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# Environmental Performance Evaluation of Ro-Ro Passenger Ferry Transportation

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## Abstract

With increasing focus on the environmental performance of different transport modes (for example trucks, trains, ships and aircraft) it is of utmost importance that the different transport modes are compared on an equal basis so that the environmental impact, defined as energy demand and/or emissions per transport unit, is related to the same unit for the different transport forms.

For Ro-Ro passenger ferries it can be difficult to find a suitable common transport unit, as they often transport a mix of cargo, such as passengers, passenger cars, trucks, lorries, busses and other rolling transport units. In this paper a method for determination of a common transport unit for Ro-Ro passenger ships will be described.

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## Ro-Ro Passenger Ships (Fig. 1 and 2)

A Ro-Ro passenger ship (often also called a Ro-Ro ferry or even just a ferry) is a passenger ship which can carry more than 12 passengers (a ship carrying less than 12 passengers is by definition a cargo ship) and which has one or more cargo decks for carriage of rolling cargo, such as cars, trucks, lorries and other rolling cargo. The size and capacity of Ro-Ro passenger ships vary considerably with a length ranging from 20 m up to more than 200 m (the largest Ro-Ro passenger ship delivered in 2010 has a length of 240 m and an overall Ro-Ro capacity of 5500 lane metres).



Fig. 1 1200 lane metre Ro-Ro passenger ship (Mette Mols) for 600 passengers



Fig. 2 1000 lane metre Ro-Ro passenger ship (Pearl Seaways) for 2200 passengers

## EEDI (Energy Efficiency Design Index)

In the International Maritime Organization (IMO) there has been a debate over the last two to three years about the so-called Energy Efficiency Design Index (EEDI) expressing the CO<sub>2</sub> emissions per unit transport work. For most ships the unit for the EEDI will be gram CO<sub>2</sub> per ton deadweight per nautical mile. Originally, this unit was also suggested for Ro-Ro passenger ships. However, this led to a very large scatter in the statistical data of the EEDI in calculations of the Index for a large statistical sample of Ro-Ro passenger ships. One of the reasons for this scatter is the ship design diversity of Ro-Ro passenger ships. Some of the ships carry relatively few passengers and much cargo such as lorries, resulting in a relatively high deadweight, while other Ro-Ro passenger ferries carry many passengers and focus more on service and amusement ('eat, drink and sleep') for the passengers. Such a concept leads to large passenger spaces (cafeterias, restaurants and cabins) requiring large ships with a relatively low deadweight. In both cases a large amount of volume is needed, which in general is proportional to the gross register tonnage (GT) of the ship. Therefore, IMO has suggested that in the EEDI calculation procedure for Ro-Ro passenger ships, deadweight has to be replaced by GT, so that the unit of the EEDI for Ro-Ro passenger ships is gram CO<sub>2</sub>/GT/nautical mile.

## Energy Efficiency Operational Index (EEOI)

For existing ships, IMO has suggested introducing a so-called Energy Efficiency Operational Indicator. The Marine Environment Protection Committee (MEPC) has agreed to circulate guidelines (MEPC.1 - Circ.684) for voluntary use of the Ship Energy Efficiency Operational Indicator (EEOI). These guidelines can be used to establish a consistent approach to voluntary use of an EEOI, which can be used in the evaluation of a ship's performance with regard to CO<sub>2</sub> emissions. As the amount of CO<sub>2</sub> emitted from a ship is directly related to the consumption of bunker fuel oil, the EEOI can also provide useful information on a ship's performance with regard to fuel efficiency.

These EEOI Guidelines present the concept of an indicator for the energy efficiency of a ship in operation, as an expression of efficiency in the form of CO<sub>2</sub> emitted per unit of transport work. As the Guidelines are recommendatory in nature and present a possible use of an operational indicator the shipowners, ship operators and parties concerned are invited to implement either these Guidelines or an equivalent method in their environmental management systems and consider adoption of the principles herein when developing plans for performance monitoring.

In its most simple form the Energy Efficiency Operational Indicator is defined as the ratio of mass of CO<sub>2</sub> emitted per unit of transport work:

$$\text{EEOI} = \text{Mass of CO}_2 / (\text{transport work})$$

## Transport Work and Allocation Principle

For vessels such as Ro-Ro passenger ships carrying a mixture of passengers (either travelling with their cars or as pure 'foot passengers') and freight some operators may wish to consider as appropriate a kind of weighted average based on the relative distribution of passengers and freight or the use of other parameters or indicators.

On a Ro-Ro passenger ship some of the internal volume is occupied for the carriage of rolling cargo as for example trucks/trailers and cars, while other volume is dedicated to carrying passengers, which entails volume for restaurants, cafeterias, corridors, toilets, different types of service rooms, galleys and pantries.

For day and night ferries, cabins, including associated corridors and store rooms for bed linen etc, make up volume solely used for the passengers. The structural part and associated equipment of these volumes contribute to the lightweight of the ship, which together with the deadweight influences the propulsion power and therefore the exhaust gas emissions, including CO<sub>2</sub>.

As for allocations of the emissions to the different cargo types of a Ro-Ro passenger ship, it could be rational to allocate the emissions relatively to the volume occupied by each cargo type. Calculating the average weight (ship structural weight + cargo) for the different volume types shows that the weight is roughly independent of the volume type, so that a volumetric allocation principle can also be considered as a weight based allocation method. As the power demand is proportional to the ship's total weight (displacement) the method is therefore rational seen from a ship design and hydrodynamic point of view, which is very important to the validity and understanding of the method.

The emissions or energy demand per transport unit for each type of cargo must be related to the volume per unit divided by the total occupied volume on the actual trip (see description of the procedure later).

