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Calculating Fuel Transport Emissions

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an example of methods used in a Life-Cycle Analysis of the total Danish energy system

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ABSTRACT:

The current Danish energy system relies nearly completely on fossil energy resources. A large share of the energy carriers that are being consumed in Denmark are not being produced domestically but are imported from other regions. This means a large impact on the global environment.
In this paper the structure of the Danish fuel import is investigated with respect to the transport work necessary for the current import of energy carriers. Fuels are being produced in other countries and are being transported to Denmark. A point gaining in importance in these years is the question of the size of countries' CO_2 emissions. International transport has not been included in any countries CO_2 balances, and the question remains how large this share could be.
Earlier this year the Energy and Environment Group at IMFUFA had calculated the fuel transport related CO_2 emissions to about 5 million tons yearly. This would be considered a large amount compared to the domestic emissions of about 60 million tons.
An overview is given over other studies that have investigated transport related emissions of CO_2. It is found that there for maritime transport is a rather large spread in the specific emissions and energy demand. This necessitates care in interpreting life cycle data, when transport is shown to be an important factor.
In this report we have calculated the fuel transport related CO_2 emissions looking especially at the maritime transport. It is found that in other LCA and externality studies oceangoing ships had been considered to be emitting much more CO_2 than could be substantiated by our work. While this reduces the total import related CO_2 emissions from about 5 million to ca. 1.6 million tons yearly it is still found that maritime transport emits a comparatively large, though not the major, share. The specific emissions for other transport means could be supported.
The amount of ca. 1.6 million tons of CO_2 emitted as a consequence of the current Danish energy system especially is due to the import of coal. This factor is responsible for two thirds of the total import related emissions. For this fuel railway transport plays a large role, this is due to the fact that coal mines normally are not situated close to harbours, and that rail transport is rather energy consuming.
As a result of this work we can state that fuel import is rather energy intensive and that the emissions from it should be monitored in the future.

The text contains a table of contents, an index, and a copious literature list where the reader can find background literature used during this task.

Calculating Fuel Transport's Emissions

Transportare necessare est

For Denmark the import of fuels make up a large impact on the environment. The Danish energy sector is marked by a marked lack of domestic production with respect to fuels used by the electricity sector. The self sufficiency rate with regard to domestic production is exclusively related to the production of crude oil and natural gas. So how much CO_2 emission does the current Danish energy system create by its fuel import? We answer this question later in this paper. We can enlighten the reader with the information that the Danish coal import is responsible for two thirds of the indirect CO_2 emissions from the total Danish fuel import.

Aim and Motivation

In this paper we shall investigate the transport lengths of fossil fuels that are being imported to Denmark. We do this, as this subject has been rather badly investigated before, and we do also investigate how much the import of especially coal actually impacts the environment. The motivation for such an investigation is that we want to describe the full impacts of the Danish energy chain in a different study. And to do this we have to gain information on how the transport of fuels alone impacts the environment.
A special reason for the latter investigation is that the data base for long haul shipping emissions seems to be missleading. A pilot investigation earlier this year gained knowledge that with domestic emissions of about 60 million tons of CO_2 alone, Denmark via its import of energy carriers also was responsible for an extra 5 million tons from the import of fossil fuels. This seems to be a rather high value and one could doubt its reliability. A copy of this text can be found in the appendix.

Impacts from Transport

The impacts of today's transport systems have been investigated in a couple of recent studies (AER, 1995; Transportrådet, 1993) and remain a region of considerable research interest. As a result it has been estimated that the realised costs of the transport services that people see today do not cover the true costs that mobility means for the public *in toto*. The prices of fuels, even though they bear the mark of high consumption taxes overall in Europe, a fact that often is criticised, should include these externalities.

Transport Demand Development in Danmark

From the statistics of the Danish Transport Department we know that, with the exception of the years following the two periods of marked rises in energy prices, the Danish domestic transport amount has been growing steadily during the last decades. This has been acknowledged as posing fundamental problems for the near future, amongst others the stabilisation targets of the domestic CO_2 emissions.
It has also been acknowledged that transport is not without external costs. The transport sector is causing impacts on other sectors of the economy and a large part of the society with respect to impacts from emissions or for example noise and there have been performed studies to investigate the cost potential of such impacts (AER, 1995; Det Økonomiske Råd, 1996; Transportrådet, 1993).

Fuel Import

Transport related impacts are an important factor for a life cycle analysis of the present and any possible future form of the Danish energy system. Currently Denmark is importing a large amount of energy carriers from various parts of the World. The average transport length for a number of transport modes is illustrated in Table 1. As can be seen Coal and crude oil are being transported over rather long distances while petroleum products are not being transported about as long.

Table 1 Average transport length of fuels imported to Denmark

FuelType	Ship	Barge	Diesel	Electr	Road	Pipe	Belt
Coal	8440	402	216	382	19	0	5
Oil	3471	823	0	0	0	254	0
PetrProd	972	910	0	727	0	29	0

Data average between 1986 and 1995 from Danmarks Statistik (1987 to 1996).

Data Sources Production

The data in Table 1 arise from a synopsis of data from the Danish import and export statistics published by Danmarks Statistik. Ten years of data, from 1986 to 1995 both years included, have been used to calculate the average Danish fuel import. The reason to do this was to even out any possible trends that could lead to faulty pictures. Depending on climatological and economical situations the Danish fuel import varies from year to year and another factor that plays a role is the change in the distribution structure.

Danish utilities, responsible for the major share of the Danish coal import, take great care in not getting too addicted from any specific supplier of coal. This means that even though coal prices could be very favourable in one country the utilities will make sure not too exceed a limit of about 30 per cent of the total fuel import coming from that country. This has on the other side the effect that no monopoly rents would have to be paid to any supplier that had tried to gain a large market share by pressing out competitors via low prices.

Data Sources Transport

For the average transport lengths we used data from nautical books and for inland transport from various IEA Coal Research publications and from US government Bureau of Mines 1988 publications, see the literature list. We also used information from other sources, like Diercke (1988) or in places common sense.

Transport is seperated into seven modes: ocean ship transport, barges, diesel and electrically driven trains, road, pipe and belt transport. The distinction between ship and barge transport has been estimated to result from a combination of geographical and logistical considerations. Generally import from European countries will be taking place in smaller sized vessels than from overseas.

