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OMIT - Manual for environmental calculation of international freight transport

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Danish Environmental Protection Agency

Danish Ministry of the Environment

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The reports are, however, published because the Danish EPA finds that the studies represent a valuable contribution to the debate on environmental policy in Denmark.

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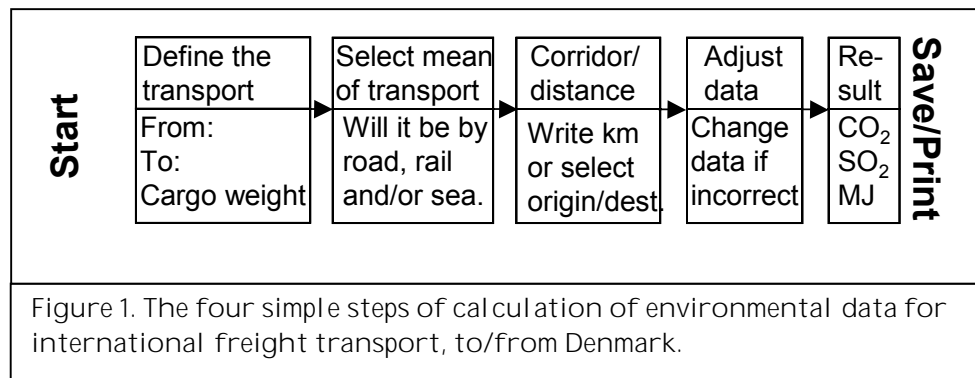
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OMIT



1 Preface

The OMIT tool has been developed to calculate the energy consumption and emissions for international freight transport to and from Denmark. The development was financed by the Danish Environmental Protection Agency's programme for promoting cleaner products. Owing to the fact that OMIT includes international transports, it is a supplement to Danish Ministry of Transports' national calculation model TEMA2000 (COWI, 2000).

OMIT was carried out in the years 2000 and 2001 by:
Institut for Transportstudier, TetraPlan A/S, Institut für Energie- und Umweltforschung Heidelberg GmbH, Danish Trade Association of International Transport, Danish Ship owners' Association, The Danish National Railway Agency, Kombi Dan A/S and DSB Traffic Planning and Environment.

TEMA2000 and OMIT are based on the same data foundation as for ship calculations, as shipping is an international trade. Regarding the calculations for railway transport, it has been necessary to provide for new European data, because the size of the trains, the energy supply and hence the environmental load depend on the country they operate in. Finally the data concerning trucks is based on a number of simulations for a 48 tons truck in TEMA2000. This increases the energy consumption and the emissions compared with the typical European 40 tons export truck, a deviation, which should be compensated by using the actual number of km/l diesel.

The project was supported by a coordination committee with participation of: The Danish Environmental Protection Agency, The Danish Ministry of Transport, The Danish National Railway Agency, DSB Traffic Planning and Environment, Danish Ship owners' Association, Association of Danish Forwarders, Danish Shippers' Council, Danish Trade Association of International Transport and Kombi Dan A/S.

The elaboration and the adjustment of OMIT and the calculation models to the need of the industry could not have been carried out without help from numerous contributors. We therefore wish to announce our appreciation to: Danfoss A/S, DFDS Tor Line Group A/S, Central Soya European Proteins A/S, the Danish Energy Agency, A/S Roulunds Fabriker, Scandlines A/S and Schenker-BTL A/S for their time and contribution, which we have done our best to include in the project.

It has been emphasized that OMIT should be easy to use. This also means that there is only a limited number of transport parameters that can be changed. The selection of the values which are changeable, was made from criteria of importance:

- They must be important to the energy consumption and environmental load of the transport
- Forwarder and transport buyer must have considerable influence on these.

This is the basic idea of OMIT; we hope you will enjoy the program. Our hope is that besides calculating environmental values, it can provide increased knowledge about how transport provider and transport buyer are able to reduce the environmental load, and that they will act accordingly.

The project was delivered to the Danish EPA, October 2001.

2 Introduction

OMIT is an easy-to-use tool for calculating the environmental load of

international freight transport to and from Denmark by truck, train and ship.

As shown in figure 2, OMIT consists of four steps, in which it is possible to define the transport chain and the parameters of the transport modes. In the manual the two first steps will be covered together, whilst the two last steps and the preconditions for the calculations will be described individually for each transport mode. Finally there will be comments on the result sheets.

The results appear in an Excel spreadsheet. It is thus possible to continue to work with data or to use these in one's own material as documentation for transports performed.

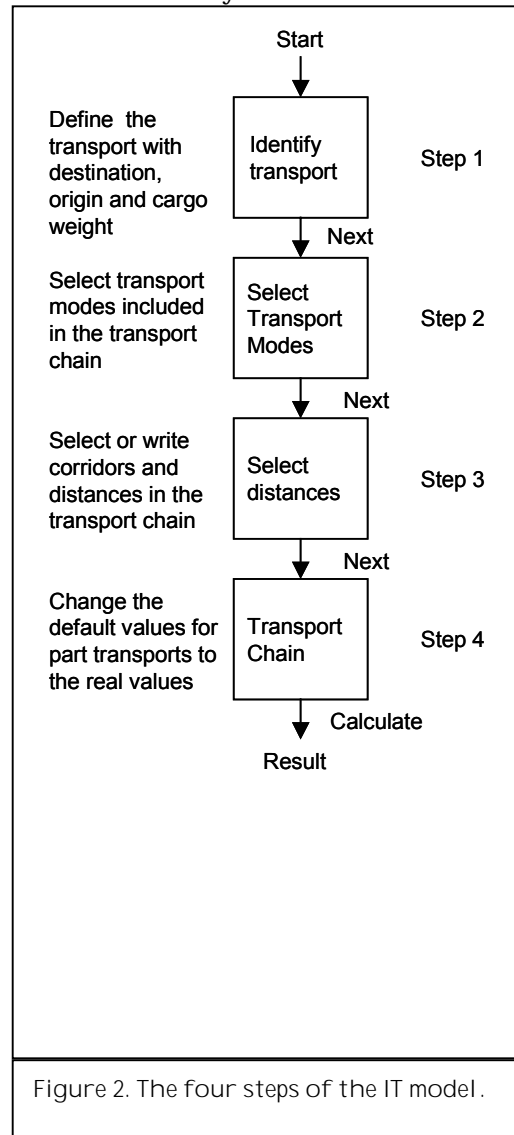
The objective of this manual is to describe how the tool is used and to give examples of the options given to adjust the calculations.

It is not always obvious, exactly how a transport will be performed. Therefore the model has default values that represent a typical transport. The user must know, however, which transport modes are

used, origin and destination of the goods, and the weight of the shipment. The more exact information is available about the transport, the more exact the results.

In OMIT the energy consumption and the emissions are allocated by the same principles as are normally used for invoicing the transports. Thus the environmental impact for ferry transport is allocated by length of the used mean of transport, on container ship by TEU (20' container unit), for train and bulk carrier by ton and for truck by ton or m³, depending on whether the freight is heavy goods or voluminous goods.

OMIT being aimed at international transports, where either the origin or the destination is not Denmark, the program language is English. This enables the



user to apply the results and share the calculations with partners in a foreign country.

The manual has been supplemented with elaborating comments, which are not required to know in order to use OMIT - *this information is written in italics*.

3 User's guide

3.1 Installation and start-up of OMIT

Follow the installation guide, which may include one or two restarts. When OMIT has been installed, the program is opened from the Windows Start menu. Accept macros, and now the calculation can begin from the Excel menu bar by choosing OMIT.

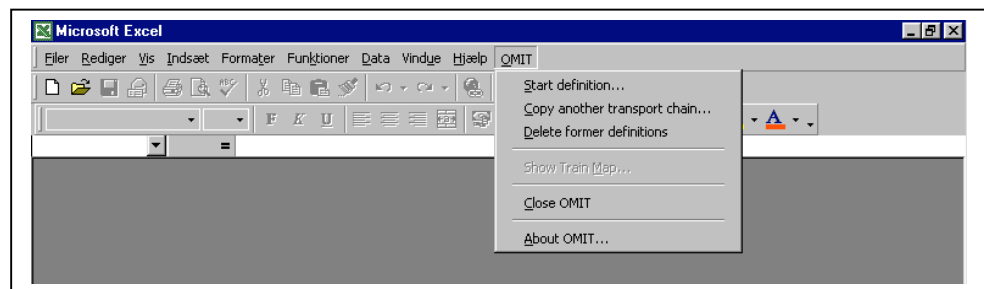


Figure 3. Excel screen when starting calculation.

There are two ways to make a calculation. Either you start from scratch by choosing "Start definition", or you work on the base of a previous calculation by selecting "Copy another transport chain".

3.1.1 Start definition

If you are going to make a new calculation, select "Start definition". You are lead through the four steps of the program. It is always possible to go back and make changes in the parameters, until you have pressed "Calculate" in step 4. Hereafter you will have to start all over by pressing "Copy another transport chain", if you wish to make changes in the calculation.

The final calculation and the preconditions will be saved as a spreadsheet in the folder "Calc", where the program is saved.

3.1.2 Copy another transport chain

When pressing "Copy another transport chain" you can select from all previous calculations described by: origin and destination, description, weight, volume of goods, date and time of calculation. Hereafter it is possible to change the calculation partially or completely, in any case it will be saved as a new calculation, and the original will not be overwritten.

It is not possible to delete parts of transports in a copied transport chain, but it is possible to add new corridors and distances and to make changes. When you change a transport, e.g. by using another corridor, the succeeding settings of the transport will return to the default values.

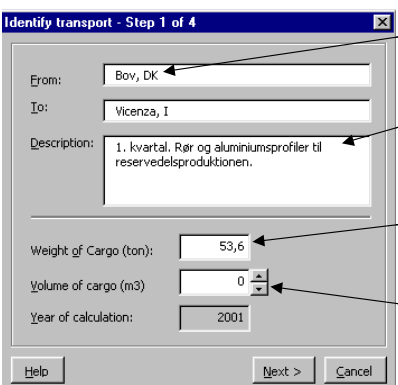
The function is good for saving a transport chain for a given customer, and quarterly or yearly it is possible to make an environmental statement based on the updated quantities.

The function can also be used for calculating different examples and see what environmental improvements can be made, e.g. by improving the capacity utilisation.

3.1.3 Delete former definitions

This function deletes the parameters of previous definitions. Thus it is no longer possible to open old calculations by using "Copy another transport chain". The result sheets will, however, still be saved in the file "Calc" and they can only be deleted manually. For documentation of improvements it may be an advantage to save old result sheets in a new file with indication of the year.

3.2 Step 1: Identify transport



Origin and destination, min. 5 letters.

Open text field for information about goods, invoice, period, customer.

Cargo weight in tons, including packaging, EUR pallets etc. for which the customer pays freight.

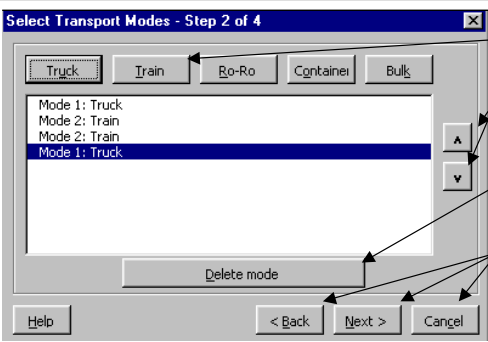
Volume in m³. Scroll up or down with the arrows to change the values by 1. By pressing Shift while scrolling, the values change by 10 and by pressing Ctrl the values change by 100.

Figure 4. In step one you must state origin and destination of the transport and the goods weight. Volume may be relevant for truck transport.

The program provides the calculation with a sequential number and a date; hence the transport is explicitly described and can be re-opened. The weight of goods is arbitrary. If it exceeds the limit of a single transport, OMIT will treat it as multiple individual transports.