## Determination of Volumes for the Different Types of Cargo

In order to determine the volumes for the different types of cargo carried on a Ro-Ro passenger ship, general arrangement plans for 60 Ro-Ro passenger ships have been analysed and the volumes for the following spaces were determined:

- Cargo space for rolling cargo
- Accommodation for restaurants, cafeterias, corridors, toilets etc
- Accommodation for pantries, galleys, air conditioning rooms and store rooms
- Accommodation for passenger cabins and associated corridors and store rooms

The analysis was carried out as a bachelor thesis work (Hagemeister) at the Technical University of Denmark and Hochschule Bremen - Schiffbau und Meerestechnik.

The ferries are considered as quite representative, typical Western European and Scandinavian ferries, built in the period from 1974 to 2009 with the following age distribution, resulting in an average age of 16 years:

1974 - 1989:	17 ships
1990 - 1999:	17 ships
2000 - 2009:	26 ships

By use of statistical data over 37 years, it is also possible to see if there is a trend towards higher standards, i.e. larger volumes with decreasing age of the ferries. The analysis shows a slightly higher volume per lane metre and per car, which is expected due to larger cars and higher standards with respect to free space on the car deck between the vehicles. As the volume is the product of area and height the area per cargo unit was also determined in the analysis.

The results of the area and volume analysis are summarised in Table 1. The area and volume for passengers include both the area for restaurants, cafeterias, corridors and toilets and the area and volume for pantries, galleys, air conditioning rooms and store rooms as the size of these spaces is related directly to the number of passengers to be carried on board.

Table 1 Area and volume equivalents.

Unit	General	Low comfort	High comfort
m <sup>2</sup> per lane metre	4	-	-
m <sup>3</sup> per lane metre	24	-	-
m <sup>2</sup> per car	15	-	-
m <sup>3</sup> per car	67.5	-	-
m <sup>2</sup> per unberthed passenger	3.5	-	-
m <sup>3</sup> per unberthed passenger	10	7	13
m <sup>2</sup> per berthed passenger	4.5	-	-
m <sup>3</sup> per berthed passenger	13	-	-

The volumes for each cargo segment are shown in Figures 3 – 7, based on the bachelor thesis work (Hagemeister).

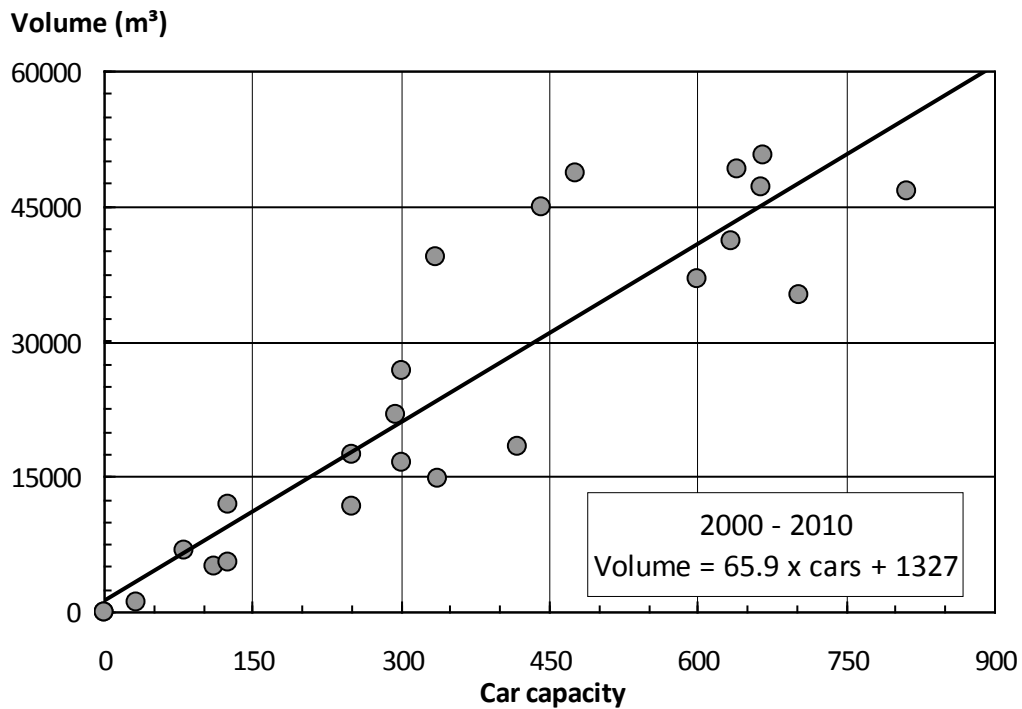


Fig. 3 Volume of cars (Hagemeister).

