External cost calculator for the SHIP-DESMO model

by

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Contents

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Introduction

This report contains a description of the background for the external cost calculations done in the generic Ro-Ro ship model program SHIP-DESMO, primary intended for calculation of the energy demand (fuel consumption) and emissions for Ro-Ro cargo and Ro-Ro passenger ships. Two separate programs have been developed, one for 1) Ro-Ro cargo ships and one for 2) Ro-Ro passenger ships. The theoretical background for these two SHIP-DESMO models is described in five separate reports:

1. Report No. 1: *"Prediction of resistance and propulsion power of Ro-Ro ships"* by Hans Otto Kristensen

2. Report No. 2: *"Analysis of technical data of Ro-Ro ships"* by Hans Otto Kristensen

3. Report No. 3: *"Energy demand and exhaust gas emissions of marine engines*" by Hans Otto Kristensen

4. Report No. 4: "*Analysis of propulsion power data of Ro-Ro ships and analysis of the CEN standard 16258 for Ro-Ro ships"* by Hans Otto Kristensen.

5. Report No. 5: "*Energy and emission model for trucks"* by Hans Otto Kristensen.

All five reports have been prepared as deliverables for the project no. 2014-122: Mitigating and reversing the side-effects of environmental legislation on Ro-Ro shipping in Northern Europe. Work Package 2.3 carried out for The Traffic Section of The Technical University of Denmark.

In Report No. 1 it is shown that propulsion power determined by using an empirical method (based on ship resistance calculated using the so-called "Ship Resistance" method, by Guldhammer and Harvald) yields results which are very close to actual results obtained from model tests with Ro-Ro ships.

Furthermore extensive technical data for Ro-Ro ships have been analyzed and described in Report No. 2, such that two generic ship design and power prediction models for Ro-Ro cargo and Ro-Ro passenger ships have been developed for this project, the so-called SHIP-DESMO models.

Implementation of the CEN Standard 16258 in the SHIP-DESMO model for Ro-Ro passenger ships

Transport services carried out by Ro-Ro passenger ships fulfils two separate transport needs, namely 1) passenger related transport of passengers and personal cars, campers, busses etc. and 2) pure freight transport of trucks and other rolling cargo such as unaccompanied vehicles/mafi trailers.

The CEN Standard 16258 describes two different allocation methods for allocation of the total ship emissions on passenger and freight transport respectively. The two methods are the so-called 1) mass method and the 2) area method. A third method might be an average allocation method, based on the mean values of the area and the mass allocation method.

All three methods, i.e. also the average method, are used in SHIP-DESMO for allocation of energy demand, emissions and external costs on the different cargo segments, 1) rolling cargo (on trucks, trailers, mafis etc.) and 2) the passengers including cars, campers, busses etc.

Mass method

Calculation of the mass shall be based on:

- Number/mass of passengers
- Number/mass of accompanied cars
- Number of accompanied caravans and mobile homes etc.
- Number/mass of accompanied busses
- Total mass of cargo being carried, including any packaging, container, and means of handling or means of transport like trailers and vehicles

Area method

The area method is based on 100 % accessible area capacity according to valid general arrangement plans including following areas:

- Accessible vehicle deck area, including hanging decks (if available and operational)
- Accessible passenger deck area

Area not in use for passenger and cargo, such as bridge, engine area, crew area, galley and other service areas are excluded.

Default values for mass, length and width presented in Table 1 may be used for both methods.

Table 1 Default values for mass, length and width

	Mass (kg)	**Length (m)**	**Width (m)**
Passenger and luggage	100	Not applicable	Not applicable
Passenger car	1500	6	3.1
Bus	15000	12	3.1
Caravan (small)	1000	3	3.1
Caravan (medium)	2000	6	3.1
Caravan (large)	2500	10	3.1
Mobile home	3500	8	3.1
Motorcycle	200	1.5	3.1
Unaccompanied trailer	8000	14	3.1
Accompanied/articulated trailer	16000	17	3.1
Road train - Continent	18500	19	3.1
Road train - Scandinavia	20000	24.5	3.1

In the CEN Standard 16258 guidelines it is mentioned that the above mentioned masses and associated areas may be used in the calculations. However for passenger cars and lane meters for rolling cargo more correct values are obtained from a paper especially on the issue of space allocation [Kristensen and Hagemeister 2011]. Based on this reference following areas in Table 2 have been found as representative for 60 Ro-Ro passenger ships. Figures showing the statistical analysis of the data for different types of area are given in Appendix A.

Table 2: Area for Ro-Ro deck space and accommodation for Ro-Ro cargo ships

Unit	General	Low comfort	High comfort
m^2 per lane metre	4.1	-	-
m^2 per car	15.0	-	-
m^2 per unberthed passenger (area for cafeteria, restaurants, halls and corridors and toilets, i.e. passenger related accommodation)	2.4	1.8	3.0
m^2 per berthed passenger (cabin area)	4.5	-	-

As no general arrangement plans are available when using the SHIP-DESMO model, the areas in Table 1 and 2 are used in the CEN Standard 16258 calculation procedures, which have been implemented in the SHIP-DESMO model for Ro-Ro passenger ships. The calculation example shown in Appendix B for the CEN standard has also been used in the implementation procedure.

The implementation of the CEN Standard 16258 is described in following report of this project: Report No. 4: "*Analysis of propulsion power data of Ro-Ro ships and analysis of the CEN standard 16258 for Ro-Ro ships"* by Hans Otto Kristensen.

Internalisation of transport external costs

Transport activities give rise to environmental impacts and accidents. In contrast to the benefits, the costs of these effects are generally not borne by the transport users. The internalisation of external costs means making such effects part of the decision-making process of transport users. A model for the internalisation of external costs has been integrated in the two SHIP-DESMO models.

There exist many different sources for calculation of external costs and the variation of values is quite large, and some of the results are ufortunately very misleading. The values depend on the geographical area, including also the area type, as example rural area versus urban area.

For the present project external cost factors are based on the work done by DTU and COWI and described in the Excel spreadsheet "*Transportøkonomiske Enhedspriser"* down loaded from: http://www.modelcenter.transport.dtu.dk/Noegletal/Transportoekonomiske-Enhedhespriser

The price of the different types of emissions are shown in table 1.

Table 1: External costs for emissions

EURO exchange rate (EURO/DKK): 7.50

CITY

	DKK/kg			EURO/kg		
	Low	**Mean**	**High**	**Low**	**Mean**	**High**
CO_2	0.05	0.08	0.08	0	0	0
Particulates	251	1,749	11,813	33	233	1575
NOx	5	53	409	1	7	55
SOx	57	241	1,147	8	32	153
CO	0.005	0.024	3.100	0	0	0
HC	1	3	17	0.133	0.400	2.267

NON CITY

	DKK/kg			EURO/kg		
	Low	**Mean**	**High**	**Low**	**Mean**	**High**
CO_2	0.05	0.08	0.08	0.0067	0.0107	0.0107
Particulates	35	244	1,647	5	33	220
NOx	0	53	375	0.00	7.07	50.0
SOx	11	209	1,260	1.47	27.87	168.0
CO	0	0.009	1.109	0	0.0012	0.148
HC	1	2	15	0.133	0.267	2.00

External costs related to road traffic is subdivided into following categories:

1. Noise
2. Accidents
3. Congestion
4. Infrastructure
5. Climate change

Three different transport modes are included in the analysis in the SHIP-DESMO models

1. Trucks
2. Busses
3. Cars

The external costs of different types and for the three different transport modes are given in table 2

Table 2: Non-emission related external cost for different transport forms

23 t truck

	DKK/km			EURO/km		
	Low	Mean	High	Low	Mean	High
Noise	0.05	0.11	0.22	0.007	0.015	0.029
Accidents	0.30	1.39	1.82	0.040	0.185	0.243
Congestion	0.15	0.64	1.89	0.020	0.085	0.252
Infrastructure	0.28	1.13	1.69	0.037	0.151	0.225
				0.10	**0.44**	**0.75**

Car for 4 persons (diesel and petrol)

	DKK/km			EURO/km		
	Low	Mean	High	Low	Mean	High
Noise	0.03	0.05	0.11	0.004	0.0067	0.015
Accidents	0.18	0.23	0.31	0.024	0.031	0.041
Congestion	0.09	0.38	1.06	0.012	0.051	0.141
Infrastructure	0.00	0.01	0.02	0.000	0.001	0.003
				0.040	**0.089**	**0.200**

Bus for 46 passengers (diesel)

	DKK/km			EURO/km		
	Low	Mean	High	Low	Mean	High
Noise	0.12	0.24	0.47	0.016	0.032	0.063
Accidents	0.40	0.52	0.66	0.053	0.069	0.088
Congestion	0.15	0.70	1.98	0.020	0.093	0.264
Infrastructure	0.15	0.62	0.93	0.020	0.083	0.124
				0.11	**0.28**	**0.54**

Climate change	**Low**	**Mean**	**High**		**Low**	**Mean**	**High**
DKK/t CO_2	53	80	80	**EURO/t**	7.1	10.7	10.7

Emission calculations for land transport modes

In order to carry out a complete emission and cost analysis such that the ship related emissions and external costs can be compared on an equivalent basis with land transportation emissions and external costs, additional emission factors are needed for trucks, busses and cars.

A truck analysis is described in the separate report: Report No. 5: "*Energy and emission model for trucks"* by Hans Otto Kristensen.

For busses and cars separate calculations have been carried out with the TEMA 2015.

Bus

A route of 442 km has been simulated and the energy demand and emissions for the complete bus are shown in table 3. On basis of these results a model for calculation of emissions per km has been developed and the results are shown in table 4 for Euro norm 4 – 6.

Car

A route of 442 km has been simulated and the energy demand and emissions for the car are shown in table 5. On basis of these results a model for calculation of emissions per km has been developed and the results are shown in table 6. Only cars fulfilling Euro norm 6 have been calculated.