Coal is normally transported in large vessels of the order of 100 000 DWT (dry weight tons) from a number of overseas countries that Denmark is importing from. This kind of transport we have called for "ship" transport, and we are thinking of bulk overseas transport. For oil, import will generally be in larger vessels while petroleum products are expected to be transported in smaller vessels. "Barges" therefore relate to vessels of about 10000 or less DWT, with an assumed mean net weight of 5000 tons. This kind of vessels we assume is being used for smaller

colli and for water based transport in Europe. As those vessels are smaller they will have a higher specific energy consumption and so lead to higher emission rates.
In several countries road transport occurs for coal from the mines to the shipping sites while we also have assumed an average belt transport length of about 5 kilometres. Train transport occurs in a number of countries where coal or petroleum products are being transported from the refineries to harbours or other countries. Alhough it is technically possible to pump coal slurries through pipelines (BLM, 1980), pipeline transport only occurs for oil and petroleum products. The transport length for this mode has been estimated mostly from Diercke (1988).

Total Danish Fuel Import

Combining the data previously described, *i.e.* the information on transport distances for import from certain countries and the amounts from the import statistics, we have calculated the total transport work related to the Danish fuel import, Table 2.

Table 2 Total average ton-kilometres of Danish Fuel Import.

FuelType	Ship	Barge	Diesel	Electr	Road	Pipe	Belt
Coal	9.67E+10	4.61E+09	2.47E+09	4.38E+09	2.13E+08	0	5.72E+07
Oil	1.60E+10	3.80E+09	0	0	0	1.17E+09	0
PetrProd	3.47E+09	3.24E+09	1.88E+04	2.59E+09	0	1.04E+08	0

Data average between 1986 and 1995 from Danmarks Statistik (1987 to 1996) and various other sources.

The question now is how these transport lengths relate to the emissions from the transport carriers? How much CO_2 emissions for example are caused by this fuel import? In order to do this one can simply multiply the data from Table 2 with the specific emission factors as given in for example IIASA (1991). This would result in a value of about 5 million tons for CO_2 which seems to be too high. Therefore it has been deemed essential to perform an investigation of the ship transport energy demand and so emission factors. We start with the energy demand for ships, *i.e.* ocean going vessels.

Energy Demand of Ship Transport

From a number of sources it was possible to gain knowledge on the energy demand for ocean transport.

Table 3 Energy Demand for Ocean Transport

Source	Type	Data	Remark
Cowi 1988b, 1-11	ship	1.1 MJ tkm^{-1}	freight ship 1988 (600 t capacity)
Cowi 1988b, 1-12	ship	0.8 MJ tkm^{-1}	freight ship best case 2010 (600 t cap.)
GEMIS 1992, 126	ship	0.1 MJ tkm^{-1}	oil tanker data
GEMIS 1992, 126	barge	0.5 MJ tkm^{-1}	inland vessel
IIASA 1991, 85	barge	0.53 MJ tkm^{-1}	inland shipping
IIASA 1991, 85	ship	0.46 MJ tkm^{-1}	transantlantic shipping
IIASA 1991, 85	*ship*	*0.16 MJ* tkm^{-1}	*upper limit at 1700 km transport length*
IIASA 1991, 85	*ship*	*0.02 MJ* tkm^{-1}	*lower limit at 13000 km transport length*
Nedergaard 1994, 26	ship	0.48 MJ tkm^{-1}	"bulkcarrier"

Typical values given in the literature for the energy demand of ship transport.

As can be seen the amount of energy varies about one magnitude from 0.02 MJ tkm^{-1} to1.1 MJ tkm^{-1} from calculations based on IIASA (1991), respectively Cowi (1988b). As we have stated before the value of 0.46 MJ tkm^{-1} for transatlantic shipping would result in emissions that seem to be too high for the overseas import of Danish fuels. We therefore illustrate the results from a range of studies that give values on energy demand and CO_2 emissions for sea transport in the following.

Transport Pollution Data

Transport causes a series of impacts on the environment: operational pollution, noise, land-use and intrusion, congestion, and risks from the transport of dangerous goods (COM, 1992). Here we shall subsume tables over the transport related emission factors that are available in the literature. The headlines indicate the reference given in the references section of the report.

IEA (1984)

IEA (1994) does not give specific emission factors for bulk carriers ship transport. However in it we can find data for the fuel consumption for four different sizes of bulk carriers. IEA (1984) also mentions that larger sized bulk carriers of the order of 100 000 to 200 000 DWT would be the standard vessels used for coal transport from the late 1980s onwards.

The data are given in tons fuel per day on sea with a march speed of 12.5 knots (nautical miles per hour) and for harbour stay during charge and discharge periods. The latter should be included in the discussion as this energy has to be provided for under all circumstances. The ships infrastructure cannot be shut off during loading and this energy consumption therefore is related to the fuel transport.

Together with the nautical distances one can infer the fuel consumption per single trip, *i.e.* not taking into account the return trip, that for Danish harbours almost never are possible in a laden condition and so only in ballast. Taking into consideration the empty return trip the real figures are therefore around double the ones given inTable 4. However we have decided to look only at single trip values, as we have not gained enough information on that matter from the other studies that we analyze here.

Table 4 Bulk Carriers Specific Energy Demand

MJ /tkm	Fuel saving				Conventional			
Size of vessel	**60 kt**	**120 kt**	**170 kt**	**250 kt**	**60 kt**	**120 kt**	**170 kt**	**250 kt**
SU	0.03	0.03	0.02	0.02	0.04	0.03	0.03	0.03
CD	0.03	0.02	0.02	0.02	0.04	0.03	0.03	0.03
USA	0.03	0.02	0.02	0.02	0.04	0.03	0.03	0.03
Venezuela	0.03	0.02	0.02	0.02	0.04	0.03	0.03	0.03
AUS	0.03	0.02	0.02	0.02	0.04	0.03	0.03	0.03

Source: Own calculation based on data from IEA (1984).

In terms of applicability we note that the values for the former Soviet Union cannot be used as a higher margin. The transport from that country can be expected to take place in shallower vessels in order to cross the Baltic Sea, and therefore even 60 000 tonnes DWT might be an overestimate for the carrying capacity of those kind of vessels.

Based from the data calculated in Table 4 we can now estimate the equivalent specific CO_2 emissions in grams per tonne-kilometre, Table 5. Please note that the number of decimals overstates the actual accuracy of this calculations. The important thing, however, is the ballpark size of the figures relative to the ones of the other studies.