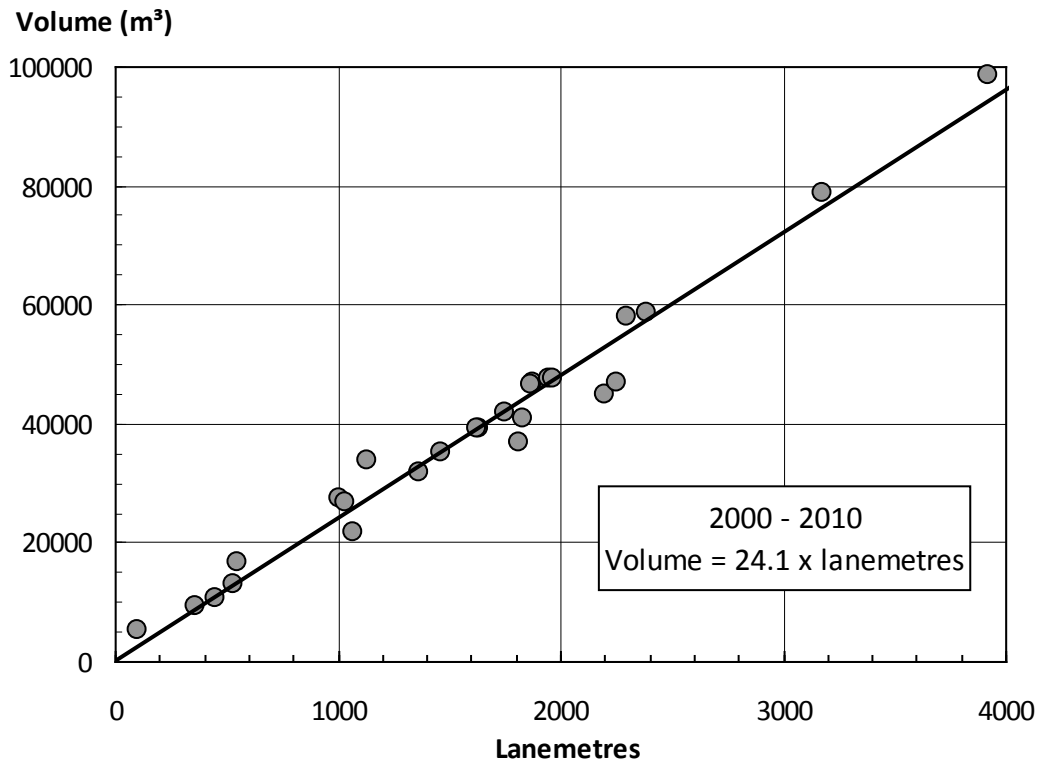


Fig. 4 Volume of trucks and lorries (Hagemeister).

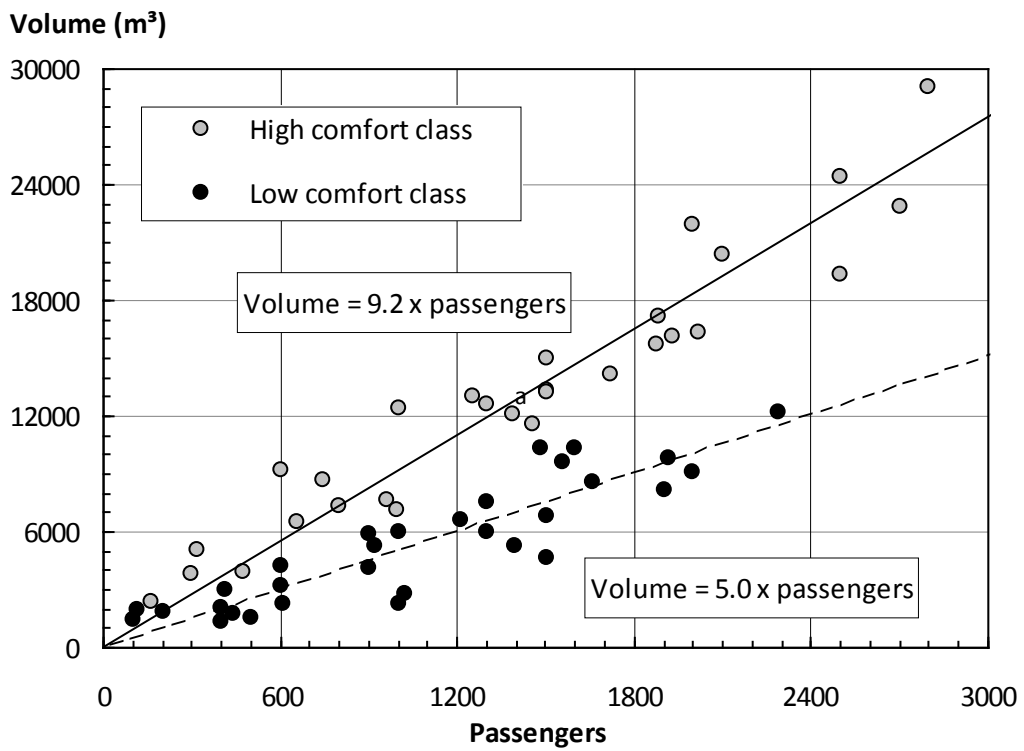


Fig. 5 Volume of passenger related accommodation (restaurants, cafeterias, corridors, toilets etc) (Hagemeister).