Statement of volume is important for transport by truck, only if the load weighs less than 333 kg per m³. In that case volume is determinant for the allocation of the environmental load in place of weight.

3.3 Step 2: Select Transport Modes



Select transport means by their order in the transport chain.

Moves the marked transport mean up/down the transport chain.

A marked transport mean is deleted by pushing here.

If there are changes to Step 1 press Back, go to Step 3 with Next or Cancel. This will not end the OMIT programme.

Figure 5. In step 2 you must state the transport modes used for the individual part transports in the chain

There is no limit to the number of part transports, modes of transport to be used or in which order they should enter in the transport chain.

The transport modes to select are:

- Truck
- Train
- Ro-Ro ferry
- Container ship
- Bulk carrier.

OMIT does not check whether or not a transport chain is coherent. It is up to the users to make sure, that the corridors cohere, and that data for the transport modes are realistic and correct.

4 Calculation of environmental data

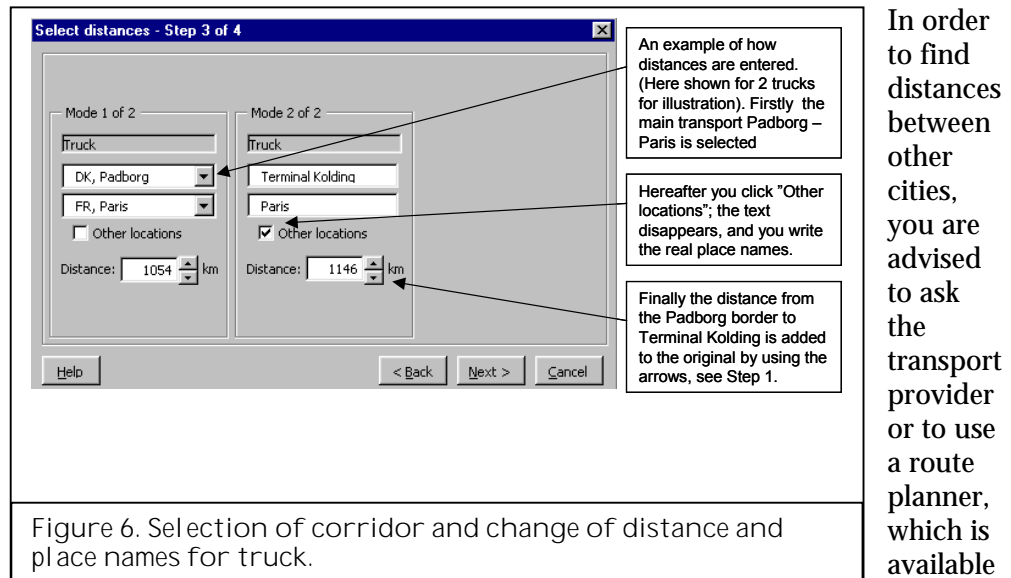
Calculation of the specific environmental data is based on the conditions under which the transport modes operate. Different corridors and parameters must be specified, depending on whether a calculation is made for truck, train or ship. Therefore step 3 and 4 in the following calculation will be described separately for each mode of transport. At last there will be comments on the result sheet.

4.1 Calculation and allocation of environmental load for truck

Truck calculations are based on simulation of long distance transport in TEMA2000 (COWI, 2000). As data in TEMA2000 are based on a national 48 tons truck, which has a bigger engine than the 40 tons truck mostly used for export, the energy consumption and emissions are not completely in accordance with reality. You are therefore advised to make your own calculations and use data for km/l in the calculations.

4.1.1 Corridors and distances

OMIT contains a distance database with road distances from the borders in Padborg and on the Oresund Bridge plus a number of ferry ports abroad to different European cities. The Danish part of the distance should be added, either from the Danish port or from the border in Padborg or on the Oresund Bridge. Names and distances can be overwritten, so that the right information appears on the print.



Internet. For reasons of comparison it is important to use the same tool each time. On the site www.reiseroute.de you can find a number of Route Planning tools.

In some cases transport by truck is divided in several part transports, from factory to the terminal of the transport provider and from there to the customer. Instead of using the direct distance, you should use the distance actually travelled. If there is a significant difference in the transport from the factory to the terminal and from the terminal to the customer, it should be divided in two part transports.

4.1.2 Calculation of environmental data

The energy consumption of the truck and the emissions per km depend on the following factors:

- Average fuel consumption (km/l)
- Average weight of load when loaded (ton)
- Euro-Norm 0,0 – 4,0 (Euro-Norm)
- Percentage of km without load.

Step 4 shows all transport means in the chain, and by pressing Parameters you can change the calculation basis.

Transport Chain - Step 4 of 4

Mode 1 of 1

Truck

Type:
Default: Truck 16.5m 40t
Year: 2001

Parameters...

Change Parameters

Mode 1 of 1

Parameter:	Value:
Average load when loaded (m3)	48
Average weight of load when loaded (ton)	16
Euro-norm	1,5
Exhaust reduction technology type	1
Average fuel consumption (km/l)	2,87
Percentage of km without load	9

OK Cancel

Help < Back Calculate Cancel

Press Calculate to get environmental data of the transport. Hereafter it is not possible to return and change the data.

Average volume and cargo weight for all goods carried on the truck(s).

The truck's EURO-norm 0-4, may be average.

If catalyst/filter is used, select the type here.

Fill in km/l, or default values are used.

% of km without load, 0 is entered if cargo weight and km/l has been calculated of all km, otherwise the % of km without payable freight is entered.

Figure 7. Parameters that can be changed. As many true values as possible should be specified, as a minimum km/l.

Transport without load is calculated as a trip, which follows upon the calculated trip. If km/l is specified, this is also used for transport without load. Otherwise the energy consumption and emissions of transport without load are calculated as 75% of what a truck carrying 16 tons freight would consume.

The Euro-norm may vary between 0 and 4. By truck transport the Euro-norm of the actual truck is specified, but when multiple trucks are used for transport of goods to a customer during a year, the average can be specified with one decimal. The average Euro-norm may also be applied, when there is no registration of the trucks that have carried out the concrete transports, but the average of the trucks used by the forwarder is known.

The diesel consumption depends on the total average goods weight. The maximum goods weight is 25 tons. Table 1 shows some rough values for km/l as function of the goods weight. If no km/l is specified, OMIT calculates km/l as function of the total average goods weight and Euro-norm.

Table 1. Km/l in intervals for an average load between 0 and 25 tons for Euro-norm 1-4

Load tons	0-½	>½-3	4-7	8-11	12-16	17-21	22-25
km/l	4	3,75	3,5	3,25	3	2,75	2,5

For Euro-norm 0, the consumption is approx. 1.5% higher.

When a smaller truck is used for a short pre- and end-haulage trip, it may be included in the calculations. You can make corrections by making a part transport for the allocation truck and add the correct values for the used truck to step 4 in "Parameters" as minimum km/l, Euro-norm and the average goods weight. Due to differences in engines etc. it will cause a minor error in the different emissions, and it ought not be used, except when the part transport accounts for a small part of the total transport (see enclosure A.1). For calculation of longer transports in Denmark please see the national calculation program TEMA2000, to be found on the homepage of the Danish Ministry of Transports: www.trm.dk.

4.1.3 Allocation of the energy consumption and emissions on the freight

The energy consumption and emissions are allocated by weight or volume depending on the specific gravity of the goods.

When the goods weigh more than 333 kg per m³, it is calculated as heavy goods, and the allocation will be according to the total weight on the truck as specified in step 4 "Parameters" "Average weight of load when loaded" (ton).

If the goods weigh less than 333 kg per m³, it is calculated as voluminous goods, and the load is charged with the share of space it takes up of a normal truckload. If volume of the goods is specified in step 1 "Volume of cargo" (m³), it is charged corresponding to the share of "Average load when loaded" (m³) in step 4.

When calculation is done according to other freight specifications than m³, e.g. loading metre or pallet space, these units may be converted to m³. This will have influence on the allocation of energy consumption and emissions between the goods on the truck, if the load weighs less than 333 kg per m³, but it will not influence the total energy consumption and emissions.

*In step 1 volume of cargo (m³) is to be specified besides weight of cargo. For loading metres the number of loading metres freight is multiplied by the volume in m³ of the truck and divided by the number of loading metres on the truck.
For 2 loading metres goods on a trailer that holds 72 m³ the calculation is:
$$= 2 \text{ loading metres} * 72 \text{ m}^3 / 13,5 \text{ loading metres} = 10,66 \text{ m}^3.$$*

*In step 4 you select the button "Parameters" and for "Average load when loaded" (m³) the average number of loading metres sold is multiplied by the volume in m³ of the truck and divided by the number of loading metres on the truck. For the above-mentioned truck the calculation would be:
Truck with average freight of 11 loading m = $11 \text{ loading m} * 72 \text{ m}^3 / 13,5 \text{ loading m} = 58,66 \text{ m}^3.$*

*In the above example the goods will now be charged with $10,66/58,66*100\% = 18,18\%$ of the total environmental load from the transport.*

4.1.4 Example of calculation

P.E. El receives a delivery of a full 20' container with partially assembled computer cabinets that have a total weight of 4 tons. Environmental data is wanted for the truck transport from Bremerhaven to the factory in Jutland. The transport provider informs P.E. El that two containers are used, but this is all the data he gets. A fair calculation of the emissions is based on the

average values for transport by truck in OMIT, including a goods weight of 16 tons.

As a 20' container fills up half a truck, P.E. El's cabinets should carry half the environmental load. This is done by setting "Volume of cargo" (m³) in step 1 to 46 and "Average load when loaded" (m³) in step 4 to 92.

If the computer cabinets are transported in a 40' container, the calculation will be made on the basis of a total load weight of 4 tons, as the truck can carry no additional goods.

4.2 Calculation and allocation of environmental load for train

Theoretically trains can go wherever there are tracks. In reality most goods are carried by complete trains in a few established corridors. European freight transport by rail predominantly takes place by electric driven trains. Shunting and short distances may be carried out by diesel driven trains, but this has hardly ever a significant influence on the total picture of the environmental load of the transport.

Trains differ from the other transport modes in the way energy is not transferred to work on the transport mean, but it is produced by water and coal power plants and is shared by a large number of users. Concerning different users of electricity, this is easy to manage, but it is difficult when the energy consumption and emissions have to be divided between consumers of electricity and heat from the same power plant.

As combined heat and power supply is rare outside of Denmark, these circumstances do not have much significance in international transports. It is, however, included in OMIT, because it is possible to use two different methods for dividing energy consumption and emissions, either the method of the EPA which presumes an energy efficiency of 200% for heating (standard), or the energy method where energy consumption and emissions are divided according to the produced energy, regardless of whether it is electricity or heat.

The use of green electricity and nuclear power has big influence on the emissions in international railway transport. When the railway companies buy electricity produced on water, wind, sun and/or nuclear power, railway transport by electric engines has no emissions.

Furthermore green electricity has lower energy consumption. For electricity produced on coal the consumption is related to the energy in the coal that was burned. Depending on the power plant, there is an efficiency of 33 to 40%, corresponding to a loss of between 67 and 60% of the coal energy in the transformation to electricity. When the energy consumption and the emissions for electricity are calculated, it includes both what became electricity and what was lost.

When using green electricity it does not make sense to talk about efficiency; what could be measured, the loss - the wind? So when for example an electric train driven by coal, uses 33 MJ electricity + 67 MJ loss, the engine, driven by green electricity, only uses 33 MJ green electricity + 0 MJ loss = 33 MJ to carry out the same work. A comparison of the energy consumption of the transport modes therefore makes no sense, while the emissions from the transport are comparable. For nuclear power the efficiency per convention is 33%.

4.2.1 Corridors and distances

For railway transport the main corridors, which are used for freight to and from Denmark were selected. Additionally some smaller railway stations are included in order to be able to account for all the way to the customer.