Table 5 CO_2 emissions for ocean ship bulk transport.

Specific Bunker Consumption gCO_2 tkm^{-1}	***Fuel-saving***				***Conventional***			
Size of vessel:	**60 kt**	**120 kt**	**170 kt**	**250 kt**	**60 kt**	**120 kt**	**170 kt**	**250 kt**
SU	2.58	2.04	1.79	1.75	3.48	2.78	2.63	2.58
CD	2.36	1.81	1.58	1.51	3.25	2.55	2.42	2.34
USA	2.35	1.80	1.57	1.50	3.24	2.55	2.41	2.33
Venezuela	2.34	1.79	1.56	1.49	3.23	2.53	2.40	2.32
AUS	2.30	1.76	1.53	1.45	3.19	2.50	2.36	2.28

Data are given for typical import distances to Danish harbours.

The consumption values in IEA (1994) have been corroborated by Jonesarson (1996) in a telephone interview. In it data for a 122,000 DTW 16200 hp bulk carrier have been given as a daily bunker consumption of 47.5 tons at a march speed of 14.11 knots. This ship has an extra diesel driven generator[1] with a capacity of 300 kW, which at a specific consumption of 180 to 185 g fuel per kWh_{el} (Jonesarson, 1996) gives a daily consumption of about 1.3 tons. Considering the weight of bunker, fresh water and proviant the 122,000 DWT mean that the allowable load will be about 110 to 115 kt.

For a fuel saving economy engine ship the consumption would be about 35 tonnes per day, but paying a speed fine so that the marching speed would be reduced to about 13 knots. Priorities with regard to speed or fuel consumption have then be made, but it seems as if fuel saving ships have not been so attractive, probably due to the increasing demand for just in time supplies that make speed a determining competitive factor.

The consumption is also dependent on the region where the ship is sailing. In cold surroundings the heating of the bunker oil to prevent paraffin flocking, which occurs at about 40 C, by the exhaust fumes' heat might not be sufficient so that extra heat has to be provided by a supplementary heating system, thus increasing the fuel consumption (Jonesarson, 1996). For the Danish fuel import we should take this factor into consideration, but it is difficult to estimate the extra energy that has to be used during winter time for imports from *e.g.* the Baltic states.

HVID AND JENSEN (1995)

Hvid and Jensen (1995) do not give specific emission factors but specific fuel oil consumption values (Table 6). From them it is possible to compute the specific CO_2 emissions.

Table 6 Specific fuel oil consumption for several ship types.

Type of ship	**full speed 100 % capacity oil consumption (g/DWT/nm)**	**march speed 100 % capacity oil consumption (g/DWT/nm)**	**full speed 100 % capacity energy demand (MJ/DWT/km)**	**march speed 80 % capacity energy demand (MJ/DWT/km)**	**march speed 80 % capacity energy demand (MJ tkm^{-1})**
Large bulk carrier	1.2	0.3	0.03	0.01	0.01
Large containership	6.7	1.7	0.15	0.07	0.08
Ro-Ro (2 engines)	32.0	8.0	0.70	0.35	0.65
Ro-Ro (3 engines)	71.7	28.7	1.57	0.78	1.45
Coaster	7.2	2.9	0.16	0.08	0.08

[1] There have also been developed generators that are driven by the heavy fuel oil normally used by ship engines. This saves more expensive diesel oil at the expense of higher NO_x and SO_2 emissions.

The values are given for full speed and 100 % capacity utilisation.
DWT: (dead weight tonne) contains bunkers, proviant, fresh water and net load.
march speed: about 80 % of full speed, energy consumption 40 % of full speed values.
To calculate the net mass movement for Ro-Ro ferries it is assumed that HGVs have a carrier weight of 14 tonnes and a load of 16.5 tonnes.
Containers are assumed to have a weight of 3.5 tonnes.

Apparently with its more elaborate composition of the data material this is the best database that we have to estimate the specific emission factors for the different ship types that play a role in the transport of goods. It is remarkable how much the factors for bulk carriers are below the ordinary figures given in the literature for ship transport generally. These figures only seem to apply to Ro-Ro ships.

Table 7 CO_2 emission factors per tonne kilometre for different ship types.

Type of ship	march speed 80 % capacity energy demand ($MJ\ tkm^{-1}$)	Emission factors ($gCO_2\ tkm^{-1}$)
Large bulk carrier	0.01	1.1
Large containership	0.08	6.7
Ro-Ro (2 engines)	0.65	52.7
Ro-Ro (3 engines)	1.45	118.2
Coaster	0.08	6.4

GRANSELL AND EKLUND (1991)

These authors only give data for the total energy consumption of supertankers, smaller tankers, and pipelines in per cent of the energy content of the load (crude oil) as equivalent bunker oil and diesel consumption. The value given is 0.6 to 0.7 per cent of the crude oil's energy content independent of the size of the carrier (Gransell and Eklund, 1994, 18). The energy content of crude oil is about 42.8 GJ per ton (DONG, 1994, 31). This is equivalent to about 278 MJ per ton of crude oil transported.
It is difficult to gain figures in tonne kilometres that we need to calculate the specific energy consumption and CO_2 emissions. We try by combining this figures with the average transport distances given in either EC (1994/4); 1700 km for the return journey; or Lübkert *et al.* (1991); 3460 km; or an estimate from our other statistical analysis on the transport length of oil, see Table 8.

Table 8 Different energy demand for crude oil transport in tankers.

Source	value ($MJ\ tkm^{-1}$)	CO_2 emissions ($g\ tkm^{-1}$)
EC (1995/4)	0.1	7.8
Lübkert *et al.* (1991) @1700 km	0.16	11.8
Lübkert *et al.* (1991) @3460 km	0.08	5.6
Lübkert *et al.* (1991) @13000 km	0.02	1.5

The energy content of crude oil is about 42.8 GJ/t (DONG, 1994, 31).
We have assumed a specific CO_2 emission of 72 g per MJ for crude oil or fuel oil (?).