Table 3: Results of TEMA 2015 model calculations for different tourist busses

Bus type	Distance km	Energy MJ	SO_2 gram	CO_2 gram	CO gram	HC gram	NOx gram	PM_{10} gram
Tourist <= 18 t, Euro norm 6	442	4191	10.06	310101	370	9.8	138	1.49
Tourist <= 18 t, Euro norm 5 - SCR	442	4061	9.75	300531	687	9.59	1382	9.94
Tourist <= 18 t, Euro norm 5 - EGR	442	4276	10.26	316398	358	19.5	1143	14.8
Tourist <= 18 t, Euro norm 4	442	4203	10.09	311051	353	19.15	1912	14.59
Tourist > 18 t, Euro norm 4	442	4347	10.43	321672	365	20.52	2037	15.41
Tourist > 18 t, Euro norm 3	442	4379	10.51	324050	705	144.07	2865	62.4
Tourist > 18 t, Euro norm 5	442	4435	10.64	328175	373	20.94	1223	15.64

Table 4 Emissions per km based on an analysis of the data in table 3

Tourist bus - diesel - according to TEMA 2015

Euronorm (3 - 6)		4	5	6
Energy demand per km	MJ/km	9.7	9.7	9.7
CO_2 emissions per km	g/km	718	718	718
NOx emissions per km	g/km	4.481	2.852	0.320
SOx emissions per km	g/km	0.0233	0.0233	0.0233
CO emissions per km	g/km	0.815	1.086	0.854
HC emissions per km	g/km	0.0450	0.0378	0.0227
Particulate emissions per km	g/km	0.0340	0.0306	0.0039

Table 5: Results of TEMA 2015 model calculations for Euro norm 6 cars

Car type	Engine Litres	Distance km	MJ	SO_2 gram	CO_2 gram	CO gram	HC gram	NOx gram	PM_{10} gram
Diesel, Euro Norm 6. <1.4 L	1.4	442	866	2.08	64049	8.99	3.05	171.68	0.77
Diesel, Euro Norm 6. 1.4 - 2 L	1.7	442	825	1.98	61061	6.59	2.24	125.81	0.57
Diesel, Euro Norm 6. < 2 L	1.9	442	1101	2.64	81464	6.2	2.11	118.41	0.63
Benzin, Euronorm 6, <0.8 L	0.8	442	737	1.77	53646	337.26	7.06	2.45	0.45
Benzin, Euronorm 6, 0.8-<1.4 L	1.1	442	802	1.93	58409	337.26	7.06	2.45	0.45
Benzin, Euronorm 6, 1.4 - 2 L	1.7	442	1082	2.6	78749	410.42	8.2	2.83	0.53
Benzin, Euronorm 6, > 2 L	2.1	442	1308	3.14	95238	414.67	8.27	2.85	0.05

Table 6 Emissions per km based on an analysis of the data in table 5

Car (Euro 6) according to TEMA 2015

Diesel (1) or petrol driven (2) car		1	2	2
Normal (1) or hybrid (2)		1	1	2
Engine volume (0.8 - 2.2 litres)		1.6	1.6	1.6
Energy demand per km	MJ/km	2.05	2.40	1.60
CO_2 emissions per km	g/km	151.4	174.4	116.3
NOx emissions per km	g/km	0.3347	0.0063	0.0042
SOx emissions per km	g/km	0.0049	0.0058	0.0038
CO emissions per km	g/km	0.0176	0.8980	0.5987
HC emissions per km	g/km	0.0060	0.0183	0.0122
Particulate emissions per km	g/km	0.00156	0.00086	0.00057

Comparison between transport modes

For Ro-Ro passenger ships the emissions and external costs are related to lanemeters per nautical mile and passengers per nautical mile respectively, according to the different allocation methods as previously described. With the introduction of emission calculation procedures for trucks, busses and cars SHIP-DESMO makes it possible to compare the transport by sea with an equivalent transport by road of the same amount of cargo (rolling cargo and passengers) which is carried on the ship.

Example calculations

In order to illustrate the capabilities of SHIP-DESMO different typical calculation examples are shown in Appendix C and D.

References

- Kristensen H. O: *Prediction of resistance and propulsion power of Ro-Ro ships*. August 2015. Report No. 01 of project No. 2014-122: Mitigating and reversing the side-effects of environmental legislation on Ro-Ro shipping in Northern Europe.

- Kristensen H. O: *Analysis of technical data of Ro-Ro ships.* July 2016. Report No. 02 of project No. 2014-122: Mitigating and reversing the side-effects of environmental legislation on Ro-Ro shipping in Northern Europe.

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- Kristensen H. O: *Energy and emission model for trucks.* September 2015. Report No. 05 of project No. 2014-122: Mitigating and reversing the side-effects of environmental legislation on Ro-Ro shipping in Northern Europe.

- *Significant Ships 1990 – 2014,* published annually by Royal Institution of Naval Architects (RINA)

- Kristensen H. O and Hagemeister C: *Environmental Performance Evaluation of Ro-Ro Passenger Ferry Transportation*. August 2011. Trafikdage på Aalborg Universitet. ISSN 1603 9696.

- CEN Standard 16258: Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers).

Appendix A - Different interior areas of Ro-Ro passenger ships

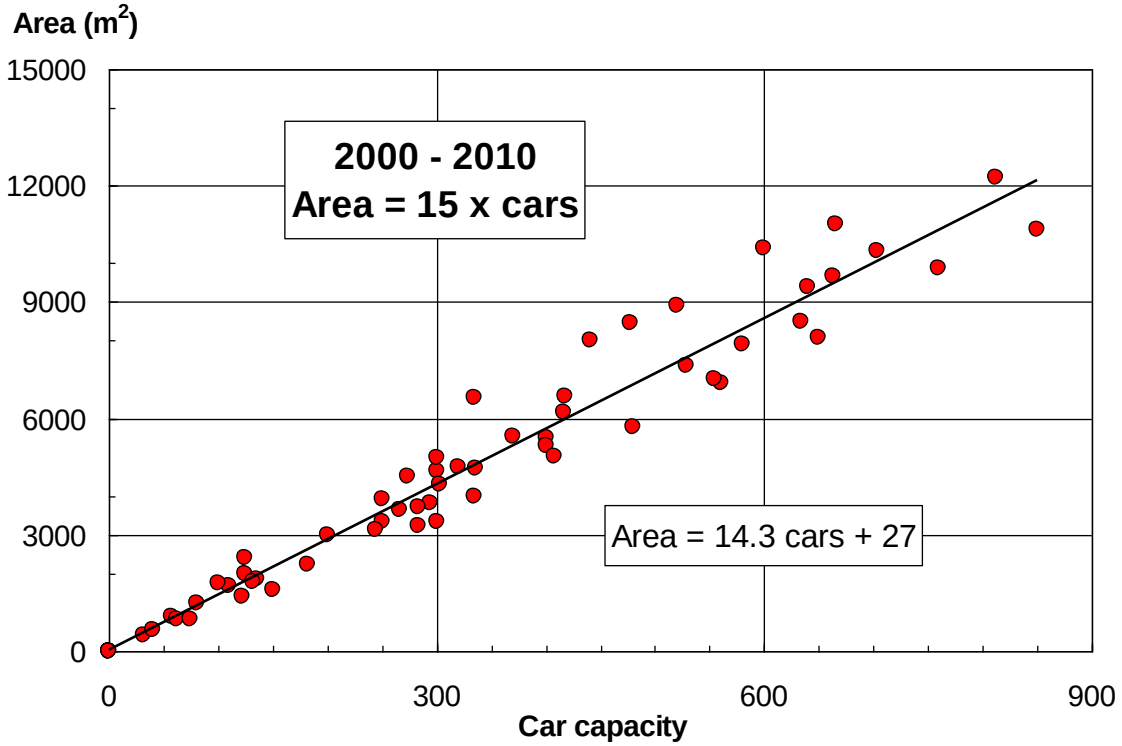


Fig. A1 Car deck area of Ro-Ro passenger ships (Hagemeister thesis work 2011)

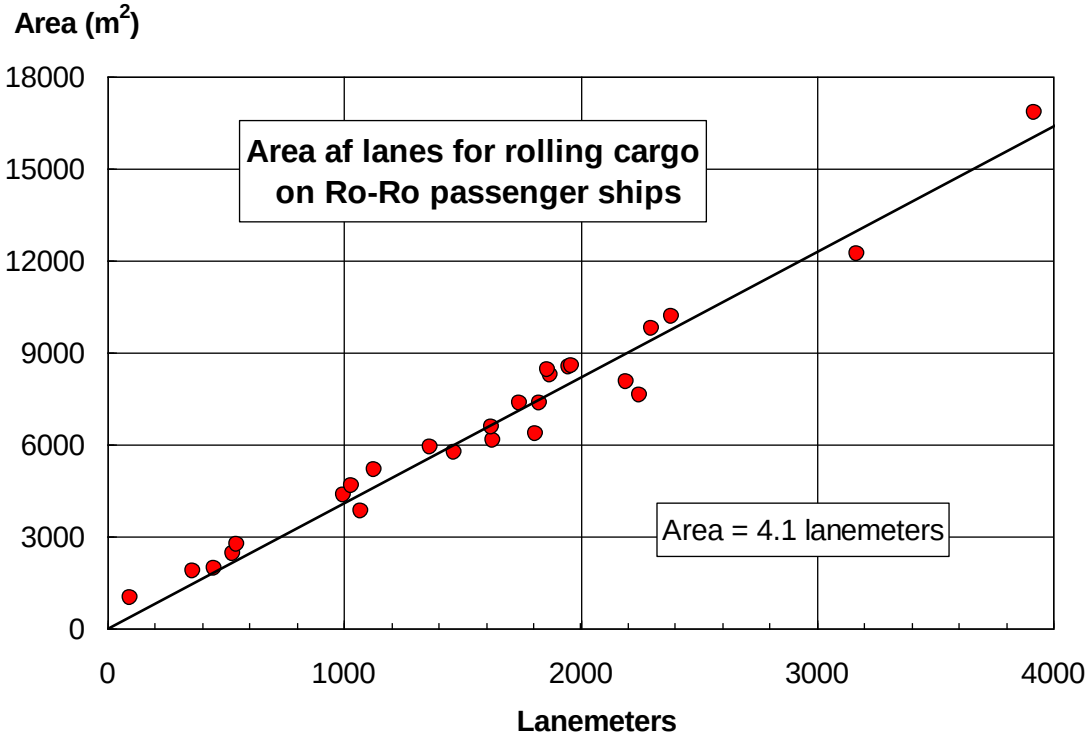


Fig. A2 Area of cargo lanes of Ro-Ro passenger ships (Hagemeister thesis work 2011)