In the principal network systems the distances cannot be changed, as they are often crossing country borders and thus using different sources of electricity. In the secondary network system, which is situated within an area of electricity production, distances and names of places may be changed so that it corresponds with the actual situation. If the secondary railway station to which the goods are transported is not listed, select another in the same country and overwrite name and distance with the correct data.

It is characteristic for secondary railway stations that if they are selected in the upper box, there will only be railway stations from the same country in the lower box, try for example with respectively Hamburg (main stations) and Bochum (secondary stations) in Germany.

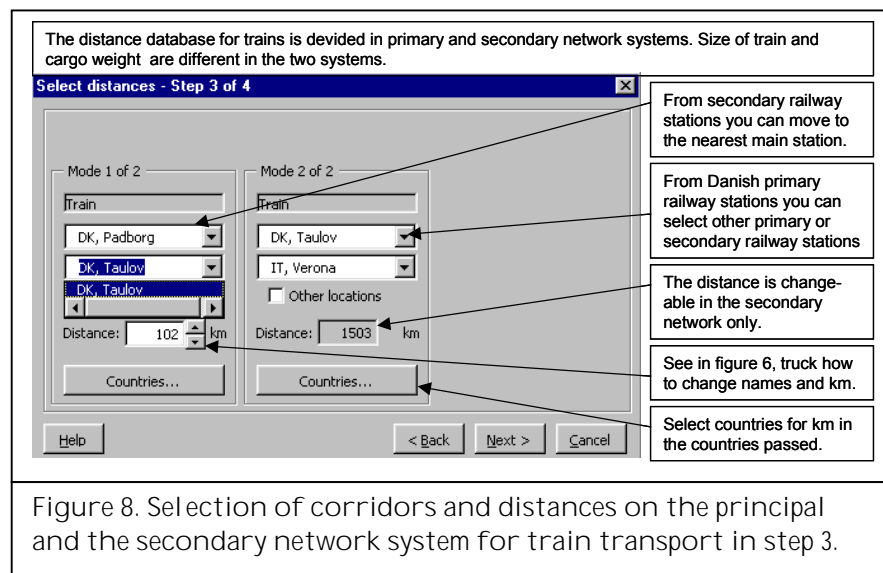


Figure 8. Selection of corridors and distances on the principal and the secondary network system for train transport in step 3.

When diesel trains are to a great extent used for the transport, the place name must be specified "Dummy location 1" and "Dummy location 2", which can later be overwritten with the real place names. First you find the distance for electric trains then you select the Dummies, overwrite the distance, which is 100 km as default, and correct the place names.

You may get the railway distances from the transport provider, or for short distances, you may measure them on a map. They are also available on some homepages, e.g.:

- www.railcargo.at under "kundenservice/serviceleistungen/DIUM/"
- www.greencargo.com under "miljökalkyl".

4.2.2 Calculation of environmental data

On the distances mostly used, the principal network system, the trains are full most of the time, whilst outside the principal network system a mix of full and empty wagons is transported. The allocation of the environmental load is therefore calculated on the basis of the average load in the principal network system respectively in the secondary network system.

In OMIT energy consumption and thus emissions, is calculated as a function of the total weight of the train not including the locomotive. The total weight of trains is calculated as number of wagons multiplied by the weight of an empty wagon including the weight of for example swap bodies and containers plus the total average weight of goods carried on the train.

The locomotive is not included in the calculation as a variable, as it is usually changed in case of border crossings. Furthermore the engine must have a certain basis weight to be stable and pull the wagons; therefore the weight does not vary very much.

The necessary energy and the resulting emissions are calculated by the country for an average of the electricity production of the country, unless the railway company buys or produces specific electricity. The electricity production data used for the individual countries is showed in enclosure B.1

In Step 4 all transport means in the chain are shown, and by pushing Parameters it is possible to change the calculation basis.

Parameter:	Value:
Energy allocation model	1
Average weight of wagons excl. goods (ton)	23
Total weight of cargo (ton)	650
Number of wagons	24

Press Calculate to get environmental data of the transport. Hereafter it is not possible to return and change the data for the transport.

Figure 9. Basic data for train transport depend on whether the principal network system or the secondary network system is used.

Environmental data for railway may vary a great deal from year to year, e.g. if a railway company changes from buying green electricity without emissions to buying electricity produced in a coal power plant.

4.2.3 Allocation of energy consumption and emissions on the goods

The total energy consumption and emissions are allocated on the freight carried on the train. The allocation is always done in relation to the share of the total average weight of goods carried on the train. The total average goods weight is the average of both outgoing and returning trips in the corridor used.

The default data used are calculated on the basis of block trains with swap bodies, so-called combined trains. As a freight train is a very variable unit, it is recommended to collect data from the operator of the trains used. If this is not possible, the following values may be used in step 4 "Parameters" for the remaining traffic in the principal network system.

Table 2. Values for international trains with closed or open wagons, respectively containers

	Weight of empty wagon	Total weight of freight	Number of wagons
Closed wagons	21,6	561	22
Container wagons	25,6	473	22
Open wagons	16,6	671	22

See enclosure B.2 for basic data for train.

For trains in the secondary network system the total weight of goods should be reduced by 60% and the number of wagons by 20%. These are estimated values based on, among other things, Danish figures in "Godstransportkæder" (TetraPlan A/S, 1999).

4.2.4 Example of calculation

65 tons freight transported in the principal network will be charged with 10% of the environmental load for a train carrying 650 tons goods. When the train returns empty, the total average goods weight stated would be 325 tons, and the goods will be charged 20% of the environmental load instead.

The allocation of environmental load takes place only on the basis of weight, i.e. it doesn't matter if the freight fills up 2 or 12 wagons.

4.3 Calculation and allocation of environmental load for Ro/Ro ferries

The term ferry includes a mixed group of ships, which carry passengers, passenger cars, trucks and containers that are placed on deck. All this may be carried individually or mixed; that is a ferry is not a well-defined unit with few characteristic parameters as is the case for the other ship types - container ships and bulk carriers.

In order to maintain OMIT as an easy-to-use model, one calculation model was selected, which covers the so-called Ro-pax ships and Ro/Ro cargo ships, latter of which can carry only few or no passengers besides the rolling goods.

4.3.1 Corridors and distances

Figure 10. The ferry services are selected in the list. See fig. 6 for truck for description of the functions of the screen.

In step 3 you select the actual ferry service. OMIT contains the distances for the ferry services to and from Denmark and across the Channel, that are used most frequently.

If other ferry services are used, you may get the distance from the shipping company or you may measure it on a

map. The latter may apply if e.g. small amounts of goods are transported to Cyprus by truck. Here the work effort should be in relation to the importance in the total result. It is also possible to find sea distances on the Internet, for example: http://pollux.nss.nima.mil/pubs/pubs_j_show_sections.html?dpath=DBP&ptid=5&rid=102 or via link from www.skibstekniskselkab.dk. (1 nautical mile = 1,852 km).

4.3.2 Calculation of environmental data

Ferries maintain regular service with more or less capacity utilisation, and as mentioned they are not a homogeneous group. In OMIT it has been chosen to carry out calculations for a typical cargo ferry with 2000 lane metres (1m = metre lane). As ferries, however, have very different sizes, speed, oil consumption/h and capacity utilisation, it is strongly recommended to use the real values for oil consumption. You may get them from the shipping company.

Freight transport by ferry is settled by use of lane metres and this is the unit used for calculation and allocation of energy consumption and emissions.

The following parameters are included in the calculations of energy consumption and emissions:

- Specific oil consumption (ton/h)
- Capacity lane metre
- Capacity utilisation (%)
- Average weight per lane metre (ton/lane metre)
- Speed (knots)

Step 4 shows all transport means in the chain, and by pressing Parameters it is possible to change the calculation basis.

Transport Chain - Step 4 of 4

Mode 1 of 1

Ro-Ro Ship

Type: Default: Ro/ro long distance
Year: 2001

Parameters...

Change Parameters

Mode 1 of 1

Parameter:	Value:
Capacity (lanemetres)	2000
Length of Truck/trailer/container (metre)	14
Weight of cargo on truck/trailer/container (ton)	16
Speed (knots)	18,9
Specific oil consumption (ton/h)	0
Reduction technology, Nox (g/kWh)	12
Sulphur content of oil (percentage)	1,5
Capacity utilization (percentage)	75
Average weight per lanemetre (ton/m)	1,755

OK Cancel

Help < Back Calculate Cancel

Capacity in lane metres. Default is 2,000 lm.

The length of truck/trailer/container in lane metres.

Total cargo weight on carrier in tons.

Speed can be changed +/- 10%.

Oil consumption per hour should be stated if known.

NOx reduction technology if known.

Percentage of sulphur content in oil.

Capacity utilization, default 75%.

Average weight per lane metre for the entire ferry. Trucks weigh 2 t/lm, un-accompanied trailers weigh 1,5 t/lm.

Press Calculate to get environmental data for the transport. Hereafter it is not possible to return and change data for the transport.

Figure 11. Basic data for Ro-Ro ferries long distance (> 500 km). For shorter distances "Length of truck/trailer/container" is default t 16,5 m. The speed must be changed if the ship size is changed.

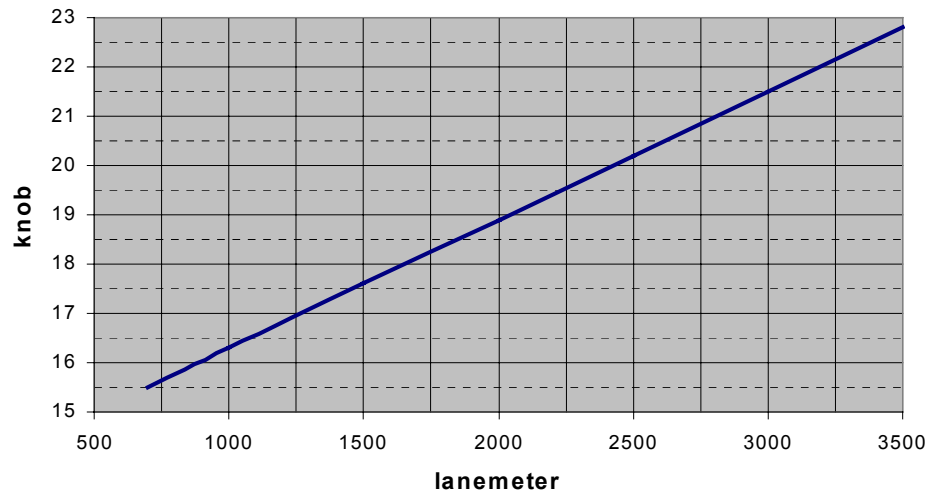


Figure 12. Normal ferry service speed in knots as a function of lane metres for Ro-Ro cargo ferry.

If the size of the ship is changed, the user must also change the speed. In OMIT the deviation may be up to +/-10% from the service speed shown in figure 12.

The oil consumption per hour primarily depends on the speed and the size of the ship, and secondarily on the weight per lane metre and the capacity utilisation. The oil consumption is default 0, and if no value is specified, OMIT will calculate on the base of the default values. Enclosure C.1 shows the oil consumption per hour as function of lane metre.

4.3.3 Allocation of energy consumption and emissions on the freight

Energy consumption and emissions are allocated on the total of used lane metres and are hereafter charged the truck/trailer/container according to length. (Length of Truck/trailer/container (lane metre)).

A trailer measures approx. 14 lane metres, a semi-trailer 16,5 lane metres, a road train approx. 18,5 lane metres and one TEU approx. 6,1 lane metres.

If containers are double-stacked on a Ro/Ro ferry, the increased capacity utilisation can be corrected by dividing the length of the deck used by the containers. In the field "Length of Truck/trailer/container (lane metre)" 3,05 lm per double-stacked TEU is specified.