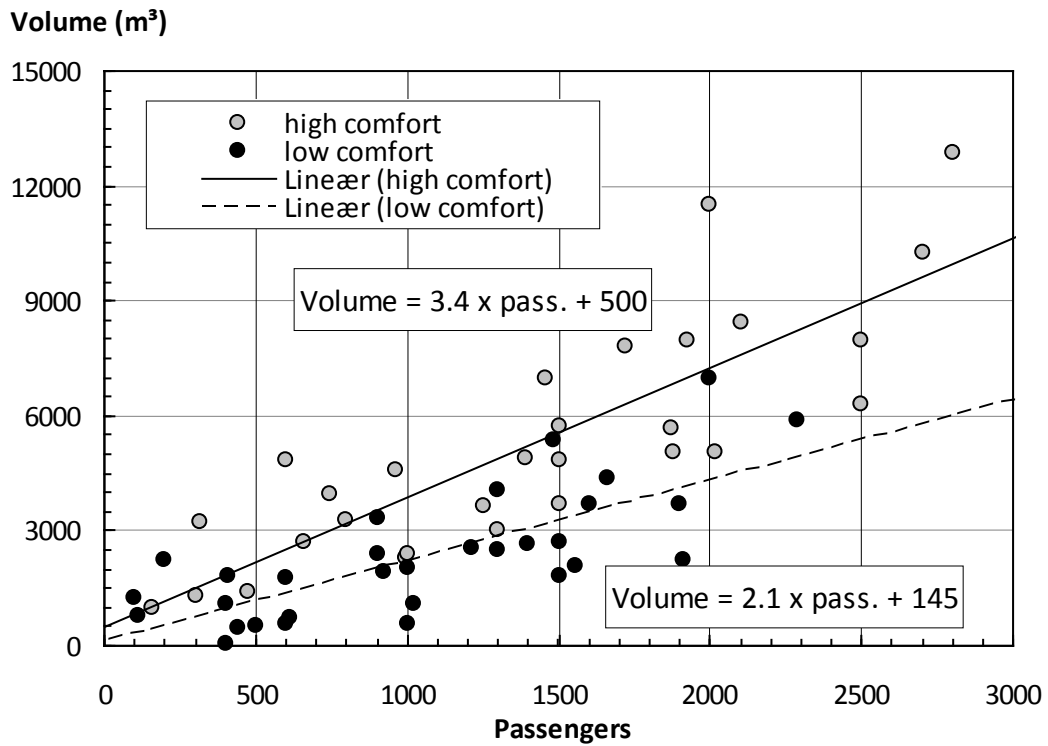


Fig. 6 Volume of service accommodation for passengers (pantries, galleys, air conditioning rooms and store rooms) (Hagemeister).

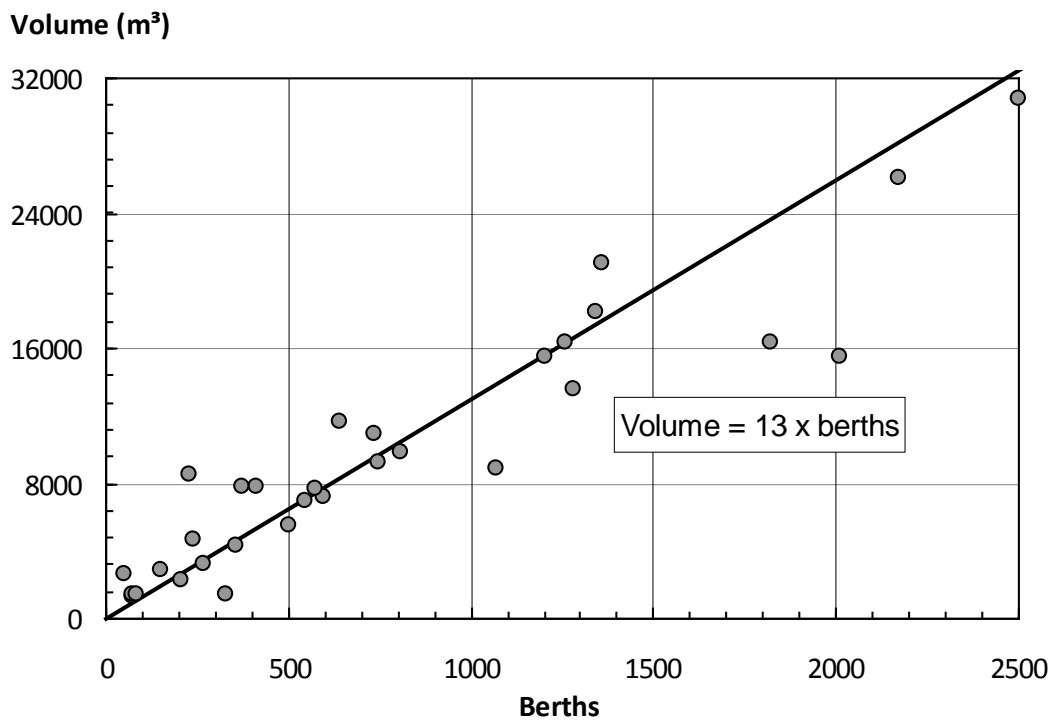


Fig. 7 Volume of passenger cabins and associated corridors and store rooms (Hagemeister).

## Allocation Principles

After establishing the volume for each separate cargo type, it is now possible to set up the allocation principles.

For a specific sailing condition the occupied volume ( $V_{tot}$ ) is calculated as follows. The number of utilised lane metres is referred to as lanes, number of cars as cars, passengers as pass, and the number of occupied berths as berths:

$$V_{tot} = 24 \times \text{lanes} + 67.5 \times \text{cars} + 10 \text{ (or 7 or 13 as appropriate)} \times \text{pass} + 13 \times \text{berths}$$

The comfort class of the ship concerned must be judged individually so that the volume per passenger can be evaluated correctly to be either 7, 10 or 13 m<sup>3</sup> per passenger.

If the actual emissions, or energy demand per hour, are  $Q$  and the speed in knots is denoted by  $V$ , the emissions or energy demand per cargo unit per nautical mile for the trip are as follows:

Lane metre:  $24 \times Q/V_{tot}/V$

Car:  $67.5 \times Q/V_{tot}/V$

Passengers without berth:  $10 \text{ (or 7 or 13 as appropriate)} \times Q/V_{tot}/V$

Berthed passenger:  $[10 \text{ (or 7 or 13 as appropriate)} + 13]Q/V_{tot}/V$

The actual occupied volume is used instead of the maximum volume with a utilisation of 100 %. If the maximum volume is used not all the emissions or energy demand will be allocated for the trip concerned, which is incorrect as all emissions have to be distributed on the actual cargo including passengers.

## Total Volume of Ro-Ro Passenger Ships

Using ferry data from the ShipPax database (ShipPax), the total cargo volumes for a large number of ferries have been calculated, i.e.  $V_{tot}$  has been calculated assuming a utilisation of 100 %. The result of this analysis is shown in Fig. 8, where it is seen that the total volume is proportional to the length between pp in a higher order than one. It should also be noted that the scatter is relatively high up to a length of approximately 150 m. Above this length the scatter is reduced, probably because the Ro-Ro passenger ships become a bit more homogenous and similar in their lay-out.