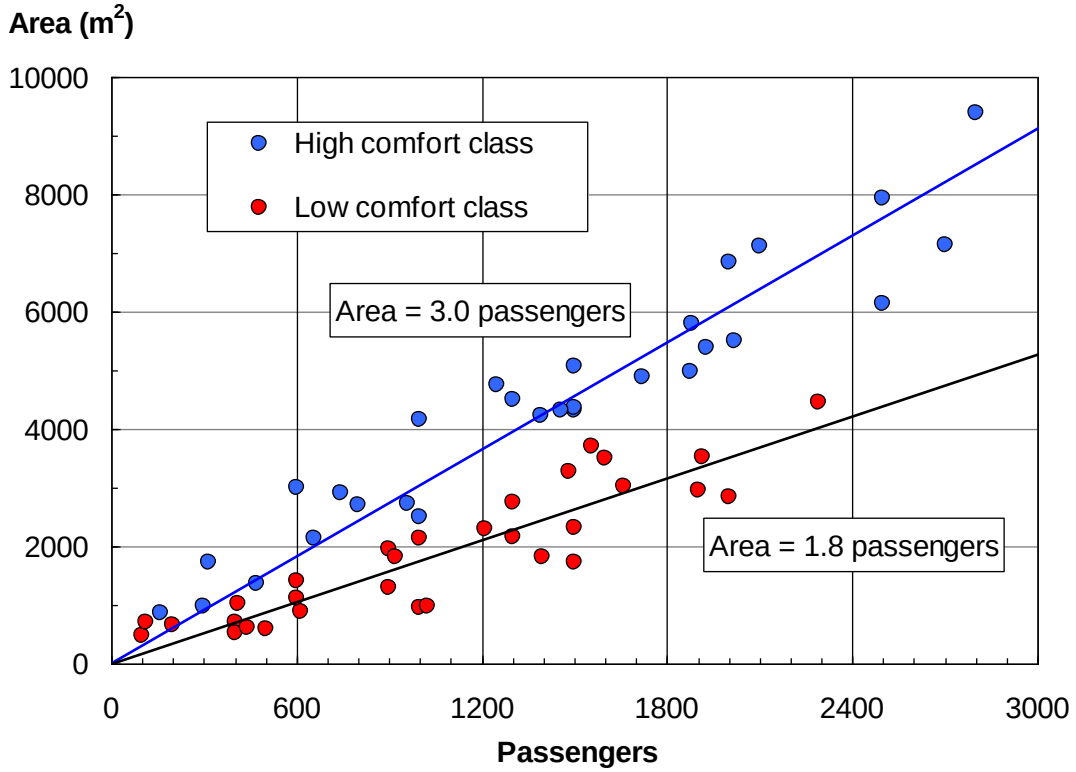


Fig. A3 Area of cafeteria, restaurants, halls, corridors and toilets (Hagemeister thesis work 2011)

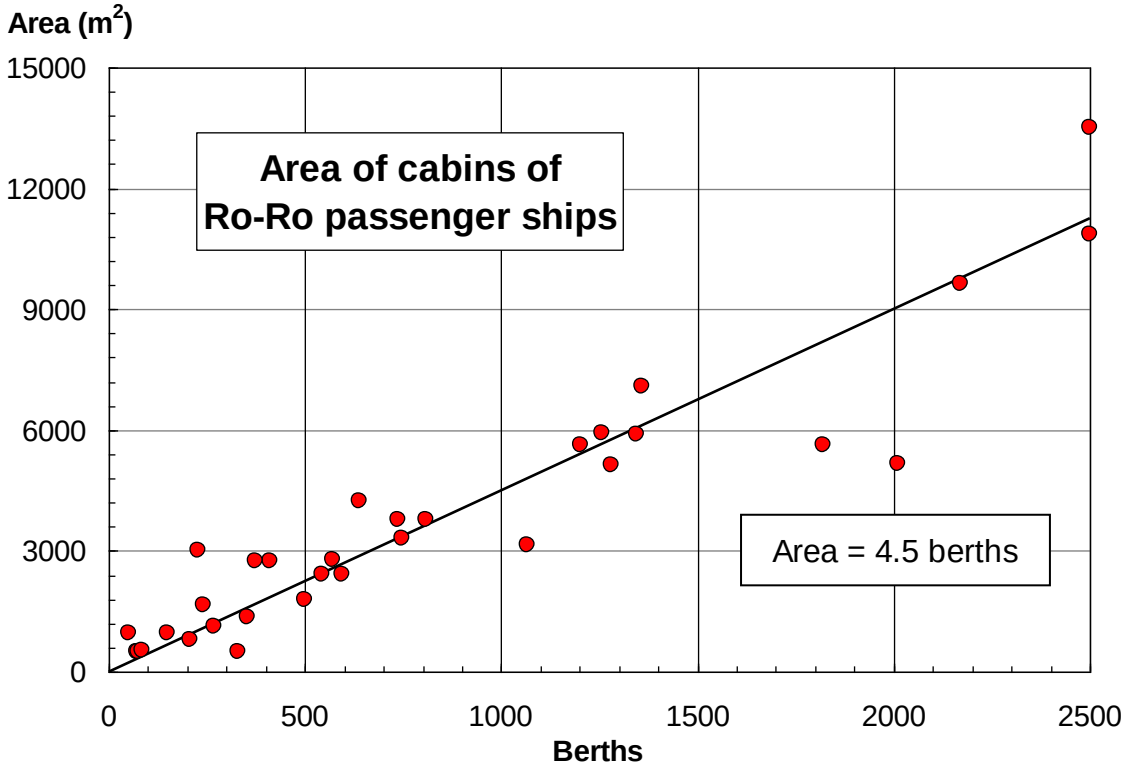


Fig. A4 Area of passenger cabins of Ro-Ro passenger ships (Hagemeister thesis work 2011)

Appendix B - Calculation example from CEN standard 16258

Example for combined passenger and freight transport: ferry lines

G.1 Description of the example

This example serves as an illustration of the impact of the two allocation methods specified in Annex B on one real ferry transport system.

The areas in the example are based on 100 % accessible area capacity according to valid general arrangement plan (GA-plan). The transport statistics used are one year real data i.e. this example presents an example of annual average allocation values. The values per entity used are the default values presented in Annex B, Table B1.

Table G.1 — Data for this example

	Annual activity data			Value per entity			
Entity	**Quantity**	**Mass (t)**	**Area (m²)**	**Mass (kg)**	**Area (m²)**	**Length (m)**	**Width (m)**
Pax deck area					7 550		
Vehicles deck area					5 770		
Passenger and luggage	478 500	47 850		100			
Passenger car	90 000	135 000	1 674 000	1 500	18,6	6	3,1
Bus	1 000	15 000	37 200	15 000	37,2	12	3,1
Caravan (small)	500	500	4 650	1 000	9,3	3	3,1
Caravan (medium)	500	1 000	9 300	2 000	18,6	6	3,1
Caravan (large)	500	1 250	15 500	2 500	31,0	10	3,1
Mobile home	-	-	-	3 500	24,8	8	3,1
Motorcycle	1 000	200	4 650	200	4,7	1,5	3,1
Unaccompanied trailer							
Empty trailer				8 000	43,4	14	3,1
Average load per trailer				19 000			
Total	4 000	108 000	173 600	27 000	43,4	14	3,1
Accompanied trailer							
Empty trailer				16 000	52,7	17	3,1
Average load per trailer				19 000			
Total	34 000	1 190 000	1 791 800	35 000	52,7	17	3,1

G.2 Results and comparison of the two allocation methods

In the mass allocation method, the weight of vehicles (including their loads for freight) and weight of passengers are based on annual activity data and values per entity presented in Table G.1. Table G.2 gives the corresponding results.

Table G.2 — Results with use of Mass allocation method

Mass allocation method	mass	%
Freight	1 298 000	87 %
Passengers	200 800	13 %
Total	1 498 800	100 %

In the area allocation method the relation between areas used by freight and passenger serves as the allocation ratio. Whole passenger deck area is allocated to passengers. Vehicle deck area is allocated according to the ratio between freight vehicles and passenger vehicles according to activity data and values per entity presented in Table G1. Table G.3 gives the corresponding results.

