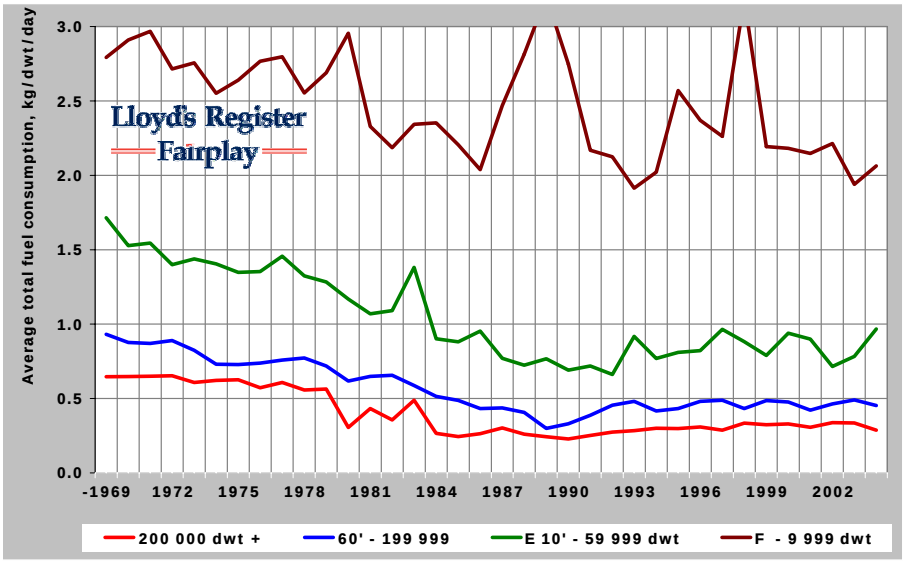


Figure 7: Oil tanker, fuel consumption development

2.4 Emission profile of the fleet

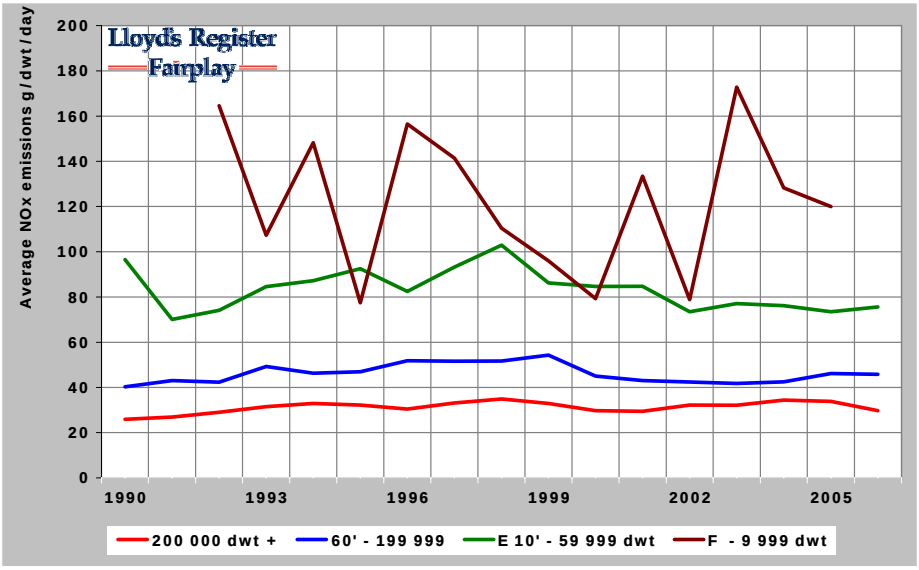


Figure 8: Oil tankers, avg. NOx emissions 1990-2006 (incl order)

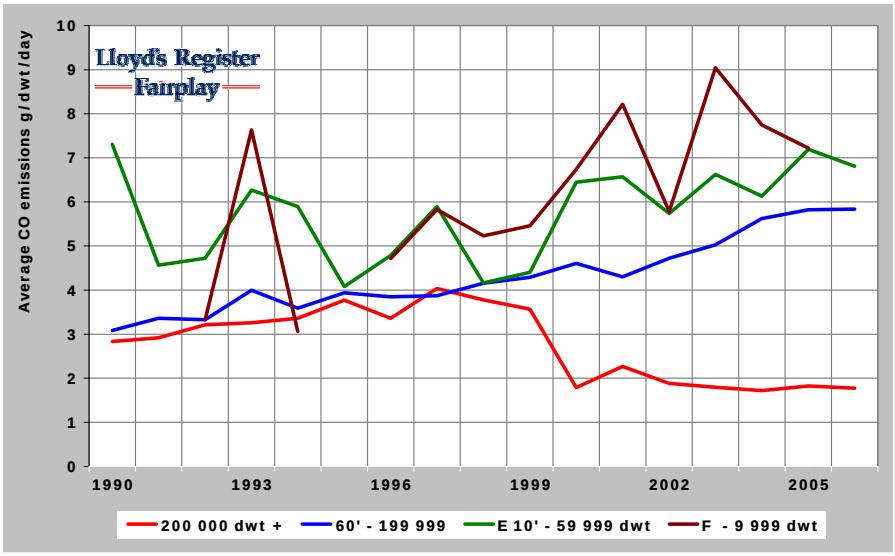


Figure 9: Oil tankers, avg. CO emissions 1990-2006 (incl order)

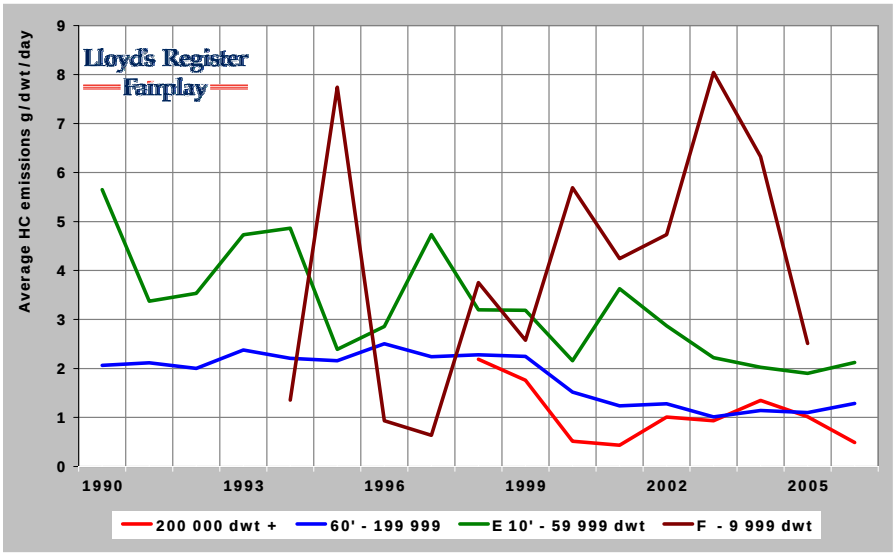


Figure 10: Oil tankers, avg. HC emissions 1990-2006 (incl order)

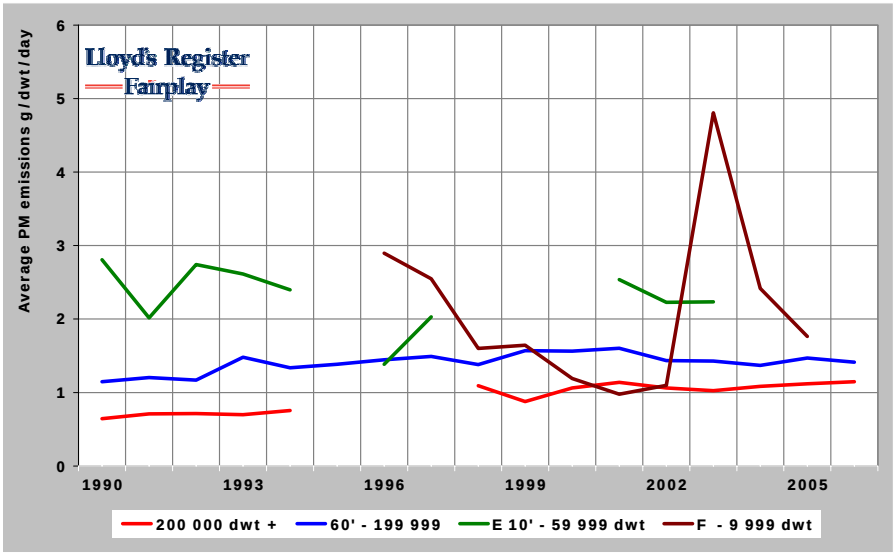


Figure 11: Oil tankers, avg. PM emissions 1990-2006 (incl order)

3 Chemical tanker

The chemical tanker market as categorised in this report is in effect two separate ones that occasionally trade overlap each other. Firstly it is a rather closed market for the transport of "sophisticated" chemicals (special products like corrosive or specially heated products) where actors like Stolt-Nielsen, Odfjell Seachem, Jo Tankers and MOL run their IMO I- or II-graded vessels that demands special steel in the tanks and special tank/pump arrangement. Secondly it is one for the less sophisticated cargoes (lubrication oils, MTBE etc) for which coated tanks are sufficient. The number of ship operators on this end of the market is fairly high. Vessels in the latter category often compete with the product tankers for the more sophisticated product tanker cargoes.

Operators in the former segment have admitted to a certain degree of co-operation in violation of US price-fixing regulations. Some of them are in financial difficulties. The strong growth in China might offer some relief.

The world chemical tanker fleet has shown an impressive growth of 679 ships between 1995, when the fleet stood in 2,078 ships (19.8M DWT), and July 2003, when it reached 34.6M DWT. Based on DWT, this is an average growth of more than 7 per cent per annum.

As a consequence, much of the chemical tanker fleet is young, with few candidates for demolition. The intense contracting activity over the last years is partially due to a number of combined chem/oil tankers replacing product tankers. Increased flexibility is the key driver.

3.1 Age profile of the fleet

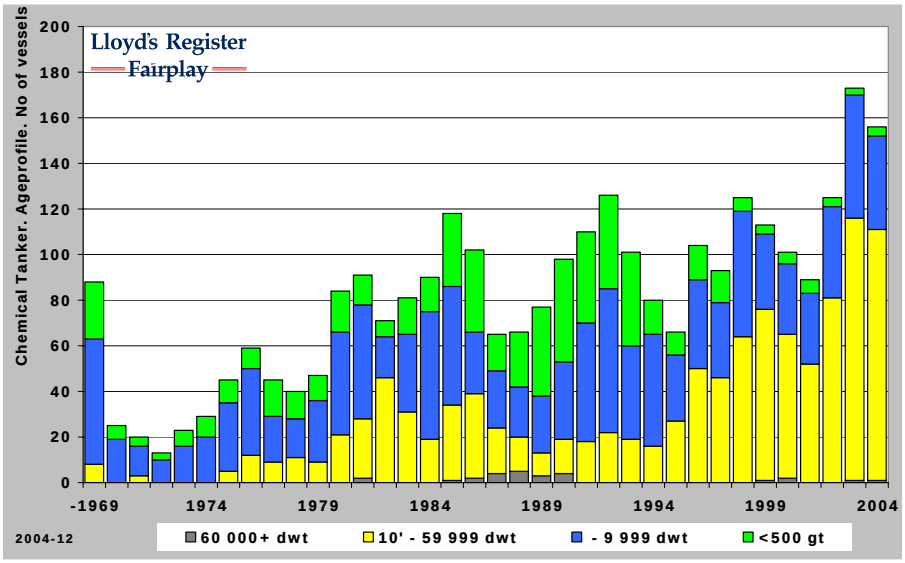


Figure 12: Chemical tanker age profile, numbers

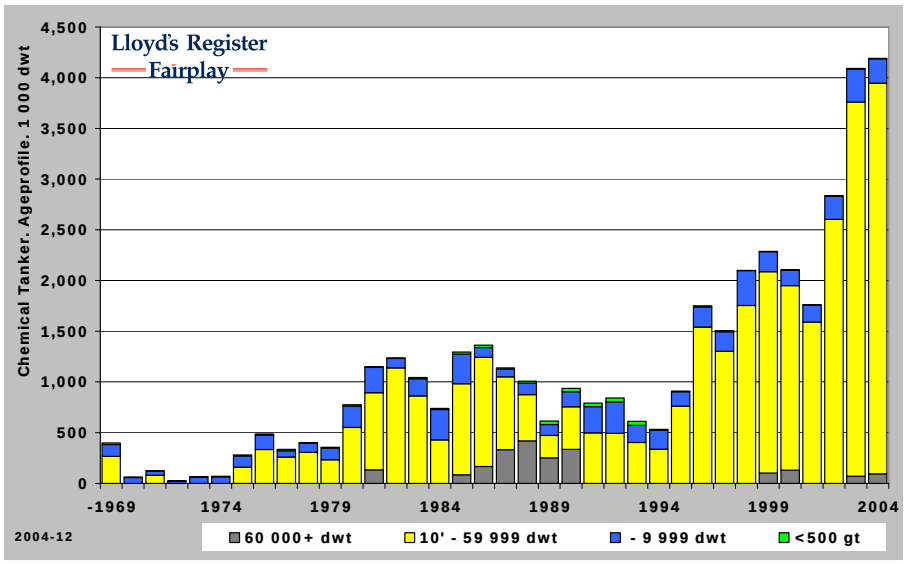


Figure 13: Chemical tanker age profile, dwt capacity

3.2 Speed profile & development

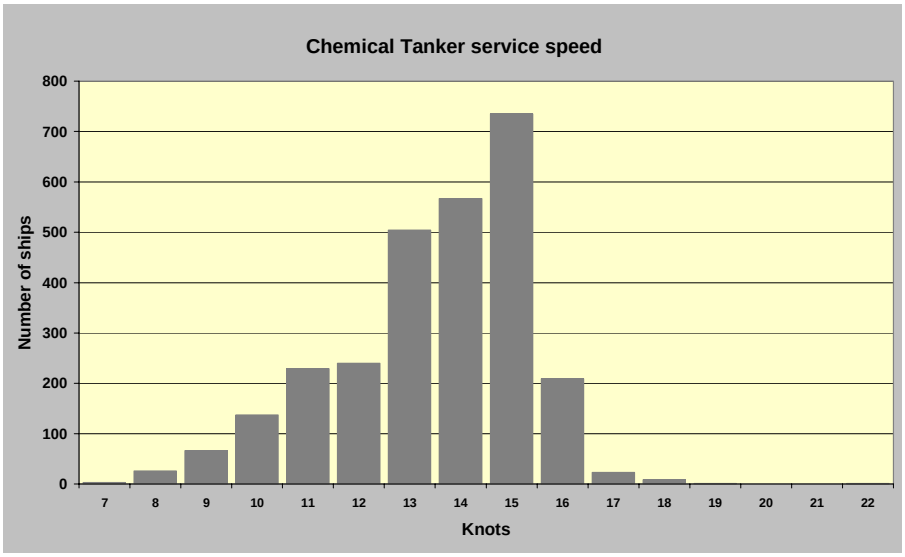


Figure 14: Chemical tanker, fleet service speed

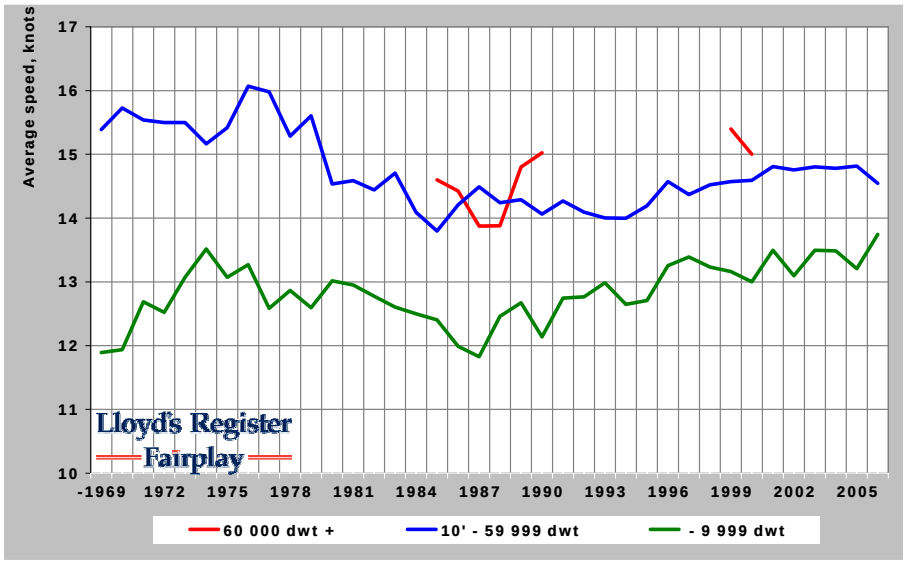


Figure 15: Chemical tanker, avg. speed development

3.3 Fuel consumption development

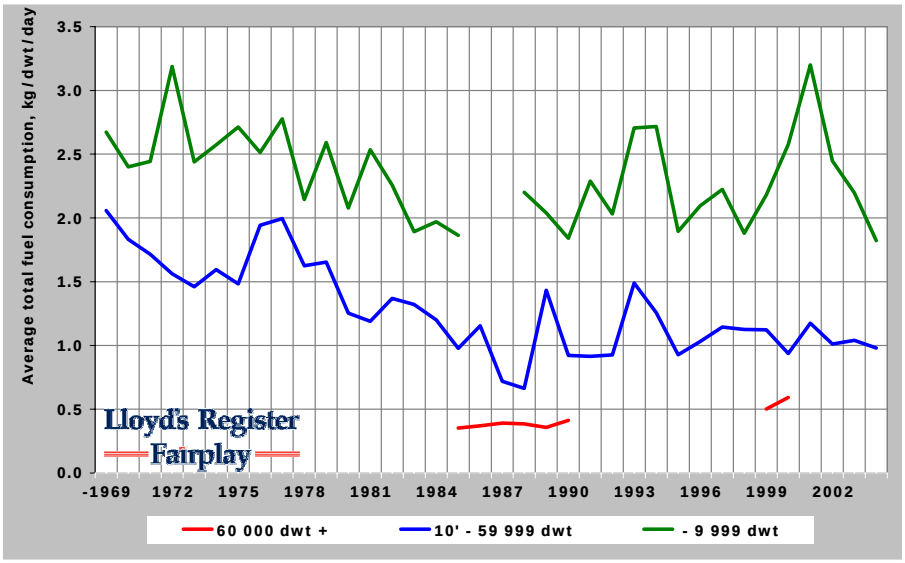


Figure 16: Chemical tanker, fuel consumption development

3.4 Emission profile of the fleet

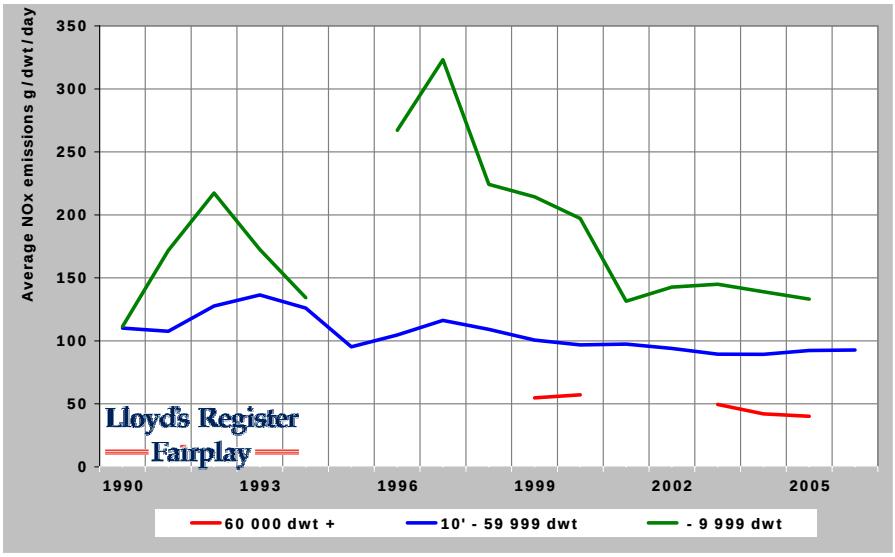


Figure 17: Chemical tankers, avg. NOx emissions 1990-2006 (incl order)

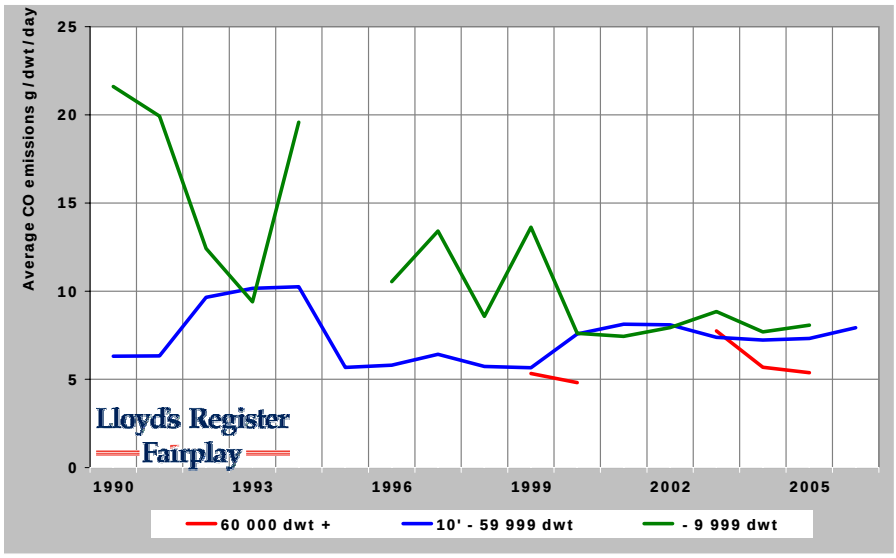


Figure 18: Chemical tankers, avg. CO emissions 1990-2006 (incl order)

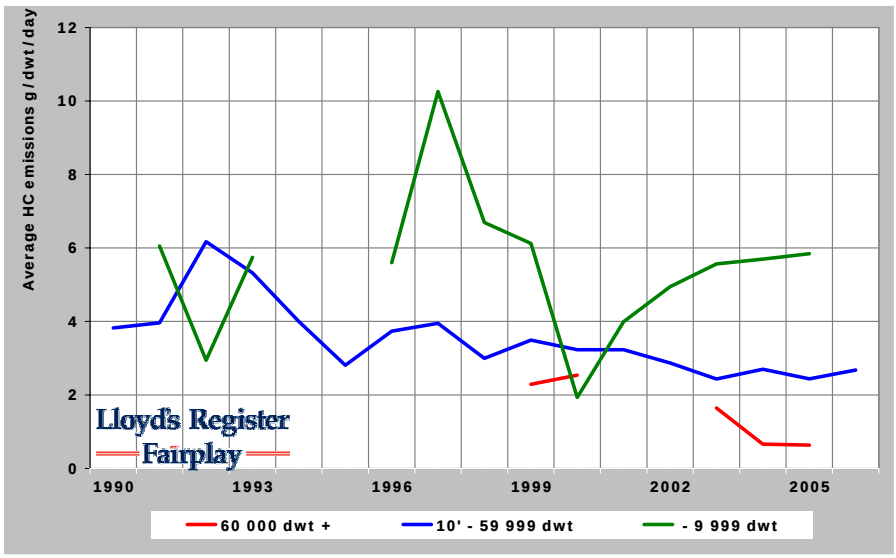


Figure 19: Chemical tankers, avg. HC emissions 1990-2006 (incl order)

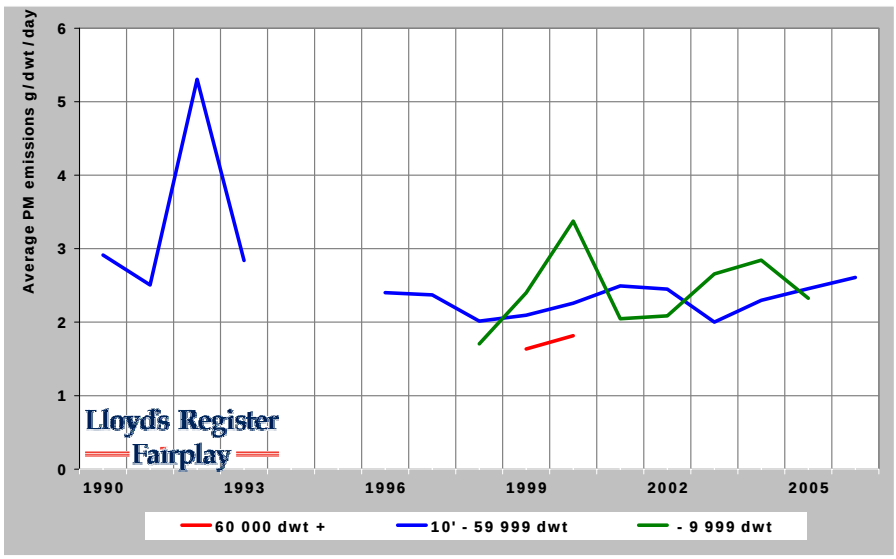


Figure 20: Chemical tankers, avg. PM emissions 1990-2006 (incl order)

4 Gas tanker

The LPG tankers call terminals that look as oil piers and can be a combined oil and gas terminal. The products are pumped in pipes.

LPG ships are used for the carriage of petrochemical and hydrocarbon gases such as ethylene, ethane and polypropylene as well as LPG (butane, propane or blends thereof). Demand for LPG shipping capacity generally benefits from high prices of natural gas. Japan and countries in Europe are the dominant importers, but Chinese imports are growing fast. The LPG production or supply side is expected to grow over the coming years.

New LPG projects in the Atlantic Basin are projected and Middle East exports are expected to grow.

Natural gas is a fast-growing energy sector (surpassed only by renewables). Most of the gas is distributed by pipeline, but the **LNG shipping market** is showing strong growth (LNG=liquefied natural gas).

Investment in a large LNG vessel (140,000 m^3) is a $170M decision and most orders are therefore being backed by medium- to long-term charter contracts, even if spot trading has caught on over recent years.

Average ship sizes are being scaled up and constructions on the drawing table are approaching 250,000 m^3.

A possible challenge to the LNG ship is the development of CNG ships (compressed natural gas).