Except for the 13000 km transport distance at an energy consumption of 0.65 % of the crude oil energy content the data comply well with the one given by EC (1995/4). The last row in Table 8 contains the calculation of the transport energy demand of oil tankers, assuming the EC

(1995/4) value given for the transport distance as 1700 km for the return journey and the energy demand of 0.65 % of the crude oil energy demand as given in Gransell and Eklund (1991)..
Lübkert *et al.* (1991) also mention the average energy consumption of tankers as 1592 MJ/t of transported load. Using the value of EC (1995/4) directly would mean an average transport distance of 15920 km. The transport of Arabian crude oil around the horn of Africa to Denmark is equivalent to a distance of 13000 kilometres, and this value would have been appropriate in the 1970s until the North Sea ressources were explored.
When we calculate the specific energy consumption as being 0.02 MJ tkm1 for oil tankers at the range of 13000 kilometres and a total energy demand of 0.65 per cent of the curde oils energy content our value of 0.02 Megajoule per tonnekilometre agrees well with estimates on the bulk goods transport from *e.g.* Hvid and Jensen (1995). This should be applicable to oil tankers, too, because there is *per se* no reason to assume that the engines in oil tankers should be much less efficient than in bulk carriers.

DK-EPA (1995)

Table 9 Primary specific energy consumption for road, rail and sea transport.

Transport Mode	Specific Energy Consumption (MJ tkm^{-1})
Truck	0.89
Diesel Train	0.76
Container Ship	0.09
Ro-Ro Ship (3 engines)	1.60

Ro-Ro: "Roll on-Roll off", ferry like ships that transport lorries and cars.

We could probably use the data for Ro-Ro ships as an upper bound for waterways transport, as it seems that this kind of transport could be appropriate for a small part of the energy carriers, especially low-volume goods as certain petroleum products, that are transported on the roads where the vehicles have to cross waterways. For example Brockhoff *et al.* (1994, 31) give a map on the petrol distribution in Denmark, where there currently is some transport between Zealland and Funen or Jutland.

NEDERGAARD (1994)

As shown in Table 10 Nedergaard (1994) has given values for international ship transport that for CO_2 is in between the large values given by NORD (1993), 50 g CO_2 tkm^{-1}, or Trafikministeriet (1994), 50.60 g CO_2 tkm^{-1}, and the bulk carrier value estimated from the data given by Hvid and Jensen (1995) that we have established. The values are smaller than the 33 g CO_2 tkm^{-1}, given by Lübkert *et al.* (1993).

Table 10 Emissions for international road, rail and ship transport.

mode	SO_2	NO_x	CO_2
Road	0.13	1.45	98.38
Rail	0.18	0.40	48.00
Ship	0.26	0.40	17.62

Source: Nedergaard (1994)
in g tkm^{-1}

TRAFIKMINISTERIET (1994)

This report contains some tables for various transport modes. Data are given for several emission factors, also for CO_2 and there are also given an outlook into the emission development into the near future, up to the year 2010. The table for the specific CO_2 emission factors in the appendix of Trafikministeriet (1994) contains the following information:

Table 11 CO_2 emissions for various transport modes.

Vehicle Type	1988	1990	2005	2010
Car	104.2	105.41	94.32	90.71
Bus	53.84	55.84	47.66	45.76
Passenger Train	93.10	93.10	62.83	56.92
Ferry	621.69	621.69	574.46	559.52
Airplane	134.79	134.79	119.32	114.57
Truck	175.62	175.62	140.18	130.03
Lorry/MPV	4605.47	4605.47	3459.35	3325.61
Goods Train	82.55	82.55	49.01	48.09
Goods Ship	50.60	50.60	46.75	45.54

Car, Bus, Passenger Train, Ferry, and Airplane: $gCO_2\ tkm^{-1}$.
Truck, Lorry/MPV (light trucks), Goods Train and Goods Ship: $gCO_2\ tkm^{-1}$.

We can see that the value for goods ships are about one order of magnitude larger than the ones we gained from our investigation based on data from IEA (1984). Still, compared to land based transport, ship transport is emitting much less CO_2 for the same transport work.

COWI (1988A AND 1988B)

Cowi (1988a and 1988b) indicate possible future scenarios of the Danish transport sector for the year 2010 and give some data for the mid 1980s. In effect their data structure can be found in Trafikministeriet (1994) although the values have been changed somewhat. We have calculated the specific energy demand and the relevant emission factors from their data and note that there still was a non-negligible lead emission from petrol fuelled cars and vans at the time of their data aggregation.

Table 12 Current status

traffic mean	energy demand	CO	HC	NO_x	SO_2	Pb	Particles
petrol car	1.65	12.94	1.29	1.41	0.02	0.01	-
diesel car	1.31	0.59	0.41	0.59	0.27	-	0.12
LPG-car	1.48	0.88	0.76	1.06	-	-	-
diesel-van	63.02	20.00	12.00	80.00	11.00	-	10.00
petrol-van	46.34	425.00	42.00	46.00	0.60	0.20	-
lorry (HPV)	3.42	1.33	0.80	5.33	0.73	-	0.67
bus	0.62	0.11	0.07	0.44	0.06	-	0.06
persons-train	1.15	0.07	0.14	3.27	0.17	-	0.13
freight-train	1.17	0.07	0.15	3.33	0.17	-	0.14
ferry	7.58	0.37	0.81	18.56	0.94	-	0.75
coaster	1.13	0.04	0.08	1.78	0.09	-	0.07
plane	6.35	1.91	0.51	0.87	-	-	0.21

car, bus, persons-train, ferry, and plane: emissions gram per personkilometer.
van, lorry/MPV (light trucks), freight-train and coaster: emissions gram per tonnekilometer.
all modes: energy demand in MJ per pkm or tkm.

For the near future, around the year 2010, Cowi (1988a) assume improvements with regard all transport modes, especially for cars. The relevant CO_2 emissions could be computed from the other data published in that study, we have not done this as they can be found in Trafikministeriet, very probably in improved form and data quality.

Table 13 Outlook for 2010, advanced strategy

traffic mean	energy demand	CO	HC	NO_x	SO_2	Pb	Particles
petrol car	0.91	2.59	0.26	0.28	0.01	-	-
diesel car	0.92	0.50	0.35	0.35	0.14	-	0.03
LPG-car	1.06	0.71	0.59	0.53	-	-	-
diesel-van	43.84	16.00	9.60	40.00	5.50	-	2.50
petrol-van	29.91	44.00	4.40	4.80	0.10	-	-
lorry (HPV)	2.84	1.07	0.64	2.67	0.37	-	0.17
bus	0.43	0.09	0.05	0.22	0.03	-	0.01
persons-train	0.86	0.05	0.10	1.63	0.08	-	0.03
freight-train	0.88	0.05	0.10	1.67	0.09	-	0.03
ferry	5.68	0.26	0.57	9.28	0.47	-	0.19
coaster	0.84	0.03	0.06	0.89	0.05	-	0.02
plane	4.44	0.55	0.04	1.83	-	-	0.22

car, bus, persons-train, ferry, and plane: emissions gram per personkilometer.
van, lorry/MPV (light trucks), freight-train and coaster: emissions gram per tonnekilometer.
all modes: energy demand in MJ per pkm or tkm.