Table G.3 — Results with use of Area allocation method

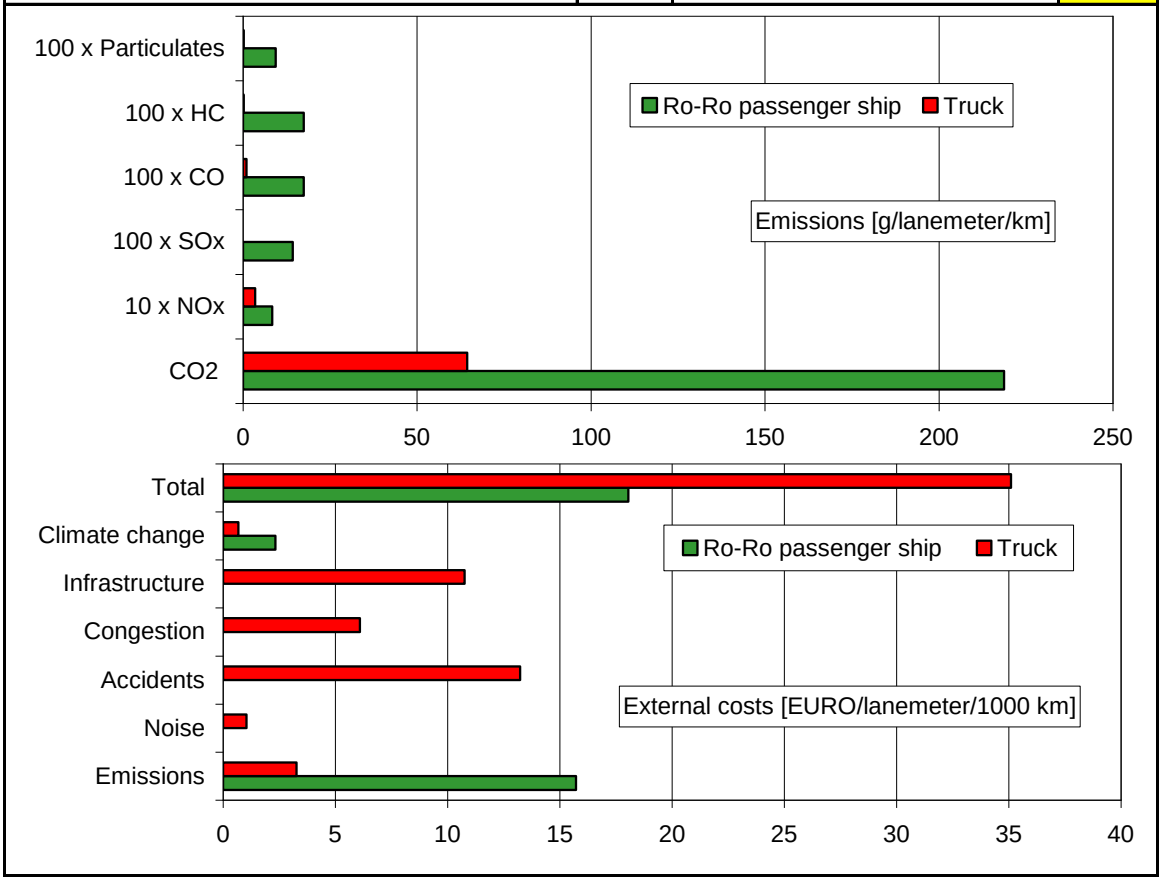
Area allocation method	area	%
Freight	3 056	23 %
Passengers	10 264	77 %
Total	13 320	100 %

In conclusion, by using one allocation method or the other for the same combined passenger and cargo ferry, the distribution of energy consumption and GHG emissions gives completely different results. Hence, if the emission and energy data includes ferry vessel operation and the receiver of the data wishes to compare results, particular attention should be paid to the consistency in allocation methodology. As stated in Annex B.1, the ferry allocation method shall be consistent over time and per ferry line unless the ship is converted or allocated to a different line. Information about the allocation method used for a particular transport service will be available to the receiver of the data, and can be found in the supporting information which accompanies the declaration of results (see 10.3.2).

Appendix C: Calculation examples of emissions and external costs with SHIP-DESMO for a Ro Ro passenger ship

Example No. 1: 2000 passenger Ro-Ro passenger ship loaded with 100 % trucks and only 200 passengers (typical off season situation). Average allocation procedure

Ship data		Truck data	
Default ship (0) or ship alternative No. 1 or No. 2	0	Total weight of truck cargo (t)	18.0
Low cargo density (1) or high cargo density (2)	1	Truck weight (empty)	10.0
Passenger capacity (persons)	2000	Truck weight (loaded)	28.0
Actual number of passengers	0	Length of truck - total (m)	14.0
Total lanemeters (100 %) = LM	1337	EURO norm (2, 3, 4, 5 or 6)	4
Total number of cars (100 %)	450	Driving distance (km)	400
Actual payload/deadweight at maximum draught (pct.)	60	Driving percentage in city area	5
Rolling cargo lanemeters in pct. of total LM	100	**Car data (Euro Norm 6)**	
Bus lanemeters in pct. of total LM	0	Diesel (1) or petrol driven (2) car	2
Car and caravan lanemeters in pct. of total LM	0	Normal (1) or hybrid (2)	1
Occupied lanemeters	1337	Engine volume (0.8 - 2.2 litres)	1.8
Normal speed (knots)	22.3	Number of passengers (max. 4)	2
Actual speed (knots)	22.3	**Bus data**	
Speed change (pct.)	0	EURO norm (3 - 6)	4
Pass. comfort class (1 = low, 2 = average or 3 = high)	2	Number of passengers (max. 45)	40
Suphur content of oil (%)	0.1	**External cost level**	
NOx emissions (IMO TIER 1, 2 or 3)	3	1 = Low, 2 = Mean, 3 = High	2
Slow speed (1) or medium speed main engine (2)	2	EURO/DKK exchange rate	7.50
Sailing percentage in harbour conditions	2.0	**Emission allocation method**	
Remaining draft reserve (m) - shall be positive !	0.02	Area (1), mass (2) or average (3)	3



Emissions (g/cargo lanemeter/km)

Ship		Truck	
CO_2	218.7	CO_2	64.4
10 x NOx	8.4	10 x NOx	3.52
100 x SOx	14.3	100 x SOx	0.04
100 x CO	17.4	100 x CO	1.00
100 x HC	17.4	100 x HC	0.15
100 x Particulates	9.4	100 x Particulates	0.20

External costs (EURO/lanemeter/1000 km)

Ship		Truck	
Emissions	15.73	Emissions	3.27
Noise	0.00	Noise	1.05
Accidents	0.00	Accidents	13.24
Congestion	0.00	Congestion	6.10
Infrastructure	0.00	Infrastructure	10.76
Climate change	2.33	Climate change	0.69
Total	**18.1**	**Total**	**35.1**

External costs (EURO/lanemeter/1000 km)

Ship		Truck	
CO_2	2.33	CO_2	0.69
NOx	5.91	NOx	2.48
SOx	4.00	SOx	0.01
CO	0.00	CO	0.00
HC	0.05	HC	0.00
Particulates	3.43	Particulates	0.09
Total	**15.73**	**Total**	**3.27**

Service allowance on ship power (%)	10

It is possible to scale the influence some of the external costs as follows:

Externality	Scaling (pct)
Noise	100
Accidents	100
Congestion	100
Infrastructure	100
Climate change	100

100 pct. means full implementation according to the quidelines by DTU/COWI (2016)

Emissions (g/passenger/km)

Ship		Bus	
CO_2	0.0	CO_2	17.9
10 x NOx	0.0	10 x NOx	1.1
100 x SOx	0.0	100 x SOx	0.1
100 x CO	0.0	100 x CO	2.0
100 x HC	0.0	100 x HC	0.1
100 x Particulates	0.0	100 x Particulates	0.1

External costs (EURO/passenger/1000 km)

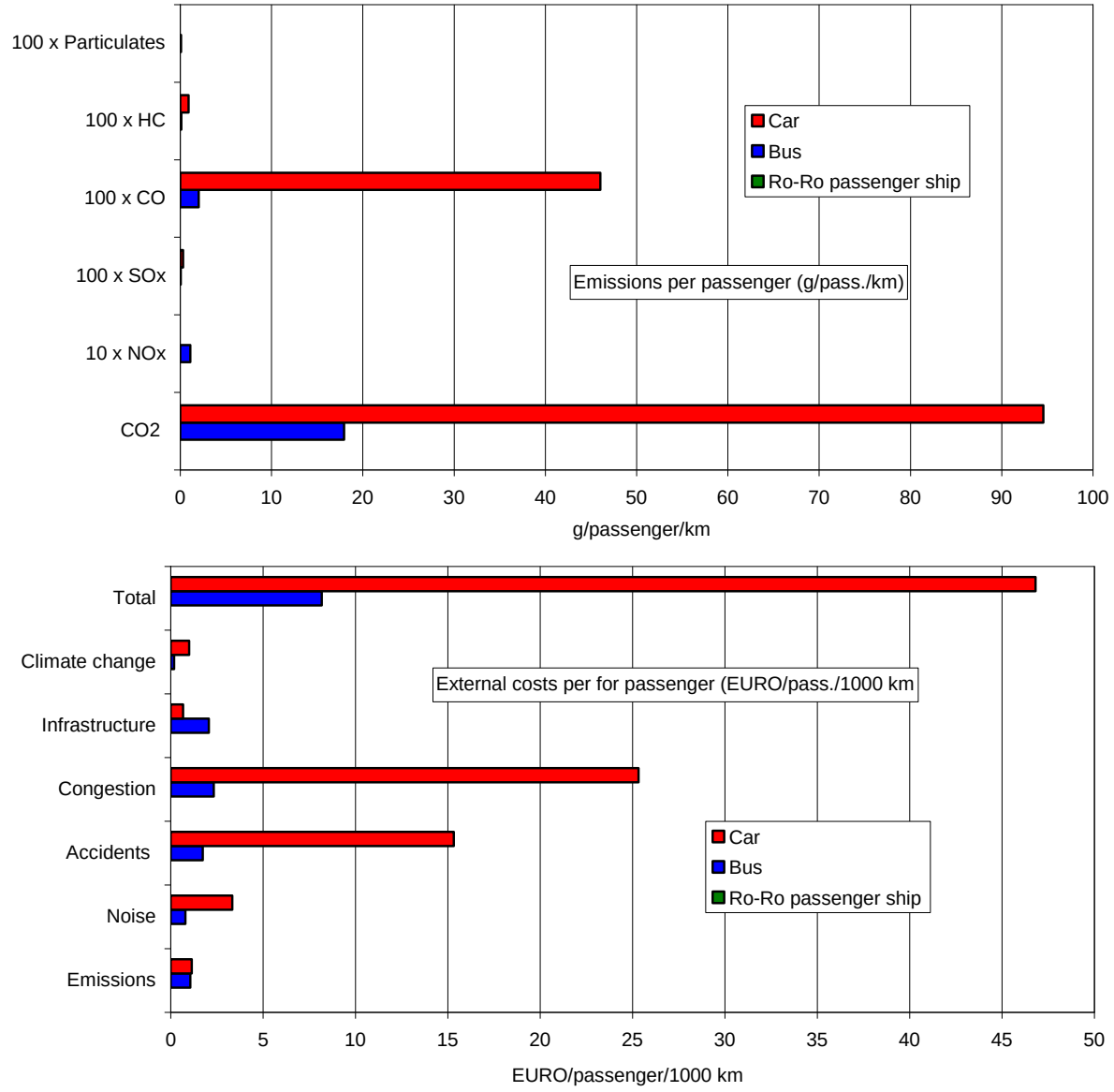
Ship		Bus	
Emissions	0.00	Emissions	1.06
Noise	0.00	Noise	0.80
Accidents	0.00	Accidents	1.73
Congestion	0.00	Congestion	2.33
Infrastructure	0.00	Infrastructure	2.07
Climate change	0.00	Climate change	0.19
Total	**0.0**	**Total**	**8.2**