4.1 Age profile of the fleet

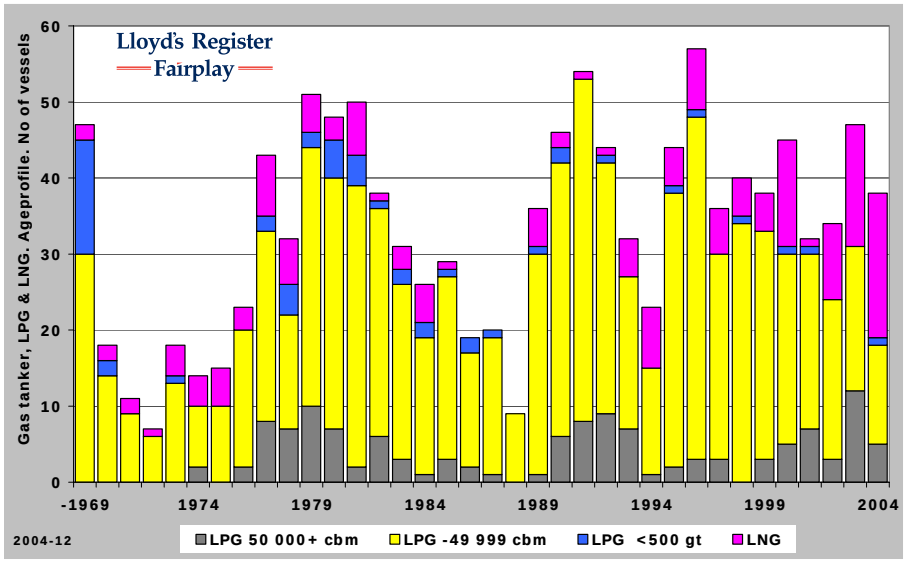


Figure 21: Gas tanker age profile, numbers

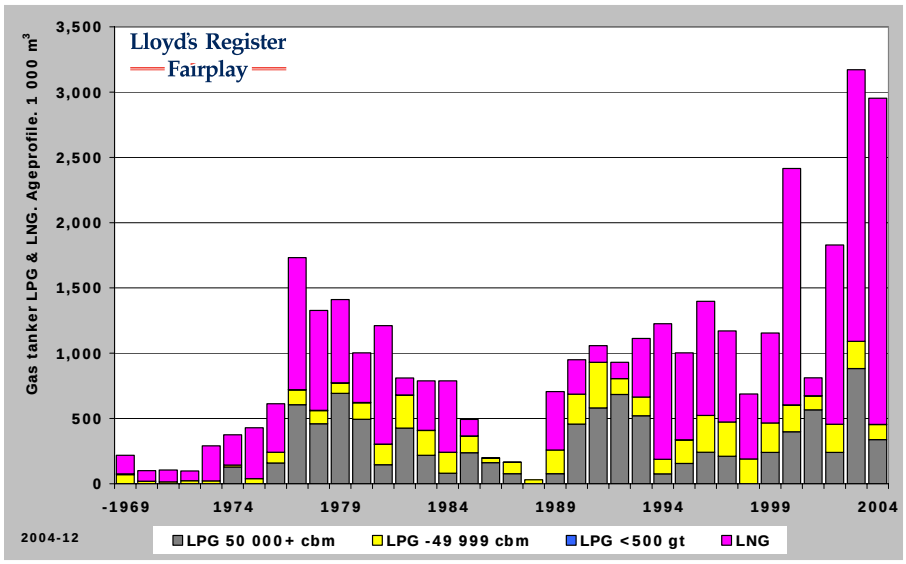


Figure 22: Gas tanker age profile, cubic meter capacity

4.2 Speed profile & development

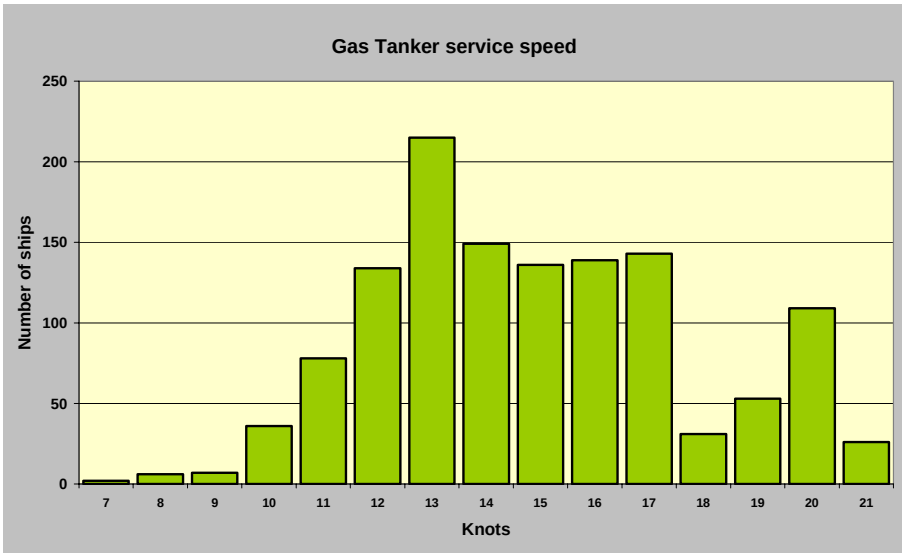


Figure 23: Gas tanker, fleet service speed

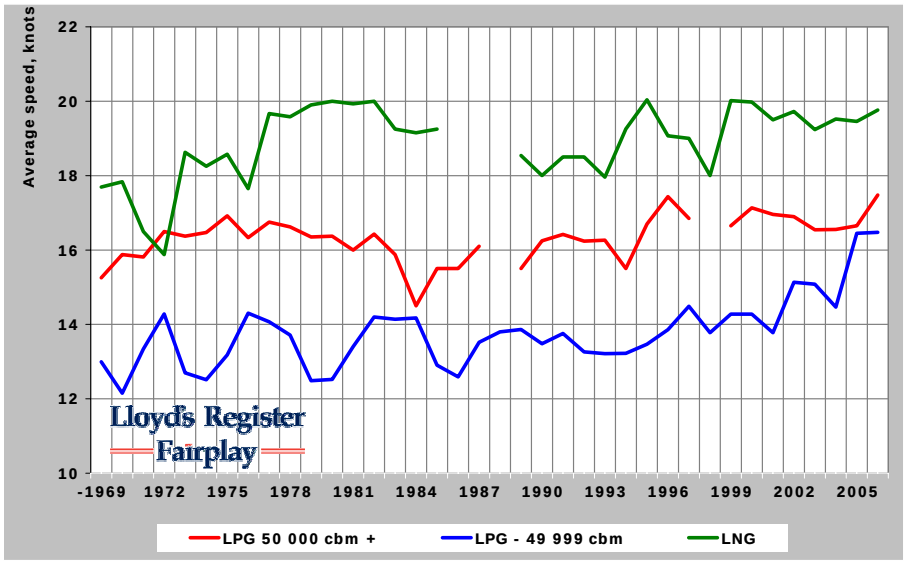


Figure 24: Gas tanker, average speed development

4.3 Fuel consumption development

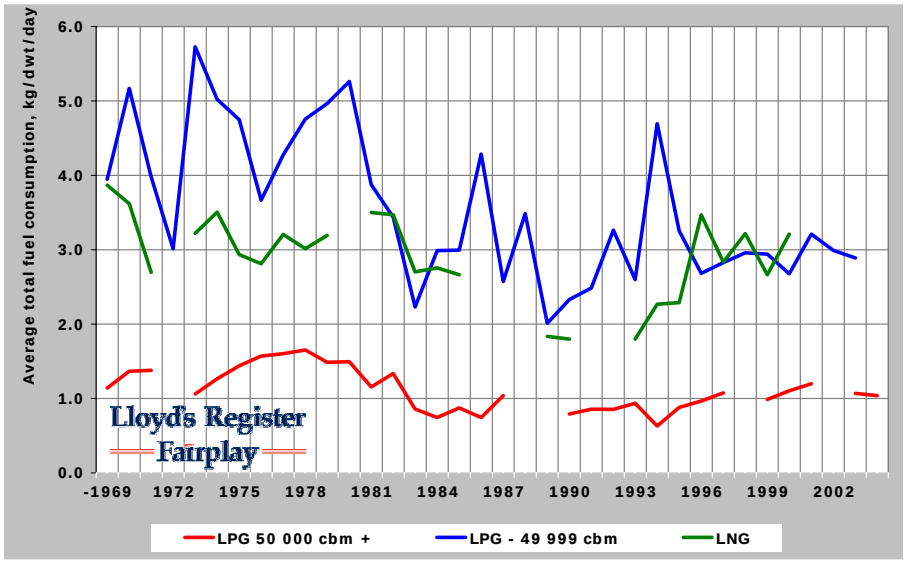


Figure 25: Gas tanker, fuel consumption development

4.4 Emission profile of the fleet

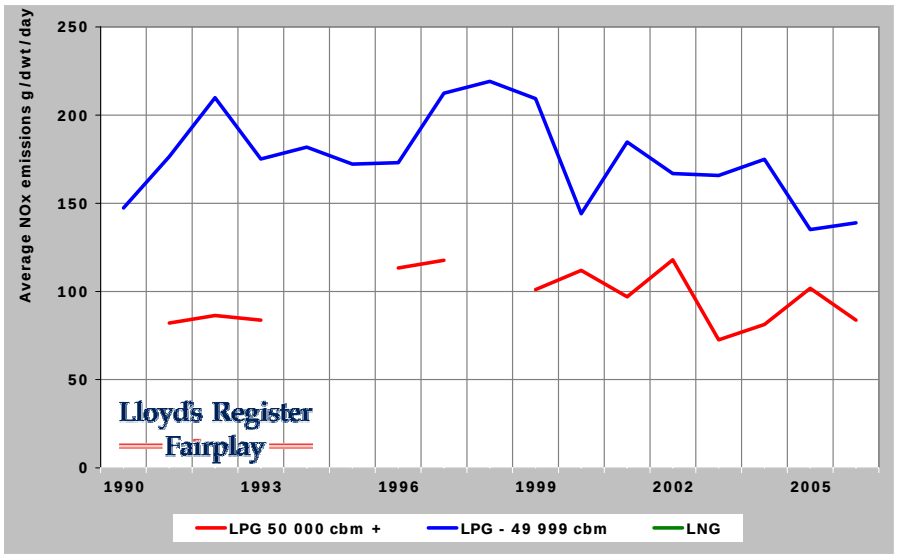


Figure 26: Gas tankers, average NOx emissions 1990-2006 (incl order)

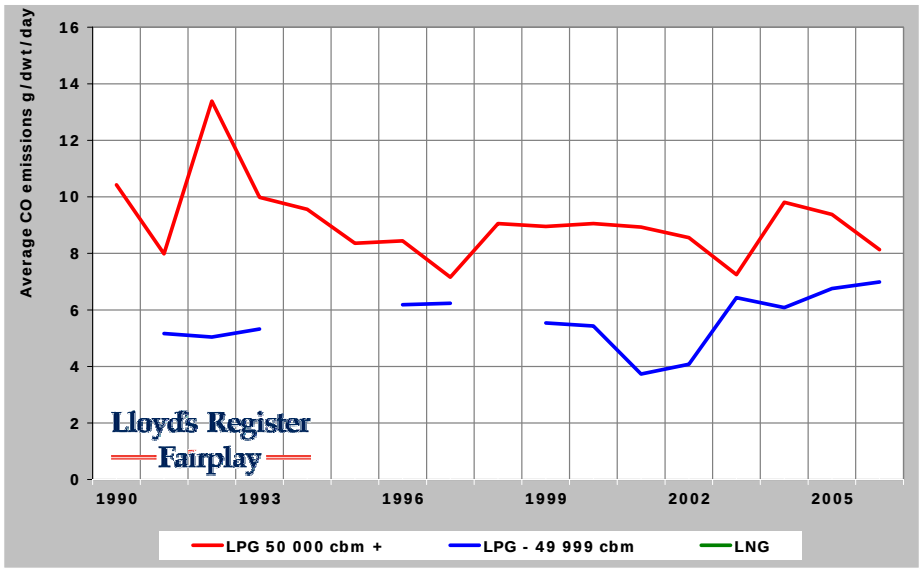


Figure 27: Gas tankers, avg. CO emissions 1990-2006 (incl order)

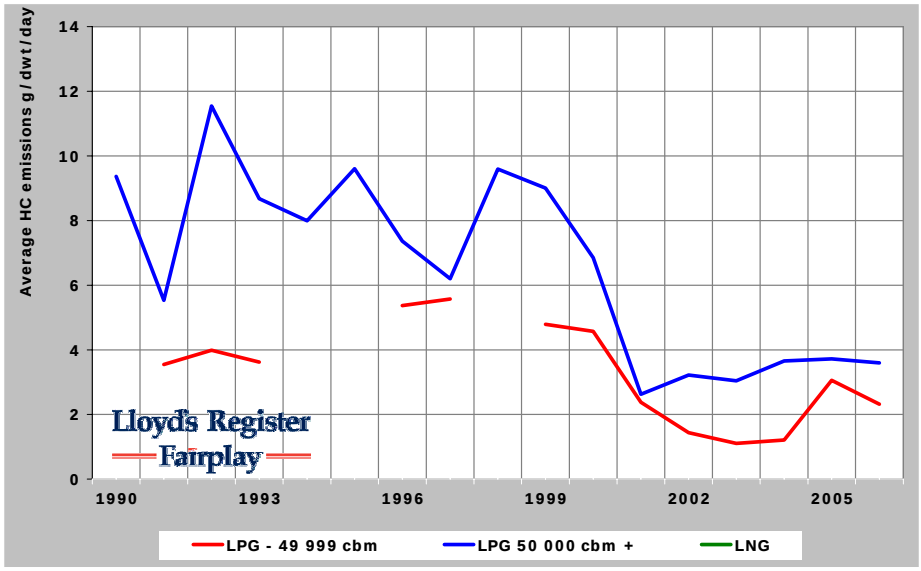


Figure 28: Gas tankers, avg. HC emissions 1990-2006 (incl order)

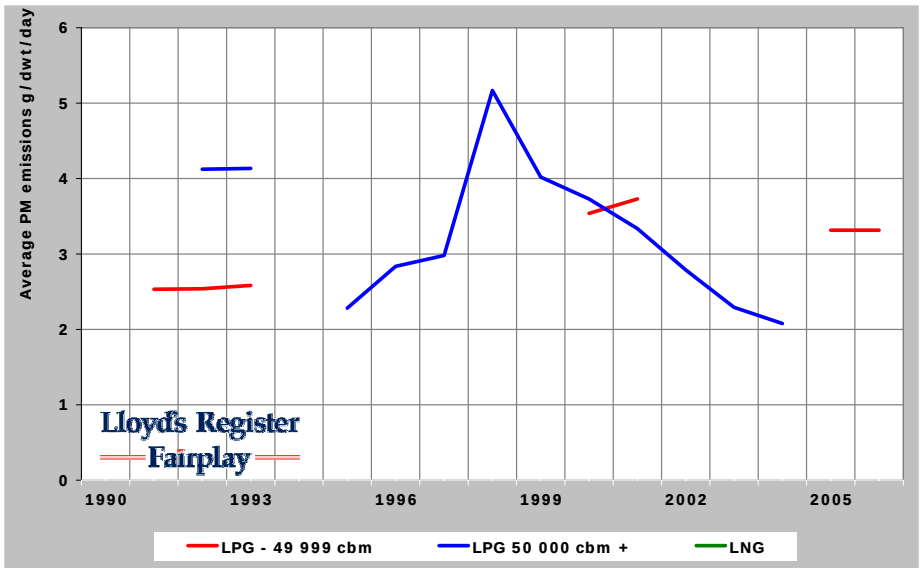


Figure 29: Gas tankers, avg. PM emissions 1990-2006 (incl order)

5 Bulker

In this segment we have also included the few still remaining combination carriers in the world fleet. The bulk carrier is the least sophisticated dry cargo ship that normally carries low value products in bulk that are stored in the ship's large holds. The simplest ships demand some type of crane of discharging equipment on the quay to discharge the products.

Loading of the bulkers always demand some kind of loading device that pours in the free flowing bulk into the ship's hold. Some bulkers are equipped with own gear enabling them to discharge the cargo without shore based assistance. This can be cranes or in some sophisticated cases discharging system that delivers the bulk on the quay with high productivity and in a continuous flow.

Some bulkers are equipped with container fittings in hold and on the hatches to be able to ship containers in bulk.

The very numerous bulk carrier fleet in the world currently amounts to over 6,000 vessels of all sizes. The majority is highly dependent on shifts in business cycles since a large proportion of the cargoes are commodities catering to the energy and construction industries. Changes in business cycles are of particular significance to trade in developing countries where infrastructural investments are intense and thus bulk commodity dependent.

The fleet of 631 Capesize bulkers (80,000 DWT and upwards) carry about 75 % of global deep-sea iron ore volumes. Iron ore is to some extent also carried by the fleet of 1,099 Panamax vessels, where ship sizes are 55,000-79,999 DWT. Coal shipments, however, are the main occupation for Panamax bulkers. Other important cargoes for these vessels are grain, bauxite/alumina and phosphate rock. Grain helps keep the Panamax sector somewhat less exposed than the Capesize segment to changes in business cycles.

Handy bulkers are below 55,000 DWT and are often sub-grouped into Handymax (35-55,000 DWT) and Handysize (10-34,999 DWT). There are currently 1,525 Handymax and 2,011 Handysize bulkers in the fleet.

These ships carry mainly minor bulks such as non-ferrous ores, iron and steel scrap, steel products, cement and forest products on all routes, but are also involved in grain and coal trade on short- to medium-hauls.

The 1,050 bulkers smaller than 10,000 DWT are with very few exceptions purely involved in regional trade. A substantial part of the transport work these vessels perform is related to the redistribution (feedering) of medium- to long-haul bulk cargoes from other continents. The reception facilities for these cargoes are often located near industries and heating plants.

The combination carrier was developed from a trading pattern of oil (crude oil) in one direction and bulk cargo (ore or coal) in the other. The idea is to minimise the empty trips for the ship. Typical combination carriers are OBO (Oil Bulk Ore) and OB (Oil Bulk) carriers.

The combination carrier fleet has been shrinking since 1992. Dry bulk shipments by combination carriers have almost ceased to exist over the past decade, while their presence in the crude sector has been shifting over the years. The exceptional development of the dry bulk market has led combination carriers back to dry trading again. The combination fleet has fallen since 1992 at an average 7.7 per cent per annum, based on DWT.

5.1 Age profile of the fleet

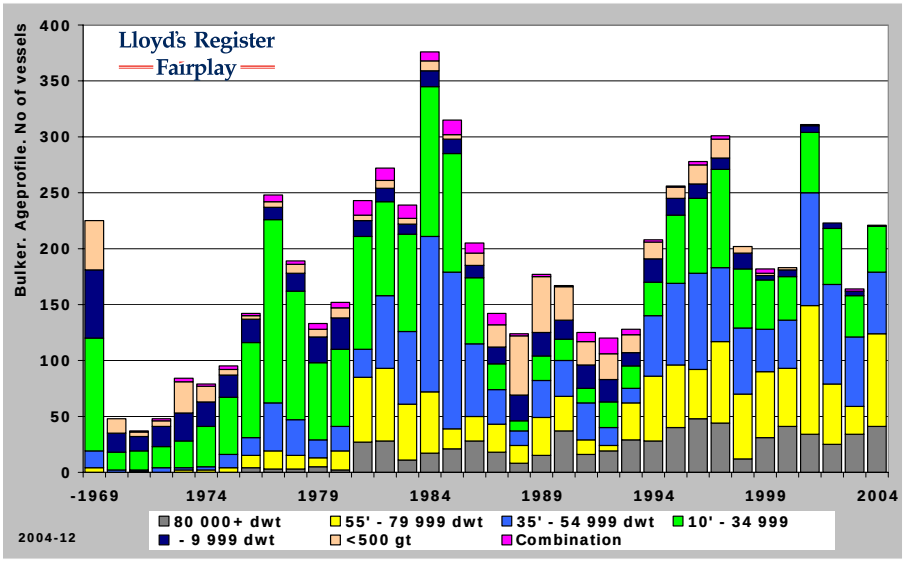


Figure 30: Bulker age profile, numbers

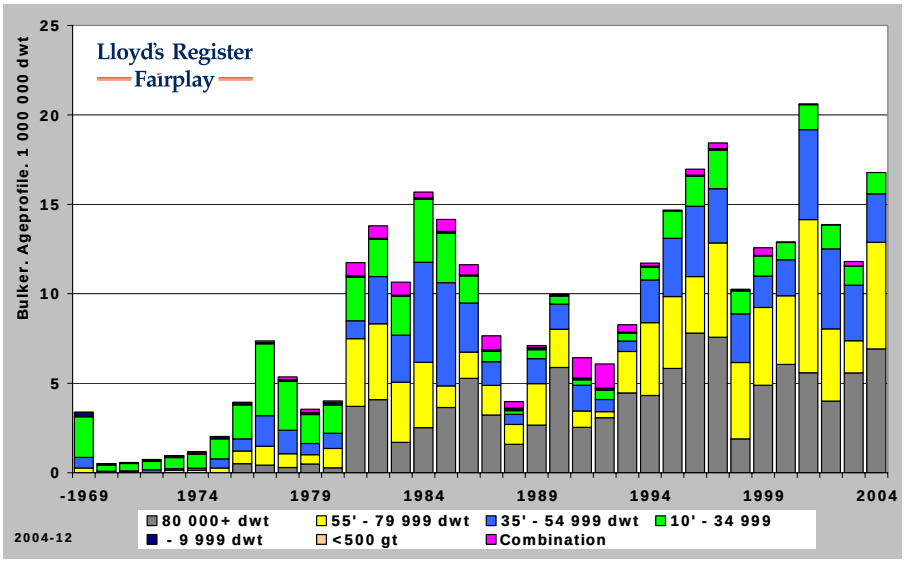


Figure 31: Bulker age profile, dwt capacity

5.2 Speed profile & development

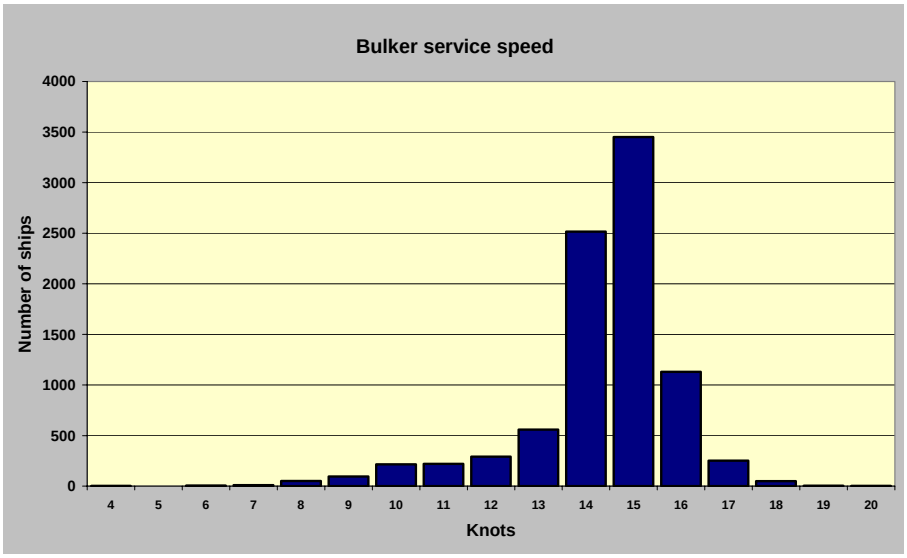


Figure 32: Bulker, fleet service speed

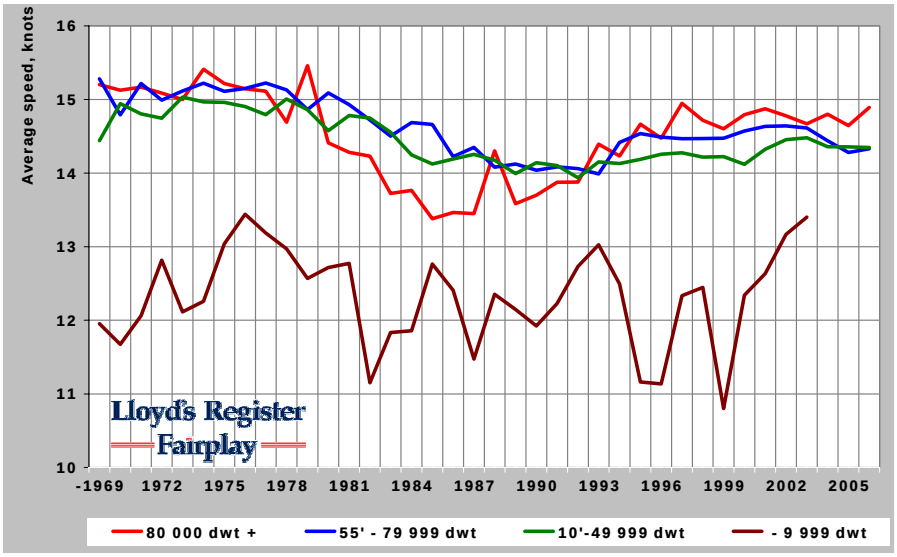


Figure 33: Bulker, avg. speed development

5.3 Fuel consumption development

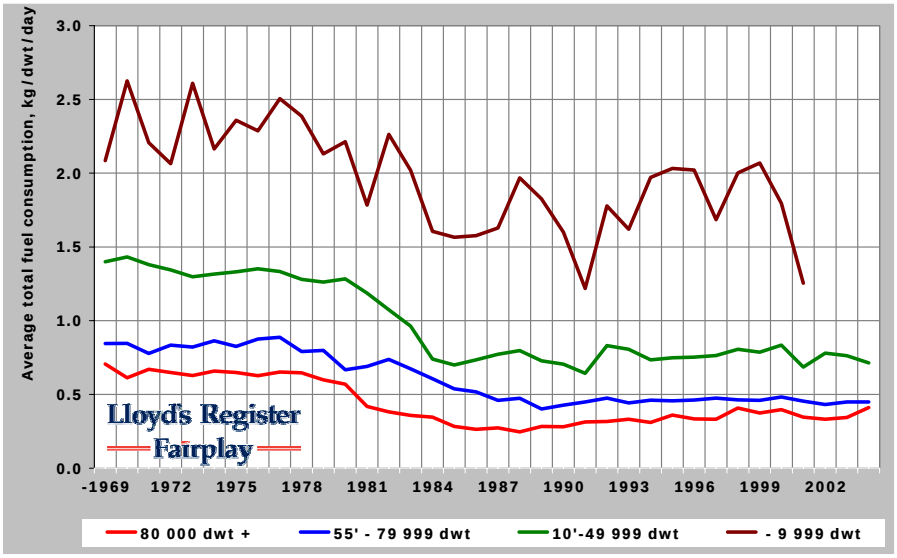


Figure 34: Bulker, fuel consumption development

5.4 Emission profile of the fleet

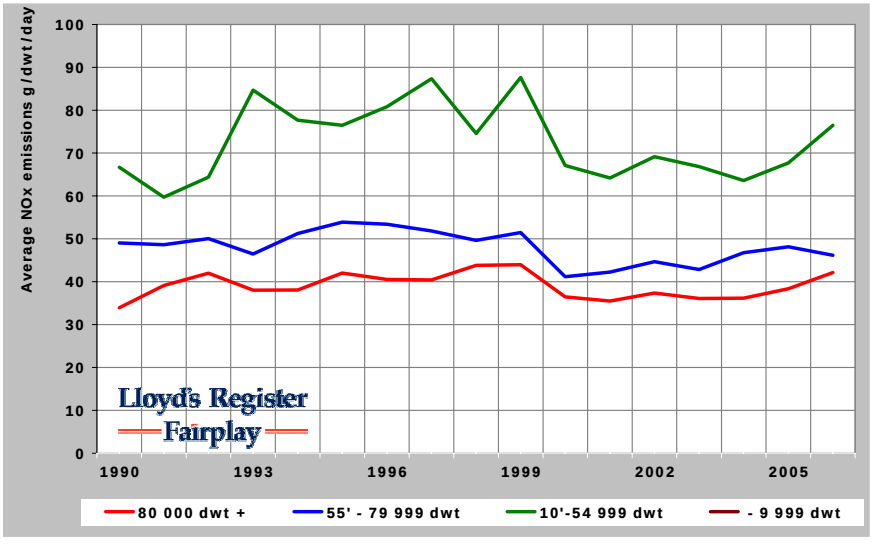


Figure 35: Bulkers, avg. NOx emissions 1990-2006 (incl order)

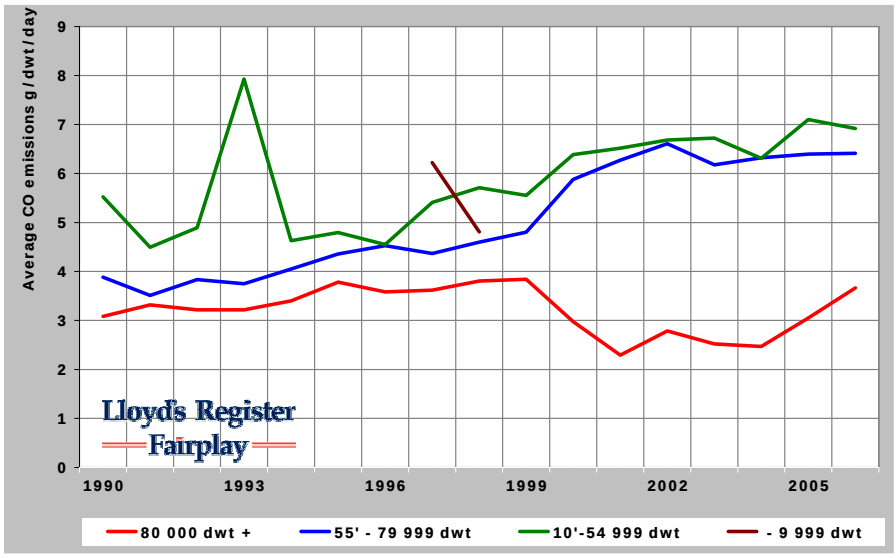


Figure 36: Bulkers, avg. CO emissions 1990-2006 (incl order)

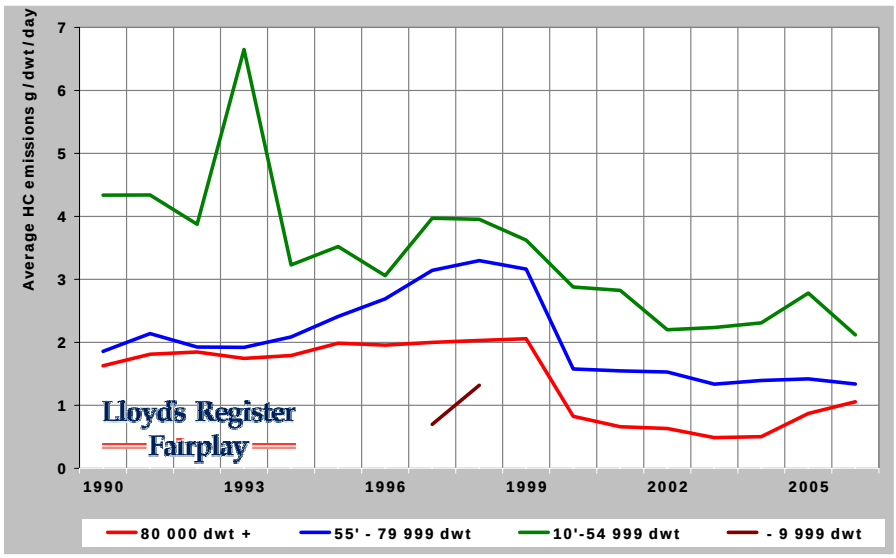


Figure 37: Bulkers, avg. HC emissions 1990-2006 (incl order)

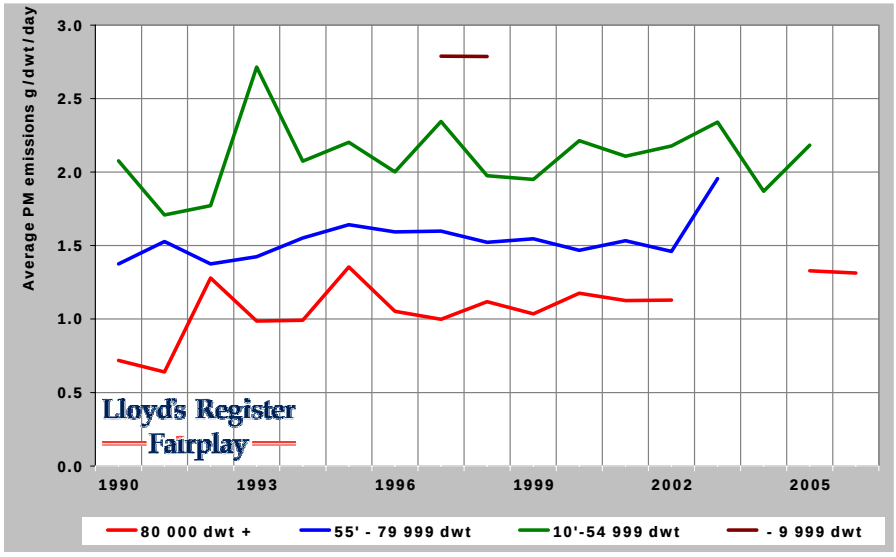


Figure 38: Bulkers, avg. PM emissions 1990-2006 (incl order)

6 Container

The unitised and dry cargo sector of the world shipping scene has been dominated by the enormous influx of containers into the system the last decade. This grand-scale containerisation of the global logistical chain is the result of the exploration of economies of scale in the deep-sea container vessel fleet. Prices have dropped over the last decade attracting cargo from competing segments such as dry cargo, reefer and minor bulk. This development has affected the formation of strategies as well as the development of products and services.