EC (1995/4)

A value is given for the fuel demand from tanker transport activities that is based on data provided by GEMIS (1992). The value is 0.1 MJ tkm^{-1}. In Table 14 we cite the original data.

Table 14 GEMIS (1992) Data

Transport Mode	Specific Energy Consumption (MJ tkm^{-1})	Specific CO_2 Emissions (g CO_2 tkm^{-1})
Ship	0.1	8
Barge	0.5	35

Source: GEMIS (1992, 126)

EC (1995/4, 38) also contains information on the transport energy demand of crude oil pipelines. An average value of the specific primary energy demand is given of 0.07 MJ_{el} per tonne kilometre.

NORD (1993)

NORD (1993) does not mention bulk transport but concentrates on passenger transport. So it is first later, Table 17, that we find data on maritime goods transport.

Table 15 CO_2 emissions (g/pkm) according to travel length and mode.

Transport mode	short trips (0-99 km)	Long trips
Car	141	97
Bus	86	36
Train	60	60
Hurtigbåd/-rute	850	660

Airplane	-	283

Hurtigbåd/-rute: Norwegian post carrier sailing the fjords, ferry like consumption pattern.

Table 16 CO_2 emissions (g tkm^{-1}) for goods transport.

Transport mode	short trips (0-99 km)	Long trips
HGV		100
LGV	400-600	
Train	34	34

HGV: heavy goods vehicle (>3.5 tonnes).
LGV: light goods vehicle.

Table 17 CO_2 emissions.

Transportmode	Goods (tkm)	Persons (pkm)
Street	100	130
Rail	34	60
Sea/Ship	50	700
Air	-	280

(g tkm^{-1}, resp. g pkm^{-1}) depending on transport mode for passenger and goods transport.

Table 17 indicates a value of the size of the one given in Lübkert *et al.* (1992).

ALEXANDERSSON *ET AL.* (1991)

The report by Alexandersson *et al.* (1991), published in a series of the Swedish Transport Research Board, has investigated thoroughly the emissions from ship transport. It even includes measurements performed on a typical ship engine during a test cycle, and so can be used as an authorative source in our investigation.

The difference between the slow going two-stroke engines and the fast going four-stroke engines, Table 18, also manifests itself by the specific fuel consumption:

- 160 g kWh^{-1} for 2-stroke, and
- 170-180 g kWh^{-1} for 4-stroke engines,

at normal speed, *i.e.* 80 % of full load. However, as ships are long-lasting, normally a relatively large amount of old capacity is in work. Those older vessels will typically have a higher specific fuel consumption of 210 about g kWh^{-1}.

Table 18 Specific emissions from ship engines.

		NO_x	CO	CO_2	THC	PM
Motortyp	Load			g/kWh		
2-stroke	80 %	17.7	0.2	600	0.8	0.9
	20 %	17.1	0.6	1000	1.3	0.9
4-stroke	80 %	14.0	1.0	620	0.2	0.4
	20 %	21.0	2.2	1120	0.4	0.6

Source: Alexandersson *et al.* (1991), p. 109.

If we, however, look at the technological development, it now seems that diesel engines also can be designed to a power rating of about 50 000 kW, which should be sufficient even for

future ULCC[2] vessels. Those ultra large capacity vessels will enable a further reduction in the specific energy consumption of bulk freight, and so consequently also of the emissions related to such transport. On the other hand a problem will arise with the harbour depths. Solutions that are already used in places today, are deloading partly in large harbours before the ship continues to end destinations without such large depth facilities.
The specific emissions can then be calculated using the data on the engine and ship sizes, as given in Table 19:

Table 19 Classes used in Alexandersson *et al.* (1991) study.

Type	Average BRT	Main engine (kW)	Help engines (kW)	Specific tonnage
1	628	654	230	0.71
2	1635	1518	346	0.88
3	3216	2757	520	0.98
4	5882	4539	786	1.10
5	9823	6535	1122	1.28
6	14792	8124	1447	1.55
7	25618	9051	1770	2.37

Classes used in Alexandersson *et al.* (1991) investigation on sea transport emissions, p. 38 ff.
Those ship classes will more apply to Swedish transport that is not very bulk intensive.

The specific tonnage *i.e.* the amount of BRT, in practice equal to the payload, that is transported for one kW of total engine power, *i.e.* the sum of main and help engine rated power, has been given in Table 19, too. This information shows very distinctly that the dead weight mass is being reduced drastically with increasing total ship mass, a phenomenon that normally is called for scale effect. The resulting total emissions can be inferred from data on the total time on sea and calling in at harbours.

Synopsis

To recapitulate our previous efforts we shall collect the amount of data given before and concentrate on the specific CO_2 emissions, *i.e.* g CO_2 per tonne kilometre transport work. Our estimate we shall then later use in order to calculate the Danish fuel import's contribution to the global CO_2 emissions.

Table 20 Typical Maritime CO_2 Emissions

EC 1995/4	tanker	7.8 g CO_2 tkm^{-1}	calculated from 0.1 MJ tkm^{-1}
Hvid og Jensen 1995	bulk	1.1 g CO_2 tkm^{-1}	
IEA 1984	bulk	1.8 g CO_2 tkm^{-1}	low value (120 kt Australia)
IEA 1984	bulk	2.4 g CO_2 tkm^{-1}	high value (60 kt Canada)
Gransell&Eklund 1991	ship	1.5 g CO_2 tkm^{-1}	calculated @ 13000 km
Gransell&Eklund 1991	ship	5.6 g CO_2 tkm^{-1}	calculated @ 3460 km
Gransell&Eklund 1991	ship	11.6 g CO_2 tkm^{-1}	calculated @ 1700 km
Nedergaard, 1994	ship	17.6 g CO_2 tkm^{-1}	
Lübkert *et al.* 1991	ship	33.4 g CO_2 tkm^{-1}	
Nord 1993	ship	50.0 g CO_2 tkm^{-1}	
Trafikministeriet, 1994	ship	50.6 g CO_2 tkm^{-1}	
Hvid og Jensen 1995	coaster	6.4 g CO_2 tkm^{-1}	
Lübkert *et al.* 1991	barge	37.3 g CO_2 tkm^{-1}	