## CO<sub>2</sub> Emissions per m<sup>3</sup> per Nautical Mile at a 100 % Cargo Utilisation

Using the data in the ShipPax database it has also been possible to calculate the CO<sub>2</sub> emissions per m<sup>3</sup> per nautical mile for the same ferries as shown in Fig. 8. The results of these calculations are given in Fig. 9. Due to the before-mentioned scatter of the total volume up to a length of approximately 150 m there is a similar scatter of the CO<sub>2</sub> emissions in the same range of length between pp.

Another factor contributing to the scatter is the scatter in service speed, which is seen from Fig. 10.



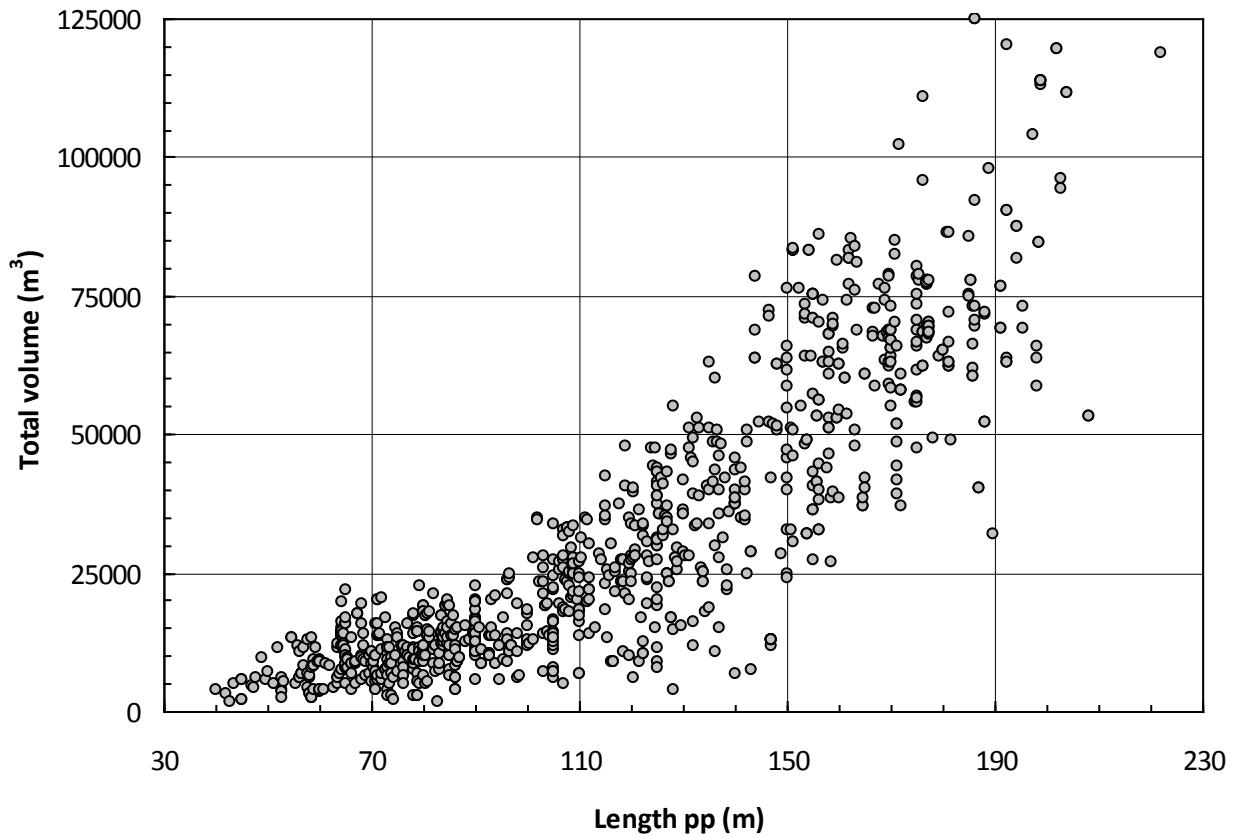


Fig. 8 Total volume for rolling cargo and passengers of Ro-Ro passenger ships (ShipPax 2011).