The last ten-year period has been a roller-coaster ride for the container operators, with profits going up and down. Fleet expansion has been especially rapid in capacity terms. For every added year, the TEU capacity per vessel is increased. The newest and largest vessels are being deployed on the Asia-Europe and Asia-US trades, sending the existing ships cascading into other trades. Such a development is finite, and there are size restrictions (length, beam, draught, height, port handling capacities) interrupting the cascade potential.

All the large global operators want to take part in this development, and this is reflected in new ordering activities. Most of them have substantial orderbook/ fleet ratios. Without doubt more of the cargo being offered to the transport market will be carried by container ships, even if we foresee a decline in the orderbook relative to the fleet over the next years.

Today we face a situation where ship operators are chartering tonnage at increasing rates to secure operation at decreasing rates. Lower freight rates increase the attractiveness of the container as such. Goods are now being shipped in boxes that were previously earmarked for bulk or break-bulk, such as timber and sawn wood. Reversals when rates bounce upwards seem to be lagging somewhat, but the competition from break-bulk is there.

The container-shipping sector is facing some major challenges ahead, and coping with over-supply of tonnage is one of them. Being able to offer the lowest cost per unit on the major trades has been and will continue to be an important incentive for the ordering of new and larger vessels.

The multi-national industrial conglomerates have got used to transport costs decreasing over time. Should the transport sector be able to continue offering services at these terms, then the empty container issue has to be addressed. Increased efficiency in container handling ashore is another target area.

6.1 Age profile of the fleet

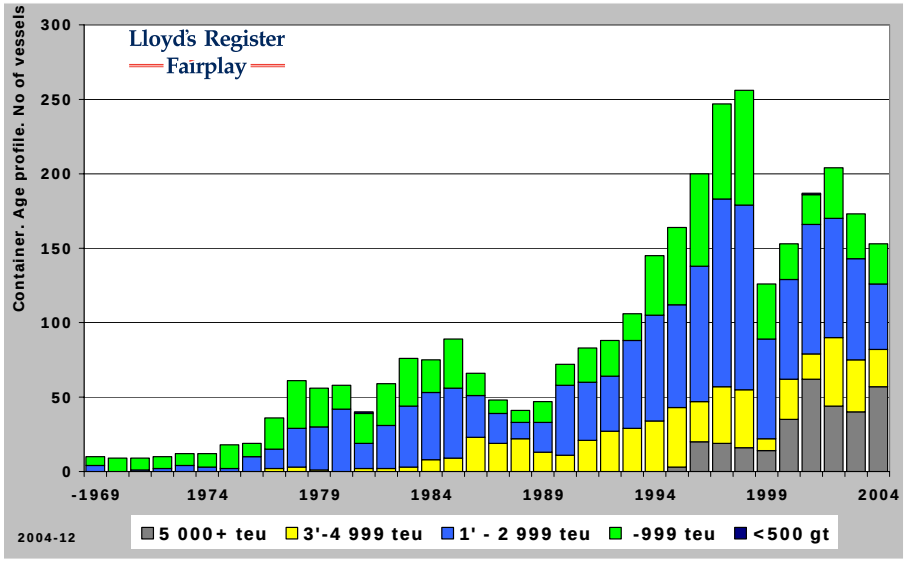


Figure 39: Container age profile, numbers

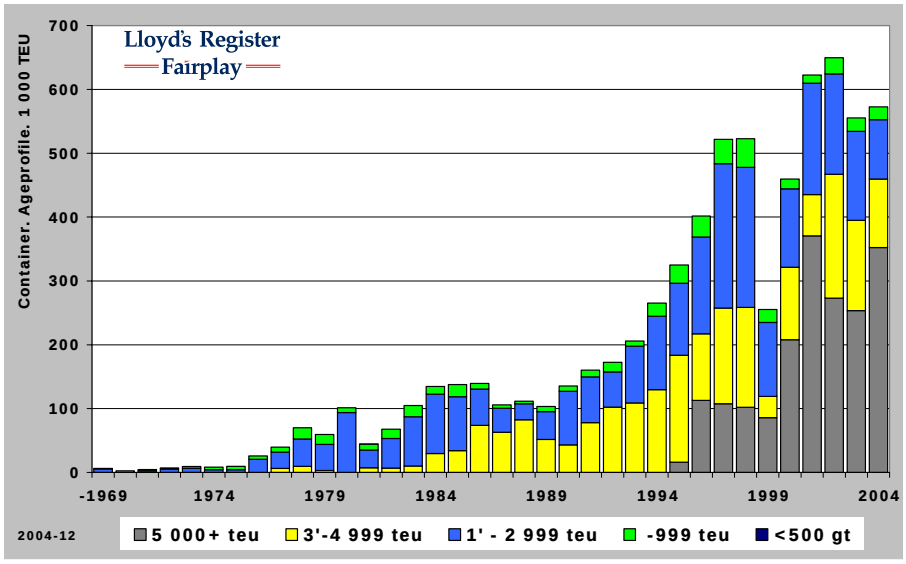


Figure 40: Container age profile, TEU capacity

6.2 Speed profile & development

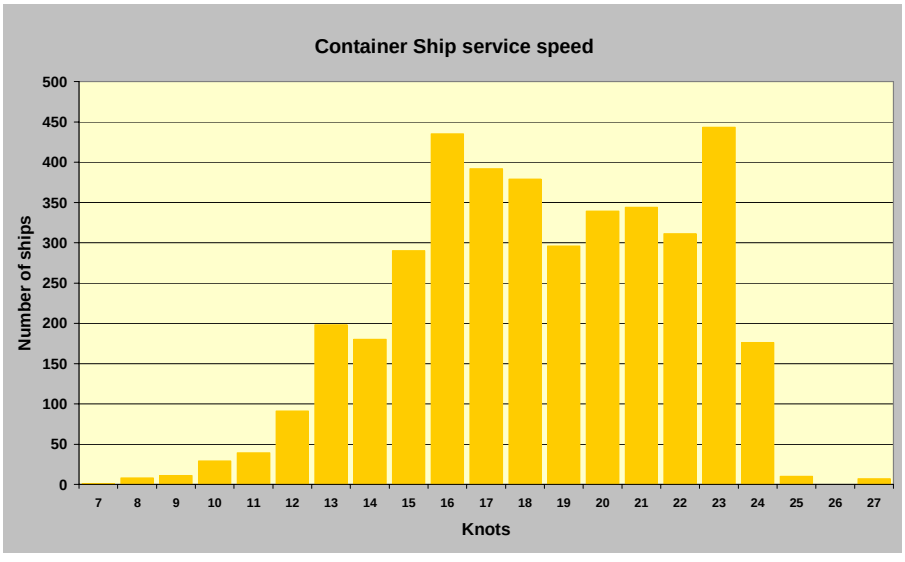


Figure 41: Container, service speed

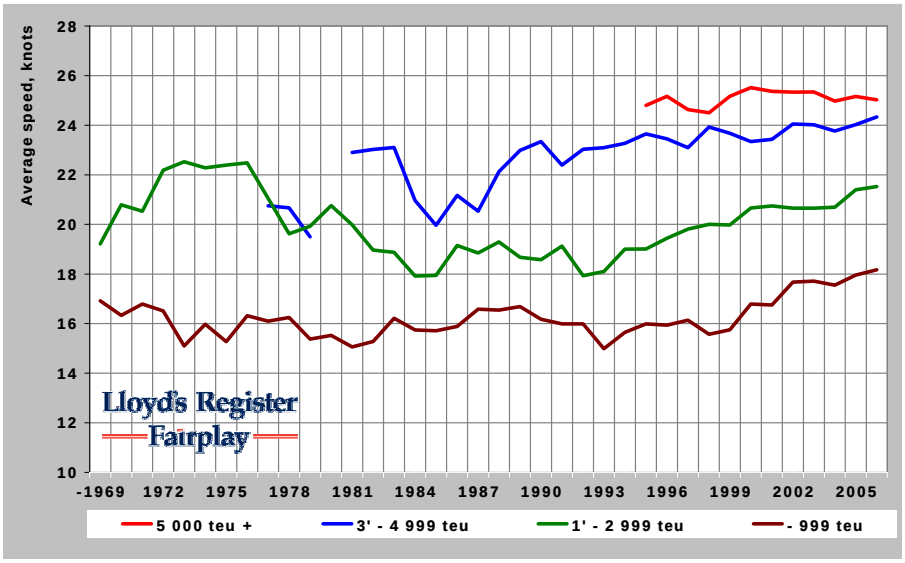


Figure 42: Container, avg. speed development

6.3 Fuel consumption development

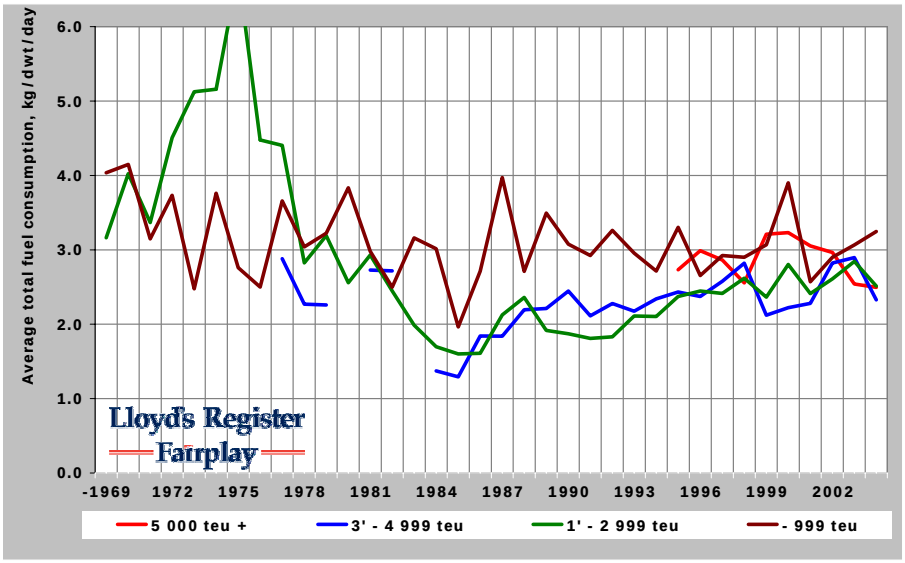


Figure 43: Container, fuel consumption development

6.4 Emission profile of the fleet

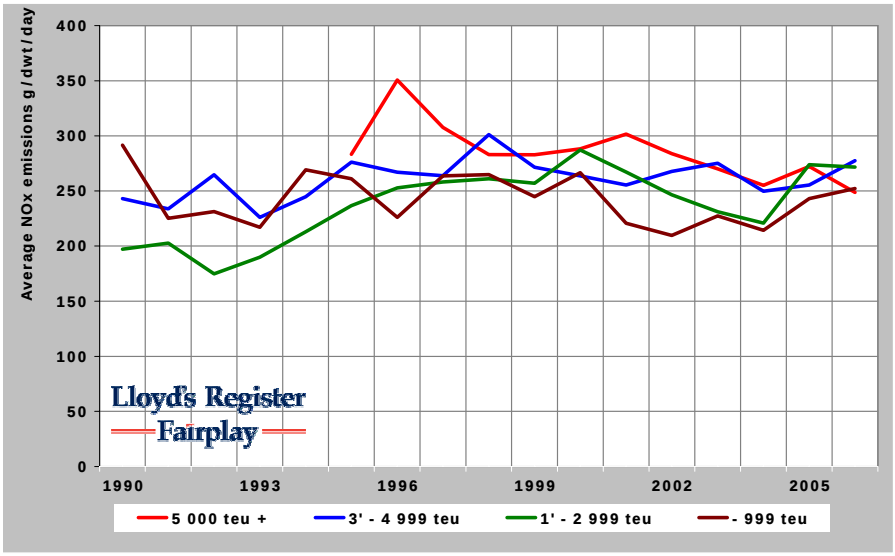


Figure 44: Container, avg. NOx emissions 1990-2006 (incl order)

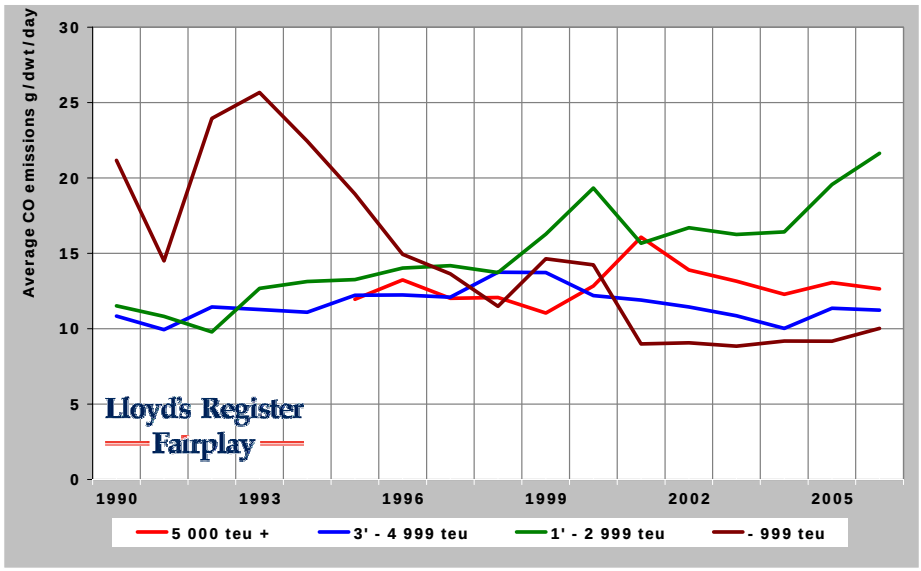


Figure 45: Container, avg. CO emissions 1990-2006 (incl order)

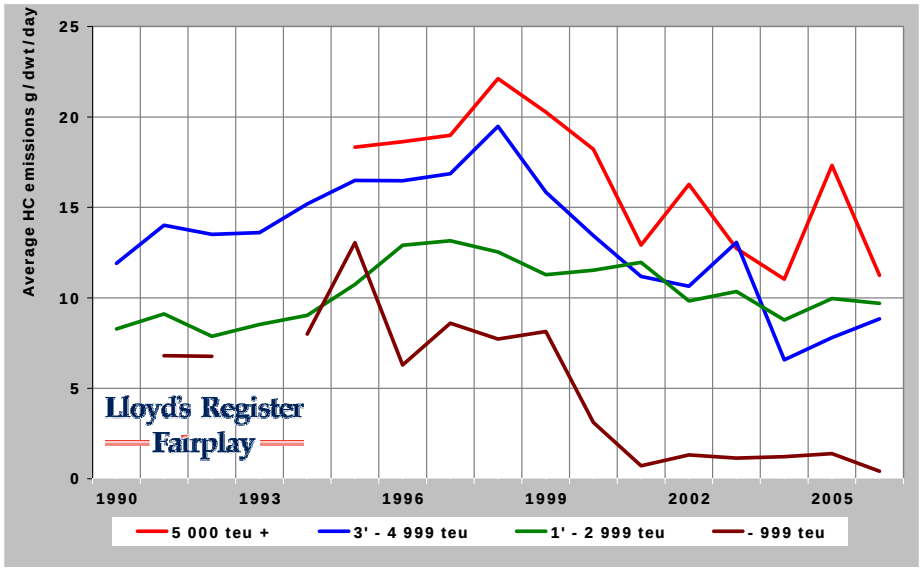


Figure 46: Container, avg. HC emissions 1990-2006 (incl order)

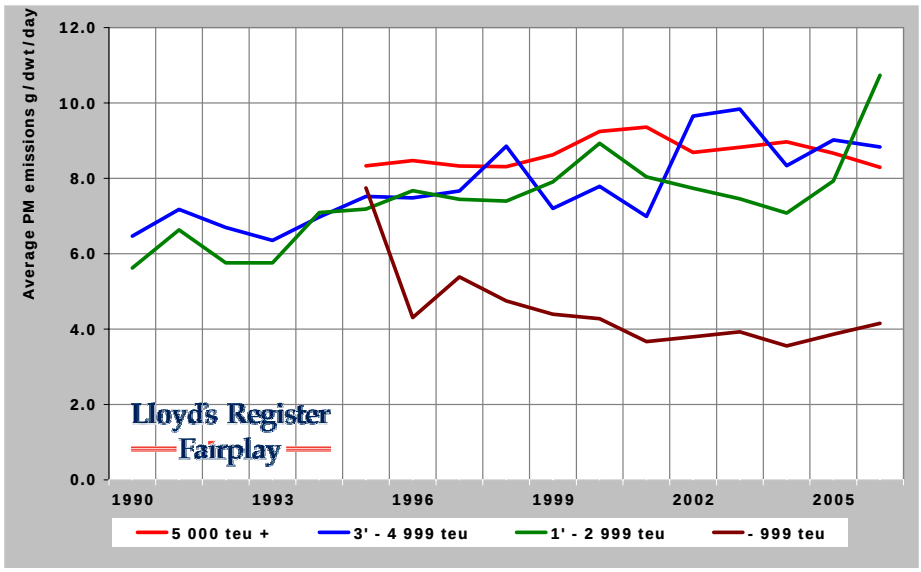


Figure 47: Container, avg. PM emissions 1990-2006 (incl order)

7 Dry cargo n.e.s.

The definition of dry cargo n.e.s. (not elsewhere specified) means dry cargo carriers other than container vessels, ro-ro ships, reefers and dry bulk carriers. These vessels are generally known as general cargo ships. The market for the general cargo fleet is diversified with a lot of different players, mainly in local/regional markets. This fleet is one of the three shipping fleets beside the container fleet that have substantial container-handling capacity. The larger ship segment is in decline since these vessels compete directly with the container ships, while many of the smaller ones supplement the container feeder system. These smaller ships often carry a combination of break-bulk and containers. The combination makes the future for these smaller ships more robust than that for the larger dry cargo ships.

There are still a lot of places where the total cargo volume cannot justify a dedicated container feeder service, but in combination with other cargo, these ships can allow even smaller ports/cities to enjoy the advantages of being connected to the container-shipping network.

The negative impact of containerisation on the reefer segment affects the general cargo fleet in the same way. The fleet of ships of 10,000 DWT and above is predicted to decrease by some ten per cent up to 2007, whereas the smaller segments will remain unchanged. This is explained by the use of dry cargo vessels to carry containers.

The world fleet consists of more than 16,000 ships, of which 11,000 are larger than 500 GT.

7.1 Age profile of the fleet

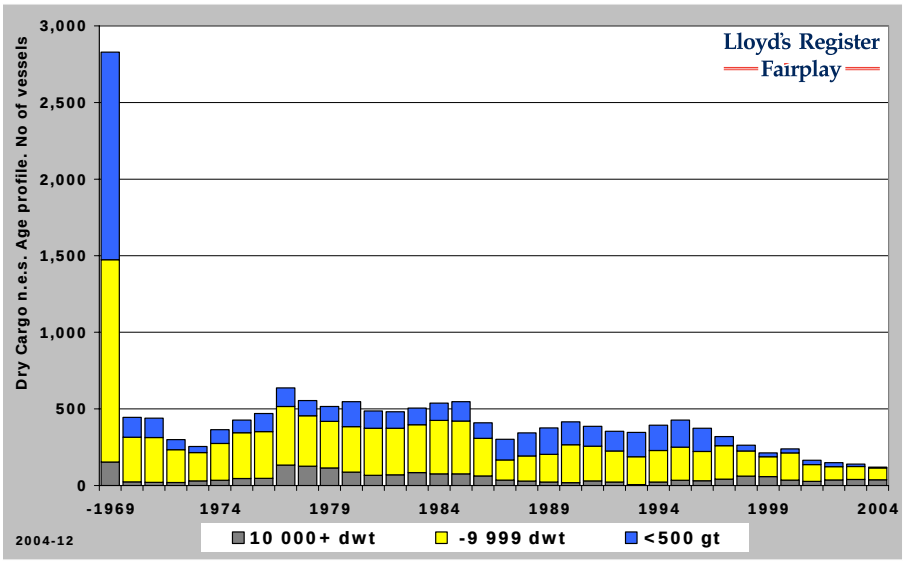


Figure 48: Dry cargo n.e.s. age profile, numbers

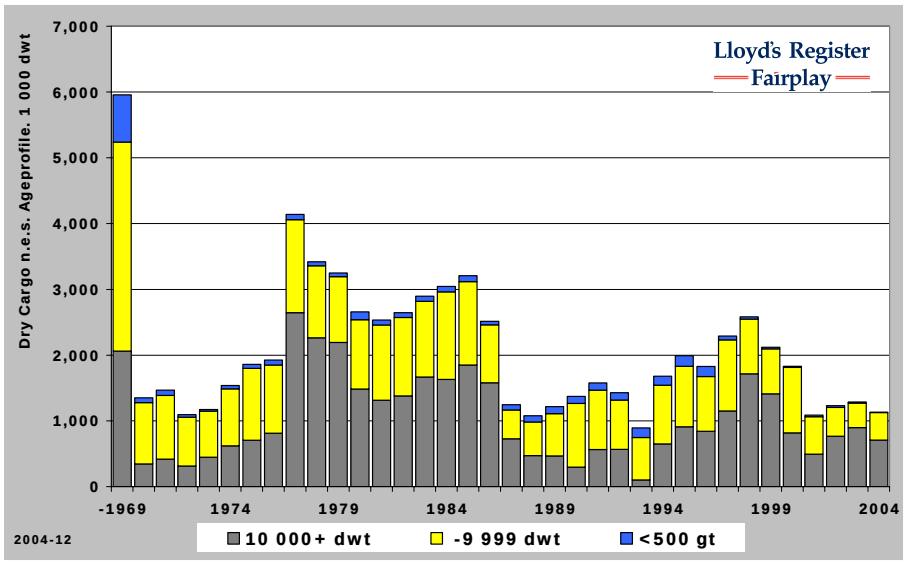


Figure 49: Dry cargo n.e.s. age profile, dwt capacity

7.2 Speed profile & development

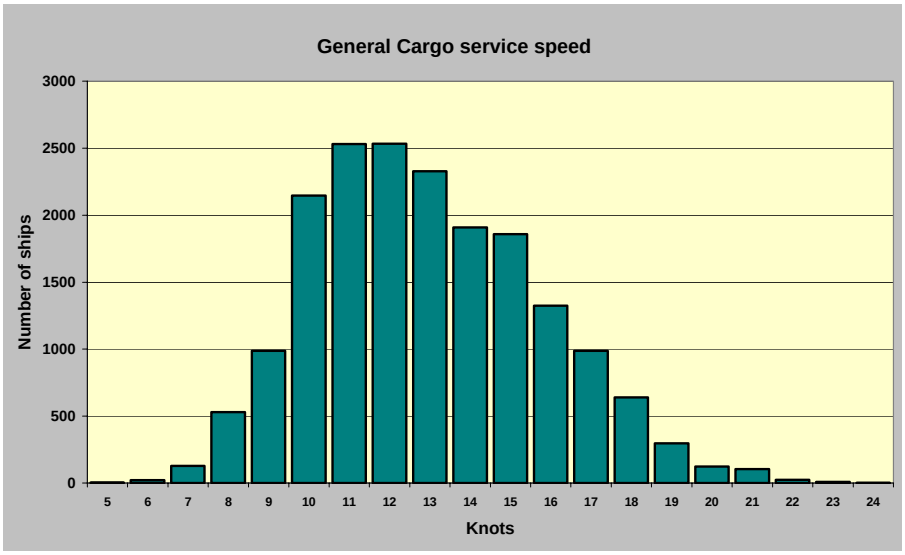


Figure 50: General cargo, fleet service speed

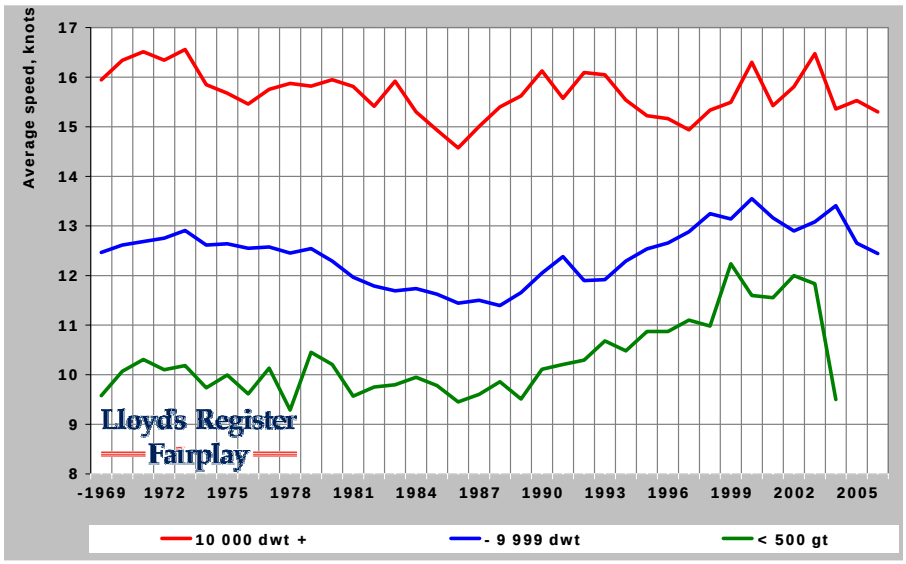


Figure 51: Dry cargo n.e.s., avg. speed development

7.3 Fuel consumption development

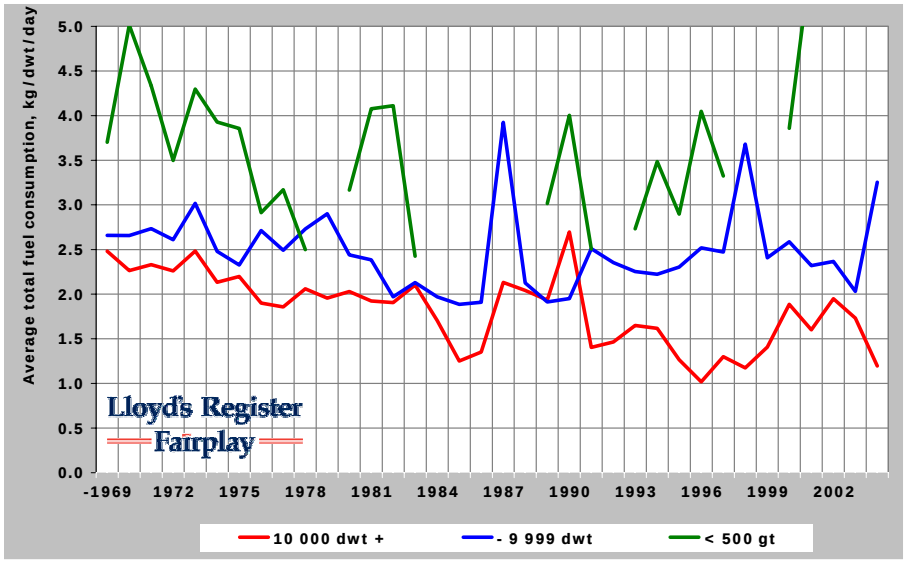


Figure 52: Dry cargo, fuel consumption development

7.4 Emission profile of the fleet

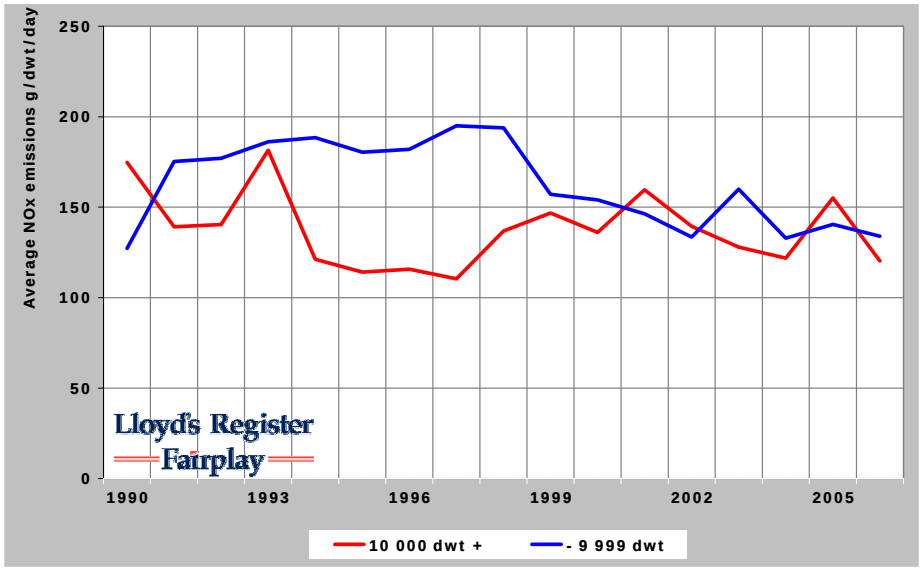


Figure 53: Dry Cargo, avg. NOx emissions 1990-2006 (incl order)

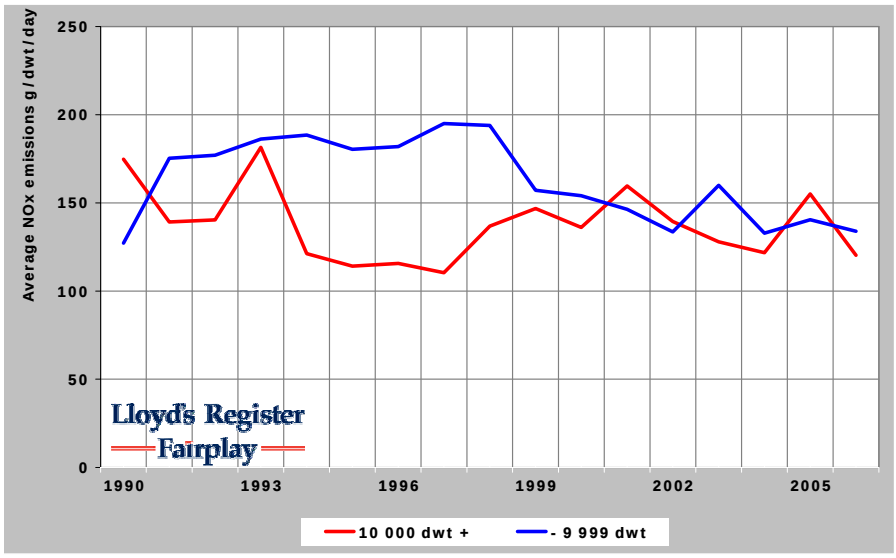


Figure 54: Dry Cargo, avg. CO emissions 1990-2006 (incl order)

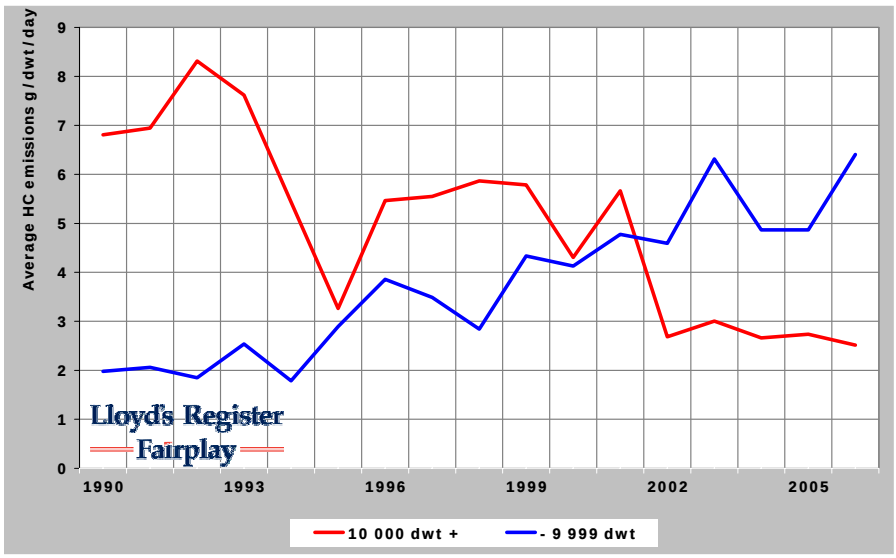


Figure 55: Dry Cargo, avg. HC emissions 1990-2006 (incl order)

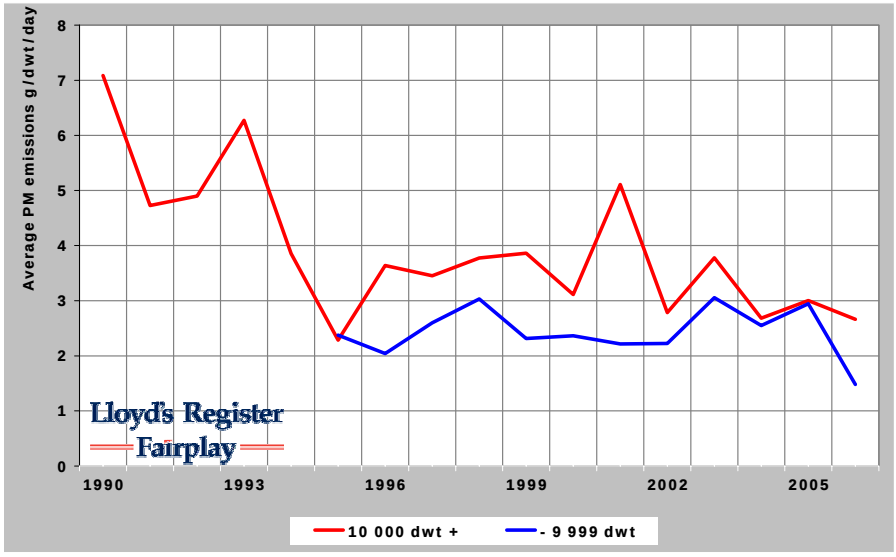


Figure 56: Dry Cargo, avg. PM emissions 1990-2006 (incl order)

8 Reefer

Basically, reefer ships are general cargo ships built for handling pallets. The ship holds are refrigerated and the ships carry all types of products that need to be cold. Typical examples are fruit and meat. The reefer call ports equipped with cold stores. Demand for the transport of refrigerated products has been positive over the last decade, in line with reduced trade barriers. The fruit trade, for example, has grown from 42Bn tonne-miles in 1990 to 60Bn in 2002, where bananas account for 33Bn tonne-miles.