2 Ultra Large Crude Carriers.

GEMIS 1992	barge	35.0 g CO_2 tkm^{-1}	
Cowi 1988b	coaster	85.8 g CO_2 tkm^{-1}	calculated from 1.1 MJ tkm^{-1}
Hvid og Jensen 1995	container	6.7 g CO_2 tkm^{-1}	
Hvid og Jensen 1995	Ro-Ro 2	52.7 g CO_2 tkm^{-1}	
Hvid og Jensen 1995	Ro-Ro 3	118.2 g CO_2 tkm^{-1}	
DK-EPA 1995	Ro-Ro	140.4 g CO_2 tkm^{-1}	calculated from 1.6 MJ tkm^{-1}

Collected to the various maritime transport modes, where known or appropriate.
Calculations were done by applying a factor of 78 g CO_2 MJ^{-1} (Andersen and Trier, 1995, 154)

Depending on the assumptions that one does especially on the size of the transport means our investigation has brought enough evidence to support the following exclamations:

- The emission, or energy consumption, data on maritime transport means are not homogenous. The vessels used in this kind of transport range over several orders of magnitude, from class 1 of Alexandersson *et al.* (1991) around 500 tons freight weight capacity to around 250 kt as described in IEA (1984). The latter class of vessels are used for bulk transport exclusively.
- There is an apparent danger in using the data for maritime transport from other studies without a proper background investigation into the data sources of those studies and which kind of vessels that have been investigated. Like in a former calculation done by us we have overestimated the CO_2 emissions from maritime bulk transport of fossils to Denmark.
- We have to find values for the two vessel classes that we concentrate on in our study.

Conclusions

We have shown that for maritime transport the emissions of CO_2 depend on the classes of vessels that are being used for the transport. This leads us to the following conclusions:

- For the bulk transport of coal and oil to Denmark we are well advised to use a low value. As a result of our investigations it has therefore become clear that bulk transport of coal only will result in emissions of the order of about 2 grams CO_2 per tonne-kilometre. We have to stress that this value does not take into account the typical transport lengths for the vessels. For bulk transport of coal we should assume a return trip of the vessel of about the same length as the one to the first destination (see also below).
- For the transport of fuels in Europe by barge we have to choose a different value, as clearly scale efficiency will not be as important in that area. We have decided to use the value given in IIASA (1991) as it also is supported by the GEMIS study (GEMIS, 1992, 126).

All in all the value for ships is significantly lower than the values given in most of the other official publications on emission factors from maritime transport. The higher values might, however, be very relevant in other areas of goods transport, like for ferries and ro-ro ships. Their travel speeds are higher, climate shedding is provided for passengers and truck drivers, and especially the ratio of transported ship to goods mass is much higher. All those factors point to higher energy demand, and emission factors for ship transport other than bulk carriage. It therefore necessary in our investigation to reduce the value of the emission factors for bulk transport by about 10 to ensure a fair treatment of this part of our investigation. So in the database on the emission factors ship transport will be extended to only mean bulk transport.
This gives the following data for the emissions from the Danish fuel import:

Table 21 Total CO_2 Emissions from Danish Fuel Import

	Ship	Barge	Diesel	Electr	Road	Pipe	Belt	Total

	Ship	Barge	Diesel	Electr	Road	Pipe	Belt	Total
Coal	232	171	270	326	37	0	1	*1037*
Oil	38	141	0	0	0	18	0	*197*
PetrProd	8	120	0	193	0	2	0	*323*
Sum	*279*	*431*	*270*	*520*	*37*	*20*	*1*	
Total								*1558*

CO_2 emissions from the Danish fuel import in kt per year.

As Table 21 shows us the Danish fuel import is responsible for CO_2 emissions of about 1.6 million tons yearly. The maritime transport, however, with the new emission data elaborated before now is not any more the largest contributor. Electrical train and barge transport are the main contributors each about 50 % larger than maritime transport. These transport modes have specific emission rates that are several times the ones of maritime transport. So even though the transport work, as seen in Table 1, is much shorter for those transport means they generate the largest part of the indirect effects of the current Danish energy system.
If we, however look at the share of the different fuels imported by Denmark then it becomes clear that coal import by far is the most important energy carrier with regard to CO_2 emissions. It is responsible to two thirds of those indirect emissions. This stems from the fact that coal is very bulky and of the large transport distances, as Denmark is importing from various overseas nations. For coal import the large shares of train transport is related to the fact that coal has to be transported a rather long distance from the mines to the harbours 216 and 382 kilometres for diesel and electrical trains respectively.

International Perspective

Relative to the current Danish energy system's CO_2 emissions of about 60 million tons yearly the import of fuels is responsible for an extra amount of about 3 per cent of the domestic emissions. This amount is not included in the official Danish statistics, and it remains difficult to include it in relevant public statistics. Partly because the exact emissions depend on the exact transport work, *i.e.* such a calculation has to take into consideration the capacity utilisation of the transport means, *e.g.* by including the empty return trips. Partly because there is no international clearing instance yet to allocate emissions from international transport to the various countries.

Appendix

Characterisation of Transport Modes

Train Transport

Train transport has been the bearing factor in the industrialisation that started with the invention of the steam engine in 1698 by Thomas Savery (James Watt did not market his model until 1769, but he was more successful! (Basis, 1993)). This development opened for the exploitation of coal to satisfy the energy needs of both a growing population and the rapid industrialisation of the European and North American societies.
Steam engines were not only used to pump up ground water to dry the shafts. The connection of the coal sector to the railway (steam engines!) is illustrated by the fact that in Europe still 95 per cent of all coal transport is railbased (Daniel and Jamieson, 1989; Porter, 1993). This, of course, is explained by the exploitation of the domestic coal reserves in nations like Germany, the United Kingdom, Poland, the Check and Slovakian Republics or the Federation of Independent States.
Railway transport utilises the energy contents of electricity, fuel oils and coal. The last feature can still be found in many developing countries, like in the Peoples' Republic of China. In this report we have only used data for the electrically and diesel driven locomotives from Lübkert *et al.* (1991). If we had knowledge of a major part of the railway transport being based on solid fuel, like in China, the data for the electrical train systems have been scaled to imitate the lower efficiency of coal based steam locomotives.
For the purpose of establishing the modal split of the railway transport we had to infer information from publications of the IEA coal research publications and other sources, like the U.S. Department of the Interior's foreign trade analyses. Not for all exporting nations could stringent data for the kind of the railway transport mode be found. The resultant insecurities are however not a major source of errors as the difference of the emission rates between electrically and diesel driven transport is negligible.