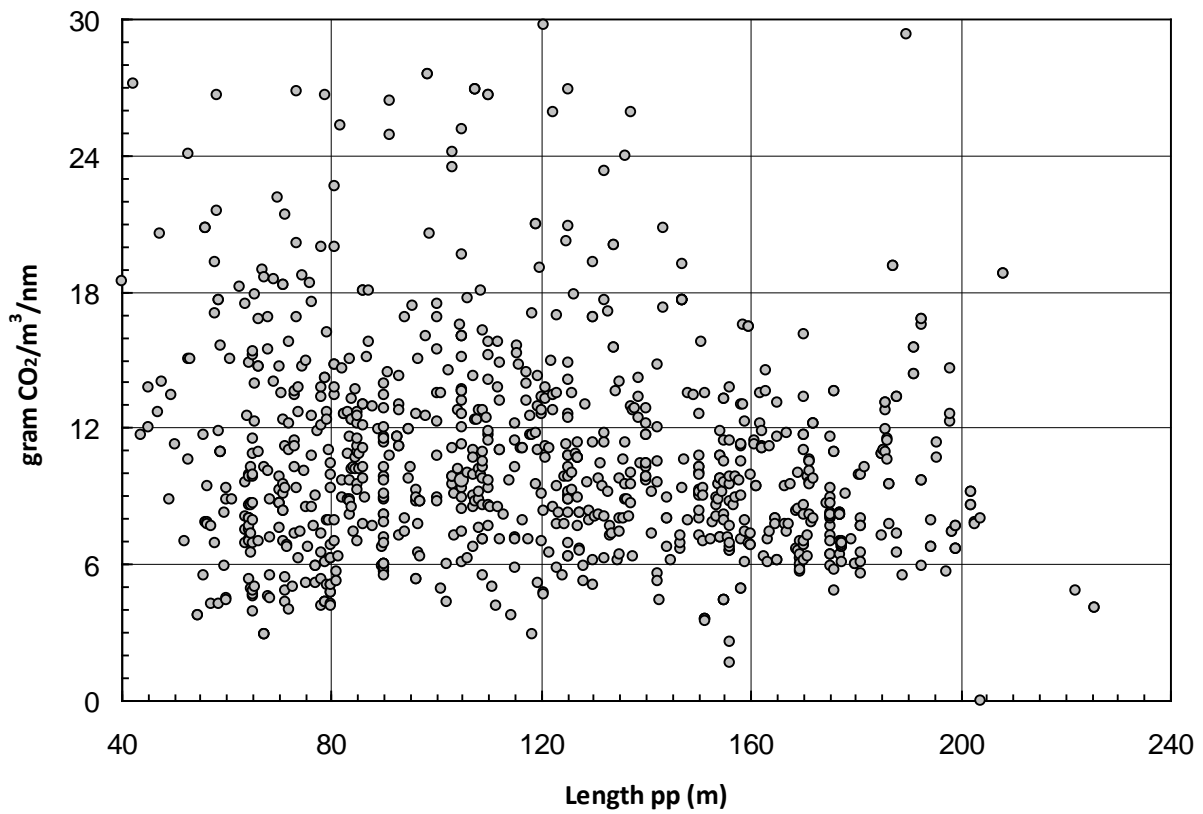


Fig. 9 CO<sub>2</sub> emissions per m<sup>3</sup> per nautical mile of Ro-Ro passenger ships (ShipPax 2011).

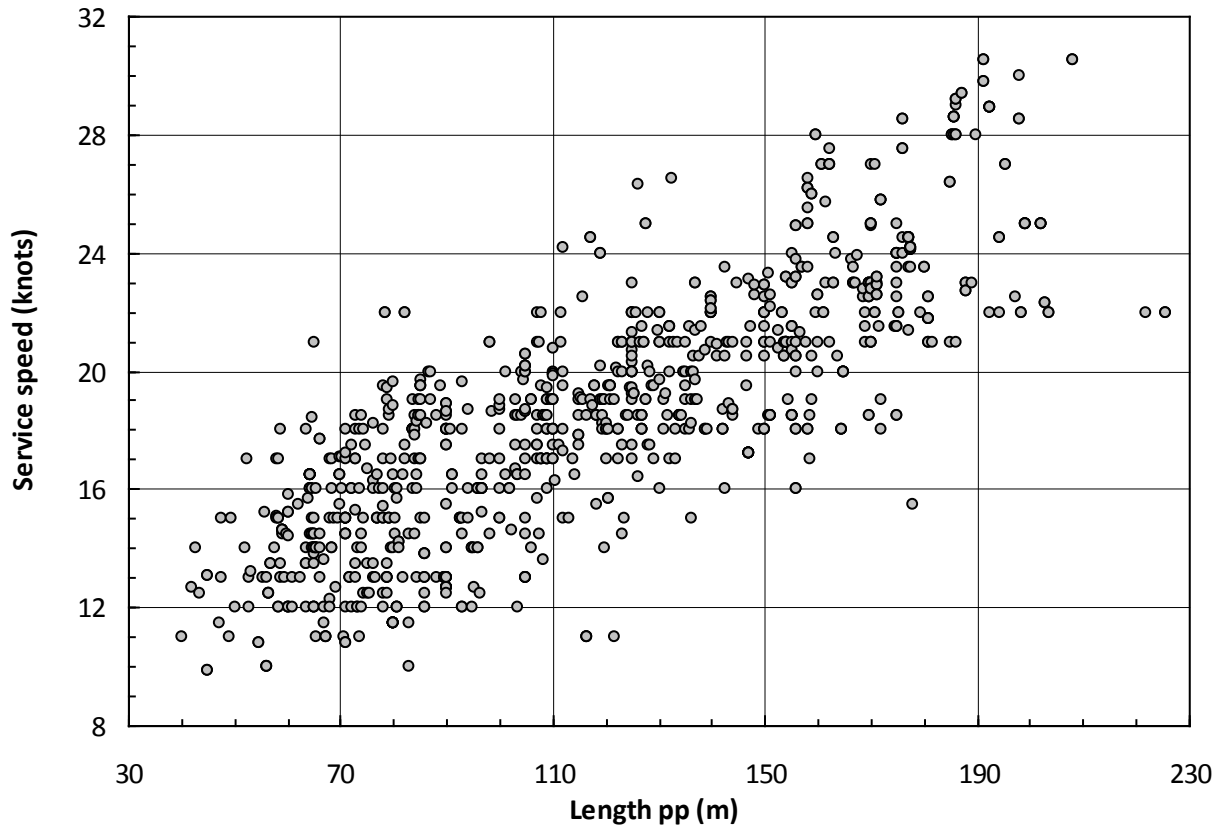


Fig. 10 Service speed of Ro-Ro passenger ships (ShipPax 2011).

## Comparison of CO<sub>2</sub> Emissions per t Payload on Ro-Ro Ship and on Road

It is seen from Fig. 9 that the average CO<sub>2</sub> emissions for Ro-Ro passenger ships are roughly 10 g/m<sup>3</sup>/nautical mile with a 100 % utilisation of the ship. The average CO<sub>2</sub> emissions per lane metre are therefore 24 x 10 = 240 g/lm/nautical mile = 240/1.852 = 130 g/lm/km. For Ro-Ro cargo ships operating at a normal service speed (Fig. 11) the corresponding figure is approximately 150 g/lm/nautical mile = 80 g/lm/km, depending on the ship's size, according to Fig. 12. For a 15 m long truck carrying 30 t cargo the average CO<sub>2</sub> emission is approximately 70 g/lm/km.