The development of reefer capacity in the container fleet has of course had a negative impact on the reefer ship market. Some loading ports for reefer cargo have not been, and a few still are not, geared for container handling, which has protected the reefer branch somewhat. This protection, however, will not last forever.

The existence of smaller geared container vessels with reefer slots as well as reefers with container-carrying capacity ensures a continued gradual penetration of the container even into the smaller reefer ports.

The reefer fleet has not grown over the last five years, and operators have experienced severe problems with earnings. Earnings improved the last six months of 2004 though, which came as no surprise. The container market has been reasonably good and operators have not been offering additional cargo at low prices to the same extent.

Container ships are the cause of the turmoil. Reefers are comparatively small for the deep-sea trade. A large reefer ship is about 15,000 DWT with some 20,000 m³ cargo-carrying capacity. The refrigerated TEU capacity on modern large container ships is about 50 % more than that. With the heavy ordering of large container ships seen over the past years, the reefer market will now have an even larger competitor than it did six months ago. Speaking in favour of reefer operation is the sheer size of the newest container vessels. They are simply too large to trade on a number of the current reefer routes. Heavy container vessel deliveries over the forecast period will probably increase the interest in offering slot capacity for refrigerated cargo. Reefer fleet capacity is forecast to fall by ten per cent up to 2007.

8.1 Age profile of the fleet

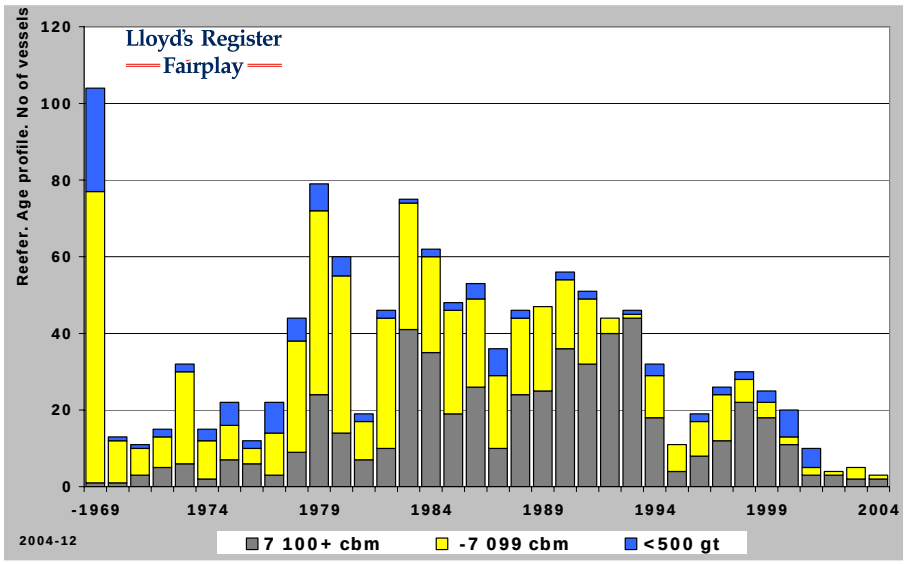


Figure 57: Reefer age profile, numbers

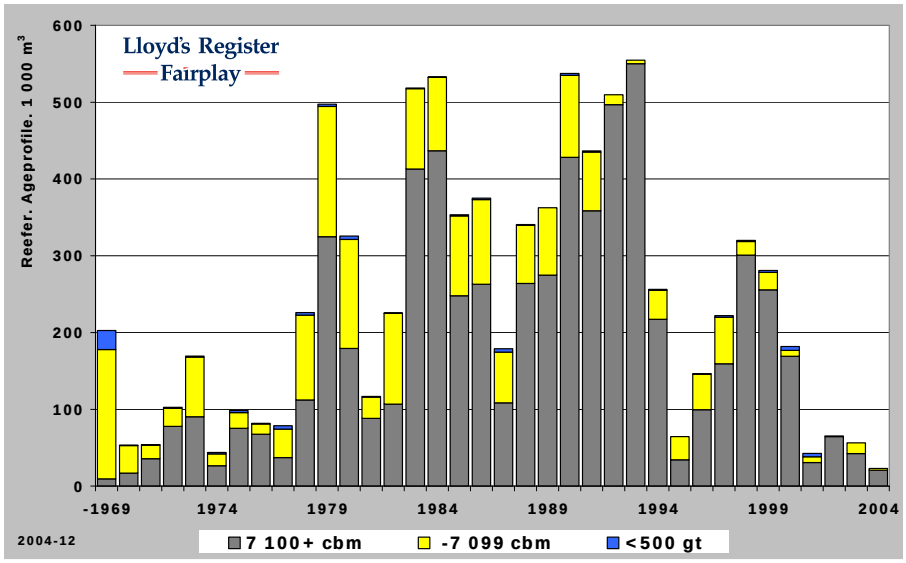


Figure 58: Reefer age profile, cubic meter capacity

8.2 Speed profile & development

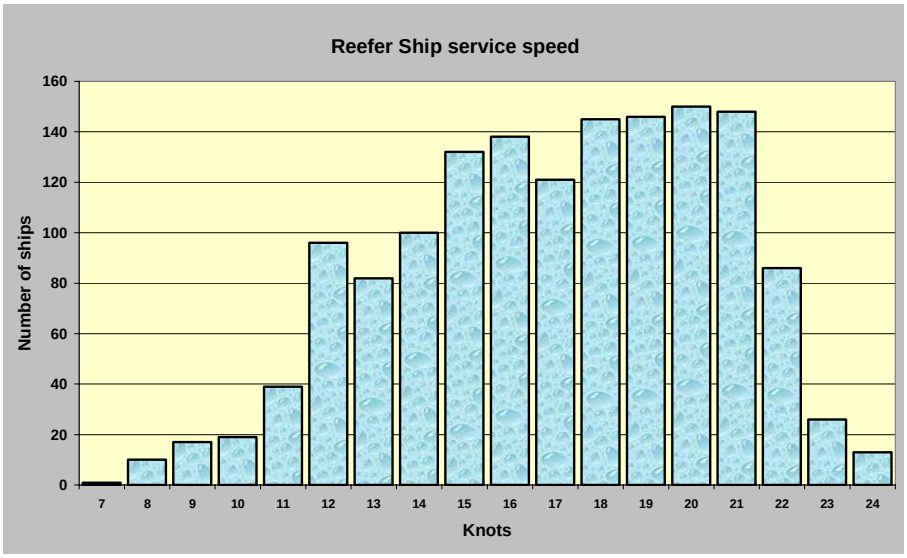


Figure 59: Reefer, fleet service speed

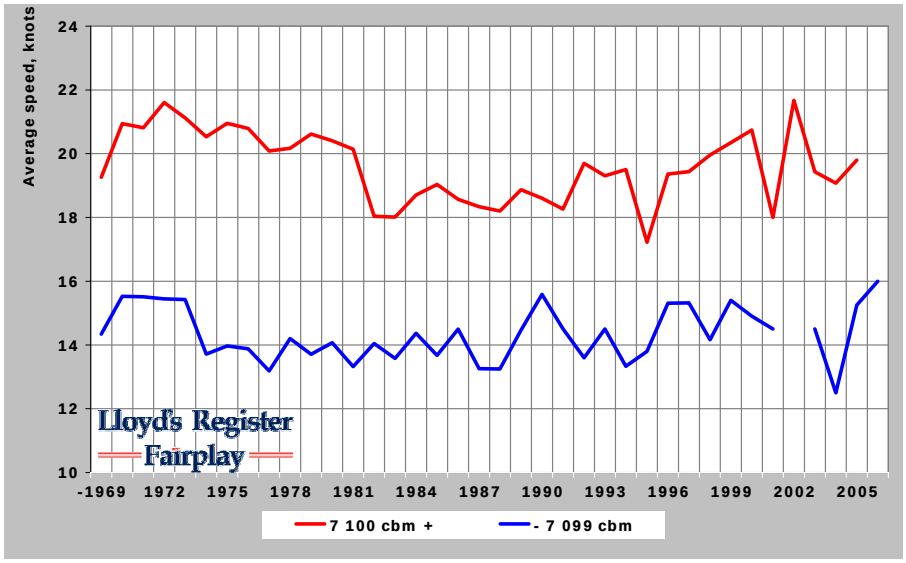


Figure 60: Reefer, avg. speed development

8.3 Fuel consumption development

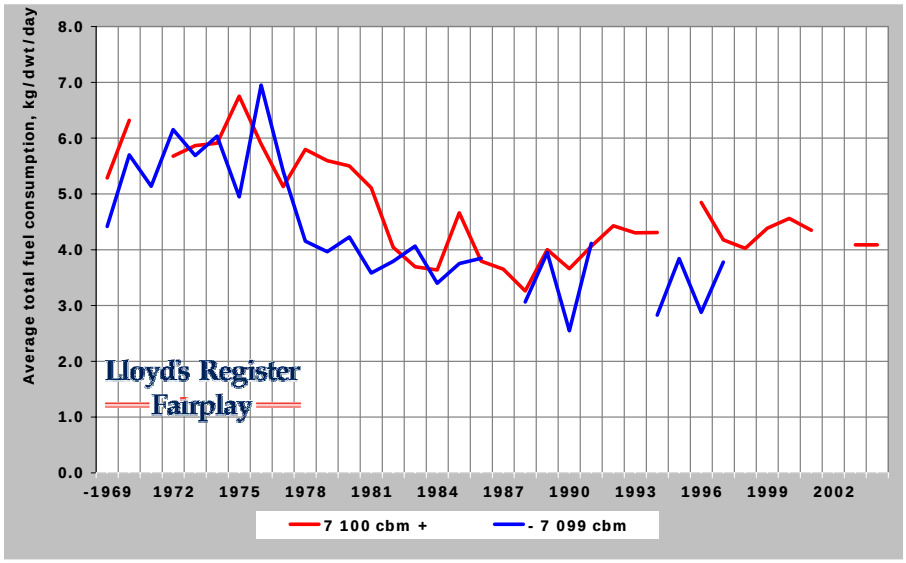


Figure 61: Reefer, fuel consumption development

8.4 Emission profile of the fleet

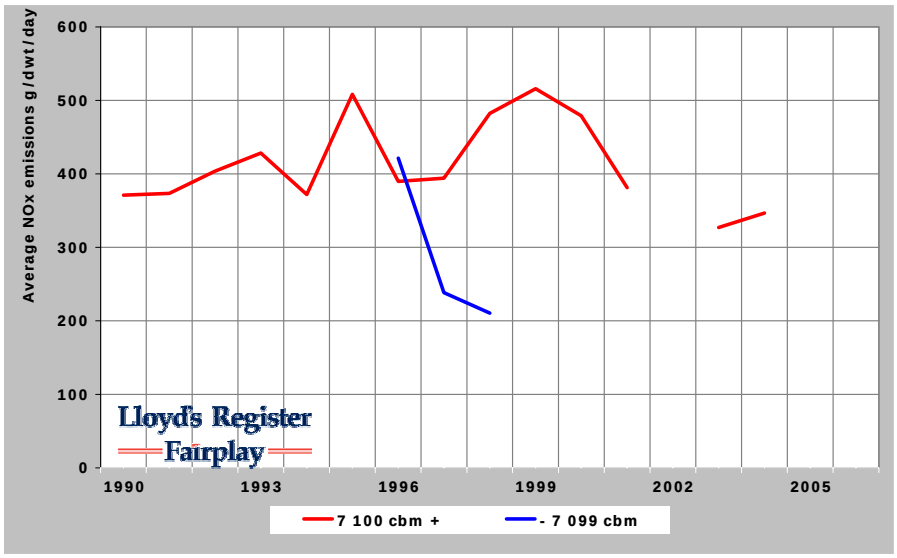


Figure 62: Reefer, avg. NOx emissions 1990-2006 (incl order)

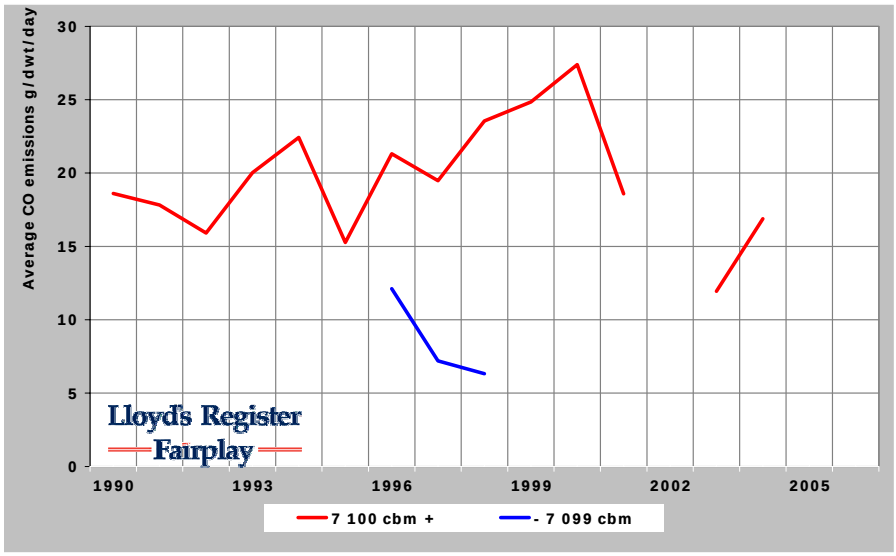


Figure 63: Reefer, avg. CO emissions 1990-2006 (incl order)

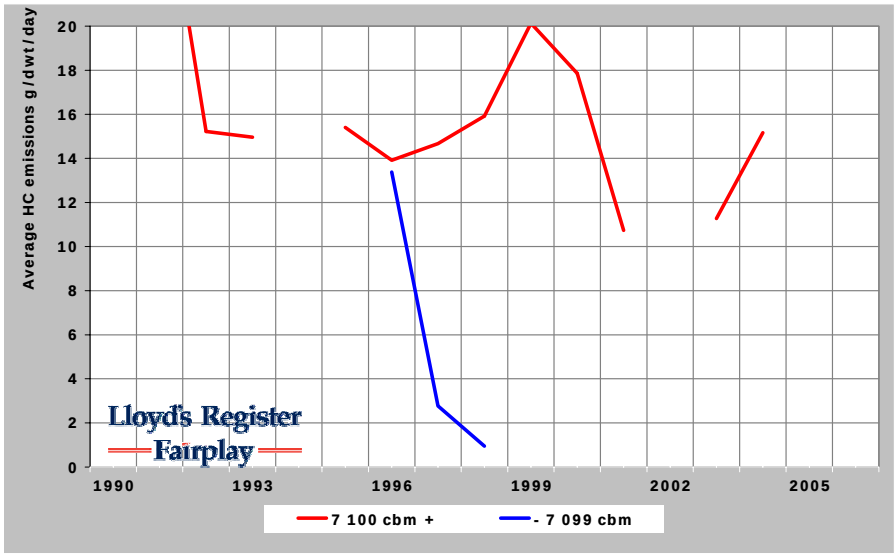


Figure 64: Reefer, avg. HC emissions 1990-2006 (incl order)

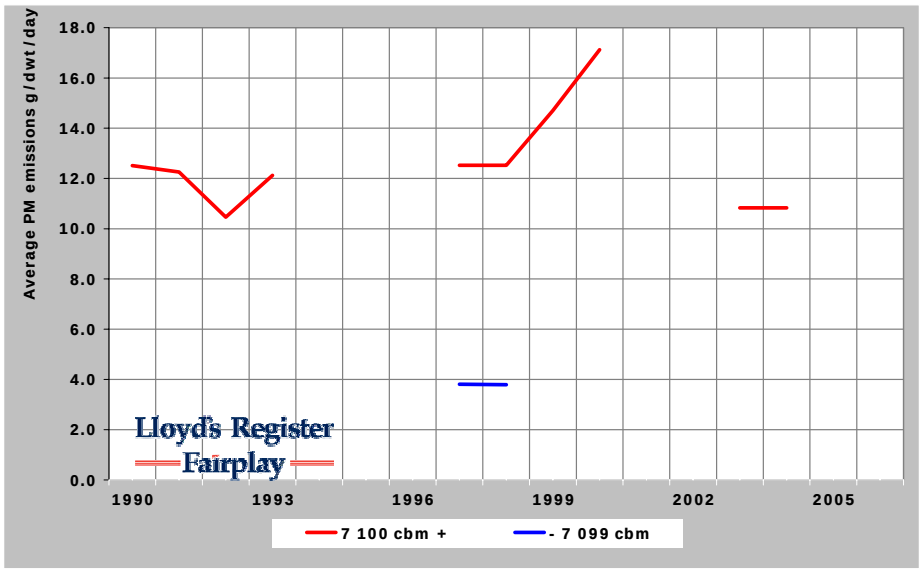


Figure 65: Reefer, avg. PM emissions 1990-2006 (incl order)

9 Vehicle ro-ro

Vehicle carriers are large “car parks” that distribute the new built cars all over the world. The vehicle carriers call ports that have import sites for cars. In these sites the cars will be prepared for the market and fitted according to the local regulations.

The vehicle ro-ro market has a structure with rather few operators and high barriers to entry. A few Japanese owners and the Swedish/Norwegian Wallenius Wilhelmsen are among the big players. However, Japanese interests have a massive showing in the current orderbook.

China is the fastest-growing car manufacturing country in the world at present, calling for a restructuring of the car transport logistics network.

Cars are high-value goods and even though container operators do not currently pose a threat to the vehicle ro-ro market, they definitely form a potential one. Container operators already take care of transporting exclusive cars to distant places, i.e. when the volumes are low. The recent development on the container shipping market as described above further underlines this statement.

The capacity of the vehicle ro-ro fleet has been growing since 1985 at an average 3 per cent p.a. The fleet has grown in steps, which partially finds an explanation in the relatively few operators and vessels involved in deep-sea trading, resulting in a marked impact of any fleet renewal programme. Several new orders for large vehicle carriers were placed by Japanese interests the second half of 2004 to be delivered in 2005-2006.

Despite the strong development of the container carrier sector, the automotive industry does not yet seem prepared to make a move towards large-scale containerisation for the transport of new vehicles. Should we see the introduction of a logistical innovation aimed at improving the efficiency of container use for new vehicle shipments, then the switch away from PCC/PCTCs could be very quick.

9.1 Age profile of the fleet

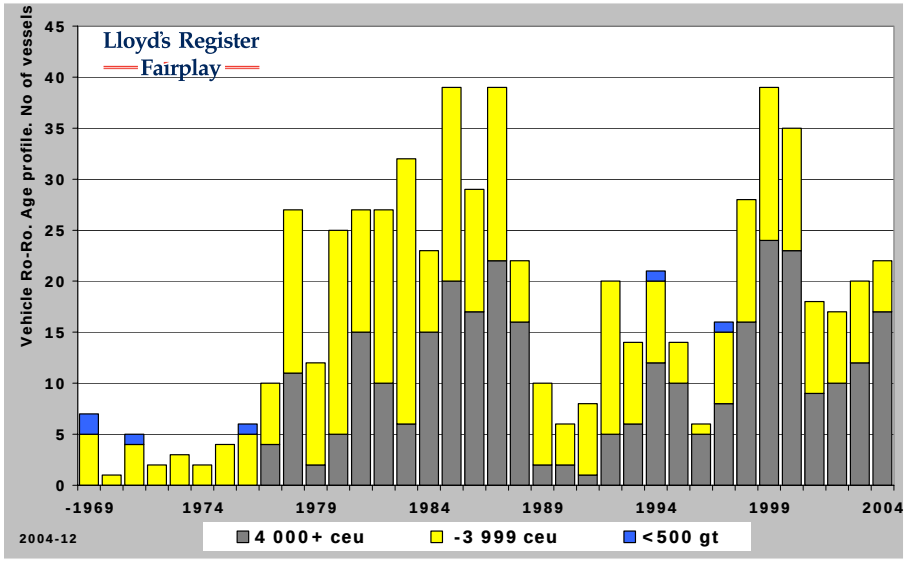


Figure 66: Vehicle roro age profile, numbers

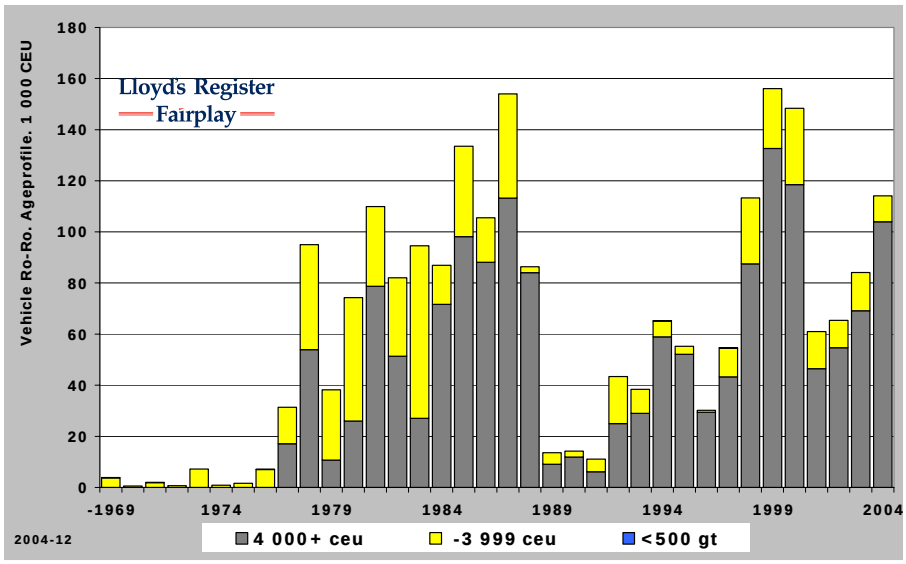


Figure 67: Vehicle roro age profile, car eqv. units capacity

9.2 Speed profile & development

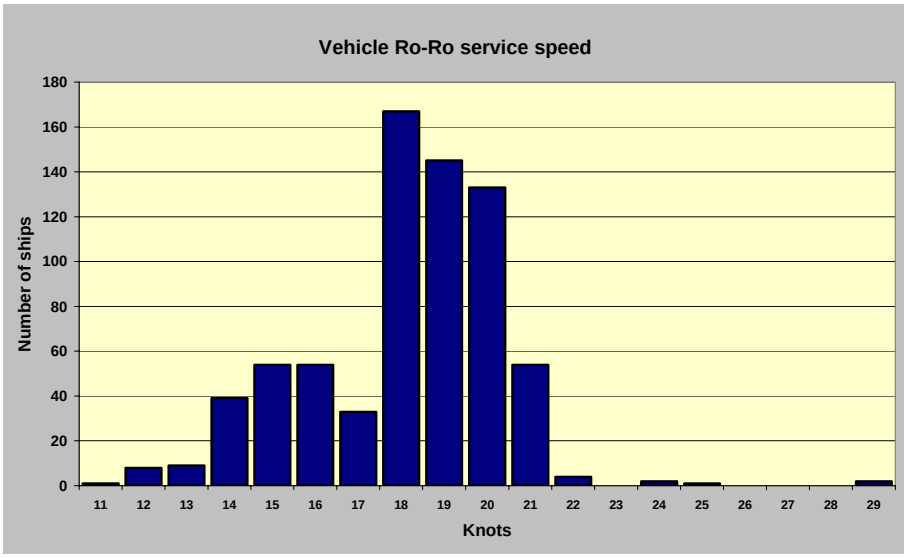


Figure 68: Vehicle ro-ro, fleet service speed

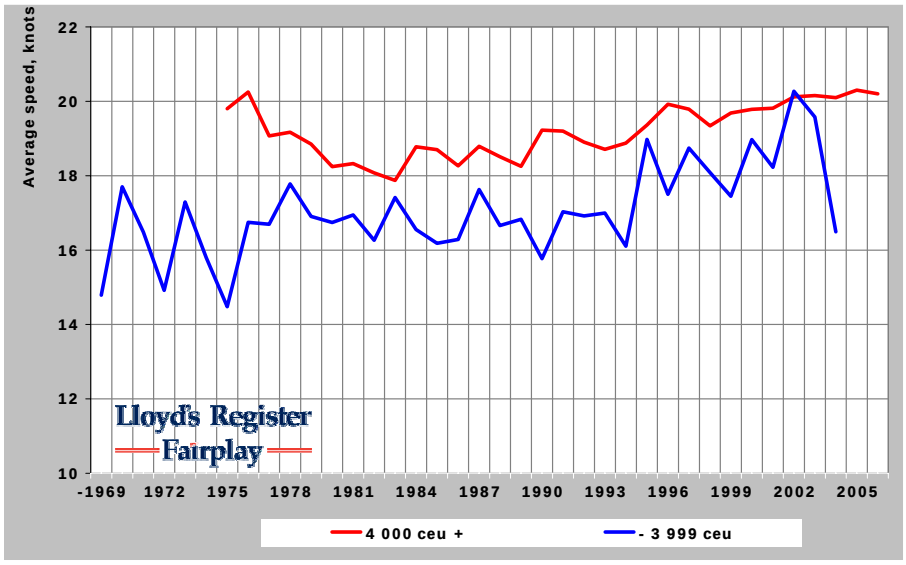


Figure 69: Vehicle ro-ro, avg. speed development

9.3 Fuel consumption development

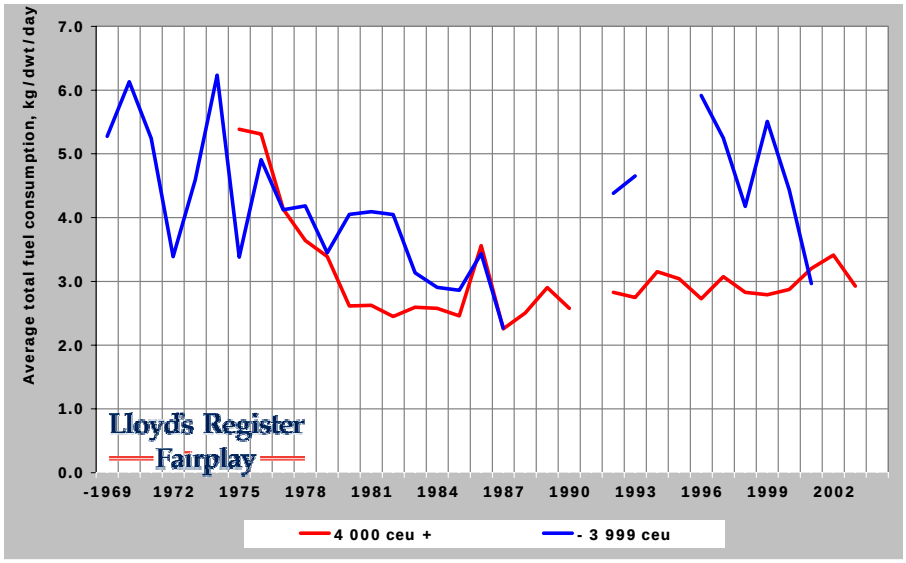


Figure 70: Vehicle ro-ro, fuel consumption development

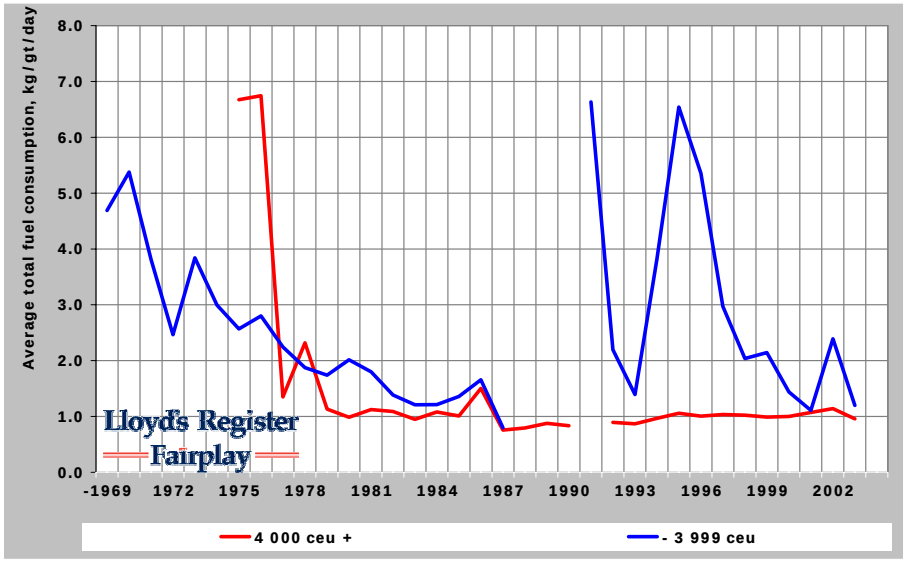


Figure 71: Vehicle ro-ro, fuel consumption development

9.4 Emission profile of the fleet

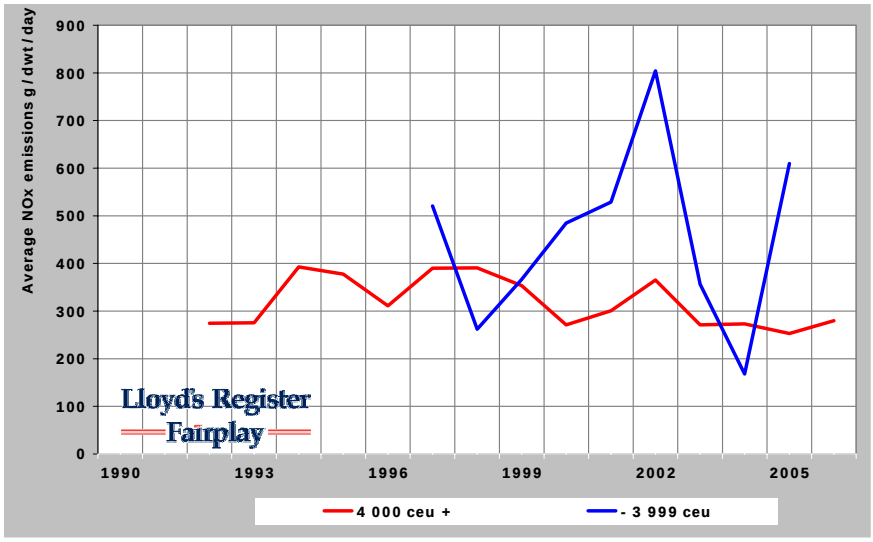


Figure 72: Vehicle ro-ro, avg. NOx emissions (dwt) 1990-2006 (incl order)