Barge

Barge transport is river or canal based transport, that can be transnational, but will not leave inland water masses to sail the seas. Data for barge transport in Europe are not available, but we have assumed that transport on rivers and on the baltic sea would be barge based, like between Poland and Denmark. The difference to ship transport is the higher specific fuel consumption of barges.

Ship

Ship transport in this report means the transport by ocean going ships and not domestic transport on rivers, canals. It also includes cabotage, which is sea transport following the coast line. From the production data on fuels and other materials we have gained knowledge of the shipping harbours for the import, and assumptions on the localtion of the receivers in Denmark. We have to stress that Denmark is not a large country, still the difference between Copenhagen and Aarhus for example is 225 nautical miles. Some transport is going via the Kiel Kanal in Northern Germany, while other transport is around the Skaw north of Jutland. Most distances

from foreign harbours were given for transport to Copenhagen, and we have typically used these directly. Only in a few cases have we considered shipping to other harbours, for example would crude oil normally be landed at the refineries in Fredericia or Kalundborg (Gundermann, 1996).
For the database the distances of overseas transport performed by oceangoing ships have been gained from the maritime standard distances tables, ie Reed's and the US Navy's tables on nautical distances (Ganey and Reynolds, 1988, US Navy, 1940, Wittingham and King, 1920). Distances were given in nautical miles that were transformed to kilometres using a factor of 1,852 km per international nautical mile (Global 2000, 1409 ff.). This was necessary as the specific emission factors given in Lübkert *et al.* (1991) were to kilometres.
The distances so far only cover the laden conditions, *i.e.* when the ships carry the bulk goods from the shipping to the receiving harbour, here the Danish utilities. From a telephone interview it became clear that coal transport is taking place in Capesized carriers (Røjgård, 1996), and the distances for transport of Australian or Bolivian Coal are quite impressive. An idea of this is given in (IEA, 1984) where typical round trip services are described:

Table 22 Transport mode for round trip coal transport to Europe and Japan

From	Mode	To
Australia	laden	Northern Europe
Northern Europe	ballast	South Africa
South Africa	laden	Japan
Japan	ballast	Australia

It is obvious that the transport of the good to Danmark shall be considered as Danish energy consumption, and the respective emissions as being related to the Danish budgets for externalities calculation. This is also true for the return trip of shuttle services only going between the importing and exporting country. There are no possibilities to load *e.g.* iron ore or bauxite as ballast for the Europe return trips (IEA, 1984). But it is not so clear how the ballast return trip in the round trip scheme shall be calculated.
We have here taken the values given in IEA (1984) and IEA (1985c) and only calculated with shuttle services, laden for trip and ballast for return, for all the import when we calculated the import related energy demand and emissions. The ballast bunker consumption is about 65 per cent of the laden condition (IEA, 1984).

ROAD

For a few countries we do have information that part of the coal is transported on the road like between the mine and the railroad station. We have found values for Canada (Jamieson, 1986, 64; Porter, 1993, 58), the United States (Jamieson, 1993, 57) and Colombia (Jamieson, 1985, 57). For all the other countries we assume no road based transport. This might lead to some underestimation, as we could assume that *e.g.* also in Australia and the Republic of South Africa road based transport would occur. For the energy consumption and CO_2 emissions from road based transport we have chosen to use the Danish values from Trafikministeriet (1994, 83), namely: 176 g CO_2 tkm^{-1}.

CONVEYOR BELTS

For the calculation of the total transport work for coal import we have assumed an average transport distance of 5 kilometre with regards coal, and 0.5 kilometres with regards coke. This should be equivalent to the typical distance covered from the pit to the shipping site. For the energy demand we have used the same value as for pipelines, see below.

PIPELINES

Although coal transport via slurry pipelines is feasible we have not assumed that any coal is transported via this means. On the other hand for a number of countries we have assumed that oil and petroleum products are transported via pipeline. The transport lengths have been established via visual interpretation of maps in Diercke (1988), or where appropriate have been gained from the other publications[3] that we have used.
For the specific end-use energy demand we use the value given in GEMIES (1992, 126) of 0.06 MJ tkm^{-1}. For natural gas pipelines this energy is provided for by gas driven compressors with an efficiency of 30 per cent, and for oil and petroleum products the motor pumps are electrically driven with an efficiency of 92 per cent.

Data Collection

Let us in brief present the data that we have collected so far, before we calculate the emissions related to the Danish fuel imports, Table 23.

Table 23 Transport Modes specific Energy Consumption and Emissions

	Diesel	Electr	Barge	Ship	Road	Pipe	Belt
spec. energy (MJ tkm^{-1})	1.57	0.59	0.57	0.03	2.34	0.06[&]	0.06[&]
CO_2 emission (g CO_2 tkm^{-1})	109.3	74.6	37	2.4	175.62	15.4	15.4
NOx emission (g NOx tkm^{-1})	1.884	0.221	0.584	0.381	1.51	0.045	0.045
VOC emission (g tkm^{-1})	0.157	0.0047	0.138	0.0048	0.33	0.0028	0.0028
CO emission (g CO tkm^{-1})	0.895	0.013	0.170	0.011	1.60	0.0056	0.0056
Particle emission (g tkm^{-1})	0.094	0			0.15	0.0056	0.0056
SO_2 emission (g SO_2 tkm^{-1})	0.369	0.893	0.108	0.0081	0.22	0.018	0.018
CO_2 emission (g CO_2 tkm^{-1})						3[$]	

Sources: Trafikministeriet (1994), Lübkert *et al.* (1991), own calculations built on IEA (1984).

[&] from end-use energy with 37 per cent efficiency in coal fired power stations USA/AUS (GEMIS, 1992, 27).

[$] for natural gas transport only. not relevant here, as Denmark is not important natural gas.