By assuming that the same truck is transported (with a load of 30/15 = 2 t/lane metre) on a Ro-Ro passenger ship and a Ro-Ro cargo ship, the following specific CO<sub>2</sub> emissions are obtained:

Ro-Ro passenger ship:	$130/2 =$	65 g/t/km
Ro-Ro cargo ship:	$80/2 =$	40 g/t/km
Truck:	$70/2 =$	35 g/t/km

Fig. 13 shows a comparison of CO<sub>2</sub> emissions per lane metre per nautical mile for Ro-Ro passenger ships and Ro-Ro cargo ships.

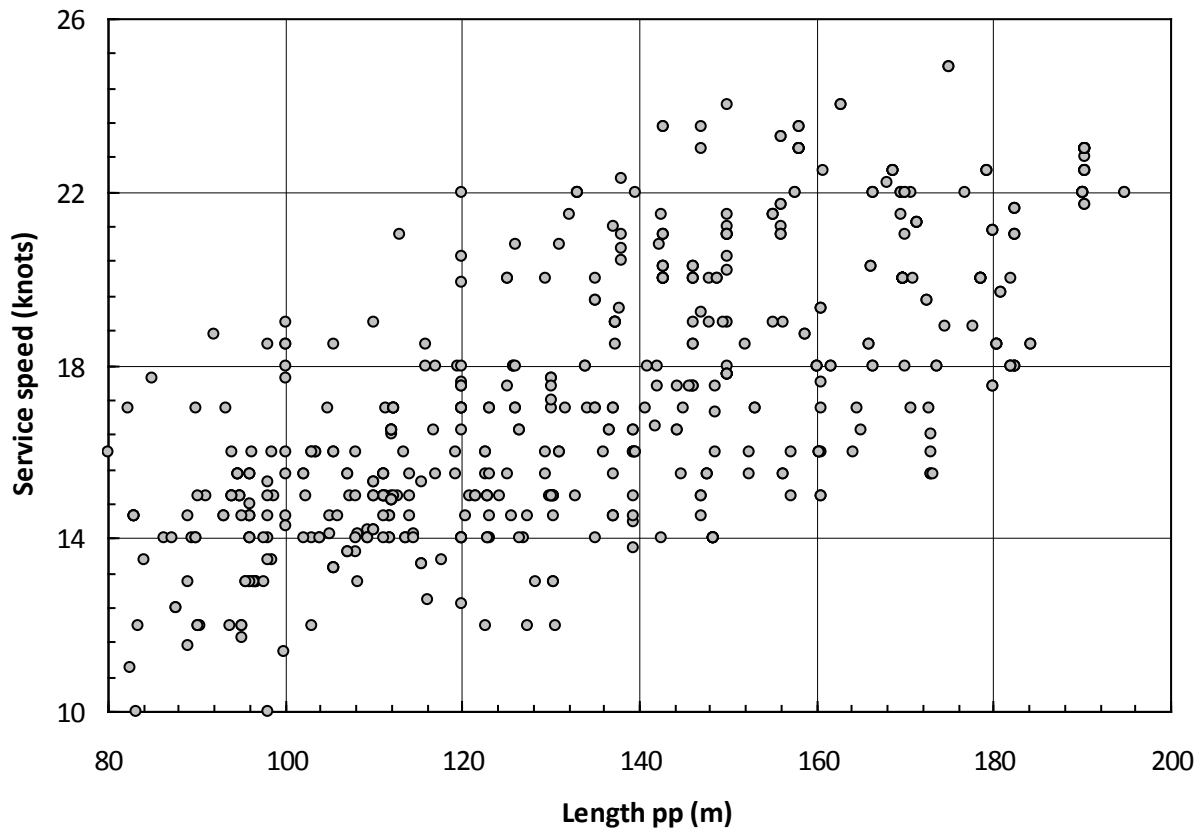


Fig. 11 Service speed of Ro-Ro cargo ships (ShipPax 2011).