When goods from different shippers are carried on the same truck/trailer/container, the environmental load is allocated according to share of weight. (Total weight of cargo on Truck/trailer/container (ton)).

4.3.4 Example of calculation

A shipping company informs that the ferry has 2400 lane metres, and no further specifications are given for the service. Figure 12 indicates a speed of 20 knots. For a 16,5 m truck with standard values the energy consumption will then be 2,0 MJ per tonkm.

The itinerary indicates, that the forward speed is 21,5 knots. When this value is specified in step 4, "Parameters" under "Speed" (knots) it is seen that the

energy consumption is 2,5 MJ per tonkm, or an increase of 25% by an increase in speed of 7½%.

4.4 Calculation and allocation of environmental load for container ships

Container transport by ship is a comprehensive and specialized line of transport. This gave the effect, among other things, that the different lines are served by ships of very different sizes. OMIT therefore has typical sizes for the container ships, depending on the covered distance between the ports. These distances are only intended as a guide, as a container ship serving Europe-Asia, could have 2 calls of port in Europe with a distance of 1.000 km between them, although it holds 6,000 TEU.

Table 3. Ship size as function of distance covered

Interval km	0 - 926	927 - 2779	2780 - 4629	4630 - 6483	6484 - 10186	10187 - r
TEU	500	1000	2000	3000	4000	6000

The size of the ship is expressed in number of containers it holds. The size is specified in

TEU = Twenty Foot Equivalent = 20' container.

4.4.1 Corridors and distances

For container transport you can select destination and departure ports from a list. It works in two ways, as destination and departure ports are not arbitrary:

- European container transport to and from Danish container ports, including feeder transport to the Atlantic ports
- Overseas container transport from the Atlantic ports (Bremerhaven, Hamburg, Rotterdam and Gothenburg) to the rest of the world.

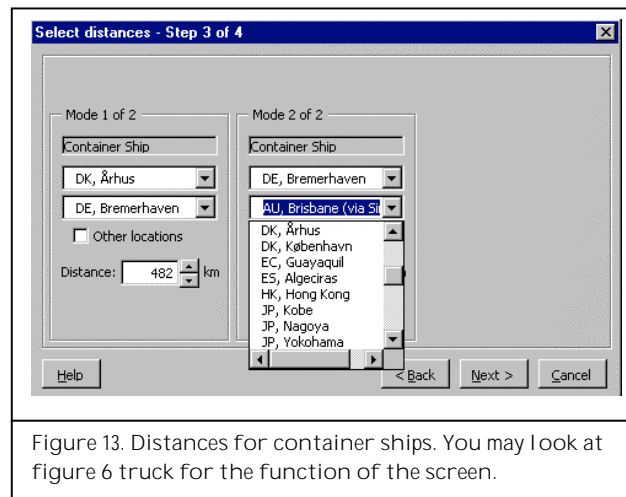


Figure 13. Distances for container ships. You may look at figure 6 truck for the function of the screen.

You can overwrite names by using the field "Other locations", and you can change distances by using the arrow keys at "Distance".

If, however, it is a matter of ship transport from Aarhus to Brisbane, not only the distance needs to be changed but also it is essential to describe the transport chain correctly. This is done by returning

to step 2 in the program and adding an extra part transport in order to divide the trip in a pre-transport from Aarhus to the called Atlantic port e.g. Bremerhaven, and a main transport from Bremerhaven to Brisbane.

As seaborne transport of containers to and from Denmark takes place on feeder ships, the distance in the database is based on passage through the Kiel Canal. For ships bigger than approx. 2,000 TEU, the distance north of Skagens Odde should be used instead.

Some of the larger shipping companies have web sites, where you can see the actual transport chain and distances. If you cannot find the distance here, you may find it on the Internet, e.g.:

http://pollux.nss.nima.mil/pubs/pubs_j_show_sections.html?dpath=DBP&ptid=5&rid=102 or via link on www.skibstekniskselkab.dk. (1 nautical mile = 1.852 km).

4.4.2 Calculation of environmental data

Step 4 shows all the transport means in the chain, and by pressing Parameters it is possible to change the calculation basis.

Number of TEU depend on the distance.

Transport Chain - Step 4 of 4

Mode 1 of 2
Container Ship
Type: Default: Container-500
Year: 2001
Parameters...

Mode 2 of 2
Container Ship
Type: Default: Container-6000
Year: 2001
Parameters...

Change Parameters

Mode 2 of 2

Parameter:	Value:
Capacity (TEU)	6000
Actual number of TEU	4500
Weight of cargo per TEU for actual container	7,5
Speed (knots)	26,2
Specific oil consumption (ton/h)	0
Reduction technology, Nox (g/kWh)	17
Sulphur content of oil (percentage)	3

OK Cancel

Percentage of sulphur in the oil. NOx reduction.

Press Calculate in order to get environmental data of the transport. Hereafter it is not possible to change the data of the transport.

Figure 14. Basic data for container ships. Please notice that the size depends on the distance but the capacity utilisation is default t 75%.

The following parameters are used in the calculation of energy consumption and emissions for container ships:

- Specific oil consumption (ton/h)
- Capacity (TEU)
- Actual loading (TEU)
- Speed (knots)

When the ship capacity is changed, you are required to change the speed, see fig. 15.

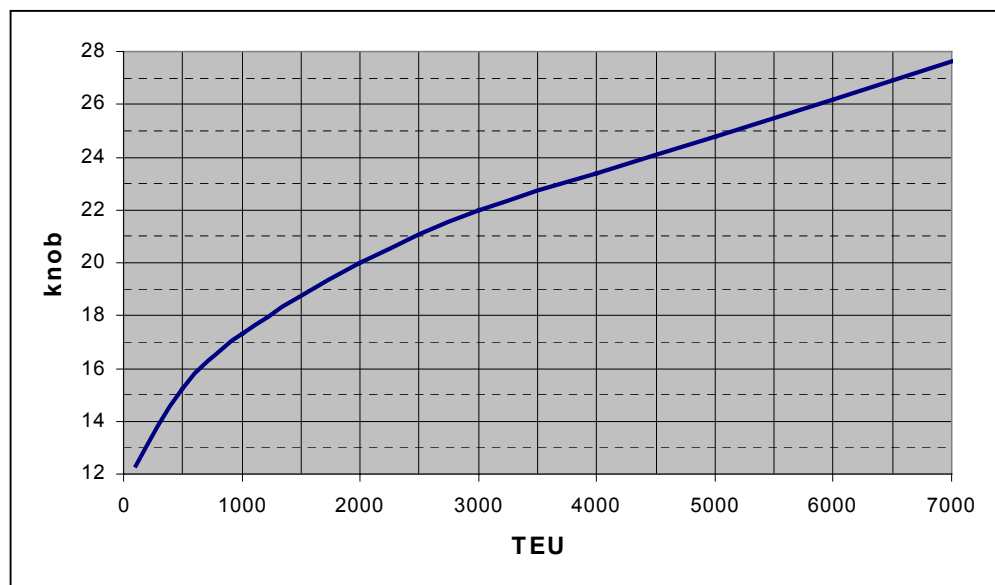


Figure 15. The normal service speed of a container ship depends on the size. Calculation can be made for normal service speed of the container ship +/- 10%.

In C.2 an oil consumption/h as function of ship capacity in TEU by 75% capacity utilisation is showed.

A container (TEU) on the ship has an average weight of 10 tons incl. 7.5 tons of goods. This cannot be changed. The used average weight per TEU being only 10 tons is owing to the fact that the maximum loading capacity of a container ship corresponds to ten times the total number of TEU that the ship can carry.

Weight of cargo per TEU for actual container is only valid for the containers that transport the goods, which are basis for calculation. The figures are used for allocation of environmental data on the goods in the actual container; see section 4.4.3.

4.4.3 Allocation of energy consumption and emissions on the goods

As freight for containers is calculated according to the number of TEU, the total environmental load for a trip is allocated evenly on the number of TEU carried on the ship, regardless of the weight of the TEU in question.

When goods from or for different customers are carried in the same container – general cargo/consolidated goods/part loads, the total emissions for the container are allocated on the goods according to the *weight of cargo per TEU for actual container* that the customer's goods account for.

4.4.4 Example of calculation

A transport of 22 tons meat is carried out in a 40' container from Aarhus to Bremerhaven. In step 4 "Weight of cargo per TEU for actual container" 11 tons is specified, and the total energy consumption is 124 MJ per ton.

If the shipment were 26 tons in a 40' container instead of 22, the energy consumption would drop to 105 MJ per ton. This is in accordance with reality, as the additional goods weight in one container has next to no influence on the total energy consumption of the ship.

4.5 Calculation and allocation of environmental load for bulk carriers

Default for a bulk carrier in OMIT is 45,000 tons loading capacity, but it is possible to make calculations from 2,000 to 150,000 tons loading capacity. As bulk carriers are often chartered for the actual transport tasks, it is important to use the right size in order to find the real environmental load.

4.5.1 Corridors and distances

Transport of bulk cargo by bulk carriers mostly takes place from A to B. Loading takes place in one port and unloading in another. In OMIT there is a database, which includes direct distances from Aarhus, Copenhagen and Esbjerg to a number of ports in Europe and to major overseas ports.

If there is only little freight, it is an option to measure the distance on a map, otherwise the correct distance should be acquired from the shipping company or via the Internet, e.g.:

http://pollux.nss.nima.mil/pubs/pubs_j_show_sections.html?dpath=DBP&ptid=5

&rid=102 or via link on www.skibstekniskelskab.dk. (1 nautical mile = 1,852 km).

For bulk carriers the distance is calculated under the presumption that the ship goes via Skagens Odde and not via the Kiel Canal, which is too small for many of the ships used. (A maximum of depth 9.5 m and approx. 28,500 tons loading capacity).

The Suez Canal can be passed by bulk carriers with up to approx. 142,500 tons loading capacity. If larger ships are used, the distance south of Africa must be calculated.

4.5.2 Calculation of environmental data

The energy consumption per km is a function of:

- Specific oil consumption (ton/h)
- Capacity (ton)
- Actual loading (ton)
- Speed (knots)
- Ballast in % of total distance travelled