Emissions (g/passenger/km)

Ship		Car	
CO_2	0.0	CO_2	94.6
10 x NOx	0.0	10 x NOx	0.032
100 x SOx	0.0	100 x SOx	0.312
100 x CO	0.0	100 x CO	46.0
100 x HC	0.0	100 x HC	0.93
100 x Particulates	0.0	100 x Particulates	0.036

External costs (EURO/passenger/1000 km)

Ship		Car	
Emissions	0.00	Emissions	1.14
Noise	0.00	Noise	3.33
Accidents	0.00	Accidents	15.33
Congestion	0.00	Congestion	25.3
Infrastructure	0.00	Infrastructure	0.67
Climate change	0.00	Climate change	1.01
Total	**0.0**	**Total**	**46.8**

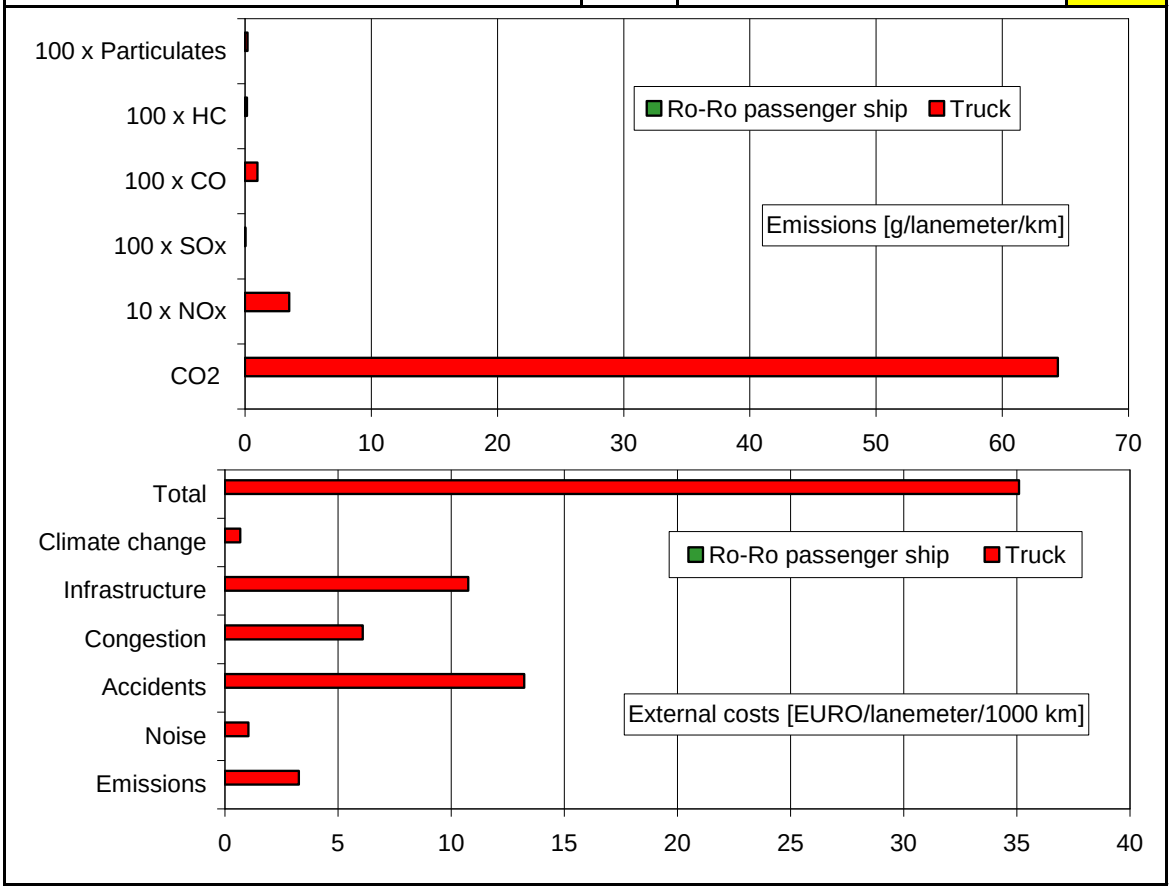


Total external costs for all transported items for a Ro-Ro passenger ship versus road (EURO/km)

By sea		**By road (trucks and cars only)**	
Area allocation method	EURO/km		EURO/km
Cargo	24.14	Cargo	46.93
Passengers	0.00	Passengers by car	0.00
Total	**24.14**	**Total**	**46.93**
Mass allocation method		**By road (trucks and busses only)**	
Cargo	24.14	Cargo	46.93
Passengers	0.00	Passengers by busses	0.00
Total	**24.14**	**Total**	**46.93**
Average allocation method			
Cargo	24.14		
Passengers	0.00		
Total	**24.14**		

Example No. 2: 2000 passenger Ro-Ro passenger ship loaded with 100 % cars (450) and 2000 passengers (typical summer season situation). Average allocation procedure

Ship data		Truck data	
Default ship (0) or ship alternative No. 1 or No. 2	0	Total weight of truck cargo (t)	18.0
Low cargo density (1) or high cargo density (2)	1	Truck weight (empty)	10.0
Passenger capacity (persons)	2000	Truck weight (loaded)	28.0
Actual number of passengers	2000	Length of truck - total (m)	14.0
Total lanemeters (100 %) = LM	1337	EURO norm (2, 3, 4, 5 or 6)	4
Total number of cars (100 %)	450	Driving distance (km)	400
Actual payload/deadweight at maximum draught (pct.)	60	Driving percentage in city area	5
Rolling cargo lanemeters in pct. of total LM	0	**Car data (Euro Norm 6)**	
Bus lanemeters in pct. of total LM	0	Diesel (1) or petrol driven (2) car	2
Car and caravan lanemeters in pct. of total LM	100	Normal (1) or hybrid (2)	1
Occupied lanemeters	1337	Engine volume (0.8 - 2.2 litres)	1.8
Normal speed (knots)	22.3	Number of passengers (max. 4)	2
Actual speed (knots)	22.3	**Bus data**	
Speed change (pct.)	0	EURO norm (3 - 6)	4
Pass. comfort class (1 = low, 2 = average or 3 = high)	2	Number of passengers (max. 45)	40
Suphur content of oil (%)	0.1	**External cost level**	
NOx emissions (IMO TIER 1, 2 or 3)	3	1 = Low, 2 = Mean, 3 = High	2
Slow speed (1) or medium speed main engine (2)	2	EURO/DKK exchange rate	7.50
Sailing percentage in harbour conditions	2.0	**Emission allocation method**	
Remaining draft reserve (m) - shall be positive !	0.59	Area (1), mass (2) or average (3)	3



Emissions (g/cargo lanemeter/km)

Ship		Truck	
CO_2	0.0	CO_2	64.4
10 x NOx	0.0	10 x NOx	3.52
100 x SOx	0.0	100 x SOx	0.04
100 x CO	0.0	100 x CO	1.00
100 x HC	0.0	100 x HC	0.15
100 x Particulates	0.0	100 x Particulates	0.20

External costs (EURO/lanemeter/1000 km)

Ship		Truck	
Emissions	0.00	Emissions	3.27
Noise	0.00	Noise	1.05
Accidents	0.00	Accidents	13.24
Congestion	0.00	Congestion	6.10
Infrastructure	0.00	Infrastructure	10.76
Climate change	0.00	Climate change	0.69
Total	**0.0**	**Total**	**35.1**

External costs (EURO/lanemeter/1000 km)

Ship		Truck	
CO_2	0.00	CO_2	0.69
NOx	0.00	NOx	2.48
SOx	0.00	SOx	0.01
CO	0.00	CO	0.00
HC	0.00	HC	0.00
Particulates	0.00	Particulates	0.09
Total	**0.00**	**Total**	**3.27**

Service allowance on ship power (%)	10

It is possible to scale the influence some of the external costs as follows:

Externality	Scaling (pct)
Noise	100
Accidents	100
Congestion	100
Infrastructure	100
Climate change	100

100 pct. means full implementation according to the quidelines by DTU/COWI (2016)