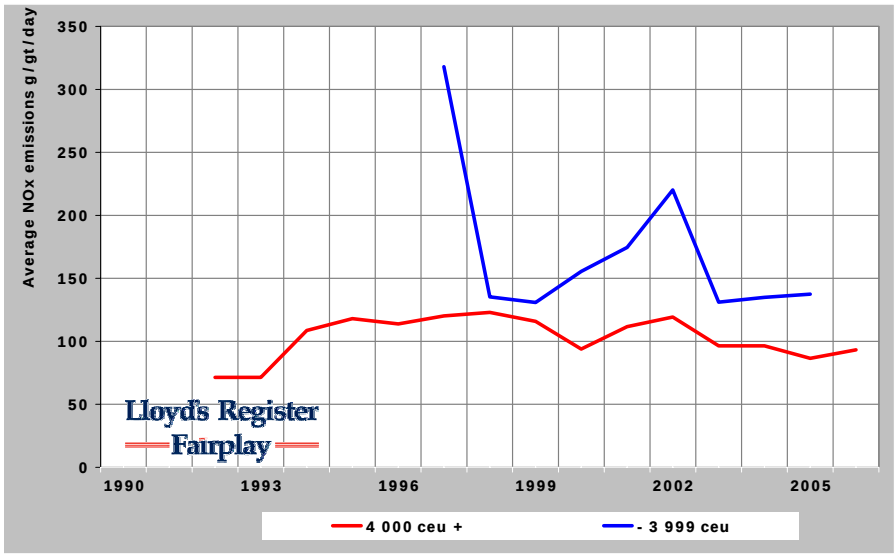


Figure 73: Vehicle ro-ro, avg. NOx emissions (gt) 1990-2006 (incl order)

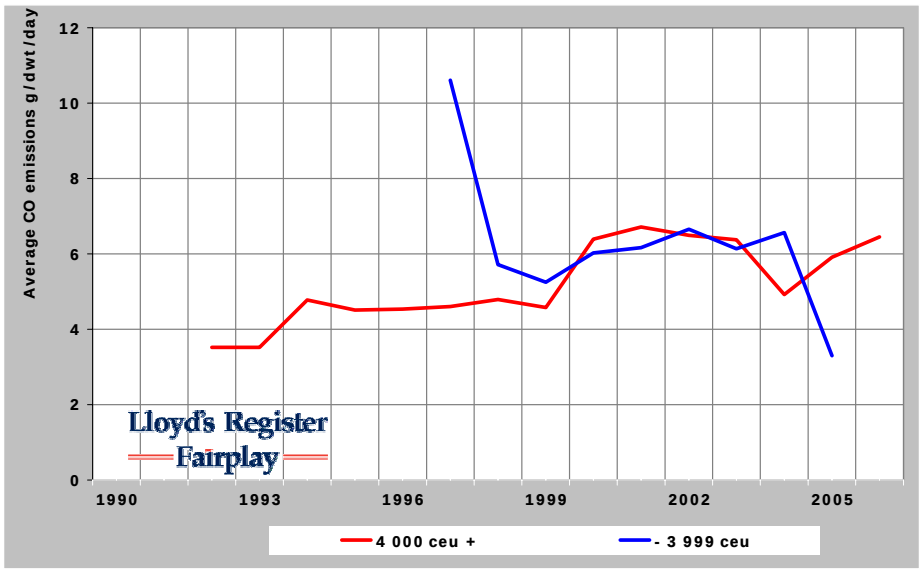


Figure 74: Vehicle ro-ro, avg. CO emissions (dwt) 1990-2006 (incl order)

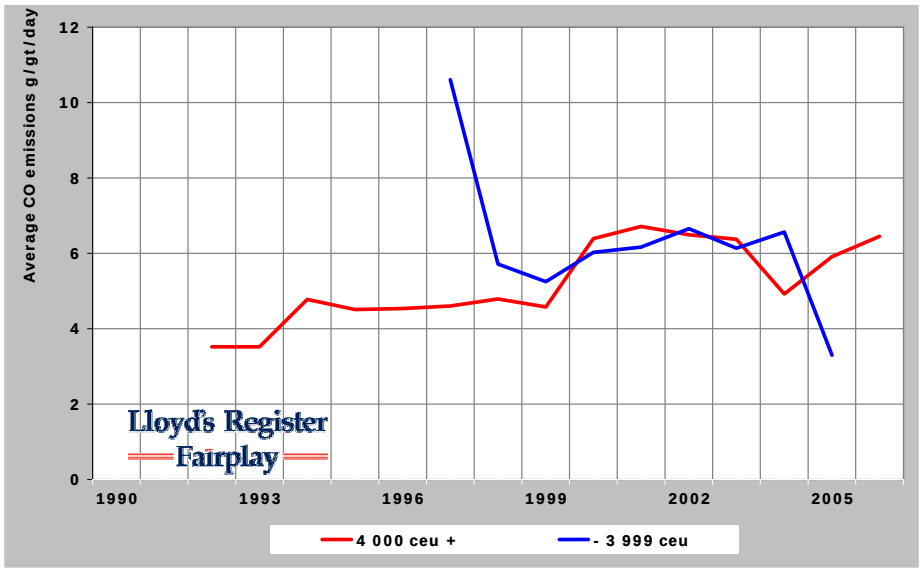


Figure 75: Vehicle ro-ro, avg. CO emissions (gt) 1990-2006 (incl order)

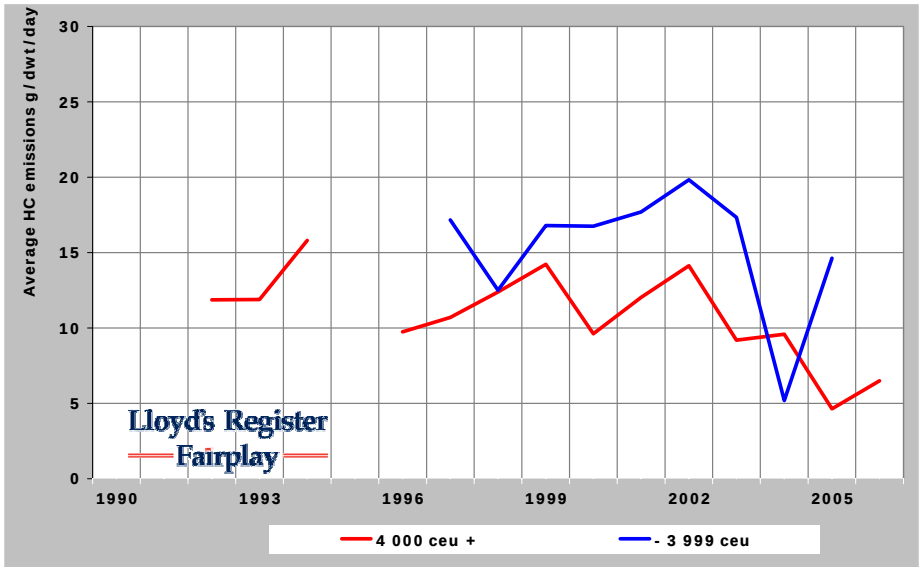


Figure 76: Vehicle ro-ro, avg. HC emissions (dwt) 1990-2006 (incl order)

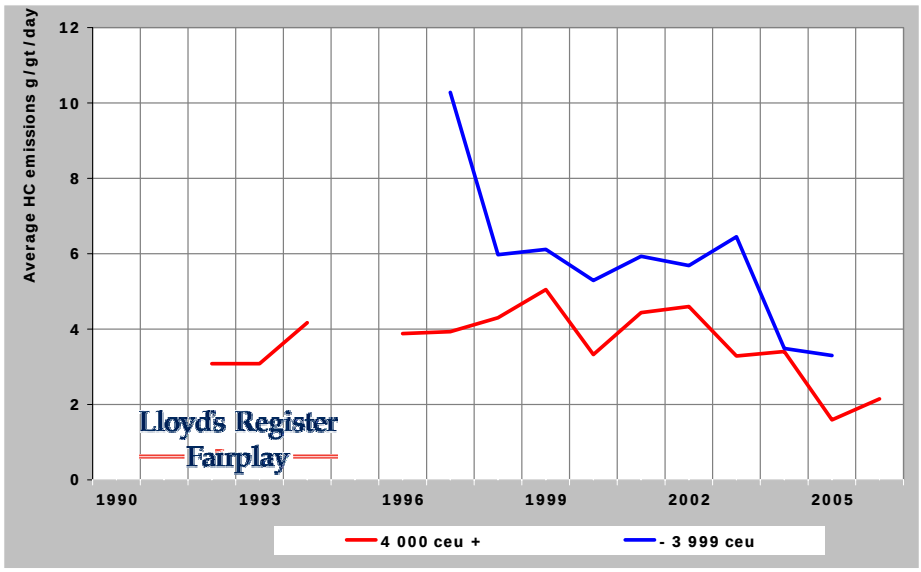


Figure 77: Vehicle ro-ro, avg. HC emissions (gt) 1990-2006 (incl order)

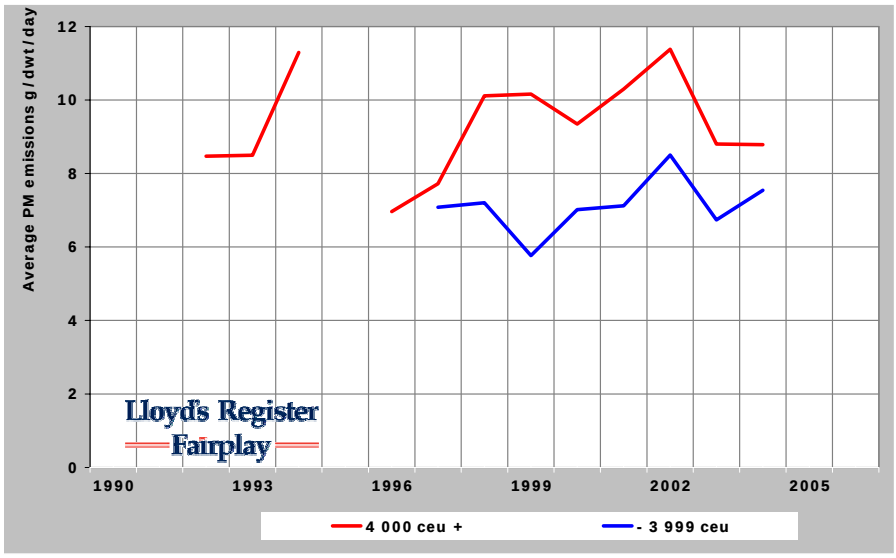


Figure 78: Vehicle ro-ro, avg. PM emissions (dwt) 1990-2006 (incl order)

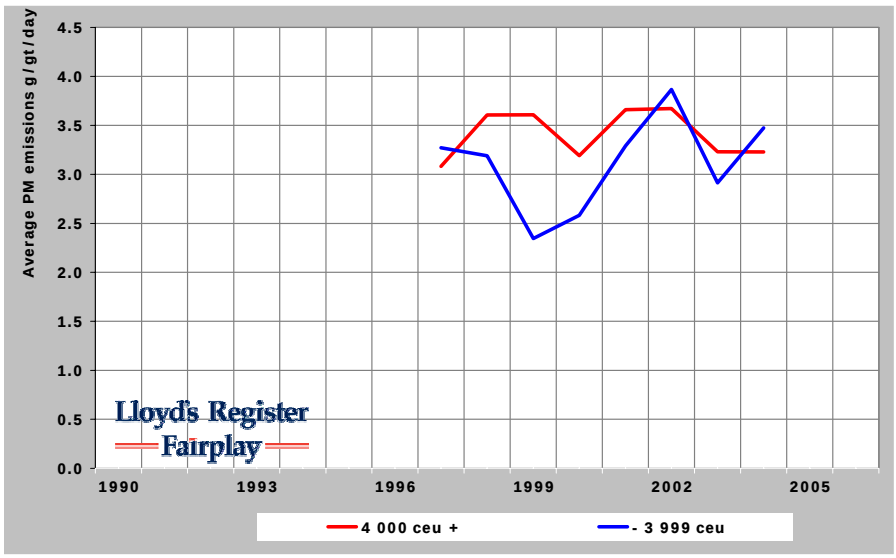


Figure 79: Vehicle ro-ro, avg. PM emissions (gt) 1990-2006 (incl order)

10 Ro-ro n.e.s

This section covers the ro-ro vessels not included elsewhere, i.e. exclusive of car carriers and ferries. The ro-ro ships need a quayside with a ramp to meet the ships ramp. The ship type is relatively large for its carrying capacity in tons. The concept of ro-ro aims at increasing the port efficiency by carrying rolling cargo carriers that speeds up the productivity in the port and increase the flexibility in carrying different kinds of cargo. A ferry is the solution for ships carrying vehicles between ports and the ro-ro ship carry the same vehicles plus containers and break bulk on trailers between ports at a longer distance.

The short sea ro-ro operation is losing market shares to the container services in several regions. The fast containerisation of the market gives new opportunities and higher productivity for smaller volumes that the market finds more interesting than using the ro-ro ferries. Ro-ro cargo that was transferred and containerised in the central European container terminal are now containerised closer to the shipper or stripped by the consignee.

The ro-ro ships were introduced in deep sea trading during the 80ies but several services did not give the economy that was anticipated. Some major cross Atlantic services are still running. So are some services cross Pacific, Australia-US.

The market share for the **ro-ro ships** in transoceanic trades has thus decreased following the rapid development of containerisation. When the ro-ro technique is employed in short sea shipping the flexibility in carrying goods and the fast load and unloading makes up for the disadvantages of the rather expensive trailer units (high capital, maintenance costs and port dues). The load carriers, roll-trailers, cassettes and semi-trailers are suitable for both carrying forest products in outbound shipments and consumables on the return trip. Trailers are mainly transported as single units on the ship (drops). These units are picked up in the other end by local truckers that deliver the cargo or deliver the trailers to the hucke-pack (piggy-back) terminal.

The ro-ro fleet is relatively fragmented with a lot of smaller operators all over the world.

Today there are several ro-ro ships in order varying from 13,000 DWT up to 18,000 DWT. Several are ordered especially for the market in the Baltic Sea region. The trades for some of them is not disclosed but it can be assumed that they will add in to the cross Atlantic service between Scandinavia and US-Canada.

10.1 Age profile of the fleet

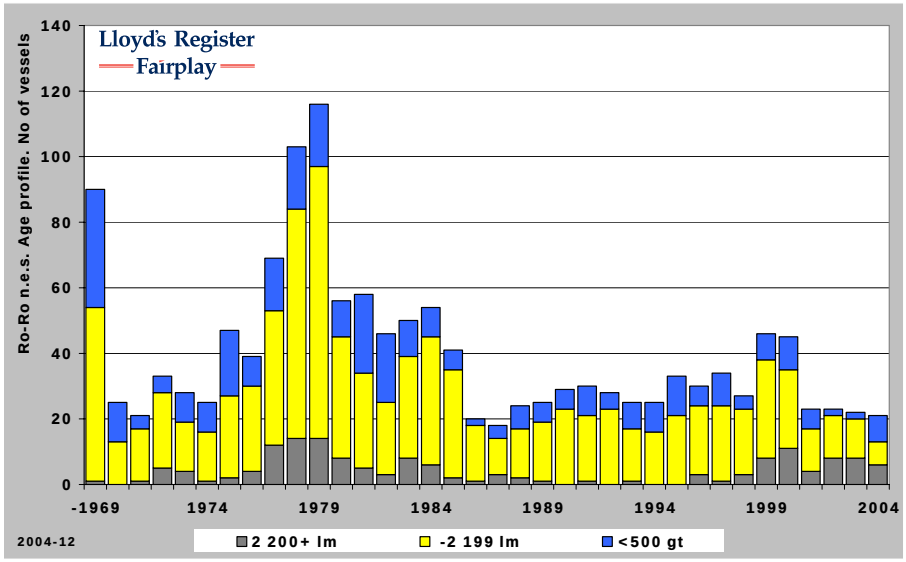


Figure 80: Ro-ro n.e.s. age profile, numbers

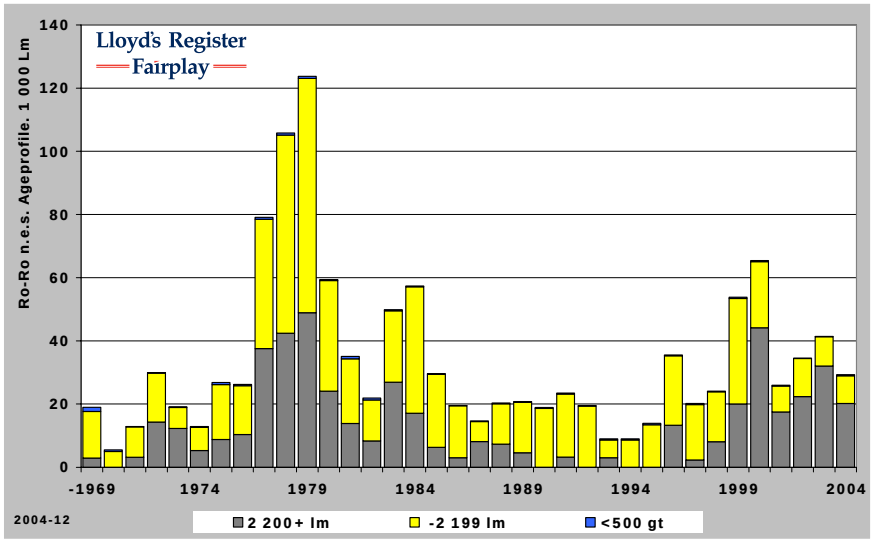


Figure 81: Ro-ro n.e.s. age profile, lanemeter capacity

10.2 Speed profile & development

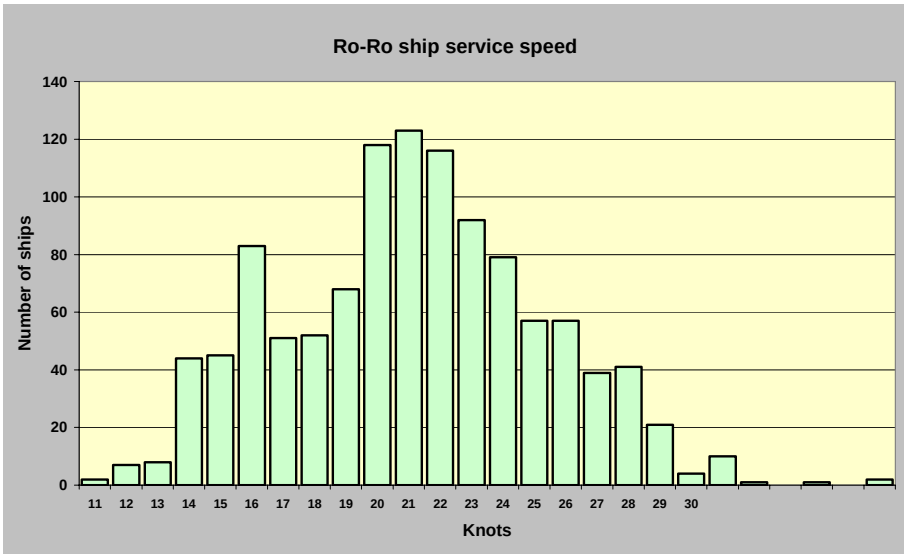


Figure 82: Ro-ro, fleet service speed

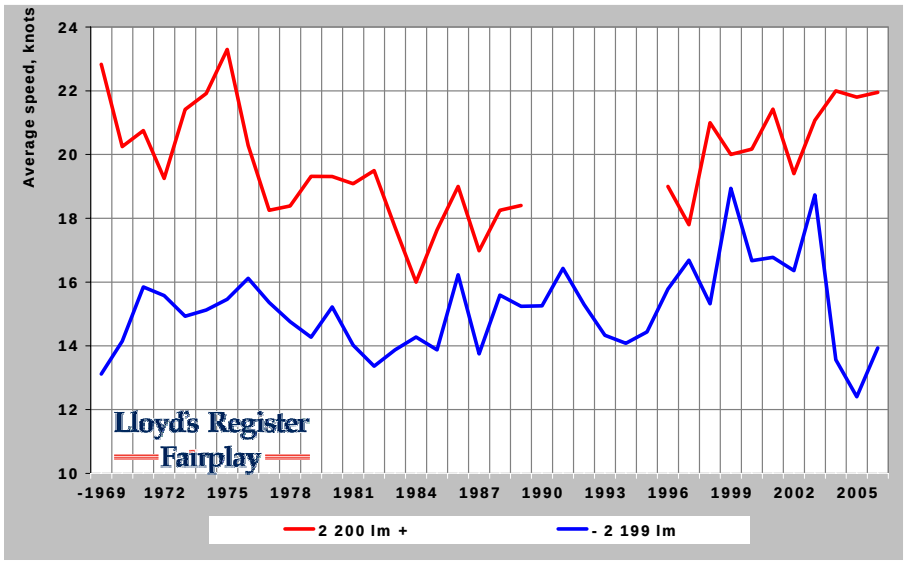


Figure 83: Ro-ro n.e.s., avg. speed development DWT

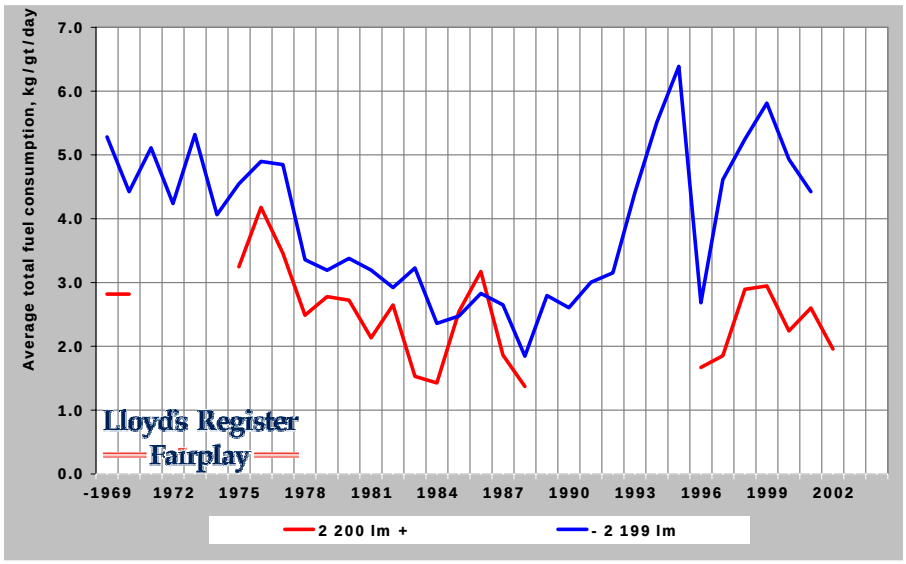


Figure 84: Ro-ro n.e.s., avg. speed development GT

10.3 Fuel consumption development

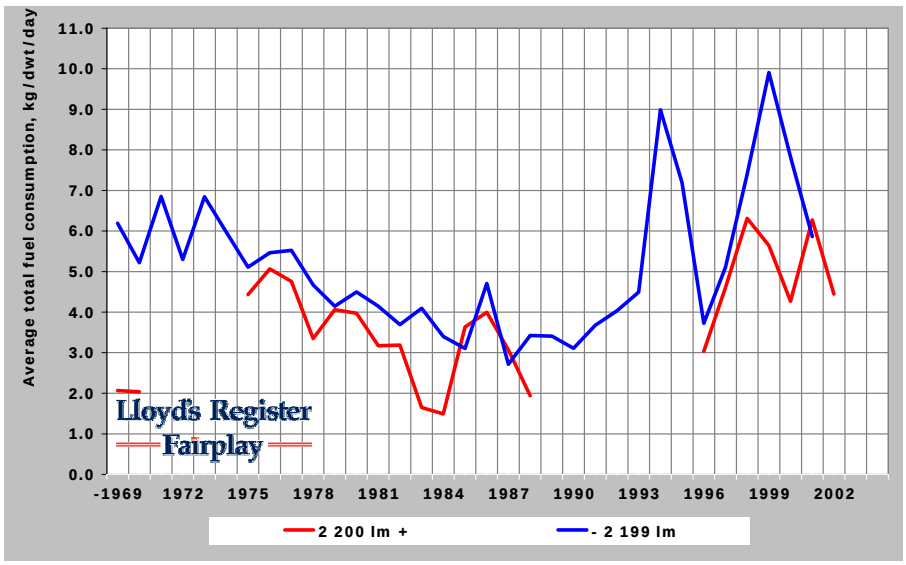


Figure 85: Ro-ro n.e.s, fuel consumption development

10.4 Emission profile of the fleet

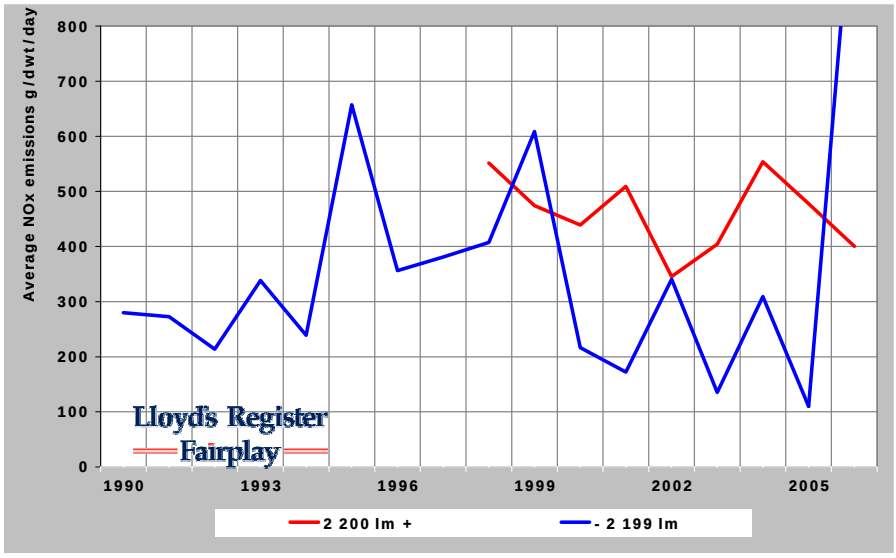


Figure 86: Ro-ro n.e.s, avg. NOx emissions (dwt) 1990-2006 (incl order)