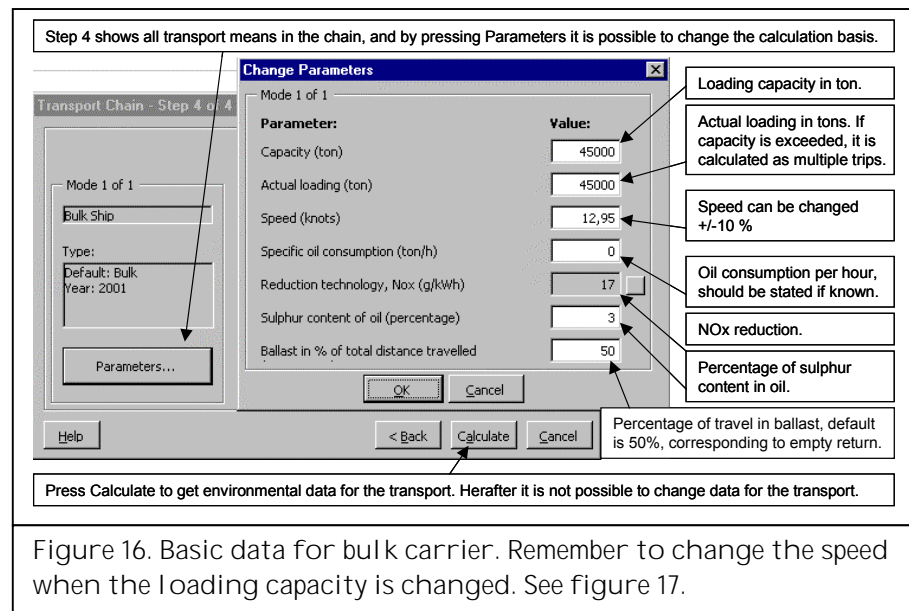
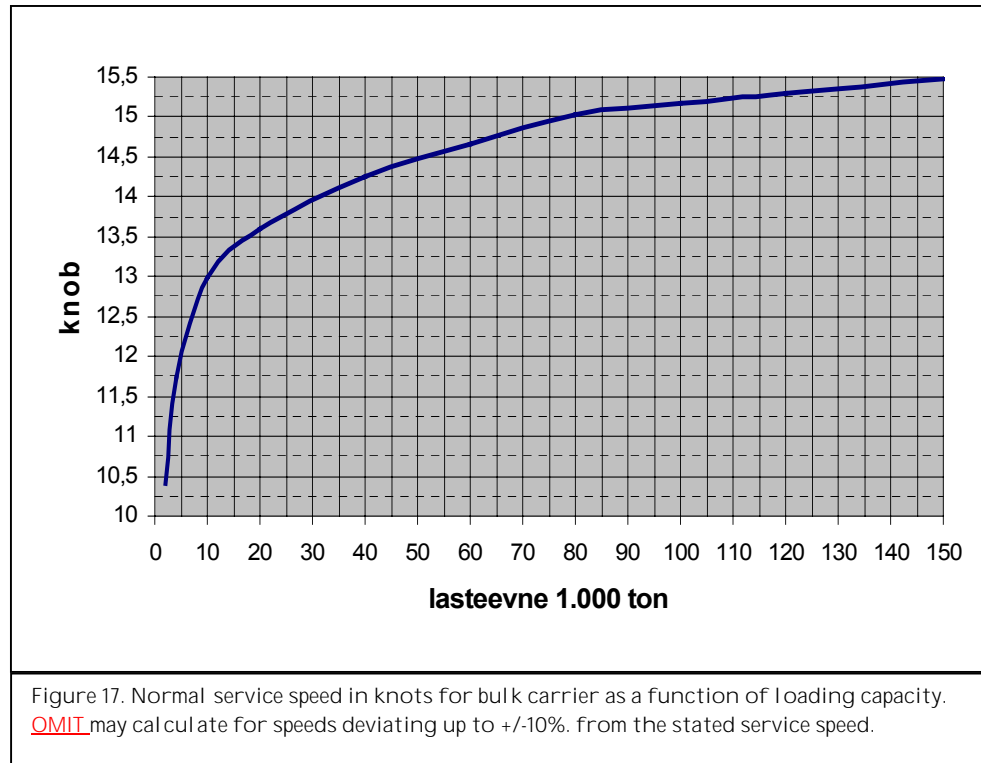


Figure 16. Basic data for bulk carrier. Remember to change the speed when the loading capacity is changed. See figure 17.

Enclosure C.3 shows the oil consumption/h for a bulk carrier as a function of the size of ship with 100% loading and before ballast voyage.

When the share of ballast voyage is included it is owing to the fact that bulk cargo often include some transport without load. An example of this is the oil tankers that carry raw oil to Europe and return empty; they have a ballast share of 50%. The energy consumption for an empty bulk carrier is approx. 94% of what it is, when it is fully loaded. This high value is due to the fact that the speed is typically higher in ballast, than when the ship is loaded, and that the ship must fill up its ballast tanks in order to press the propeller sufficiently, but also in order to keep a certain draught ahead.

The ballast share has influence on the calculations, because it increases the energy consumption per km depending on the ballast percentage, while the distance is not influenced.



4.5.3 Allocation of energy consumption and emissions on the goods

The allocation of the energy consumption and the emissions is often done by goods weight; i.e. the shipment is charged with a share of the energy consumption and emissions according to the share, the weight of the shipment makes up of the actual shipload. If the weight of the shipment exceeds the actual capacity, it will be calculated as succeeding trips.

4.5.4 Example of calculation

A feedstuff business has purchased 88,000 tons of grain in France. The options are to have it shipped via Aarhus on a coaster with a capacity of 8,000 tons in the same pace it is sold, respectively to rent warehouse capacity in the port and charter a bulk carrier with 44,000 tons loading capacity.

By using the small ship, the energy consumption will be 433 MJ per ton and by using the big ship it will be 171MJ per ton.

4.6 Results

The results are showed in two Excel spreadsheets. One shows the results and the other one shows the preconditions for the calculations. In the one showing the preconditions, the changes in default values are highlighted for easy control.

It is possible to arrange the results and paste them into different Windows applications for environmental reports for customers or to draw data and make further calculations with them in a spreadsheet.

OMIT 1.0

User:WS
Company:Fabrikk
Calculation date:13-04-01
Calculation time:12:26

Origin:Fabrikk 1
Destination:London
Description:Marts måned leverancer af bacon.
Weight of Cargo (ton):72
Volume of Cargo (m3):0
Year of calculation:2001

	Distance in km	Energy Consumpti on in MJ	Emission CO2 in g	Emission SO2 in g	Emission CO in g	Emission HC in g	Emission PM10 in g	Emission NOx in g	Emission CH4 in g	Emission Particles in g
Mode										
Truck	127	5768	422804	14	460	194	86	4389	0	n/a
Ro-Ro Ship	626	55218	4086100	40639	10864	3395	n/a	81482	n/a	2958
Truck	136	6177	452766	15	493	208	92	4700	0	n/a
	889	67163	4961670	40668	11817	3797	179	90571	0	2958

	Distance in km	Energy Consumpti on in MJ	Emission CO2 in g	Emission SO2 in g	Emission CO in g per km	Emission HC in g per km	Emission PM10 in g per km	Emission NOx in g per km	Emission CH4 in g per km	Emission Particles in g per km
Mode										
Truck	127	45,4	3329,2	0,1	3,6	1,5	0,7	34,6	0,0	n/a
Ro-Ro Ship	626	88,2	6527,3	64,9	17,4	5,4	n/a	130,2	n/a	4,7
Truck	136	45,4	3329,2	0,1	3,6	1,5	0,7	34,6	0,0	n/a
	889	75,5	5581,2	45,7	13,3	4,3	0,2	101,9	0,0	3,3

	Distance in km	Energy Consumpti on in MJ	Emission CO2 in g	Emission SO2 in g	Emission CO in g per ton	Emission HC in g per ton	Emission PM10 in g per ton	Emission NOx in g per ton	Emission CH4 in g per ton	Emission Particles in g per ton
Mode										
Truck	127	80,1	5872,3	0,2	6,4	2,7	1,2	61,0	0,0	n/a
Ro-Ro Ship	626	766,9	56751,4	564,4	150,9	47,2	n/a	1131,7	n/a	41,1
Truck	136	85,8	6288,4	0,2	6,8	2,9	1,3	65,3	0,0	n/a
	889	932,8	68912,1	564,8	164,1	52,7	2,5	1257,9	0,0	41,1

	Distance in km	Energy Consumpti on in MJ	Emission CO2 in g	Emission SO2 in g	Emission CO in g per tonkm	Emission HC in g per tonkm	Emission PM10 in g per tonkm	Emission NOx in g per tonkm	Emission CH4 in g per tonkm	Emission Particles in g per tonkm
Mode										
Truck	127	0,6	46,2	0,0	0,1	0,0	0,0	0,5	0,0	n/a
Ro-Ro Ship	626	1,2	90,7	0,9	0,2	0,1	n/a	1,8	n/a	0,1
Truck	136	0,6	46,2	0,0	0,1	0,0	0,0	0,5	0,0	n/a
	889	1,0	77,5	0,6	0,2	0,1	0,0	1,4	0,0	0,0

Figure 18. Result sheet. Standard Excel spreadsheet, layout and decimals defined by the user. The use of particles or PM10 is defined by the units of the basic models.

Basic assumptions			
Sequence no.:			
Transport Mode:	Truck	1	
Mean of Transport:	Truck 16.5m 40t		
From:	Fabrikken.	...	Dummy location
To:	Esbjerg.	...	Dummy location
Distance (km):	127		0
Parameter 1 - Average load when loaded (m3):	48		
Parameter 2 - Average weight of load when loaded (ton):	24		16
Parameter 3 - Euro-norm:	2		1,5
Parameter 4 - Exhaust reduction technology type:	1		
Parameter 5 - Average fuel consumption (km/l):	2,36		0
Parameter 6 - Percentage of km without load:	9		
Sequence no.:			
Transport Mode:	Ro-Ro Ship	2	
Mean of Transport:	Ro/ro long distance		
From:	DK, Esbjerg		
To:	UK, Harwich		
Distance (km):	626		
Parameter 1 - Capacity (lanemetres):	2000		
Parameter 2 - Length of Truck/trailer/container (metre):	16,5		14
Parameter 3 - Weight of cargo on truck/trailer/container (ton):	24		16
Parameter 4 - Speed (knots):	18,9		
Parameter 5 - Specific oil consumption (ton/h):	0		
Parameter 6 - Reduction technology, Nox (g/kWh):	12		
Parameter 7 - Sulphur content of oil (percentage):	1,5		
Parameter 8 - Capacity utilization (percentage):	75		
Parameter 9 - Average weight per lanemetre (ton/m):	1,755		
Sequence no.:			
Transport Mode:	Truck	3	
Mean of Transport:	Truck 16.5m 40t		
From:	UK, Harwich		
To:	UK, London		
Distance (km):	136		
Parameter 1 - Average load when loaded (m3):	48		
Parameter 2 - Average weight of load when loaded (ton):	24		16
Parameter 3 - Euro-norm:	2		1,5
Parameter 4 - Exhaust reduction technology type:	1		
Parameter 5 - Average fuel consumption (km/l):	2,36		0
Parameter 6 - Percentage of km without load:	9		

Figure 19. Basic data for the calculations. Where standard values are changed and for km/l the original values are to the right of the new value.

4.6.1 Using the results

A large number of factors have significance to the total energy consumption and emissions of a transport. It is therefore important to include all factors when looking at changes in the elaboration of the transports.

A change in time of dispatch of the goods may thus influence the entire transport chain.

There may be direct impact on both number of km covered, the average weight of goods on the truck and percentage of empty load. More indirectly the Euro-norm, filter technology and km/l may be influenced, when changing transport provider.

Further in the transport chain the new time of shipment may imply a different station of departure or use of a different ferry service.

Optimisation of freight transport is, as appears of the above example, a complex task which is never ending.

OMIT does not deliver easy solutions, but it may contribute to an indication of whether or not the course is right towards less energy consumption and emissions for each ton of goods.

5 List of words

CO	Carbon monoxide. Develops from incomplete combustion of coal and carbonaceous substances, e.g. in internal combustion engines. CO is a very toxic gas and causes death in heavy concentration.
CO ₂	Carbon dioxide. Greenhouse gas, developing from incomplete combustion of carbonaceous fuels and from oxidation of CO.
The Energy Content Method	Allocates the primary energy consumption and emissions on the produced electricity and heat according to the energy content.
The Method of the Danish Energy efficiency Agency	Allocates the primary energy consumption and emissions on the produced electricity and heat by the assumption of 200% in heat production.
EURO-norms	EU limits for trucks' maximum emissions (diesel) of NO _x , CO, HC and particles.
HC	Hydrocarbons. Organic compounds that stick to particles from the exhaust gas. Smells unpleasantly and can be injurious to health.
knot	1 nautical mile per hour, 1 knot = 1.852 km/h.
kWh	Kilowatt-hour. Energy unit. 1 kWh = 3.60MJ
Loading metres	Unit for number of M full width of trailer, semi-trailer or truck.
Lane metres	Unit for number of M truck lane available on a ship.
MJ	Mega joule. Energy unit. Equals 1,000 KJ and 0.278 kWh.
NO _x	Nitrogen oxide. Nitrogen compound. Most processes of combustion develop different nitrogen compounds, typically NO and NO ₂ . NO _x er may cause irritation of the respiratory tracts, asthmatic reactions, acid rain and it contributes to developing ozone and photochemical smog.
Pallet spaces	Unit of area which states how many pallets, each 0.8 x 1.2 M, (EURO-pallets) can be transported.
Particles	Are found in e.g. exhaust gas from combustion engines. Particles may cause difficulty in breathing and irritation of lounge tissue.
PM10	Particles smaller than 10 micrometer.
Ro-Ro	Roll on/roll off ships are built to carry trains, trucks, trailers, semi-trailers, containers and other carriers equipped to be driven aboard.
SO ₂	Sulphur dioxide. Develops by burning sulphur-containing fuel. SO ₂ may cause acid rain, acidifying of lakes, watercourses and ground and corrosion of buildings.
Nautical mile	1 Nautical mile = 1,852 M, 1 km = 0.54 Nautical mile.
TEU	Twenty foot Equivalent Unit. Used as measure for size of container ships. 1 TEU = a 20' container.