Emissions (g/passenger/km)

Ship		Bus	
CO_2	129.8	CO_2	17.9
10 x NOx	5.0	10 x NOx	1.1
100 x SOx	8.5	100 x SOx	0.1
100 x CO	10.3	100 x CO	2.0
100 x HC	10.3	100 x HC	0.1
100 x Particulates	5.6	100 x Particulates	0.1

External costs (EURO/passenger/1000 km)

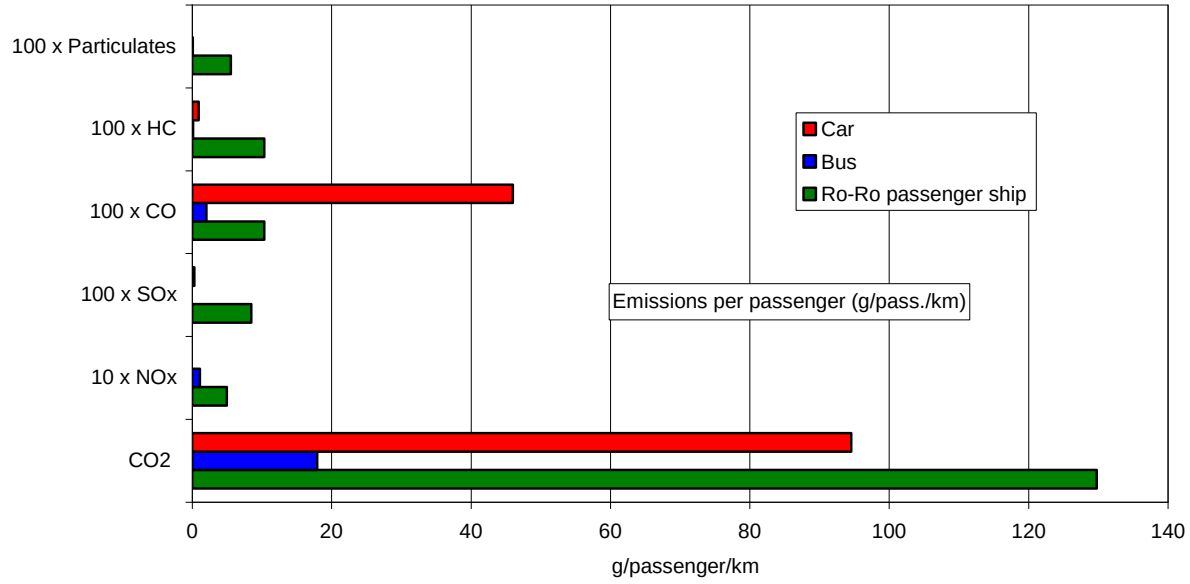
Ship		Bus	
Emissions	9.33	Emissions	1.06
Noise	0.00	Noise	0.80
Accidents	0.00	Accidents	1.73
Congestion	0.00	Congestion	2.33
Infrastructure	0.00	Infrastructure	2.07
Climate change	1.38	Climate change	0.19
Total	**10.7**	**Total**	**8.2**

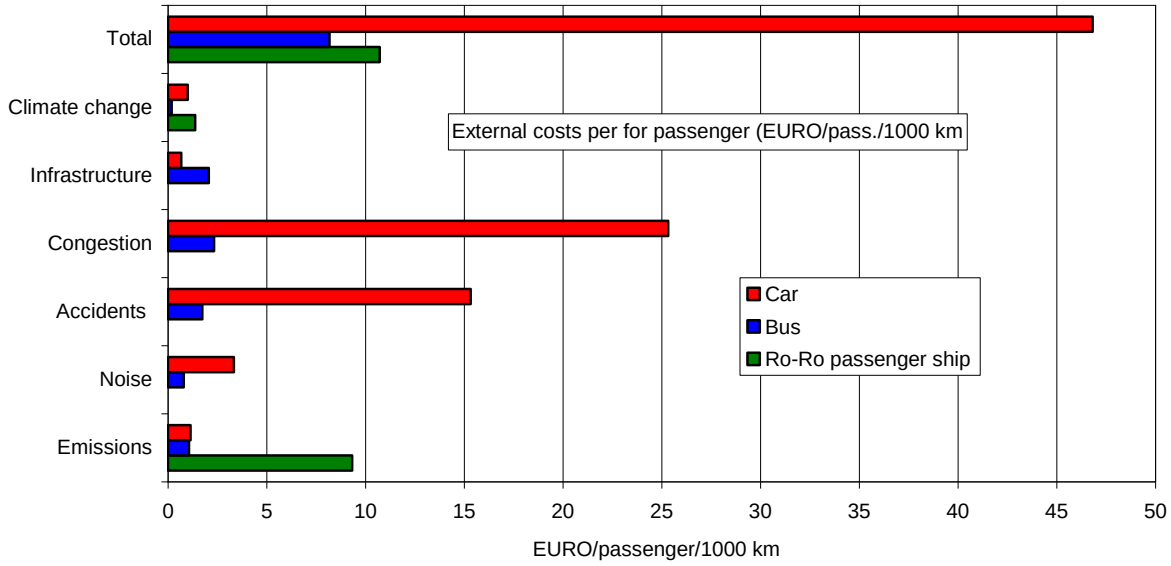
Emissions (g/passenger/km)

Ship		Car	
CO_2	129.8	CO_2	94.6
10 x NOx	5.0	10 x NOx	0.032
100 x SOx	8.5	100 x SOx	0.312
100 x CO	10.3	100 x CO	46.0
100 x HC	10.3	100 x HC	0.93
100 x Particulates	5.6	100 x Particulates	0.036

External costs (EURO/passenger/1000 km)

Ship		Car	
Emissions	9.33	Emissions	1.14
Noise	0.00	Noise	3.33
Accidents	0.00	Accidents	15.33
Congestion	0.00	Congestion	25.3
Infrastructure	0.00	Infrastructure	0.67
Climate change	1.38	Climate change	1.01
Total	**10.7**	**Total**	**46.8**



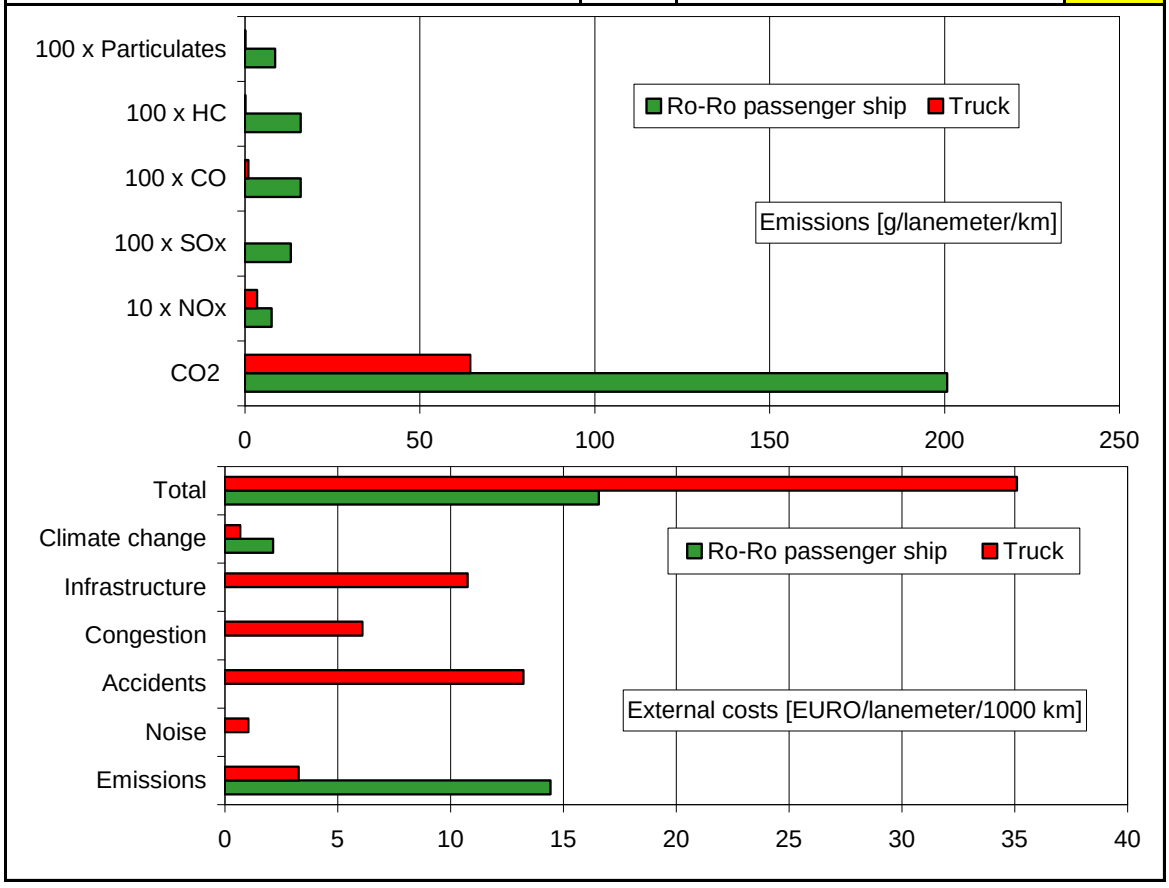


Total external costs for all transported items for a Ro-Ro passenger ship versus road (EURO/km)

By sea		**By road (trucks and cars only)**	
Area allocation method	EURO/km		EURO/km
Cargo	0.00	Cargo	0.00
Passengers	21.43	Passengers by car	93.63
Total	**21.43**	**Total**	**93.63**
Mass allocation method		**By road (trucks and busses only)**	
Cargo	0.00	Cargo	0.00
Passengers	21.43	Passengers by busses	16.37
Total	**21.43**	**Total**	**16.37**
Average allocation method			
Cargo	0.00		
Passengers	21.43		
Total	**21.43**		