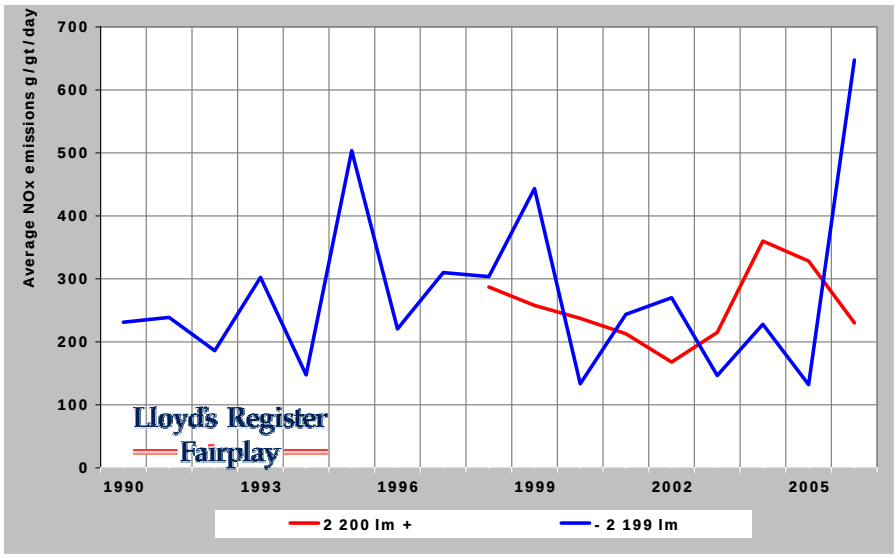


Figure 87: Ro-ro n.e.s, avg. NOx emissions (gt) 1990-2006 (incl order)

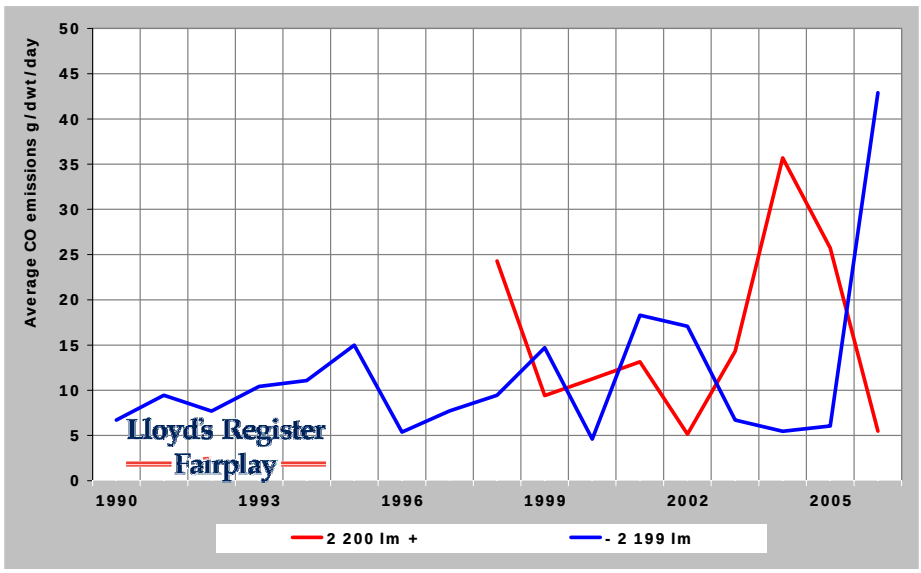


Figure 88: Ro-ro n.e.s, avg. CO emissions (dwt) 1990-2006 (incl order)

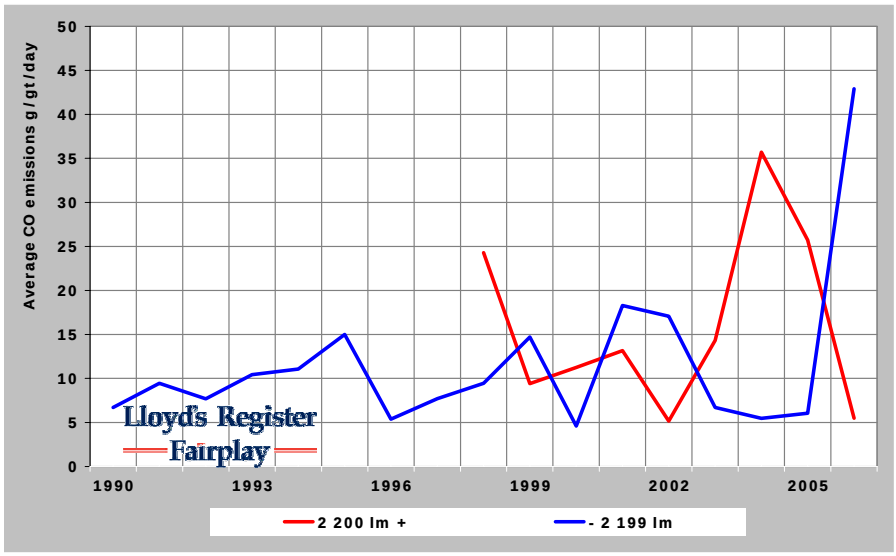


Figure 89: Ro-ro n.e.s, avg. CO emissions (gt) 1990-2006 (incl order)

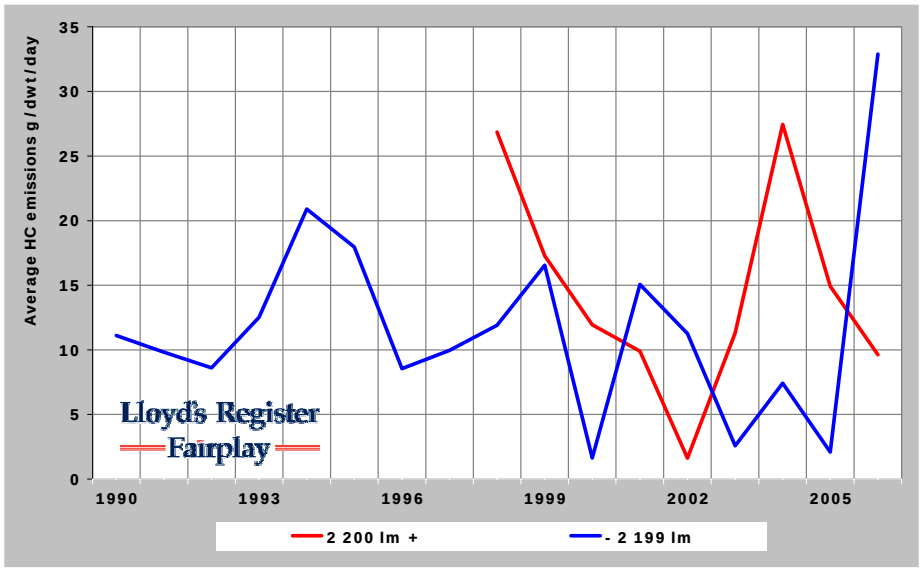


Figure 90: Ro-ro n.e.s, avg. HC emissions (dwt) 1990-2006 (incl order)

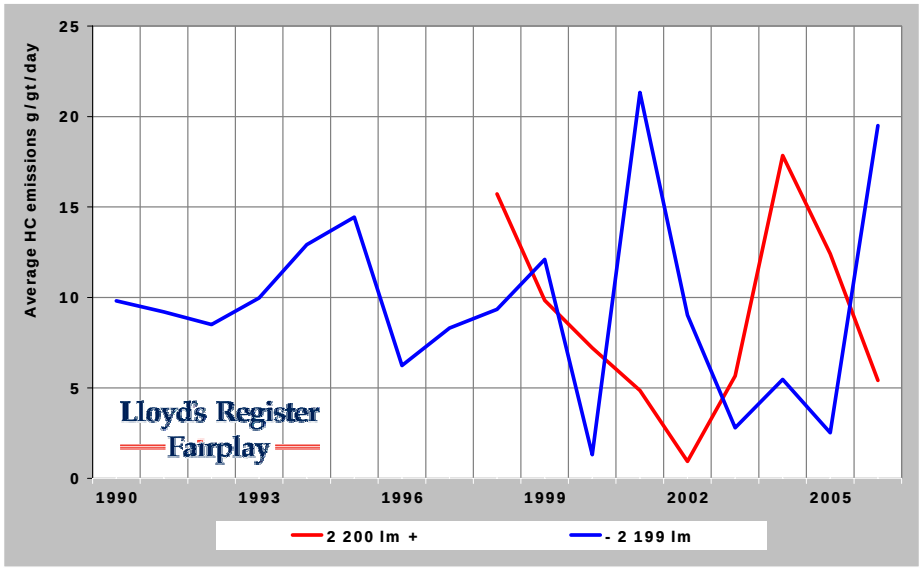


Figure 91: Ro-ro n.e.s, avg. HC emissions (gt) 1990-2006 (incl order)

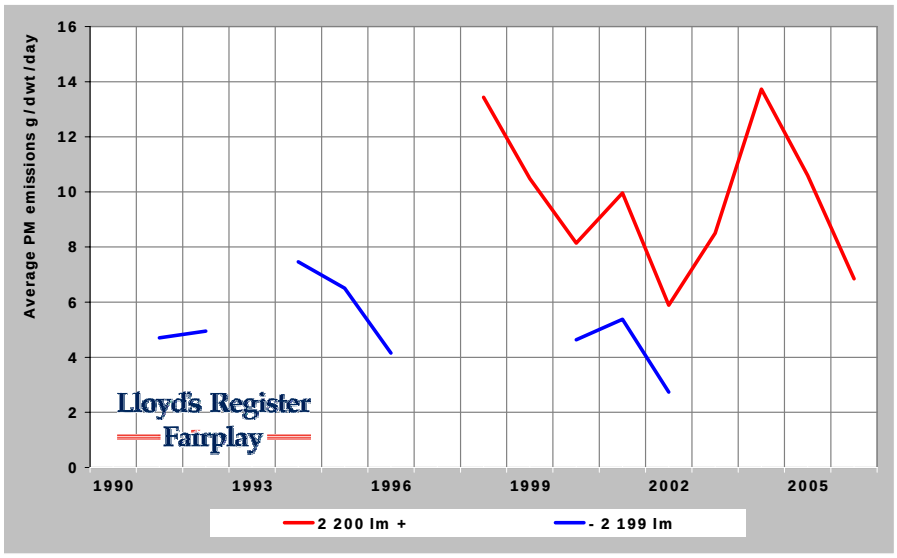


Figure 92: Ro-ro n.e.s, avg. PM emissions (dwt) 1990-2006 (incl order)

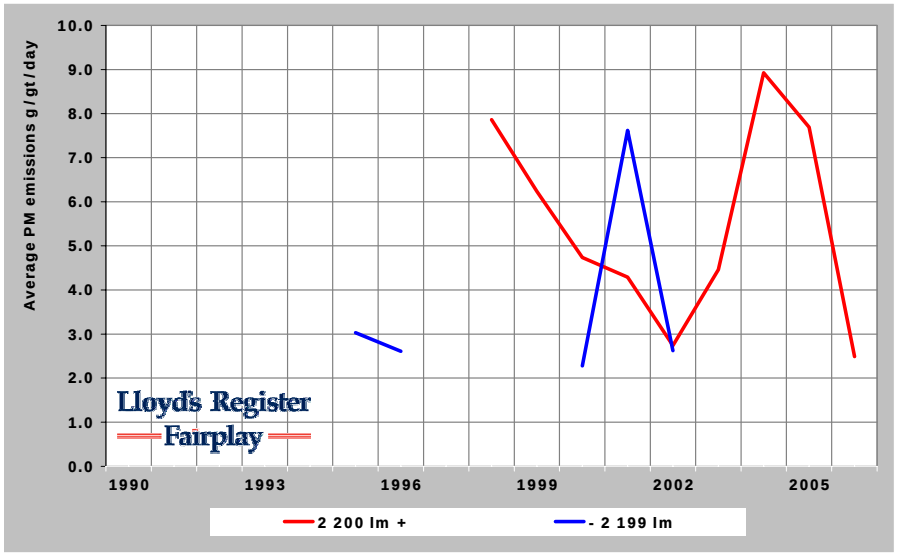


Figure 93: Ro-ro n.e.s, avg. PM emissions (gt) 1990-2006 (incl order)

11 Ferry cargo

The **ferry; cargo** market is a combined cargo and passenger service and predominantly short sea shipments of ro-ro cargo. These cargo services normally come in two port liner services where you also find a large share of runners (trailers with trucks and drivers). The drivers prefer the passenger ferries from a social point of view and for the higher level of passenger service. This can be a problem for the ferry operators in the summertime when the ferries are full of passengers and the operator would prefer to have the trucks on the ro-ro service departs.

The time for rests is also a crucial part of how much runners the service can attract. The driver needs the rest to be able to do a full day driving behind the wheel. If the service is too fast the driver do not get his rest and have to stop and rest before continuing. If the rules and regulations were followed in this respect the ideal time of passage would be 11 hours to have a full rest. However all ferry services of four hours and up are of interest to make the time as productive a possible. Today the control is not all that strict but it will be when the new EU trip recorder comes into force. Never the less the possibility to rest on the ferry will be of importance also in the future.

These drivers are important as some of them have a certain liberty to choose which service they will use and which route to take. In some services the result has been that the driver preferred the service from the larger ferry where there is a better passenger service onboard, entertainment and a more options of food and company.

In Scandinavia the actors in this market segment have gone through a consolidation process over the last five years as a result of the number of fixed links (bridges & tunnels) being constructed and the abolition of tax-free. In response, operators have also changed from a passenger to a trailer/cargo focus.

However, we find a number of exceptions where the passenger compartment of the ferries to a large extent is designed for cruise service. These ferries are normally trading in a “city-to-city” concept offering short cruise travels.

The high-speed segment within the cargo ferry market is relatively small. Merely 123 of the 3,015 ships in the fleet have a speed of 30 knots or more. 70 % of these are multi-hull vessels.

11.1 Age profile of the fleet

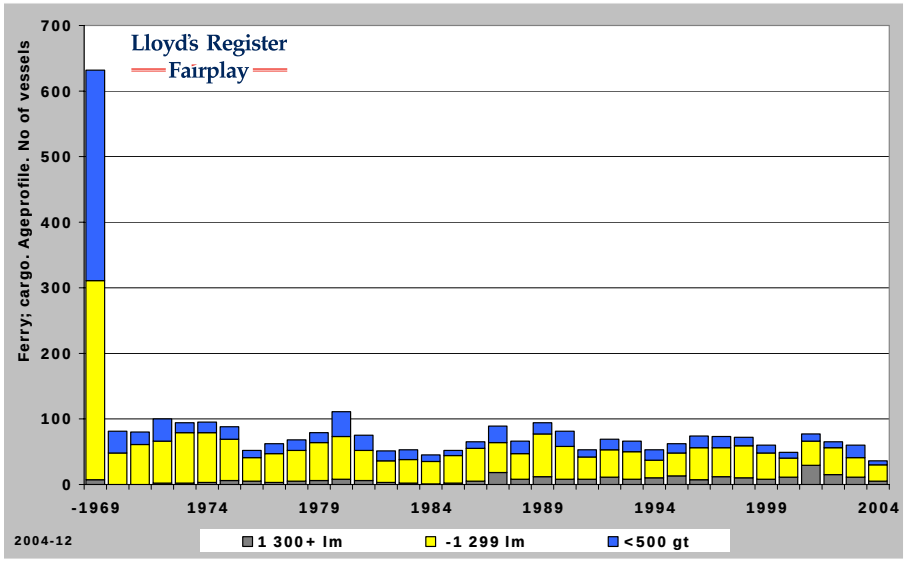


Figure 94: Ferry cargo age profile, numbers

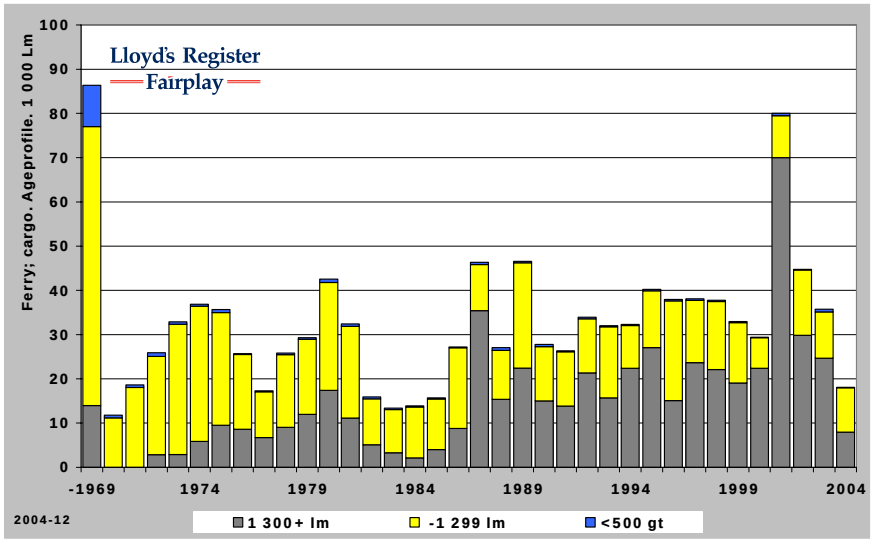


Figure 95: Ferry cargo age profile, lanemeter capacity

11.2 Speed profile & development

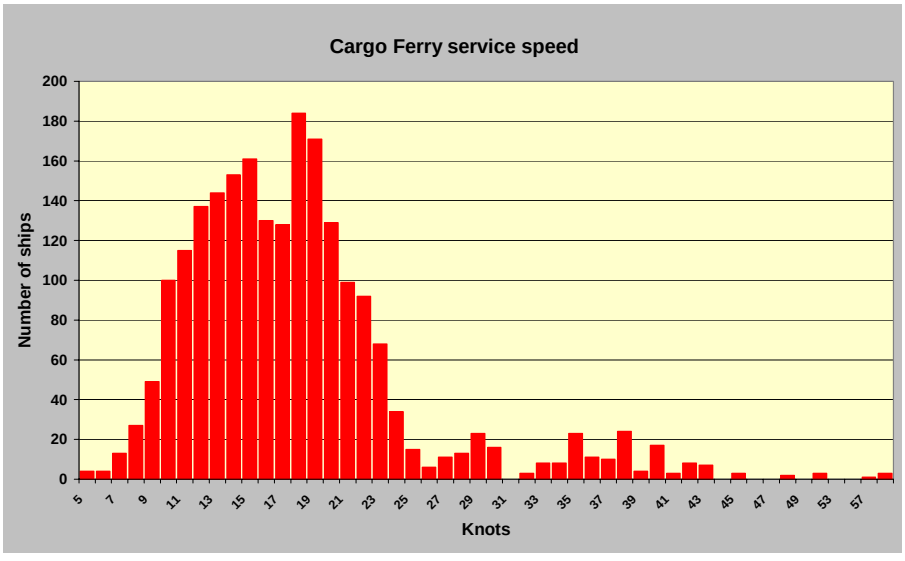


Figure 96: Cargo ferry, fleet service speed

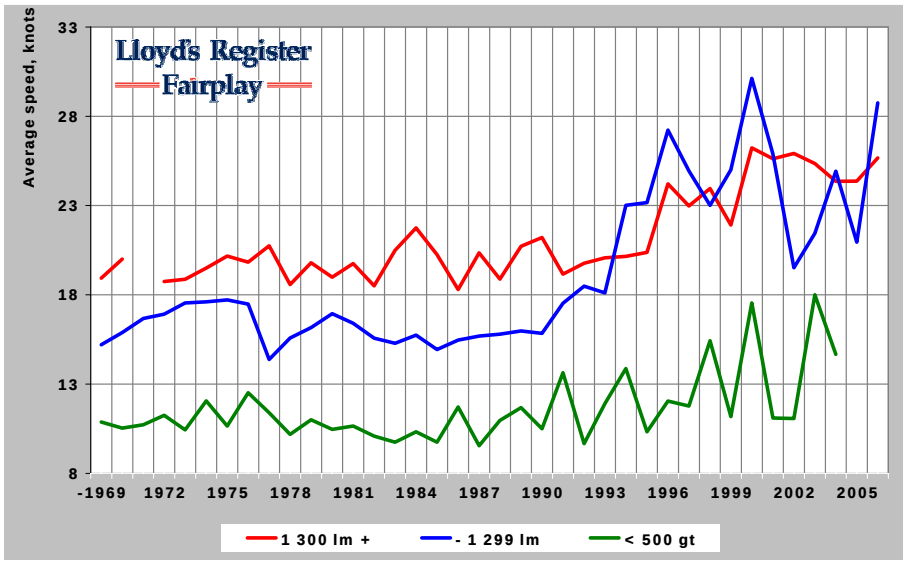


Figure 97: Ferry cargo, avg. speed development

11.3 Fuel consumption development

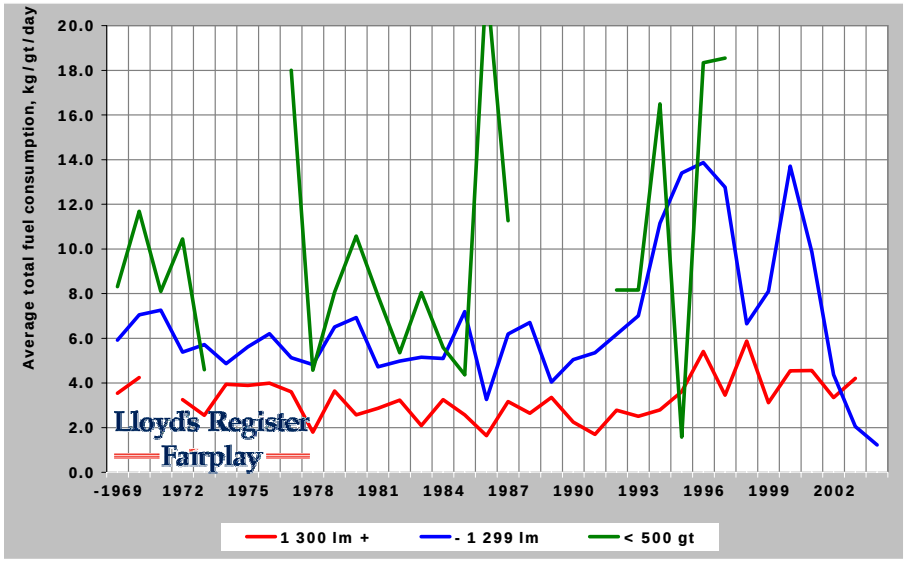


Figure 98: Ferry cargo, fuel consumption development (gt)

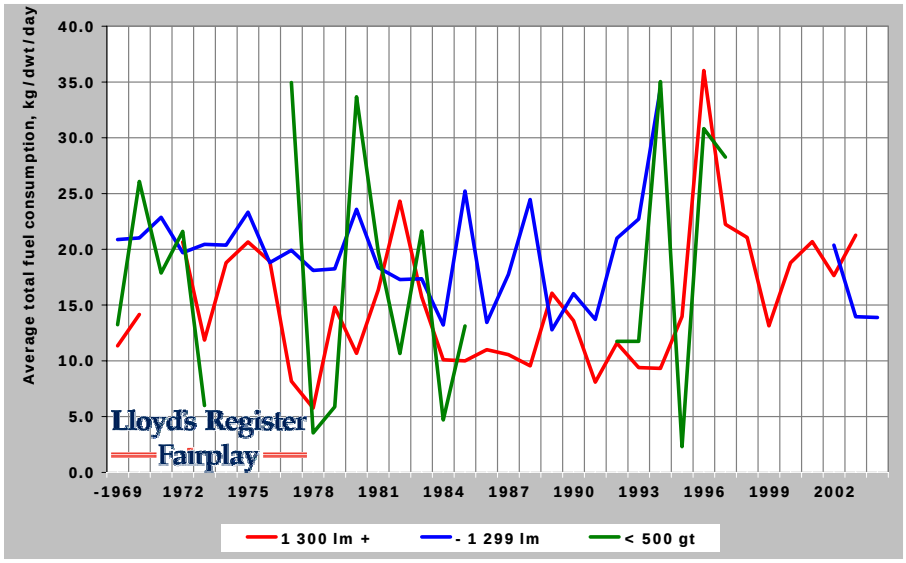


Figure 99: Ferry cargo, fuel consumption development (dwt)

11.4 Emission profile of the fleet

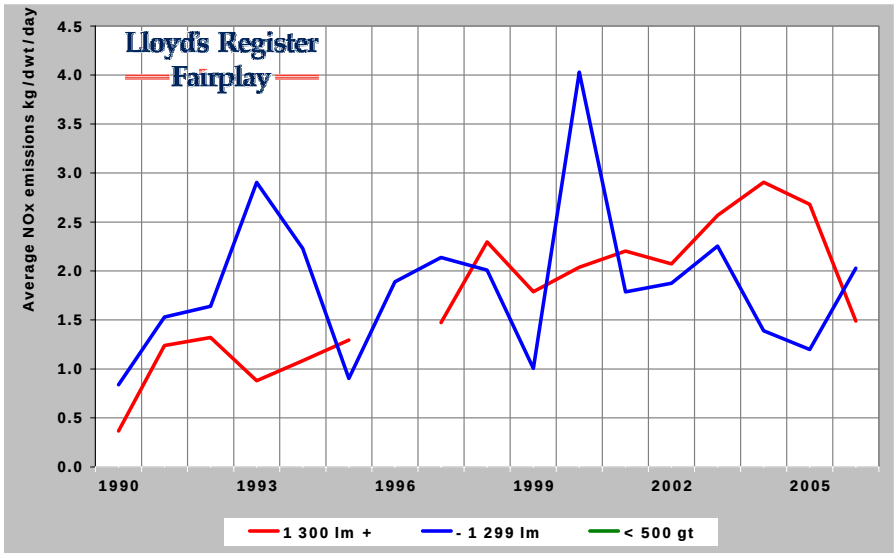


Figure 100: Ferry cargo, avg. NOx emissions (dwt) 1990-2006 (incl order)

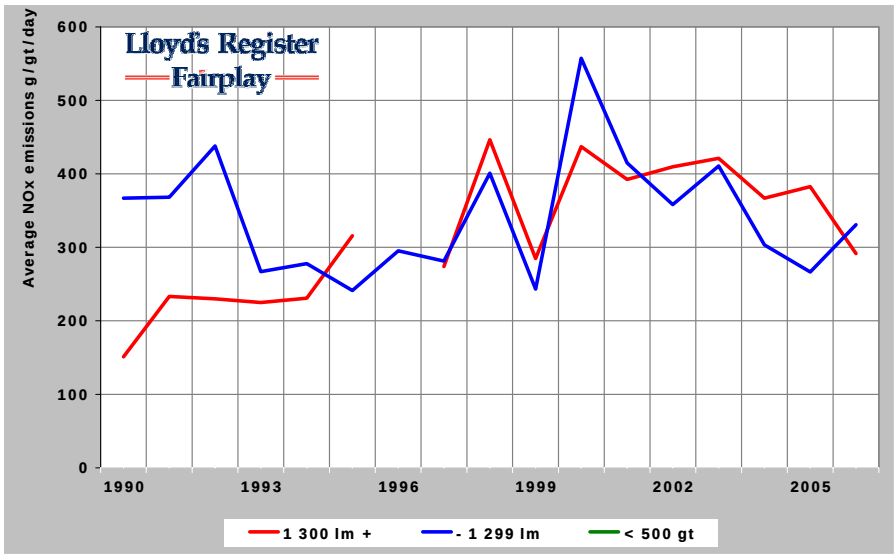


Figure 101: Ferry cargo, avg. NOx emissions (gt) 1990-2006 (incl order)

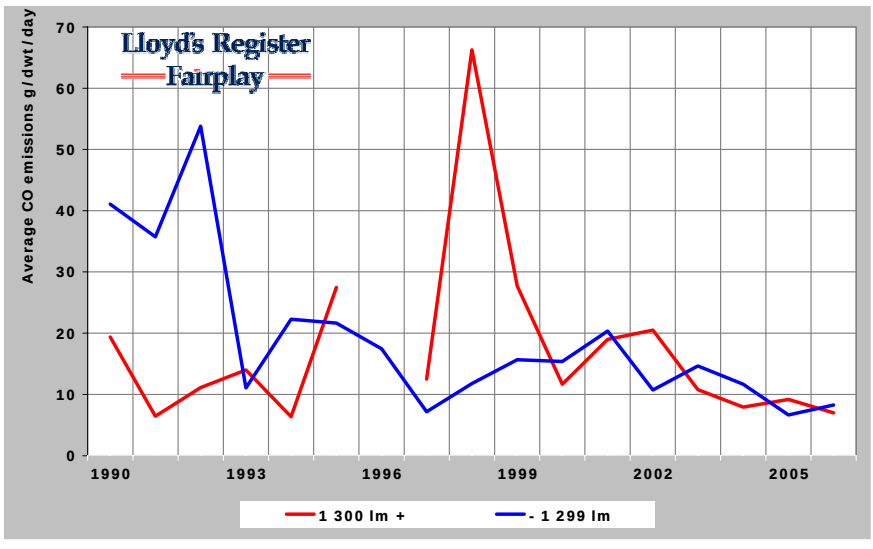


Figure 102: Ferry cargo, avg. CO emissions (dwt) 1990-2006 (incl order)