5.1 Country codes

AR	Argentina
AT	Austria
AU	Australia
BE	Belgium
BR	Brazil
CA	Canada
CL	Chile
CN	China
CZ	Czech Republic
DE	Germany
DI	Code for average European diesel driven train, emissions depend to a high extend on type of diesel oil and age of the engine
DK	Denmark
EC	Ecuador
EE	Estonia
ES	Spain
FO	Faeroe Islands
FR	France
GL	Greenland
HK	Hong Kong
HR	Croatia
HU	Hungary
IS	Iceland
IT	Italy
JP	Japan
KR	South Chorea
LT	Lithuania
MY	Malaysia
NL	Holland
NO	Norway
NZ	New Zealand
PA	Panama
PE	Peru
PL	Poland
PT	Portugal
RU	Russia
SE	Sweden
SG	Singapore
TW	Taiwan
UK	Great Britain
US	United States of America

6 References

COWI, TEMA2000

Program and Appendix reports on the homepage of the Danish Ministry of Transports, WWW.trm.dk. 2000.

TetraPlan A/S, Godstransportkæder, miljø- og omkostningsforhold, Transportrådet 1999.

7 Enclosures

List of enclosures

A: Truck

1. Data foundation truck.

B: Train

1. Basic data for train and production of electricity. Note from IFEU, Heidelberg.
2. DSB Trafikplanlægning og Miljø note about train sizes.

C: Ships

1. RO/RO oil consumption per hour, as function of loading metres at 75% capacity utilization
2. Container oil consumption per hour, as function of TEU at 75% capacity utilization
3. Bulk oil consumption per hour, as function of tons at 100% capacity utilization
4. Note about average ages.

Data basis truck

Data for a 40 tons truck are not available in TEMA2000 at present; therefore the calculations are based on a 48 tons truck. These two truck types and the transports they carry out being different in many ways causes errors in the result. Using realised diesel consumption figures in OMIT, these errors are expected to be insignificant.

The energy content in diesel is 36.295 MJ/l - at 42.7 MJ/kg diesel, 850 g / l diesel.

Km/l is found by dividing 36.295 by "Energy consumption in MJ per km" from the result sheet.

We refer to TEMA2000 for further documentation.

The calculations are based on simulation in TEMA2000 as showed in table 3.

Table 1. Energy consumption in MJ per km.

Tons cargo	EU 0	EU 1-4
1	9.4894	9.3491
2	9.6988	9.5554
3	9.9082	9.7617
4	10.1176	9.968
5	10.327	10.1743
6	10.5364	10.3806
7	10.7458	10.5869
8	10.9552	10.7932
9	11.1646	10.9995
10	11.374	11.2058
11	11.5834	11.4121
12	11.7928	11.6184
13	12.0022	11.8247
14	12.2116	12.031
15	12.421	12.2373
16	12.6304	12.4436
17	12.8398	12.6499
18	13.0492	12.8562
19	13.2586	13.0625
20	13.468	13.2688
21	13.6774	13.4751
22	13.8868	13.6814
23	14.0962	13.8877
24	14.3056	14.094
25	14.515	14.3003
26	14.7244	14.5066
27	14.9338	14.7129
28	15.1432	14.9192

The emissions depend on the cargo on the truck. They are load dependant and are thus calculated on the basis of the consumption measured as MJ/km. Table 2 shows an example of the basis of the formula for an EURO 2 engine.

Table 2. Formula for EURO II truck.

EURO II			
MJ per km as a function of cargo weight in tons			
$Y = 9.1428 \text{ (MJ/km)} + 0.2063 \text{ (MJ/tkm)} * X \text{ (tons)}$			
g/km as a function of MJ/km $Y = a * X + b * X^c$			
	a (g/MJ)	b (g/MJ)	c
CO ₂	73.3	0	1
SO ₂	0.0024	0	1
CO	0	0.3411	0.4652
HC	0	0.3398	0.1488
PM ₁₀	0	0.1186	0.2382
NO _x	0	0.8743	0.9489

Table 3. Calculation requirements in TEMA2000.

Fuel	Low-sulphur
Travel speed, motorways outside urban areas	80
Travel speed, other ways outside urban areas	70
Share of trip, motorways outside urban areas	90
Share of trip, other ways outside urban areas	10

Travel speed in km/h - Share of trip in %.

In order to maintain OMIT as an operational tool, a number of the parameters in TEMA2000 have been set on default values. Table 3 shows the parameters used in OMIT for international transport.

There is an option for using different kinds of waste gas cleaning. These influence the emissions as showed in table 4.

Table 4. Multiplication factor for waste gas technologies.

	PM ₁₀	NO _x	CO
Oxid. kat	0.81	0.95	0.1
Kat+filter	0.06	0.95	0.1

Finally it may be useful to include a short pre- or end haulage in OMIT, rather than calculating it separately. As the different engines have different emission profiles, it will cause an error. The energy consumption, however, will be correct, if you take basis in the realised km/l and distribute the emissions on the goods, which follow the model for the 40 tons trucks.

Hence the energy consumption and emissions are distributed on the goods by its share of the average goods weight or when voluminous goods, by the share of the transported volume. The calculation includes all driven km, and if the method is used for transported goods, all emissions and the energy consumption from the actual truck will be distributed on the goods. (Nothing will be "forgotten").

You can get an idea of the error by using the mentioned method and look at table 5, where data for 40 tons is compared with distribution trucks from TEMA2000.

Table 5. Deviation in % per ton goods for distribution trucks from TEMA2000 for calculation in OMIT based on diesel consumption data and the used standard export truck and driving pattern.

truck type	capacity utilisation	tons cargo	Energy consumption	SO2	CO2	CO	HC	NOx	PM10
25 t	50 %	8,5	0	0	0	19	27	0	29
10 t	50 %	2,6	0	0	0	48	64	3	62

As shown in table 5 there is no deviation for the direct diesel dependant components as energy consumption, SO2, and CO2. For the other components the deviations vary between 0 and 64%, mostly for a 10 tons truck. Thus it also appears that this approximate method can only be applied, when it is a matter of a limited part of the total transport.

Standard values for driving without load are 9%, EURO-norm is 1.5 and the average cargo weight of 16 tons is based on Danmarks Statistik, 2001:20.

Padborg, 2001.

Energy consumption and pollutant emissions from rail freight transport

This chapter gives the details of the approach and data sources for the consumption and emission figures for rail transport in Europe. This includes the emission factors from electricity production in different countries, the allocation rules between the good under consideration and the whole train and the standardised distances used.

7.1. General method

Most international rail freight transport to and from Denmark is confined to a few main lines. The attempt is to capture these typical and dominant transports while staying simple and user friendly. Therefore a limited number of corridors for rail transport is defined. Data apply for these conditions in particular. For destinations off these main corridors the user can use a delivery train recommended not to be used for more than 100 kilometres transport distance.

As trains differ a lot in size, weight of cargo and average utilisation it is recommended to get specific data from the transport operator, not the least when corridors outside the main lines are used.

The European main line corridors for rail transport to and from Denmark are specified in table 1 based on data from Kombi Dan and DSB Cargo division - 2000.

Table 1. Final destinations for main lines from DK. main stations in between are not mentioned.

	Northbound	Southbound
Destinations	Stockholm, Borlänge, Oslo	Salzburg, Verona, Luino, Milano Rogoredo, Port Bou, Hendaye, Calais, Bremerhafen

International and long distance rail transport is carried out almost exclusively by electric traction. Therefore diesel traction is treated here only as an option for delivery to and from the main lines and consequently not treated in the same detail.

Furthermore international rail transport mostly goes in block trains [KombiDan 2000]. Hence data are typical for this train configuration.

The user is not expected to know about the rail transport operation in detail. He/she is only asked to specify the transport distance along a given corridor and the transported mass. All other parameters for the calculation are given as default values.

There are two steps needed in order to determine the energy consumption and emissions from electric trains:

1. Determine the consumption of electricity of the train.

2. Determine the conversion efficiency and pollutant emissions for electricity production at power stations.

The multiplication of both values gives the respective consumption of energy and emissions from train transport¹.

Each step is considered on its own in the following.

7.2 Factors influencing the energy consumption of trains

Numerous factors influence the energy consumption of a train. Most obvious are the transport distance and the total train mass. To abstract from these only specific values, i.e. per kilometre travelled and per gross hauled mass, are discussed in the following. Further factors for freight trains are [e.g. Anderson 2000, Brunner & Pelli 1998, Meyer et al. 2000, Schwannhäuser et al. 1986, EuroTC 1997]

- Aerodynamic resistance, depending on cross sectional shape, length and body resistance and the velocity by the square,
- Rolling resistance, depending on the bearing resistance and the mass,
- Inertia, depending on mass and acceleration,
- Topology and route characteristics, in particular inclinations, tunnels and bends,
- Driving characteristics, i.e. speed and acceleration,
- Electric equipment and efficiency of the locomotive, including recuperative brakes,
- Auxiliary energy consumption, e.g. for cooling, lighting, etc.
- Weather conditions, e.g. wind and outside temperature.

For the application here a number of factors however are fixed and not influenced by the transport under consideration:

- We consider given corridors, therefore topology and route characteristics are fixed.
- The trains usually run on schedule, hence the driving characteristics are predetermined;
- We consider annual averages: Therefore we assume typical values for the train configuration, determining aerodynamic and rolling resistance, for the locomotives with their electrical and mechanical characteristics, for weather conditions etc.

In consequence when the train's configuration and operation as well as its route are given the total mass - thus indirectly also the train length - remain as parameters determining the specific energy consumption.

Empirical data show that the specific energy consumption of trains becomes less with increasing gross hauled mass, i.e. that energy consumption increases much less as the weight increases. The main task is to determine the form of this dependence.

¹ Remark: From a life cycle perspective it is necessary to include all energy input and emissions for the exploration, digging, raffination and transport of the primary energy carriers. These are neglected here to be compatible with the system boundary used in TEMA 2000, that sets the standard for this task.

7.3 Specific electricity consumption of trains

Existing data for the specific energy consumption of trains are either representative for a whole network, but not differentiated or differentiated for trains but not representative for the whole system. Therefore we combine the findings from both approaches.

Representative data are derived from top down values, typically the total electricity consumption by trains in a period divided by the transport volume in that period. Values derived this way are averaged over all driving conditions, train and locomotive types, configurations, routes etc in that period, exactly as needed for our task. They are taken as reference points for the *absolute value*. The absolute values differ from railway to railway. For the purpose here it is sufficient to differentiate between flatland networks, e.g. Denmark, midland networks, e.g. Germany, France, Italy, and mountainous networks as Switzerland and Austria.