Example No. 3: 2000 passenger Ro-Ro passenger ship loaded with 1000 passengers (50 %) and 40 % trucks, 30 % busses and 30 % cars. Average allocation procedure

Ship data		Truck data	
Default ship (0) or ship alternative No. 1 or No. 2	0	Total weight of truck cargo (t)	18.0
Low cargo density (1) or high cargo density (2)	1	Truck weight (empty)	10.0
Passenger capacity (persons)	2000	Truck weight (loaded)	28.0
Actual number of passengers	1000	Length of truck - total (m)	14.0
Total lanemeters (100 %) = LM	1337	EURO norm (2, 3, 4, 5 or 6)	4
Total number of cars (100 %)	450	Driving distance (km)	400
Actual payload/deadweight at maximum draught (pct.)	60	Driving percentage in city area	5
Rolling cargo lanemeters in pct. of total LM	40	**Car data (Euro Norm 6)**	
Bus lanemeters in pct. of total LM	30	Diesel (1) or petrol driven (2) car	2
Car and caravan lanemeters in pct. of total LM	30	Normal (1) or hybrid (2)	1
Occupied lanemeters	1337	Engine volume (0.8 - 2.2 litres)	1.8
Normal speed (knots)	22.3	Number of passengers (max. 4)	2
Actual speed (knots)	22.3	**Bus data**	
Speed change (pct.)	0	EURO norm (3 - 6)	4
Pass. comfort class (1 = low, 2 = average or 3 = high)	2	Number of passengers (max. 45)	40
Suphur content of oil (%)	0.1	**External cost level**	
NOx emissions (IMO TIER 1, 2 or 3)	3	1 = Low, 2 = Mean, 3 = High	2
Slow speed (1) or medium speed main engine (2)	2	EURO/DKK exchange rate	7.50
Sailing percentage in harbour conditions	2.0	**Emission allocation method**	
Remaining draft reserve (m) - shall be positive !	0.27	Area (1), mass (2) or average (3)	3



Emissions (g/cargo lanemeter/km)

Ship		Truck	
CO_2	200.8	CO_2	64.4
10 x NOx	7.7	10 x NOx	3.52
100 x SOx	13.2	100 x SOx	0.04
100 x CO	16.0	100 x CO	1.00
100 x HC	16.0	100 x HC	0.15
100 x Particulates	8.6	100 x Particulates	0.20

External costs (EURO/lanemeter/1000 km)

Ship		Truck	
Emissions	14.44	Emissions	3.27
Noise	0.00	Noise	1.05
Accidents	0.00	Accidents	13.24
Congestion	0.00	Congestion	6.10
Infrastructure	0.00	Infrastructure	10.76
Climate change	2.14	Climate change	0.69
Total	**16.6**	**Total**	**35.1**

External costs (EURO/lanemeter/1000 km)

Ship		Truck	
CO_2	2.14	CO_2	0.69
NOx	5.43	NOx	2.48
SOx	3.68	SOx	0.01
CO	0.00	CO	0.00
HC	0.04	HC	0.00
Particulates	3.15	Particulates	0.09
Total	**14.44**	**Total**	**3.27**

Service allowance on ship power (%)	10

It is possible to scale the influence some of the external costs as follows:

Externality	Scaling (pct)
Noise	100
Accidents	100
Congestion	100
Infrastructure	100
Climate change	100

100 pct. means full implementation according to the quidelines by DTU/COWI (2016)

Emissions (g/passenger/km)

Ship		Bus	
CO_2	169.1	CO_2	17.9
10 x NOx	6.5	10 x NOx	1.1
100 x SOx	11.1	100 x SOx	0.1
100 x CO	13.5	100 x CO	2.0
100 x HC	13.5	100 x HC	0.1
100 x Particulates	7.3	100 x Particulates	0.1

External costs (EURO/passenger/1000 km)

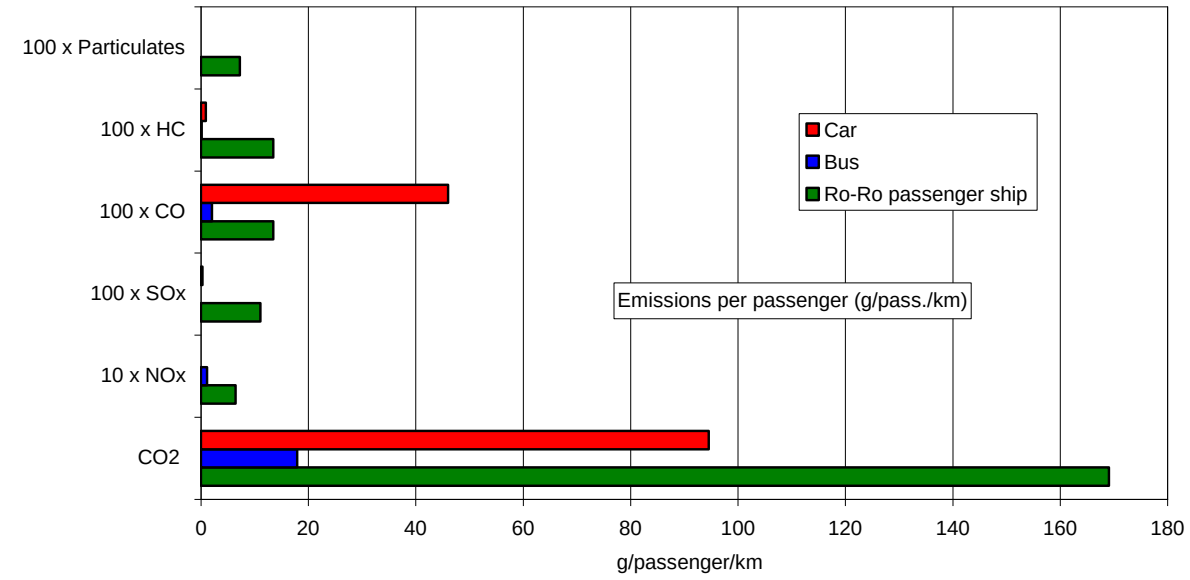
Ship		Bus	
Emissions	12.16	Emissions	1.06
Noise	0.00	Noise	0.80
Accidents	0.00	Accidents	1.73
Congestion	0.00	Congestion	2.33
Infrastructure	0.00	Infrastructure	2.07
Climate change	1.80	Climate change	0.19
Total	**14.0**	**Total**	**8.2**

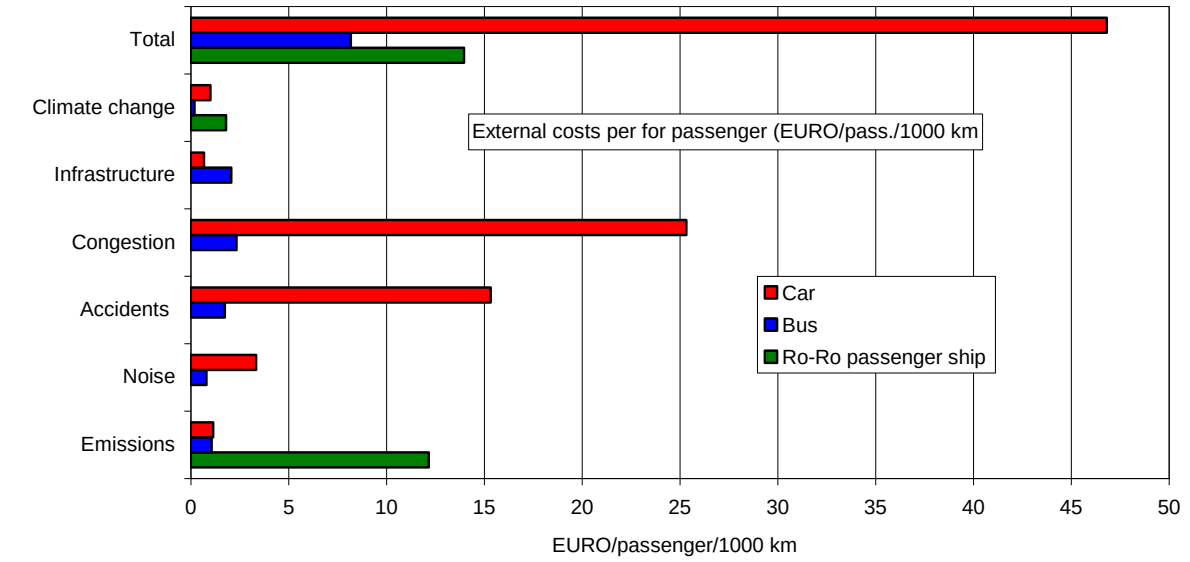
Emissions (g/passenger/km)

Ship		Car	
CO_2	169.1	CO_2	94.6
10 x NOx	6.5	10 x NOx	0.032
100 x SOx	11.1	100 x SOx	0.312
100 x CO	13.5	100 x CO	46.0
100 x HC	13.5	100 x HC	0.93
100 x Particulates	7.3	100 x Particulates	0.036

External costs (EURO/passenger/1000 km)

Ship		Car	
Emissions	12.16	Emissions	1.14
Noise	0.00	Noise	3.33
Accidents	0.00	Accidents	15.33
Congestion	0.00	Congestion	25.3
Infrastructure	0.00	Infrastructure	0.67
Climate change	1.80	Climate change	1.01
Total	**14.0**	**Total**	**46.8**