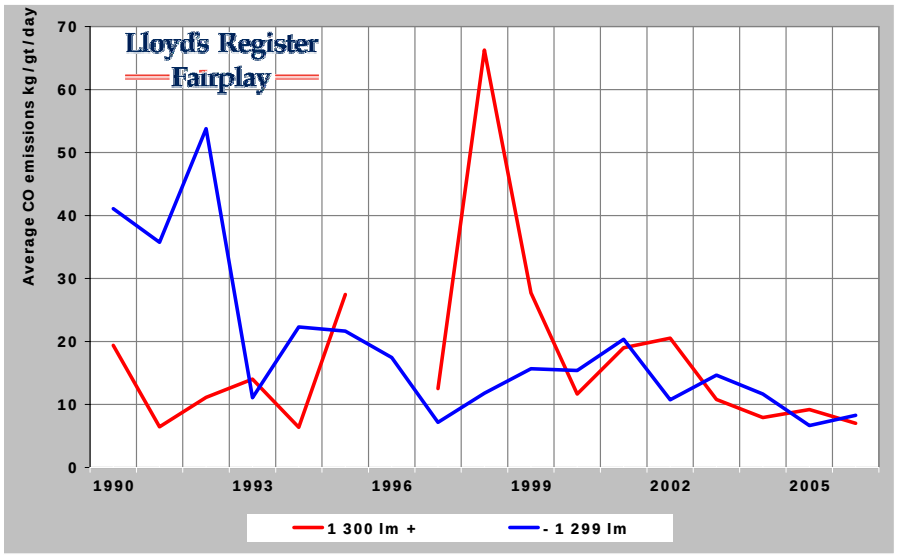


Figure 103: Ferry cargo, avg. CO emissions (gt) 1990-2006 (incl order)

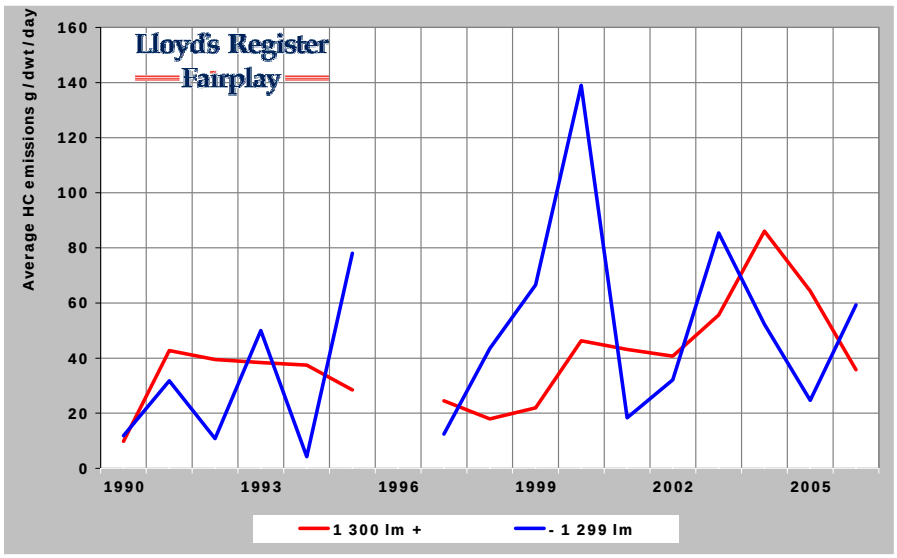


Figure 104: Ferry cargo, avg. HC emissions (dwt) 1990-2006 (incl order)

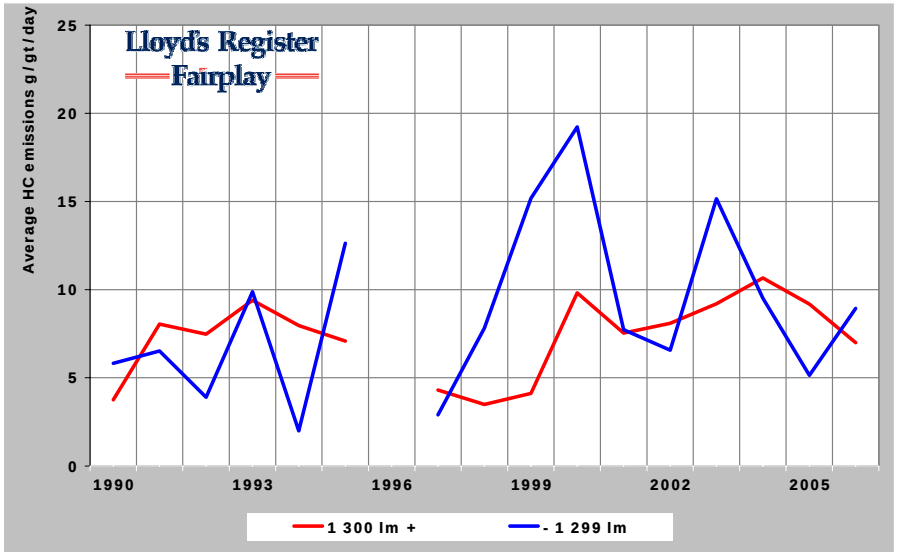


Figure 105: Ferry cargo, avg. HC emissions (gt) 1990-2006 (incl order)

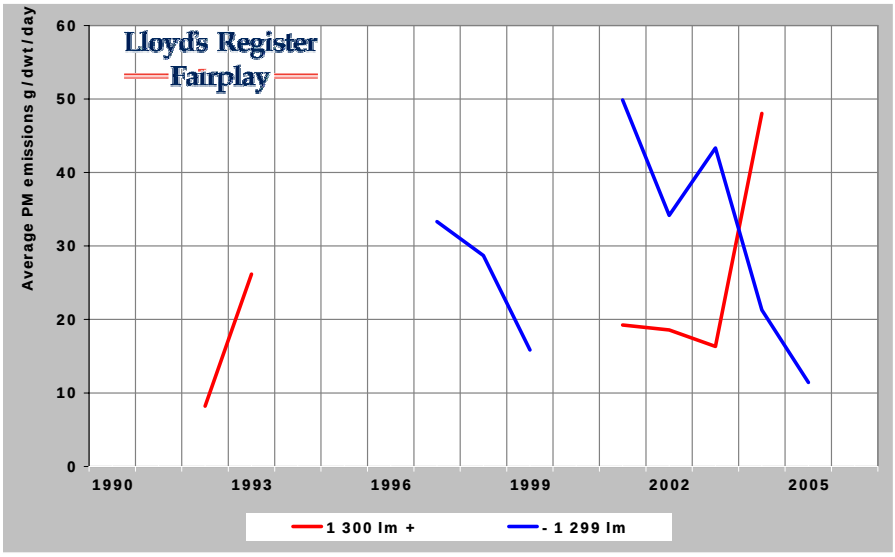


Figure 106: Ferry cargo, avg. PM emissions (dwt) 1990-2006 (incl order)

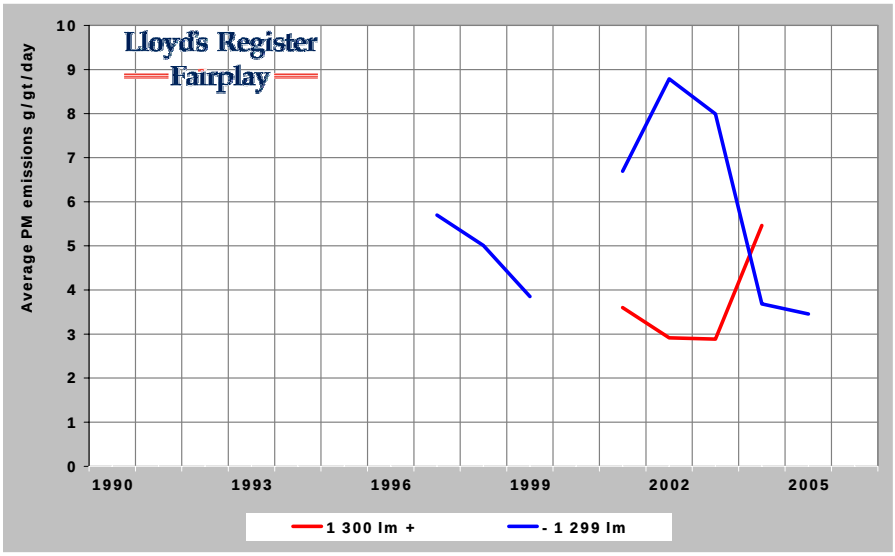


Figure 107: Ferry cargo, avg. PM emissions (gt) 1990-2006 (incl order)

12 Ferry non cargo

The **ferry; non cargo** market (i.e. passenger only vessels) is to a large extent characterised by a transport need between islands, across rivers or bays. The basic demand is generally from residents, topped off with seasonal tourist traffic.

A lot of the traffic is in domestic trade, but there are exceptions. In the ferry; non cargo segment 669 out of 2,784 ships are high-speed (30+ knots), which could be regarded as a market within a market. Out of these 50 % are multi-hulled.

Passenger service in international traffic is mainly provided by standard ferries (combined ferries) or ro-pax as described in the ferry cargo section.

12.1 Age profile of the fleet

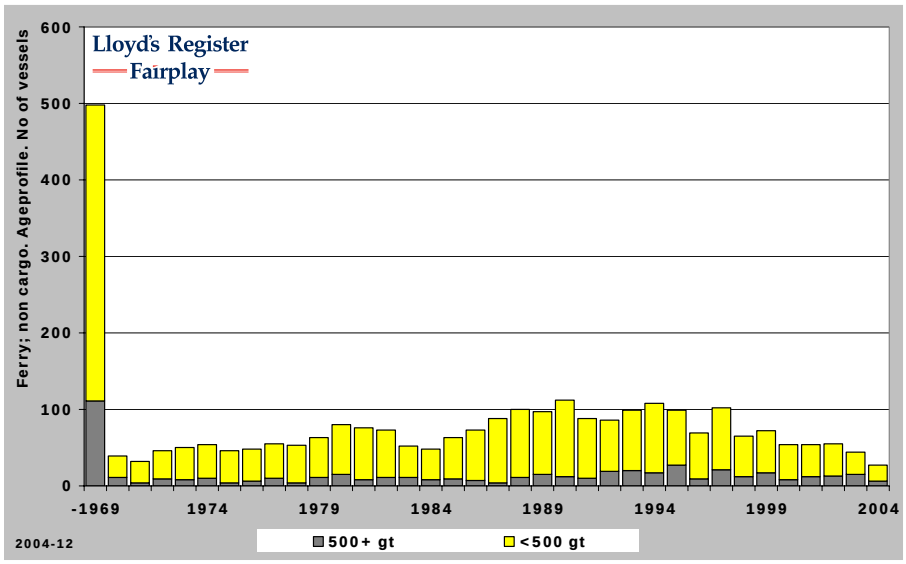


Figure 108: Ferry non cargo age profile, numbers

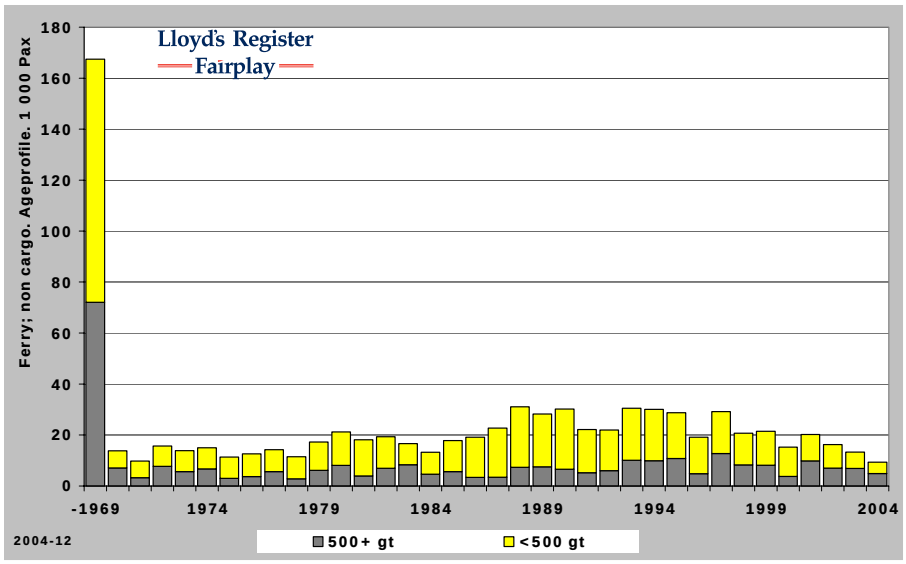


Figure 109: Ferry non age profile, passenger capacity

12.2 Speed profile & development

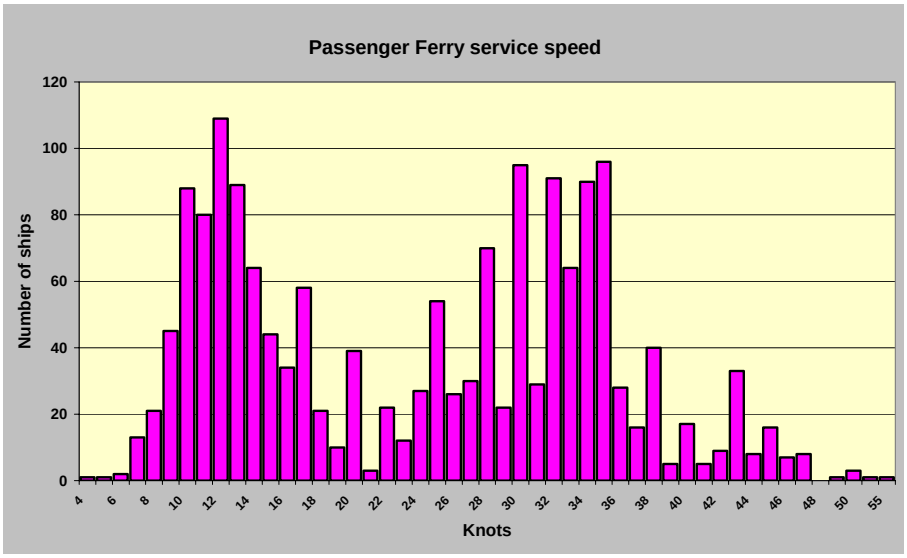


Figure 110: Ferry non cargo, fleet service speed

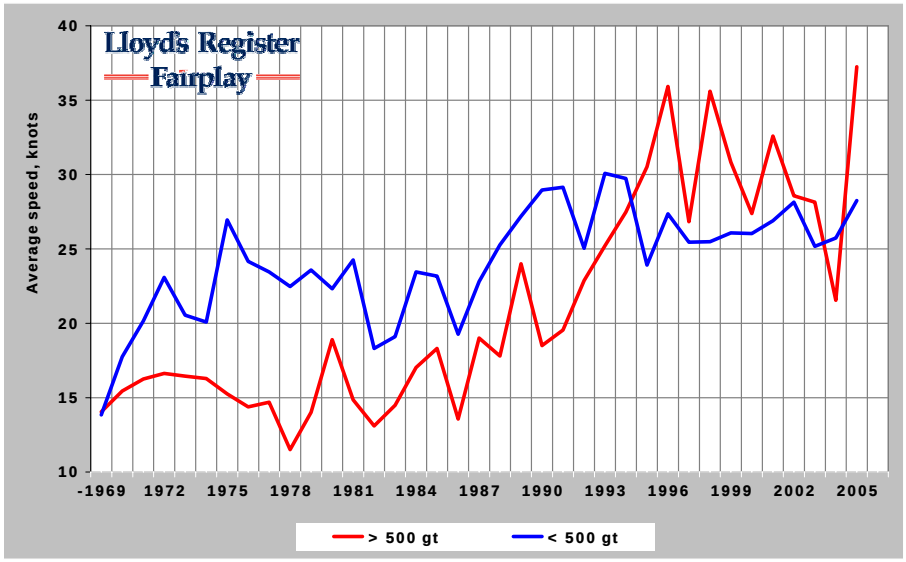


Figure 111: Ferry non cargo, avg. speed development

12.3 Fuel consumption development

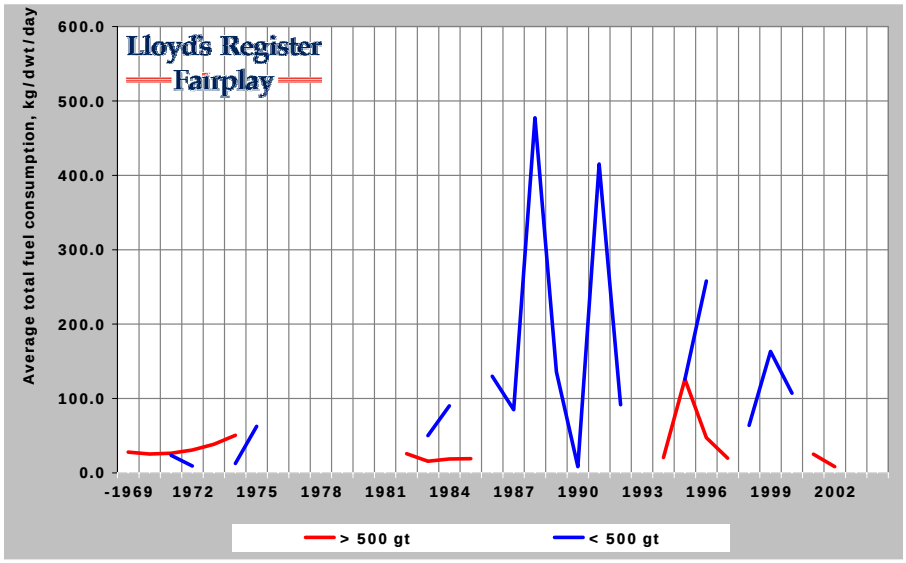


Figure 112: Ferry non cargo, fuel consumption development DWT

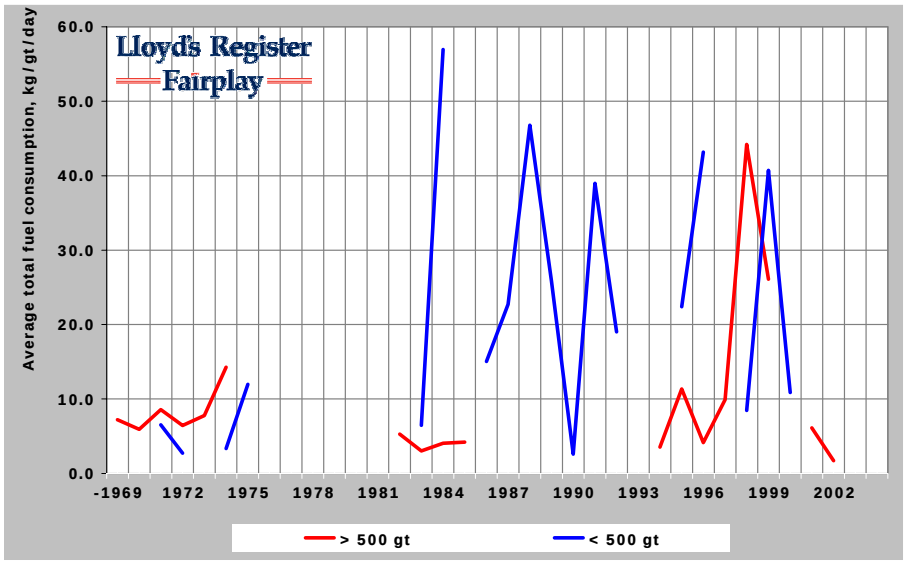


Figure 113: Ferry non cargo, fuel consumption development GT

12.4 Emission profile of the fleet

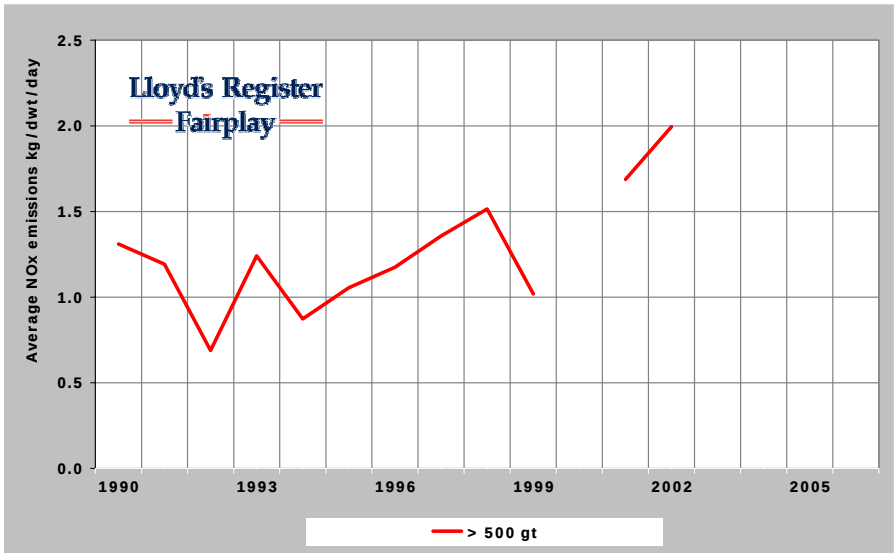


Figure 114: Ferry non cargo, avg. NOx emissions (dwt) 1990-2006 (incl order)

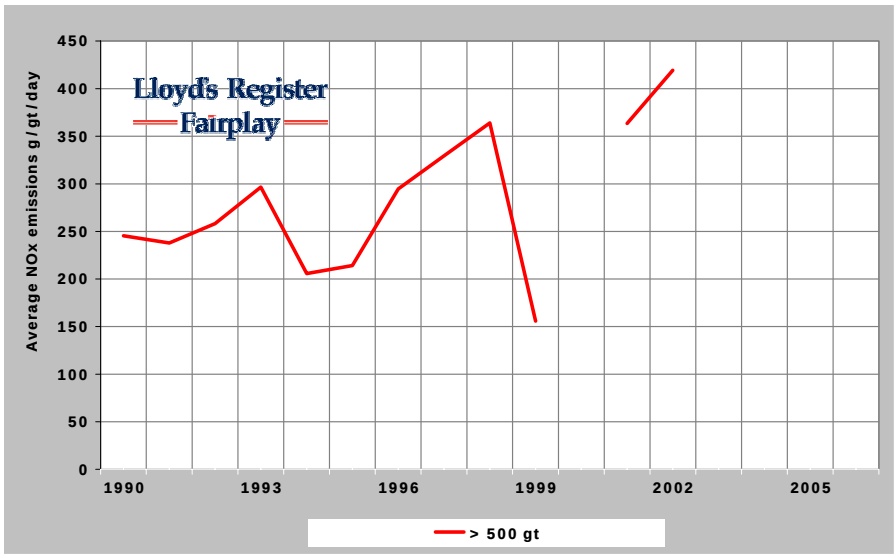


Figure 115: Ferry non cargo, avg. NOx emissions (gt) 1990-2006 (incl order)

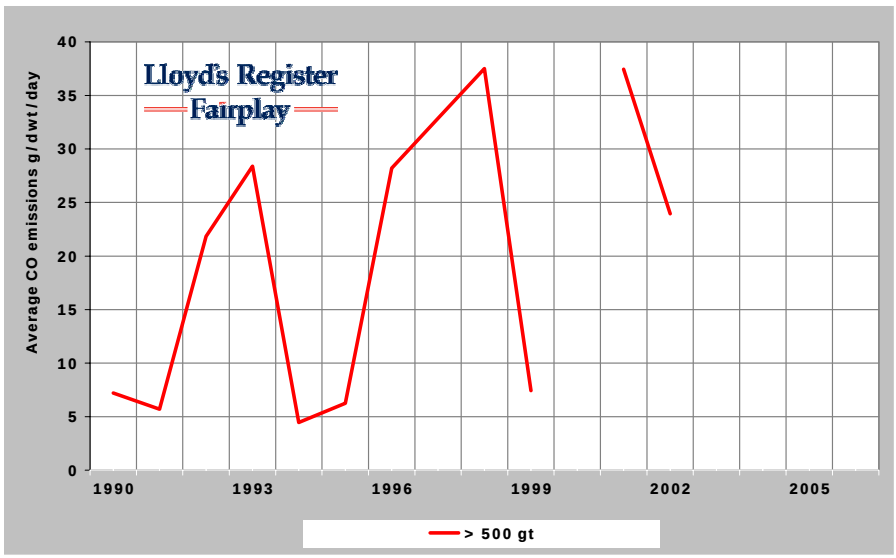


Figure 116: Ferry non cargo, avg. CO emissions (dwt) 1990-2006 (incl order)

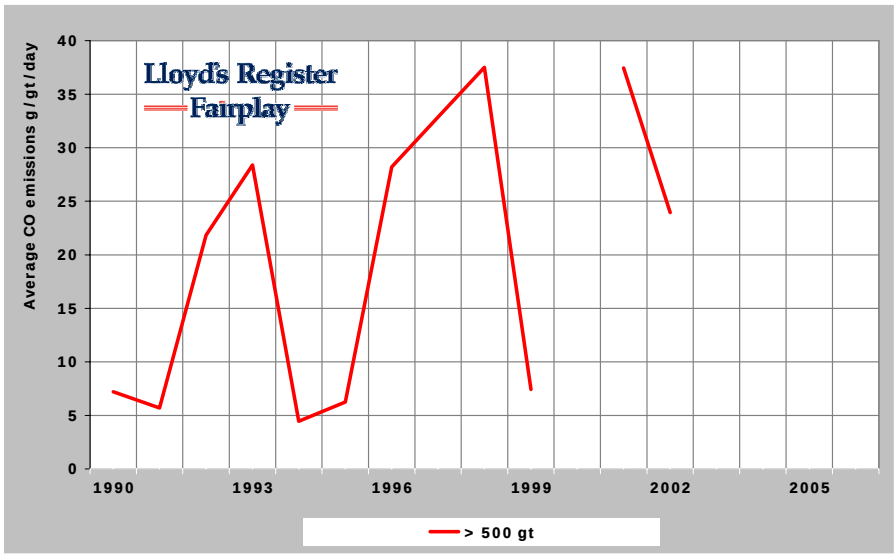


Figure 117: Ferry non cargo, avg. CO emissions (gt) 1990-2006 (incl order)

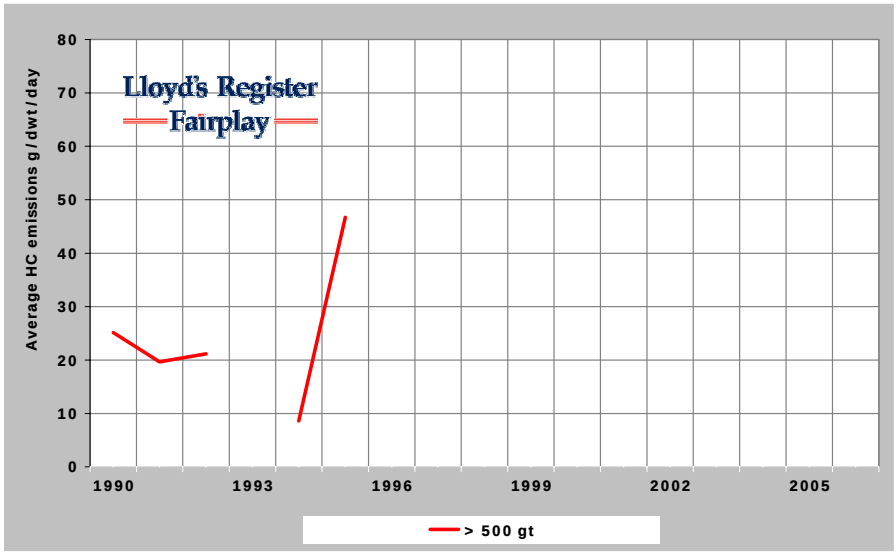


Figure 118: Ferry non cargo, avg. HC emissions (Dwt) 1990-2006 (incl order)

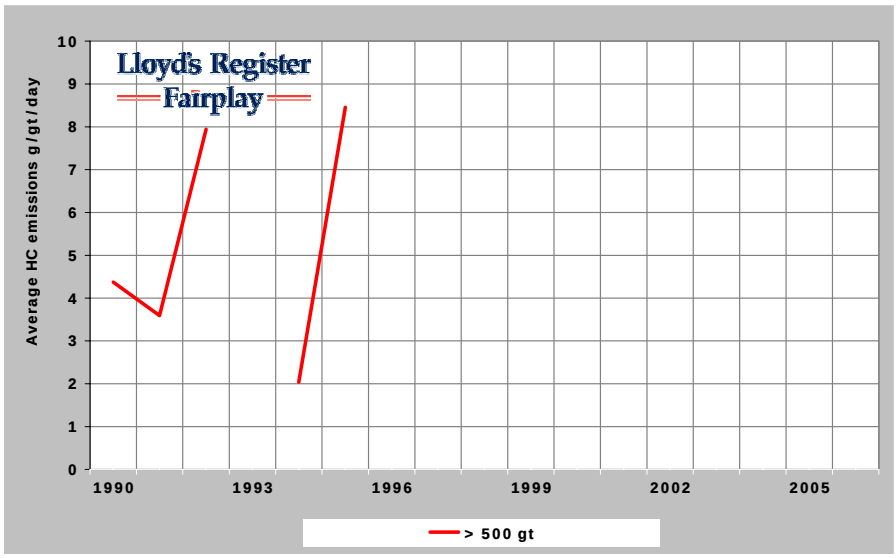


Figure 119: Ferry non cargo, avg. HC emissions (gt) 1990-2006 (incl order)

13 Cruise

In the large-scale end of the **cruise** sector, a few dominant suppliers provide the majority of services on the market. The services as such are highly differentiated and fulfil a leisure rather than a transport demand. The cruise vessel fleet is subject to favourable economies of scale, and since the second-hand market is difficult, the barriers to entry are high. Thus, there are strong reasons for the market remaining in the hands of the few.

The cruise sector had enjoyed strong growth for a number of years when it was seriously hurt first by the effects of September 11 and thereafter by the outbreak of SARS. SARS has ceased to hamper the demand for cruises. The 9/11 paralysis was starting to ease off when the situation in Iraq seemed to be resolved.

Cruising in American waters continues to dominate, but cruises in Europe have shown strong development in recent years. European cruises accounted for 23% of the total market in 2002.

The average length of a cruise is 6.9 days, and some 54% of passengers take six- to eight-day cruises. On average, the cruise passenger decides almost six months in advance where and when to take a cruise.

There is a consensus among cruise operators that the cruise passengers' decision-making process will be shorter for each passing year, making correct positioning of tonnage more complicated.

The cruise and ferry industry has made wide use of Internet based on-line booking systems. A survey by the Cruise Lines International Association (CLIA) found that 80% of its clients that have Internet access would research and gather information via the net and 50% would consider booking a cruise online.