The accuracy of the data is however considerably hampered by two circumstances: There is no physical way to differentiate the electricity consumption of freight trains from passenger trains when taken from the same electric net. Hence the allocation of the respective amounts to freight and passenger transport is up to the discretion of the railways. Second, the transport volume is usually not known exactly but is a nominal figure taken from freight papers or bills. To what extent these so-called tariff ton-kilometres coincide with the actual ton-kilometres performed, e.g. due to a different loading or diversions of the line, is not known. The related uncertainty of the top down values is estimated to be at least ± 30 percent.

Differentiated data, e.g. from dynamical models, are taken to determine the *shape* of the functional dependence of the specific energy consumption on the gross hauled mass. A functional dependence in the form

$$q = 675 * M^{0.5} \quad M \text{ in Gt, } q \text{ in Wh/Gt*km}$$

could be derived for block trains from [Schwanhäusser et al. 1983], which is compatible with the functional dependence derived by DSB [TEMA 2000] and with empirical data from DB, (fig. 1).

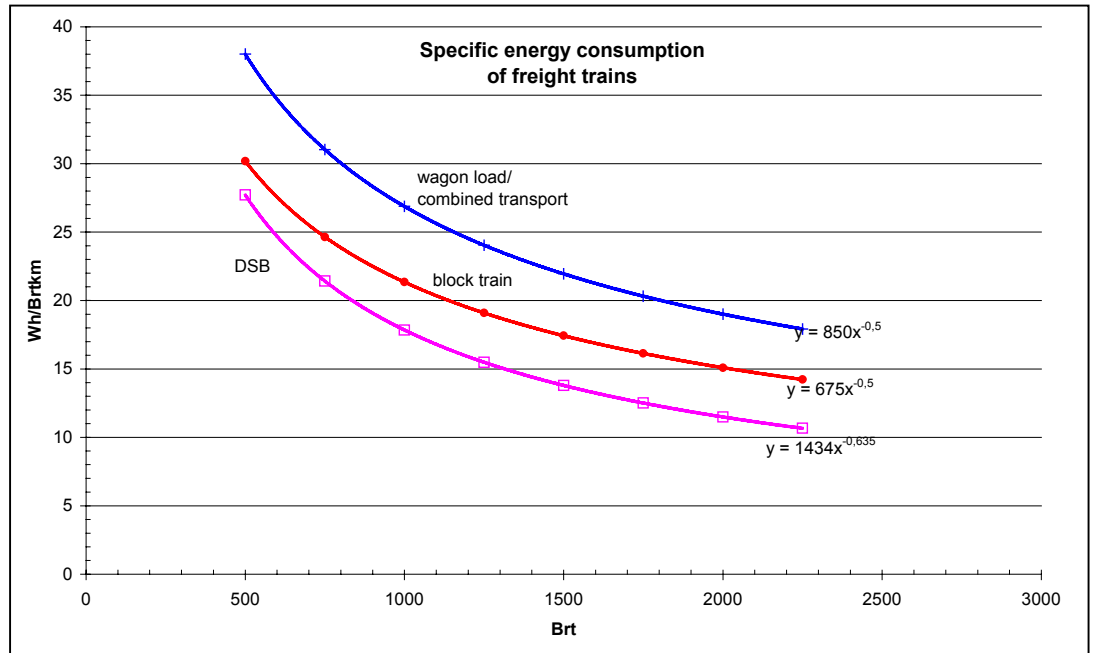


Fig. 1: Average specific energy consumption of freight trains depending on gross-hauled mass. Formulas used here.

The same functional dependence of the specific energy consumption on the gross hauled mass is assumed for all networks. The absolute value is decreased for flat countries and increased for Switzerland and Austria, i.e. for Alpine-crossing transport (table 2). Modern traction technology and recuperative brakes are positively taken into account. Yet in 2000 this modern technology is not in place for all lines, not all energy recuperated on the locomotive can be used again (and will partly disseminate therefore) and heavy freight trains must use conventional brakes as well, therefore always losing part of the kinetic energy [Meyer & Aeberhard 1999, Meyer et al. 2000].

Table 2: Specific electricity consumption of electric freight trains, averaged over the lines in the different countries (Gt: Gross hauled mass = weight on the hook).

Network	Specific energy consumption In Wh/Gt*km
Denmark, Sweden	$540 * M^{-0.5}$
Germany, France, Italy, Spain, Portugal, Belgium, UK, the Netherlands, Poland, Hungary, Czech Republic, Norway,	$675 * M^{-0.5}$
Switzerland, Austria	$810 * M^{-0.5}$

7.4 Emission factors for electricity production

The specific electricity consumption is multiplied with the energy efficiency of the electricity chain and the emission factors from the power plant to give the total emissions.

The emission factors and the efficiency of conversion for the electricity production (in g/kWh primary energy of fossil input fuels) are derived from a standard inventory [Frischknecht et al. 1996] (France, Italy and the UCTPE-Mix) and by IFEU [Knörr et al. 2000] (for Germany). For Austria and Switzerland additional information is used [ÖBB 1998, SBB 1998].

As result the data for France, Italy and the UCTPE-Mix are based on the public electricity production; for Austria the electricity mix based on the public electricity production according to [Frischknecht et al. 1996] and in addition 30% electricity produced by hydro power from ÖBB-power plants [ÖBB 1998]. The Swiss railways use only hydro power for electricity production [SBB 2001]. For Germany the electricity mix of the German Railways (DB AG) for 1998 from the TREMOD-model is used [Knörr et al. 2000].

The following tables (3-4) show the share of input energies, the average efficiency factor for fossil power plants and the emission factors which are used in the model.

Table 3. Share of primary input energies and overall efficiency factor for fossil power plants (weighted average over technologies)

In %	DK	N	D	F	I	CH, S	A	UCTPE
Share nuclear	0	0	29,0	74,5	0,0	0,0	0,0	37,0
Share green	13	95,0	11,0	15,5	22,0	100,0	78,0	16,0
Share fossil	87	5,0	60,0	10,0	78,0	0,0	22,0	47,0
Efficiency factor fossil	37,0	37,0	36,9	35,4	37,5	-	38,1	35,6

Table 4. Emission factors for fossil power plants (weighted average over technologies)

g/kWh	DK	N	D	F	I	CH, S	A	UCTPE
CO ₂	333	333	334	300	256	-	257	308
SO ₂	0,63	0,63	0,33	1,72	2,07	-	0,53	1,93
CO	0,300	0,300	0,082	0,059	0,05	-	0,05	0,04
NO _x	0,69	0,69	0,26	0,73	0,74	-	0,28	0,54
HC	0,023	0,023	0,011	0,02	0,03	-	0,02	0,02
PM	0,018	0,018	0,012	0,059	0,07	-	0,03	0,08

All countries important for Danish rail freight transport are thus treated with a country specific energy mix. The UCPTE mix is applied for all other countries, which is a simplification justified by the small transport volume.

In OMIT cogeneration of heat and power are taken into the calculations. specifically for Denmark and Norway, the latter importing 20 % of the power from Denmark [Andersen 2001]. The efficiency factor for heat for Danish fossil fuel is 32 %, thus reaching an overall efficiency of 69 % for heat and power.

The allocation of primary energy consumption and emissions on power and heat can be done by two different methods.

- The model recommended by the Danish Energy Agency, and default in the model is the so called 200 % method. This allocation model takes the quality of the produced energy into consideration and therefore uses an efficiency factor for heat of 200 %.
- The other model that can be used for allocating primary energy and emissions in OMIT on power and heat is the energy content method, the allocation is then based only on the energy content produced.

As seen from the Danish example with efficiencies of 37 % and 32 %, using cogeneration and employing the latter method for allocation of primary energy consumption and emissions, almost halves the environmental load from train transport.

7.5 Data for delivery trains (diesel)

To account for rail transport off the main lines the user can calculate a diesel driven train, typical for marginal lines. Usually they have much less capacity utilisation, frequent stops, older stock and higher aerodynamic resistance. All these factors lead to a higher specific energy consumption. On the other hand the speed is lower, reducing the specific consumption. Reliable and representative data on this transport form do not exist. The values here are not differentiated by country or network due to the low share and thus low importance of diesel trains in long distance transport.

The same functional dependence as for electric traction (for secondary lines) is taken and has to be divided by the efficiency of the diesel-electric conversion of about 37% [Feihl, 1997]:

$$q = 675810/0,37 * M^{-0,5} \quad M \text{ in Gt, } q \text{ in Wh/Gt*km}$$

The emission factors for diesel trains are linked to the fuel consumption. The following values are taken [Borken et al. 1999, TEMA 2000]:

Table 5. Diesel emission factors g/kWh.

CO ₂	266
SO ₂	0,076 assuming 450 ppm S in diesel fuel
CO	1,4
NO _x	4,61
HC	0,5
PM	0,216

Because the system boundary here had to be chosen equal to TEMA 2000's boundary the emission factors and conversion efficiencies of the refinery are disregarded.

7.6 Standardised distances for international rail freight transport

The distance data are taken from the standardised international rail freight distance tables DIUM for each country [DIUM 2000]. These data are generally used by transport operators. Moreover these standardised rail distances are also the basis for the top down values of transport volume and hence correspond well to these values. These data were modified such that the distance AC equals the sum of the distances AB and BC (assuming B is a location on the standard track between A and C).

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Information for the OMIT project about freight trains across the Danish borders

The information from extract "International trains (trains that have crossed the border in Padborg respectively Copenhagen) during the period 2.7.2000 to 23.1.2001."

The extract gives information about the maximum size at train has had in Denmark, and not the size it had when crossing the border.

Shipment weight is weight of freight (i.e. exclusive of weight of wagon) for container wagons the weight of the container is included.

TRAIN

- 50% of the wagons are found in trains consisting of more than 22 wagons.
- 50% of the freight (assessed as weight of shipment) is transported on trains with a total weight on the hook (not including locomotive) of more than 1,037 tons.
- 50% of the freight (assessed as shipment weight) is transported on trains with a total shipment weight of more than over 550 tons.

Wagons

Due to the assessment method it is not possible to see whether a wagon is loaded or empty. The calculation is thus done by dividing total goods weight for a wagon type by the number of wagons of this type.

Wagon types can be divided in the following 3 categories: closed wagons, container wagons and other open wagons.

- 50% of the freight transported in a closed wagon has a cargo weight of more than 25.5 tons (including empty wagons)
- 50% of the freight transported in a container wagon has a load weight of more than 26.5 tons (including empty wagons)
- 50% of the cargo transported in an "other open" wagon is transported in a wagon with a cargo weight of more than 30.5 tons (including empty wagons)