Fuels used in Transport

Fuel oil will in the future only be used in international maritime transport. We calculate with an average sulphur content of 2.9 per cent as given in Alexandersson *et al.* (1991, 162). Regulations have been proposed to reduce this level, for example down to 0.5 per cent sulphur. This fuel is somewhat more expensive, estimated at about 23.5 ECU per ton (do, 141). We note that a different fuel is used for inland shipping transport, *i.e.* gas oil (Nedergaard, 1994, 26).

[3] Mainly from the IEA Coal Research Institute (various years) and the U.S. Department of the Interior, Bureau of Mines 1988 publications on the mineral industries of several countries of the World.

Danish Fuel Use Resilience

Regarding the import the Danish fuel use will in some cases mean that there can arise shortages in the export countries, or that environmentally doubtful transactions take place. For example in the Peoples' Republic of China transport costs are heavily subsidized so that other customers of the railway system pay for the export of chinese coal via the railway lines to the shipping harbours (Harral *et al.*, 1992). And the Chinese coal consumption that is enhanced by the desire for export revenues also hampers the development of natural gas, a fuel with less environmental consequences that to utilize requires lower capital and maintenance costs (Albouy, 1991).

The export and import structures of fuels has other environmental consequences. As coal transport increasingly is being performed in large colliers (>90,000 DWT) harbour berths have to be prepared for deep-draught, high tonnage ships (IEA, 1984). The high capital costs of such schemes often will bind investors to realising long term uses of the infrastructure and binds societies into use of such fuels, too. Such building schemes are often accompanied by vast interferences with natural systems. In some instances this endangers existing areas of high natural value. It is difficult to estimate the monetary damages from species loss as shown elsewhere in this report.

5 Million Tons CO_2 from Danish Import of Fossil Fuels[4]

Using standard data for emission factors of the various most important transport forms and data for the Danish import of solid, and some of the other forms of, fossil fuels it has been established that this import creates the equivalent of nearly 5 million tons of carbon dioxide, a potent greenhouse gas! This amount is not represented in the official emissions statistics that Denmark has to submit in order to fulfil one of the demands the climate convention established during the second conference of parties (COP2) at Berlin in February/March 1995.

Using data for the transport amount, the typical transport distance and the average emission factors per ton-kilometer we calculated the total CO_2 emissions related to the import of fuels, solid, fluid and gaseous, to Denmark.
The Danish Import and Export statistics include data on the amount of fuels imported by Denmark. This data is available in yearly overviews and the respective exporting countries. The statistics have been published by the statistical central bureau of Denmark, *Danmarks Statistik.* In this investigation the data have been aggregated countrywise for the period 1986 till 1994 and the first half of 1995 (DS, 1986-1995) into the respective categories (*varenummer*). The data was averaged over the period to reduce yearly variations. According to the Import statistics the average yearly import of coal is 11.4 million tons, of crude oil 4.6 million tons and of petroleum derivatives 3.6 million tons.
Information for the emissions of the different kinds of transport has been gained from a report by IIASA (1991). Five different transport modes are considered: diesel trains, electric trains, oceangoing ships, barges and truck transport. Lübkert *et al.* divide road transport into a triple matrix of the three driving modes: urban, rural, and highway, and the three vehicle classes: light duty gasoline fueled, dieselfueled medium trucks, and diesel-fueled heavy duty trucks. In this investigation the data for the heavy duty rural transport mode have been chosen as the typical value, and we assumed a loading of 38 tons per lorry[5]. The figures of the specific CO_2 emissions per ton-kilometer for the five transport modes are given in Table 24.

Diesel	**Electr**	**Barge**	**Ship**	**Road**
109	75	37	33	30[6]

Table 24: CO_2 Emission factors from different transport modes.
in g CO_2 per ton kilometer.
Diesel: diesel driven locomotive
Electr: electric driven locomotive
Barge: inland ship
Ship: oceangoing ship
Road: rural diesel driven heavy truck

[4] This text has been a first version on this matter. We include it only for the interest of the reader. It does not any more give a valid picture of the current understanding.

[5] Contrary to the other emission factors the data for road transport in IIASA (1991) is only given in kilometres and not ton-kilometres.

[6] For a load factor of 100 %, at 50 % the value is 61 g CO_2 per ton-kilometer. The coal trucks would normally be filled up fully.

The transport distances data we inferred from standard nautical distances tables (Ganey & Reynolds, 1988; US Navy, 1940), where we assumed Copenhagen and Aarhus as the final harbours for coal transport and Fredericia for oil transport[7]. For interior railway transport we used publications of the IEA coal research publications and the U.S. Department of the Interior's foreign trade analyses from 1988. In many instances we found data quoting the railway transport as either diesel or electrically driven, but not for all countries could this data be found. The resultant insecurities are however not a major source of errors as the difference of the emission rates between electrically and diesel driven transport is negligible compared to the large amount of the ship transport related emissions.
With the values of the total import of fuels, the specific transport modes and the transport distances the related CO_2 emissions can be established easily. The result is shown in Table 25.

Total CO_2	**Diesel**	**Electr**	**Barge**	**Ship**	**Road**
4976425	266794	452642	25778	4224999	6209

Table 25: Transport related CO_2 emissions from the Danish import of fossil fuels.
All in all the Danish import of fossil fuels is responsible for the emission of nearly five million tons of CO_2 as a consequence of the current Danish energy system. This value does not even include the emissions related to the production of the fuels!

Concluding Remark

As noted before this statistics does only include transport related emissions, and not the other environmental impacts due to the production and conversion, like the preparation of petroleum products from crucde oil. This information is being processed.
The amount of the ship transport related emissions might be underestimated[8].

[7] The emission data for the domestic oil transport via pipelines from the Danish North Sea oil fields have not yet been calculated, we assume they will normally be included in the conversion losses given in the official Danish energy statistics. This caveat is also valid for the Norwegian and British pipeline transports.

[8] During the progress of this work we gained knowledge of the fact that the coal import from Canada is happening in Cape-size bulk carriers, and not as we had assumed in Panamax type ships that are able to pass the Panama channel. This means that the transport distance for Canadian coal is about doubled to what we have used in the statistics The same is true for Australian coal that is transported around Cape of Good Hope, and not as we have assumed via the Suez Channel. Even according for the reduced train transport length to the Canadian west coast and not to the Great lakes as we have done in this first calculation, the total CO_2 emissions will surpass the 5 million tons established here.
The data from IIASA (1991) actually refer to oil tankships. These might have a better bulk weight to dead weight ratio so that their specific emission factors are lower than for the bulk carriers carrying coal.

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