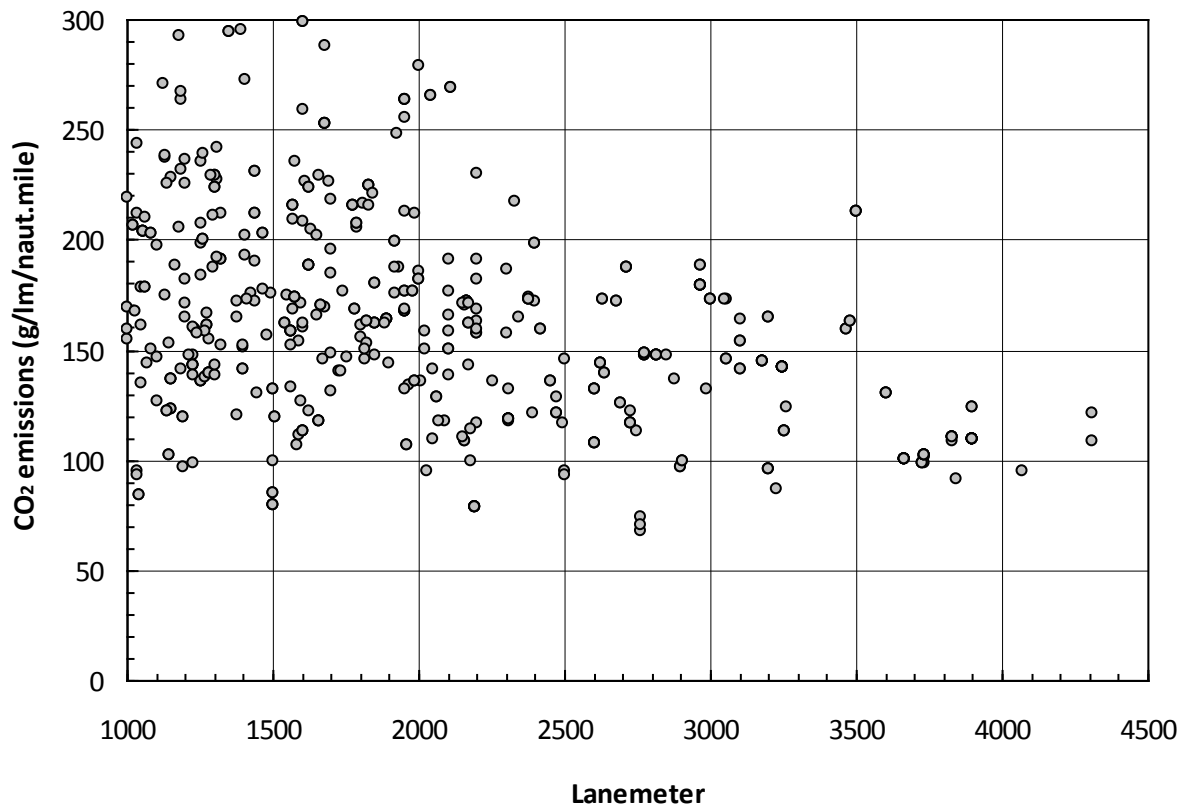


Fig. 12 CO<sub>2</sub> emissions per lane metre per nautical mile of Ro-Ro cargo ships (ShipPax 2011).

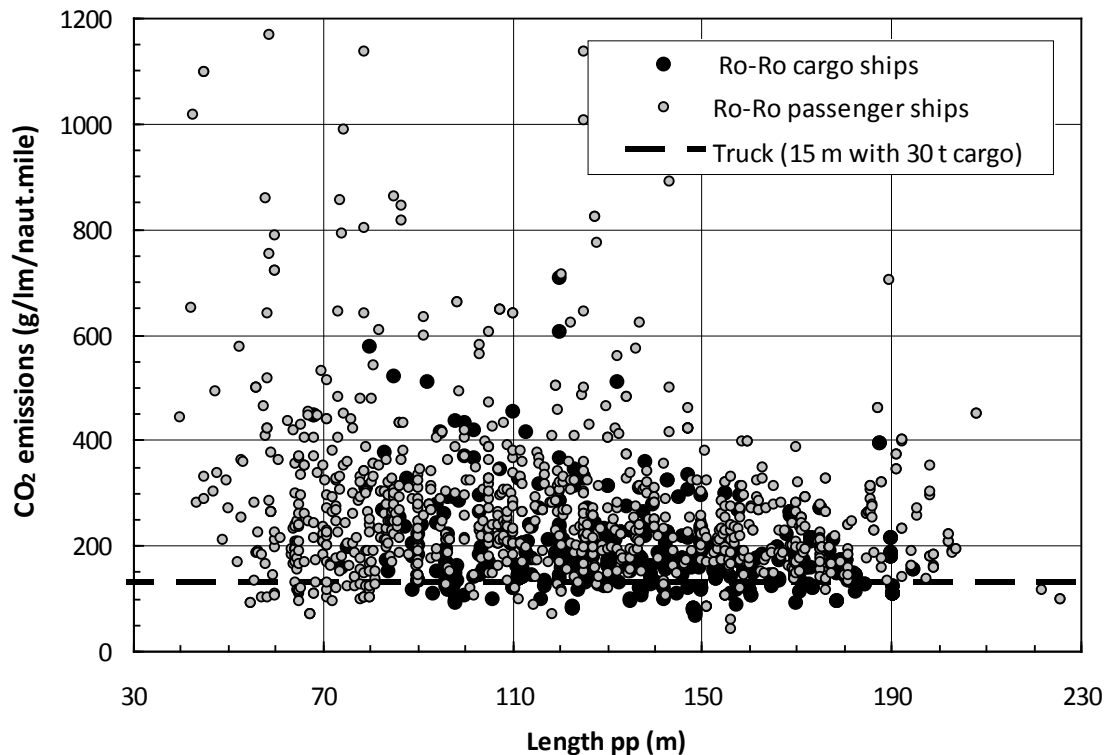


Fig. 13 CO<sub>2</sub> emissions per lane metre per nautical mile of Ro-Ro ships versus trucks.

## Conclusions

1. An analysis of the volume demand for different cargo types (lorries, cars and passengers) on Ro-Ro passenger ships shows that the volume per unit for the various cargo types is nearly independent of the ship size, i.e. it is nearly constant for the different cargo types.
2. Using the volume per cargo unit thus found, it is possible to allocate the emissions and energy demand on the different cargo segments relative to the actual volume each of them occupies. Calculations show that the average weight (ship weight + cargo weight) per volume is more or less on the same level for the different cargo segments, which means that the volumetric allocation method is also a weight based allocation method. Thus, the method is justified as the energy demand of a Ro-Ro passenger ship is proportional to the ship's displacement.
3. Due to the diversity of Ro-Ro passenger ships, it is difficult to find accurate figures for the exhaust gas emissions and energy demand per transport unit. Especially, for smaller ferries the variation is great.
4. However, calculating the energy demand per ton cargo per km shows that the energy demand is highest for Ro-Ro passenger ships, less for Ro-Ro cargo ships and lowest when the cargo is carried by lorries.

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