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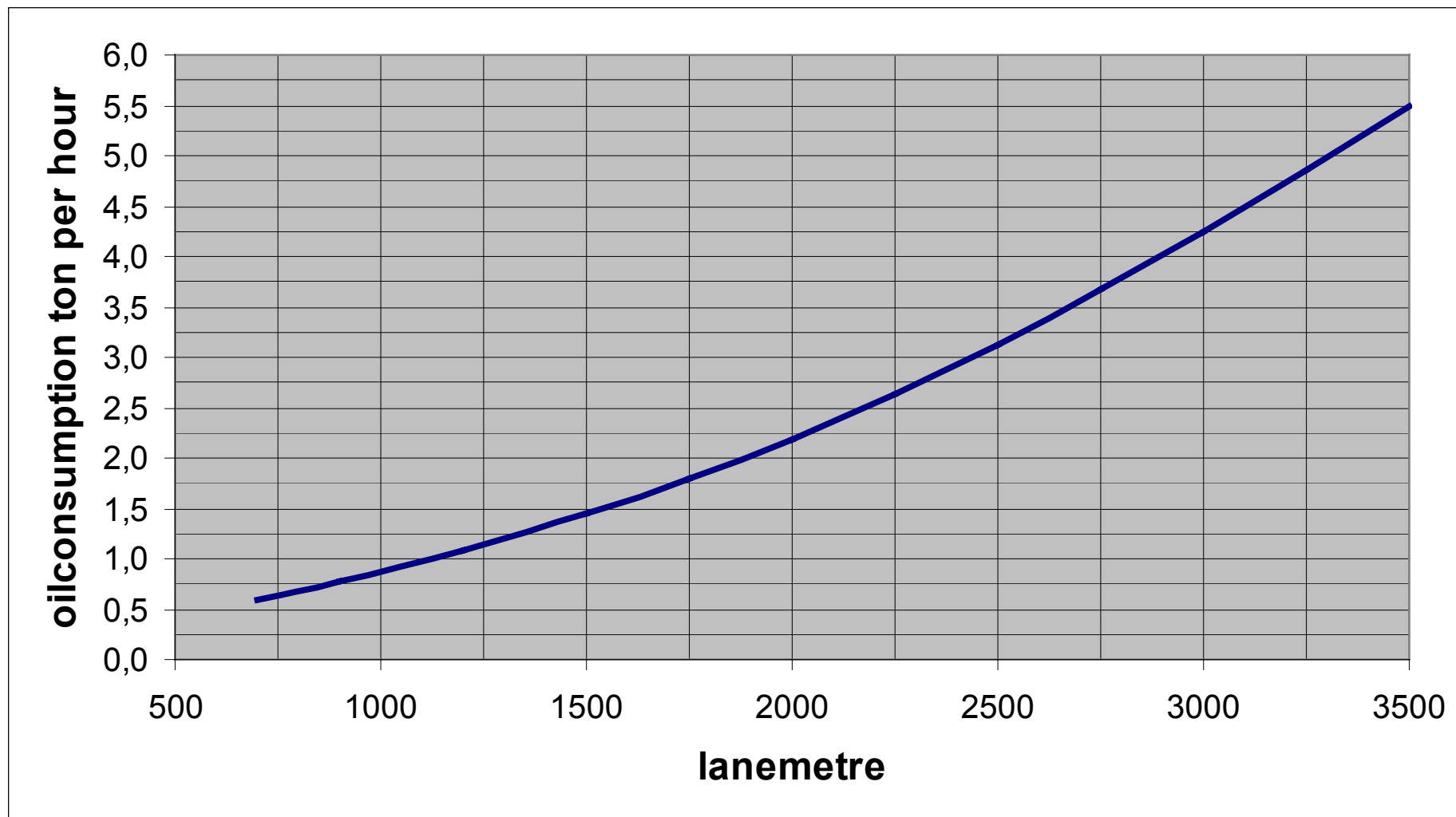
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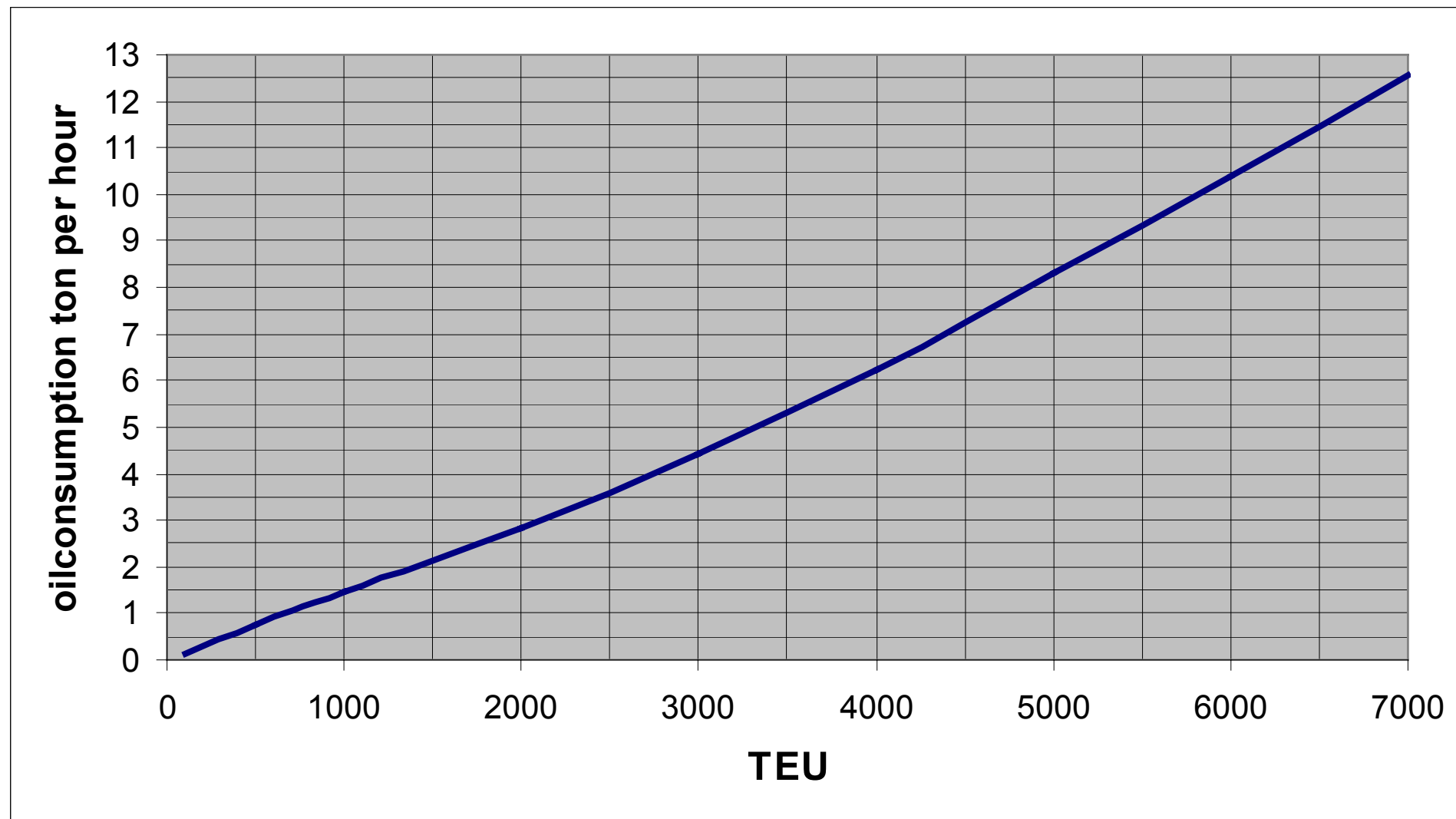
The allocation of the total transported cargo weight on the different wagon types:

- 26% of the cargo weight is transported in closed wagons
- 26% of the cargo weight is transported in container wagons
- 48% of the cargo weight is transported in "other open" wagons.

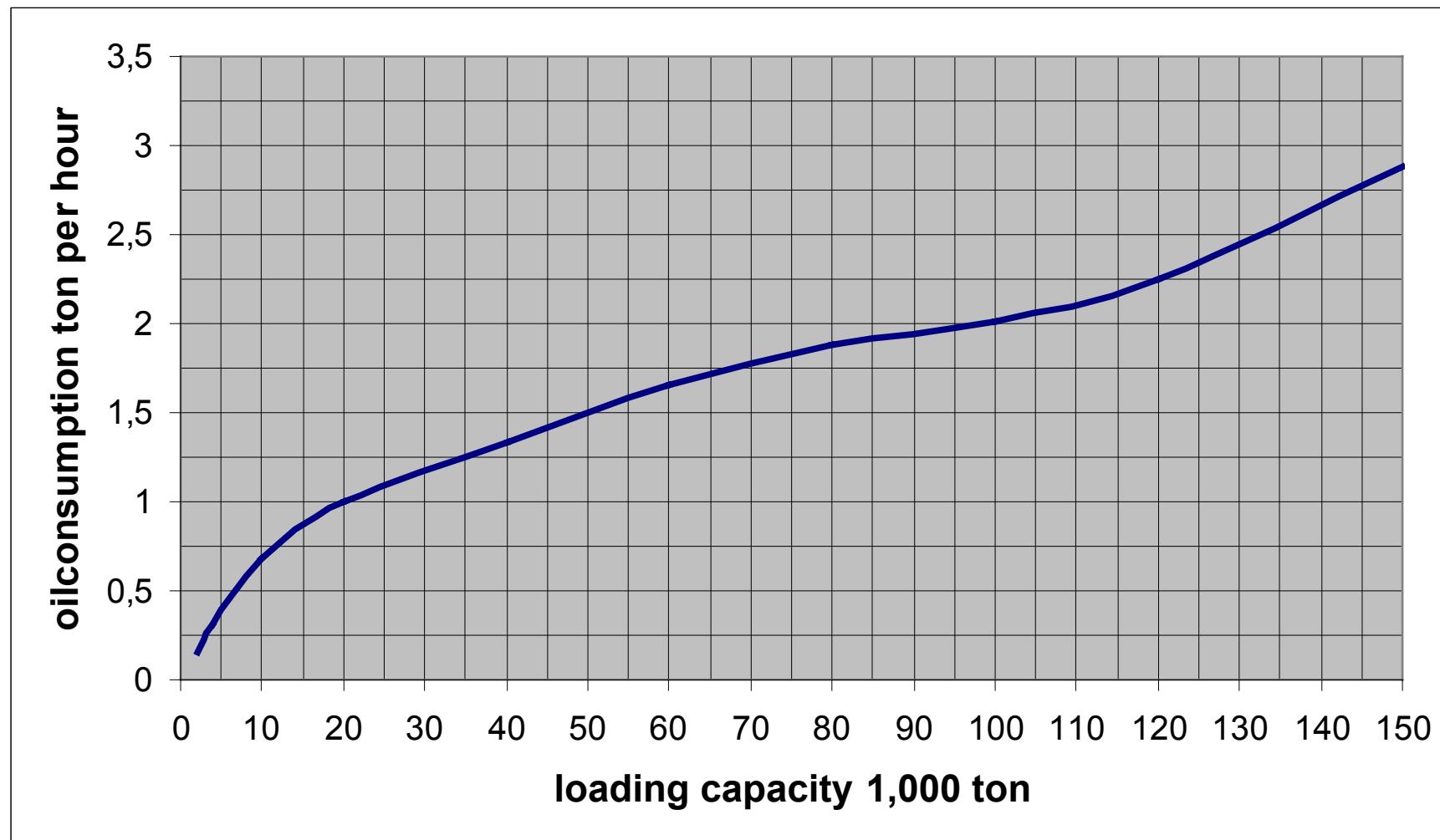
Enclosure C.1 RO-RO ferry



Enclosure C.2 Container ship



Enclosure C.3 Bulkcarrier



Ships' average age - energy consumption & emissions

1. Average age

According to the Danish Shipowners' Association, the average age of the different ship types under Danish colours is

Tramp vessels (not in line service). (Bulk carriers belong to this category):

11.7 years

Cargo vessels in line service (e.g. Container ships and Ro/Ro ships): 6.2 years

Tankers: 8.0 years

Passenger ships/ferries: 14.6 years

Special ships (Offshore vessels, ships for cattle transport etc.): 11.4 years

2. Correction of the energy consumption

Based on the average specific oil consumption in 1973 and 1999 of respectively 220 g/kW hour and 170 g/kW hour the additional oil consumption based on 2000 is as follows: $(220 - 170)/170/27 \times 100 = 1.09\%$ per year

As all calculation formulas for energy consumption apply for new ships with basis year 2000, we suggest the following correction in percentage, which means that a ship is considered as an in average older ship:

Bulk carriers: $11.7 \times 1.09 = 12.8\%$, i.e. correction factor: 1.128

Container ships and Ro/Ro cargo ships: $6.2 \times 1.09 = 6.8\%$, i.e. correction factor: 1.068

3. Correction of emission factors

In the same period of time there has been hardly any progress as for emissions, which is why only changes in oil consumption specifically have been considered, which indirectly will also result in a correction of the emissions.

the energy consumption data in Enclosure C.1 to C.3 in OMIT are based on Hans Otto Kristensen, equivalent to TEMA2000.