13.1 Age profile of the fleet

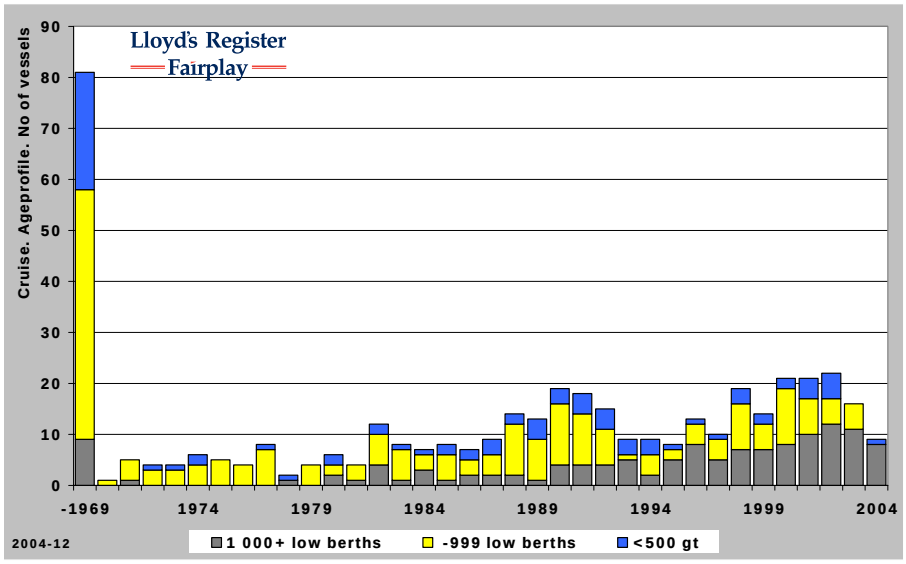


Figure 120: Cruise age profile, numbers

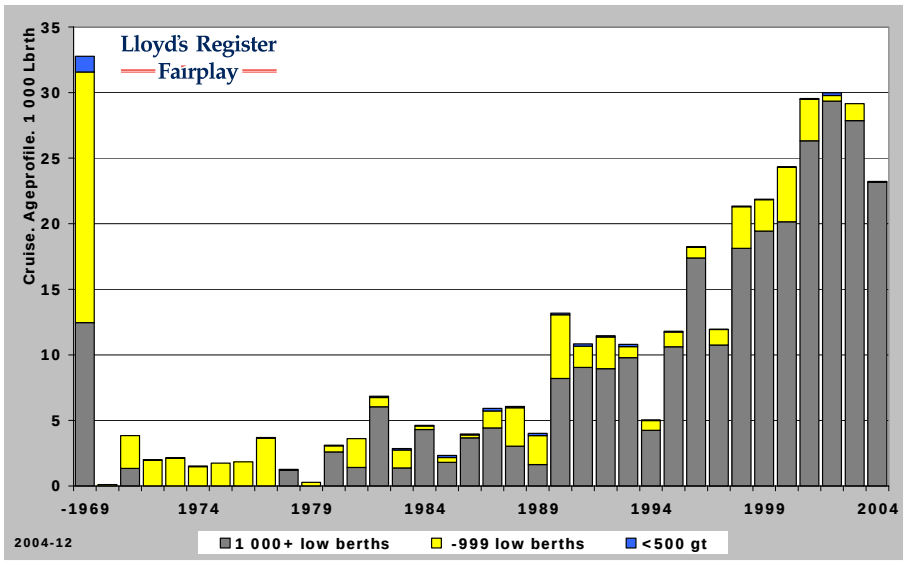


Figure 121: Cruise age profile, Lower berth capacity

13.2 Speed profile & development

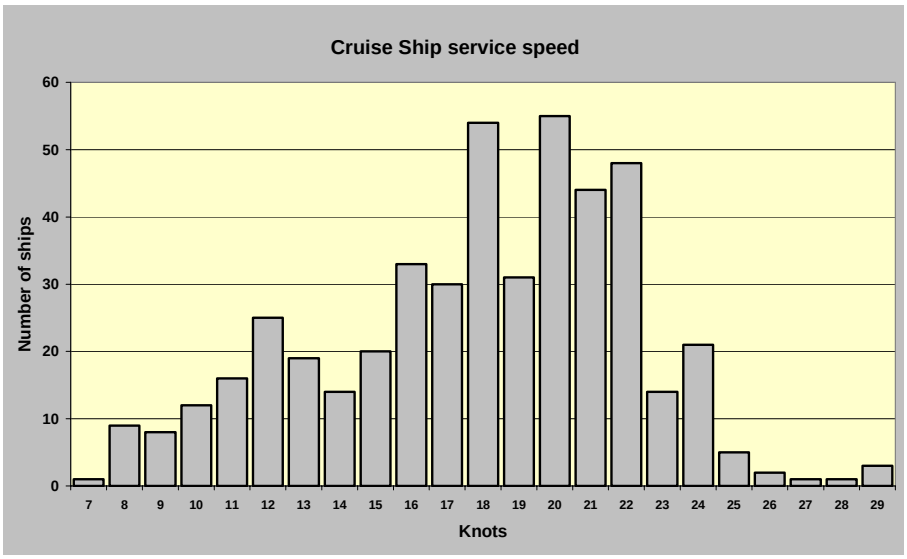


Figure 122: Cruise, fleet service speed

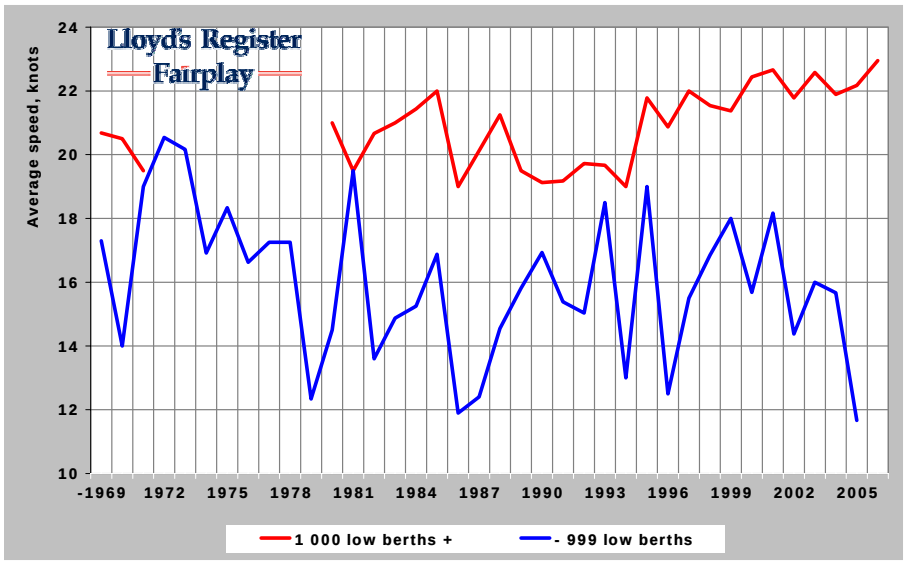


Figure 123: Cruise, avg. speed development

13.3 Fuel consumption development

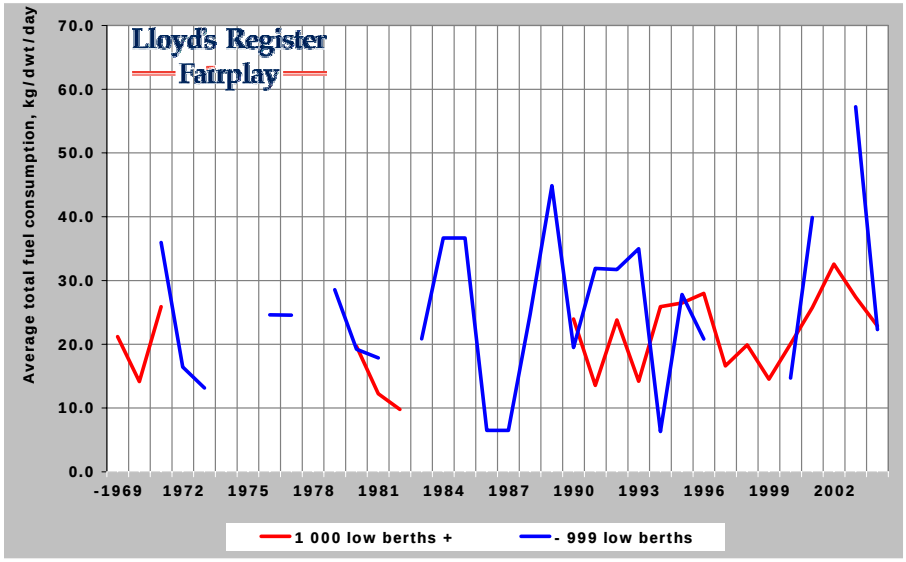


Figure 124: Cruise, fuel consumption development DWT

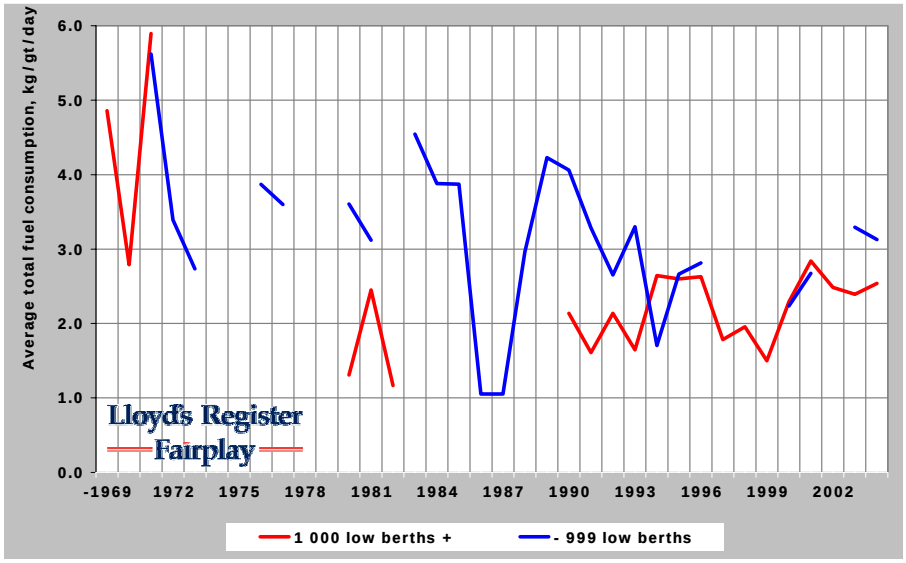


Figure 125: Cruise, fuel consumption development GT

13.4 Emission profile of the fleet

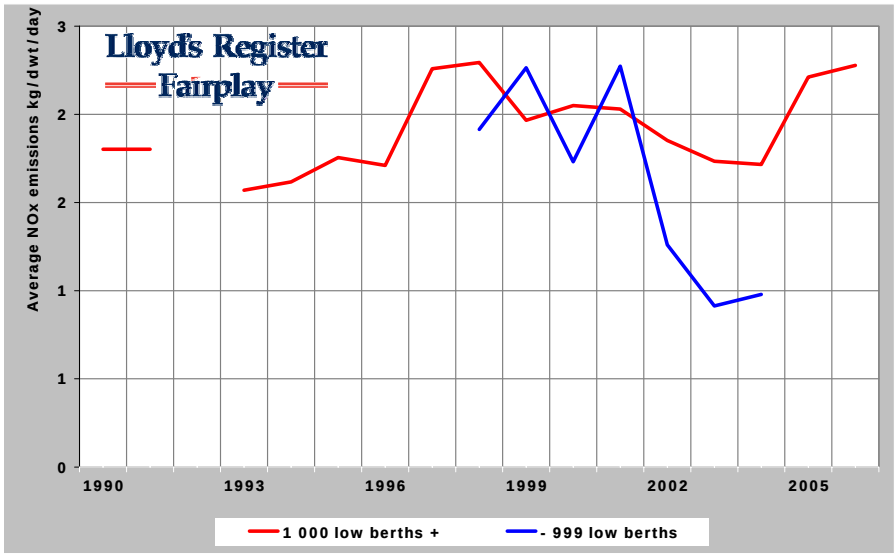


Figure 126: Cruise, avg. NOx emissions (dwt) 1990-2006 (incl order)

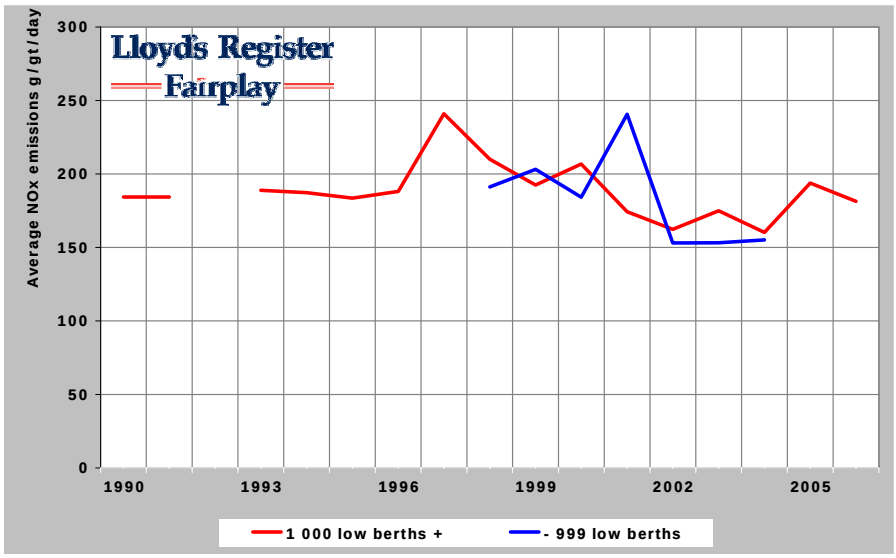


Figure 127: Cruise, avg. NOx emissions (gt) 1990-2006 (incl order)

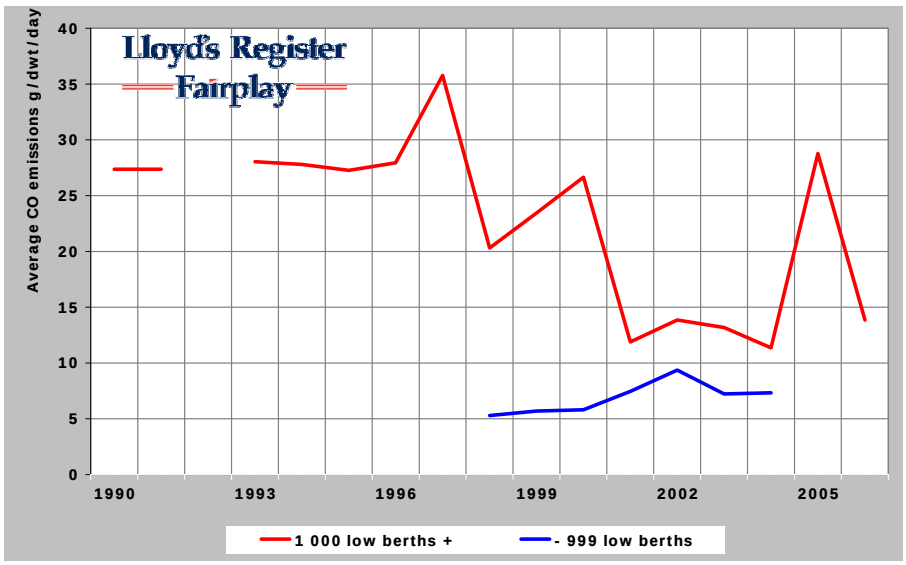


Figure 128: Cruise, avg. CO emissions (dwt) 1990-2006 (incl order)

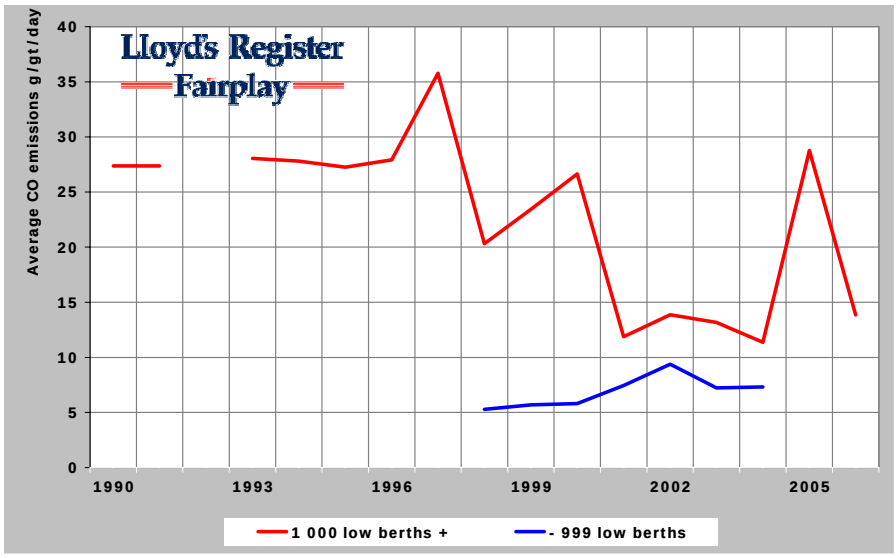


Figure 129: Cruise, avg. CO emissions (gt) 1990-2006 (incl order)

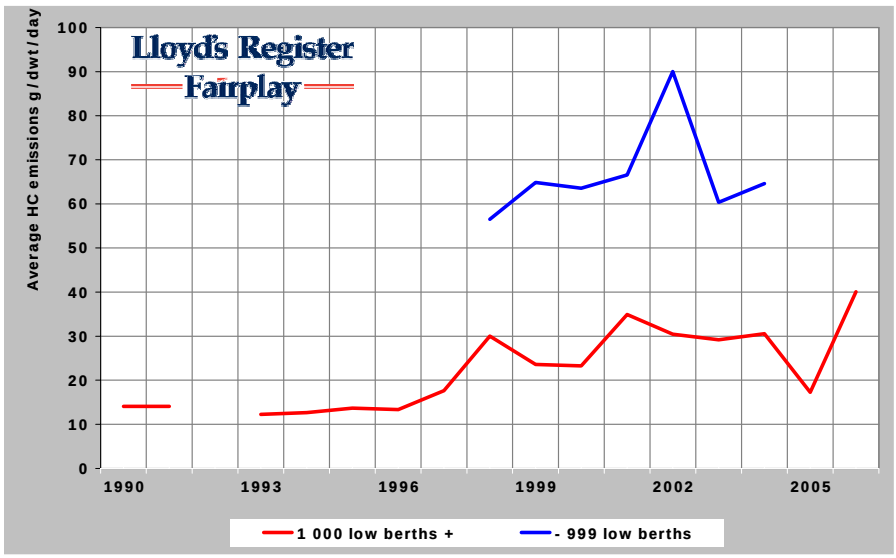


Figure 130: Cruise, avg. HC emissions (dwt) 1990-2006 (incl order)

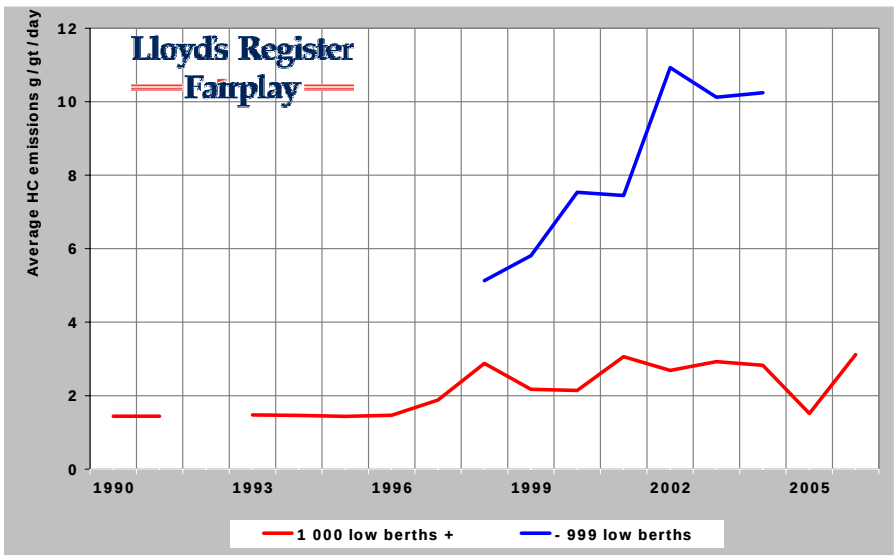


Figure 131: Cruise, avg. HC emissions (gt) 1990-2006 (incl order)

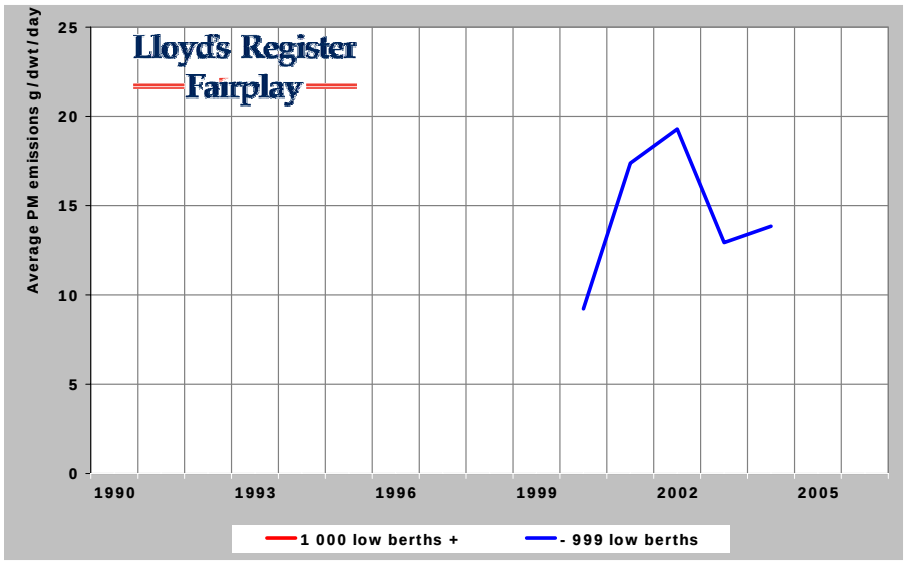


Figure 132: Cruise, avg. PM emissions (dwt) 1990-2006 (incl order)

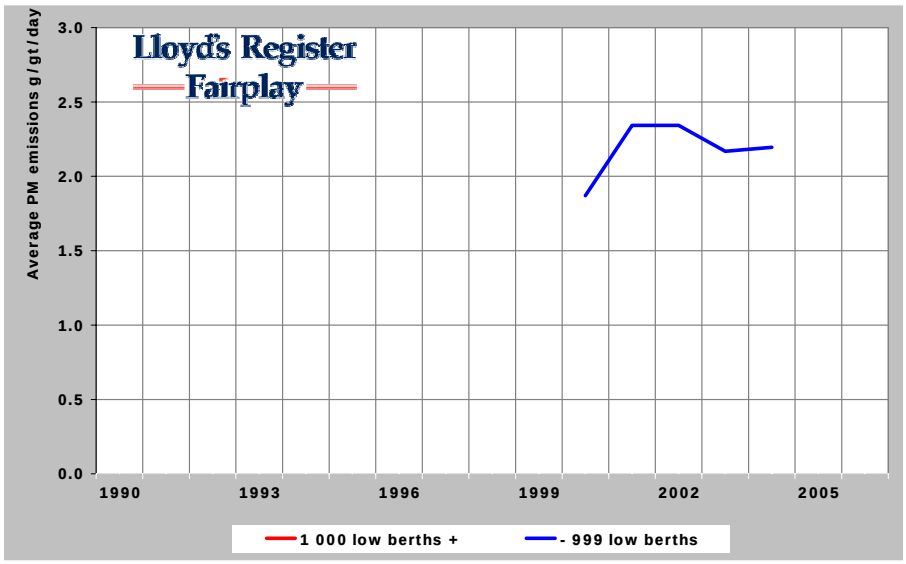


Figure 133: Cruise, avg. PM emissions (gt) 1990-2006 (incl order)

14 Summary table

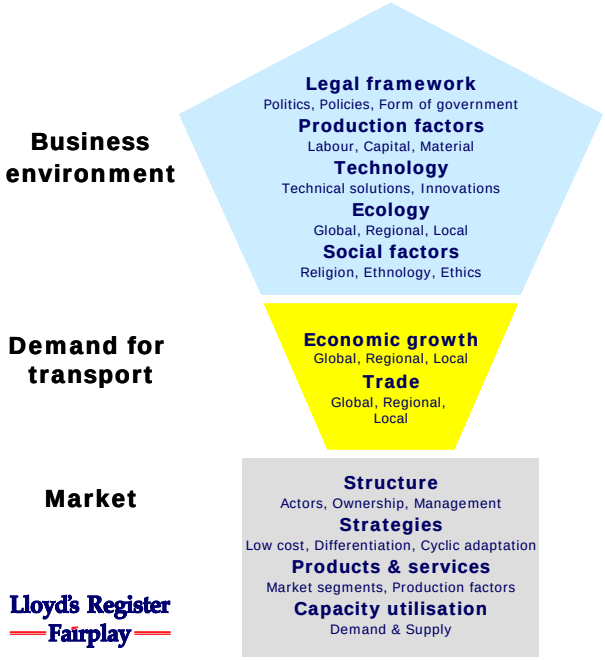
Table 3: Average emission values, ships delivered 1990-2006 (incl order)

		Average emissions of ships delivered 1990-2006 (incl order)							
		g NOx /dwt/day	g NOx /gt/day	g CO /dwt/day	g CO /gt/day	g HC /dwt/day	g HC /gt/day	g PM /dwt/day	g PM /gt/day
Oil Tanker	**200 000 dwt +**	31	58	1.4	2.7	0.9	1.6	0.9	1.7
	60' - 199 999	46	82	2.6	4.7	1.5	2.8	1.4	2.5
	E 10' - 59 999 dwt	81	129	3.7	5.9	2.8	4.4	2.4	3.8
	F - 9 999 dwt	131	190	5.0	7.2	5.1	7.4	2.5	3.7
	X < 500 gt	*Records not avilable for ships of this size*							
Chemical Tanker	**60 000 dwt +**	49	83	3.3	5.6	1.7	2.8	1.7	2.9
	10' - 59 999 dwt	96	150	4.7	7.3	2.9	4.5	2.4	3.6
	- 9 999 dwt	171	249	6.9	10.3	5.4	7.8	2.6	3.7
	< 500 gt	*Records not avilable for ships of this size*							
Gas tankers	**LNG**	114	69	9.0	5.4	1.8	1.1	0.0	0.0
	LPG 50 000 cbm +	180	217	7.5	9.0	6.1	7.3	3.4	4.3
	LPG - 49 999 cbm	89	105	4.9	5.7	2.7	3.1	2.9	3.5
	< 500 gt	*Records not avilable for ships of this size*							
Bulker	**80 000 dwt +**	39	75	1.7	3.2	1.3	2.6	1.1	2.1
	55' - 79 999 dwt	48	90	2.9	5.4	1.8	3.4	1.5	2.9
	10'-54 999 dwt	73	121	3.5	5.9	3.1	5.1	2.1	3.4
	- 9 999 dwt	183	260	3.4	4.9	1.3	1.9	2.8	4.0
	< 500 gt	*Records not avilable for ships of this size*							
Container	**5 000 teu +**	278	298	12.3	13.2	14.7	15.5	8.8	9.1
	3' - 4 999 teu	264	308	9.9	11.6	12.5	14.6	7.8	9.0
	1' - 2 999 teu	243	303	12.1	14.9	10.9	13.4	7.4	9.3
	- 999 teu	240	297	10.1	12.4	3.7	4.6	4.2	5.1
	< 500 gt	*Records not avilable for ships of this size*							
Reefer	**7 100 cbm +**	412	434	18.2	19.2	18.7	18.9	12.5	12.4
	- 7 099 cbm	334	300	9.2	8.2	6.9	5.3	3.8	4.1
	< 500 gt	*Records not avilable for ships of this size*							
Dry cargo n.e.s.	**10 000 dwt +**	135	184	6.1	8.3	4.6	6.4	3.9	5.2
	- 9 999 dwt	162	217	6.1	8.2	4.3	5.9	2.5	3.3
	< 500 gt	*Records not avilable for ships of this size*							
Vehicle Ro-Ro	**4 000 ceu +**	321	105	16.4	5.4	9.6	3.2	9.6	3.2
	- 3 999 ceu	442	162	16.0	6.1	15.7	5.8	7.0	3.0
	< 500 gt	*Records not avilable for ships of this size*							
Ro-Ro n.e.s.	**2 200 lm +**	439	249	23.9	14.4	12.4	8.0	9.0	5.3
	- 2 199 lm	368	281	13.7	10.6	11.4	9.2	4.7	4.1
	< 500 gt	*Records not avilable for ships of this size*							
Ferry; Cargo	**1 300 lm +**	1,964	361	89.8	17.3	42.7	7.8	23.0	4.4
	- 1 299 lm	1,806	341	71.4	16.5	44.9	8.8	28.1	5.8
	< 500 gt	*Records not avilable for ships of this size*							
Ferry; Non Cargo	**> 500 gt**	1,249	273	77.9	17.5	35.1	6.5	15.8	2.5
	< 500 gt	*Records not avilable for ships of this size*							
Cruise	**1 000 low berths +**	1,904	184	199.2	19.7	25.4	2.4	0.0	0.0
	- 999 low berths	1,860	202	59.7	6.8	64.7	7.4	15.0	2.3
	< 500 gt	*Records not avilable for ships of this size*							
Average all		**188**	**175**	**9.3**	**8.1**	**6.2**	**6.4**	**4.5**	**5.1**

15 Approach

The figure to the right illustrates the analytical approach used in this publication. Changes in demand for seaborne transport capacity are a function of economic growth and international trade, which in turn result from changes in the business environment.

The effects of changing demand for seaborne transport capacity depend on how the markets are organised; the market structure (e.g. monopoly, oligopoly etc), strategies used to meet demand and products and services developed to meet demand, as well as the different components of utilisation.



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