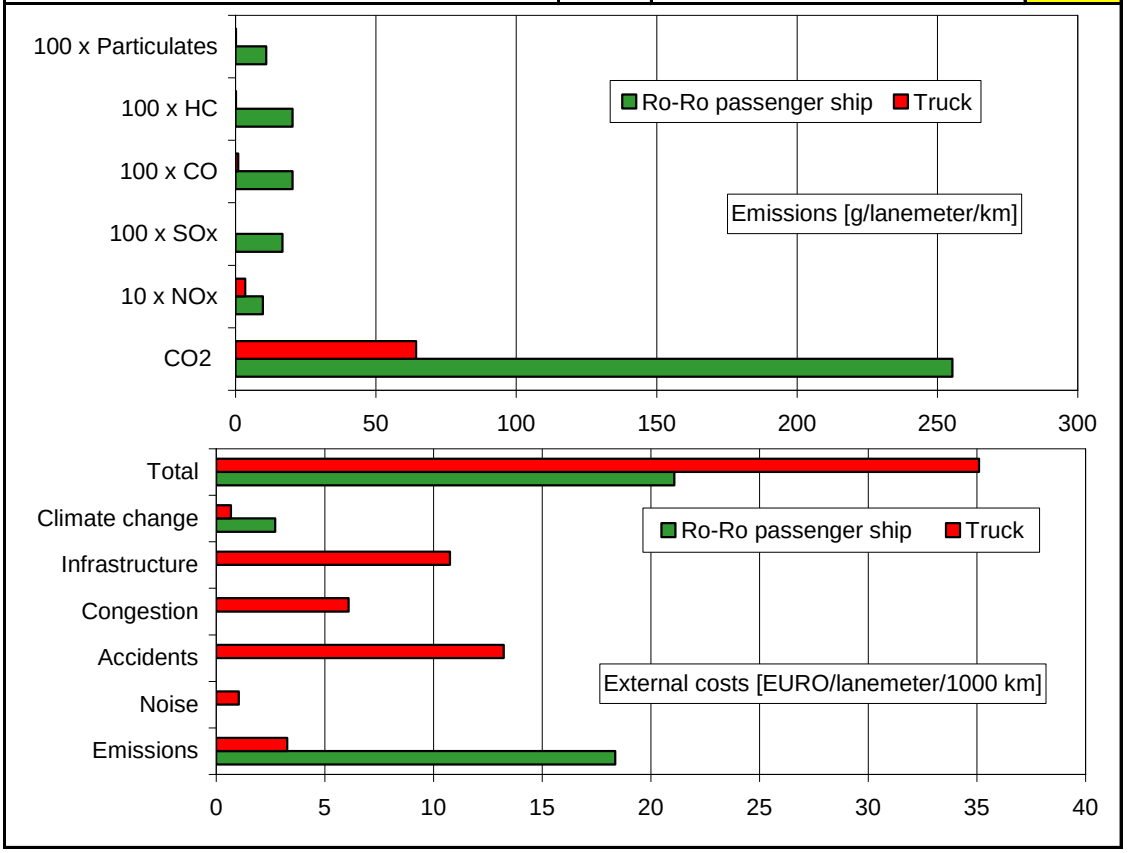


Total external costs for all transported items for a Ro-Ro passenger ship versus road (EURO/km)

By sea		**By road (trucks and cars only)**	
Area allocation method	EURO/km		EURO/km
Cargo	4.70	Cargo	18.77
Passengers	18.13	Passengers by car	46.81
Total	**22.83**	**Total**	**65.58**
Mass allocation method		**By road (trucks and busses only)**	
Cargo	13.03	Cargo	18.77
Passengers	9.80	Passengers by busses	8.19
Total	**22.83**	**Total**	**26.96**
Average allocation method			
Cargo	8.87		
Passengers	13.96		
Total	**22.83**		

Example No. 4: 2000 passenger Ro-Ro passenger ship loaded 500 passengers (25 %) and 50 % trucks, NO busses and 25 % cars (relatively poor utilization). Average allocation procedure

Ship data		Truck data	
Default ship (0) or ship alternative No. 1 or No. 2	0	Total weight of truck cargo (t)	18.0
Low cargo density (1) or high cargo density (2)	1	Truck weight (empty)	10.0
Passenger capacity (persons)	2000	Truck weight (loaded)	28.0
Actual number of passengers	500	Length of truck - total (m)	14.0
Total lanemeters (100 %) = LM	1337	EURO norm (2, 3, 4, 5 or 6)	4
Total number of cars (100 %)	450	Driving distance (km)	400
Actual payload/deadweight at maximum draught (pct.)	60	Driving percentage in city area	5
Rolling cargo lanemeters in pct. of total LM	50	**Car data (Euro Norm 6)**	
Bus lanemeters in pct. of total LM	0	Diesel (1) or petrol driven (2) car	2
Car and caravan lanemeters in pct. of total LM	25	Normal (1) or hybrid (2)	1
Occupied lanemeters	1003	Engine volume (0.8 - 2.2 litres)	1.8
Normal speed (knots)	22.3	Number of passengers (max. 4)	2
Actual speed (knots)	22.3	**Bus data**	
Speed change (pct.)	0	EURO norm (3 - 6)	4
Pass. comfort class (1 = low, 2 = average or 3 = high)	2	Number of passengers (max. 45)	40
Suphur content of oil (%)	0.1	**External cost level**	
NOx emissions (IMO TIER 1, 2 or 3)	3	1 = Low, 2 = Mean, 3 = High	2
Slow speed (1) or medium speed main engine (2)	2	EURO/DKK exchange rate	7.50
Sailing percentage in harbour conditions	2.0	**Emission allocation method**	
Remaining draft reserve (m) - shall be positive !	0.37	Area (1), mass (2) or average (3)	3



Emissions (g/cargo lanemeter/km)

Ship		Truck	
CO_2	255.4	CO_2	64.4
10 x NOx	9.8	10 x NOx	3.52
100 x SOx	16.7	100 x SOx	0.04
100 x CO	20.4	100 x CO	1.00
100 x HC	20.4	100 x HC	0.15
100 x Particulates	11.0	100 x Particulates	0.20

External costs (EURO/lanemeter/1000 km)

Ship		Truck	
Emissions	18.36	Emissions	3.27
Noise	0.00	Noise	1.05
Accidents	0.00	Accidents	13.24
Congestion	0.00	Congestion	6.10
Infrastructure	0.00	Infrastructure	10.76
Climate change	2.72	Climate change	0.69
Total	**21.1**	**Total**	**35.1**

External costs (EURO/lanemeter/1000 km)

Ship		Truck	
CO_2	2.72	CO_2	0.69
NOx	6.90	NOx	2.48
SOx	4.68	SOx	0.01
CO	0.00	CO	0.00
HC	0.05	HC	0.00
Particulates	4.00	Particulates	0.09
Total	**18.36**	**Total**	**3.27**

Service allowance on ship power (%)	10

It is possible to scale the influence some of the external costs as follows:

Externality	Scaling (pct)
Noise	100
Accidents	100
Congestion	100
Infrastructure	100
Climate change	100

100 pct. means full implementation according to the quidelines by DTU/COWI (2016)

Emissions (g/passenger/km)

Ship		Bus	
CO_2	200.1	CO_2	17.9
10 x NOx	7.7	10 x NOx	1.1
100 x SOx	13.1	100 x SOx	0.1
100 x CO	15.9	100 x CO	2.0
100 x HC	15.9	100 x HC	0.1
100 x Particulates	8.6	100 x Particulates	0.1

External costs (EURO/passenger/1000 km)

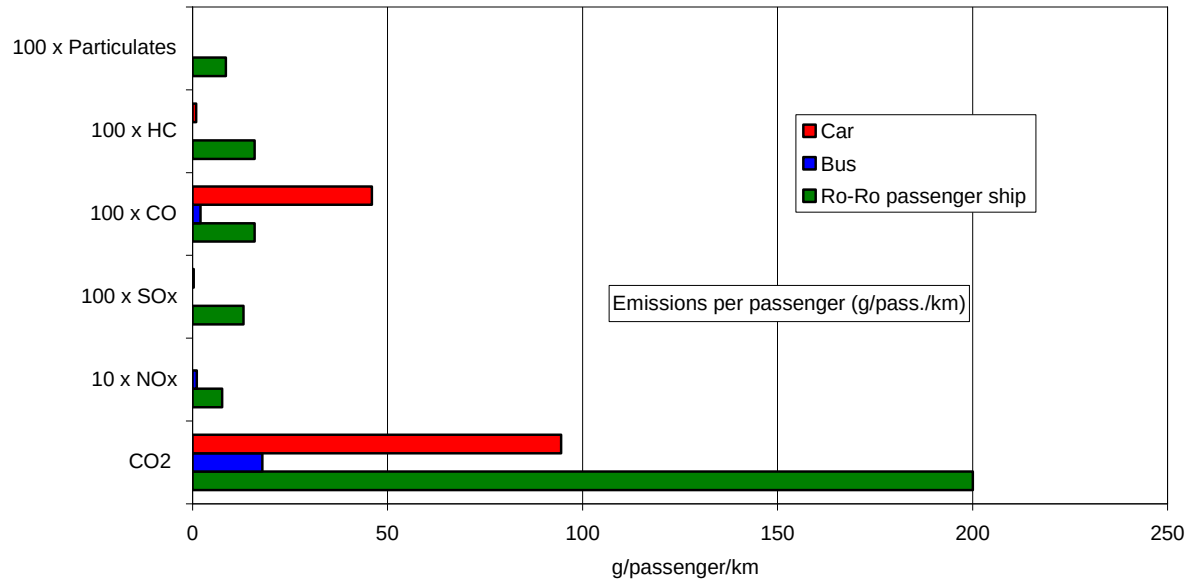
Ship		Bus	
Emissions	14.39	Emissions	1.06
Noise	0.00	Noise	0.80
Accidents	0.00	Accidents	1.73
Congestion	0.00	Congestion	2.33
Infrastructure	0.00	Infrastructure	2.07
Climate change	2.13	Climate change	0.19
Total	**16.5**	**Total**	**8.2**

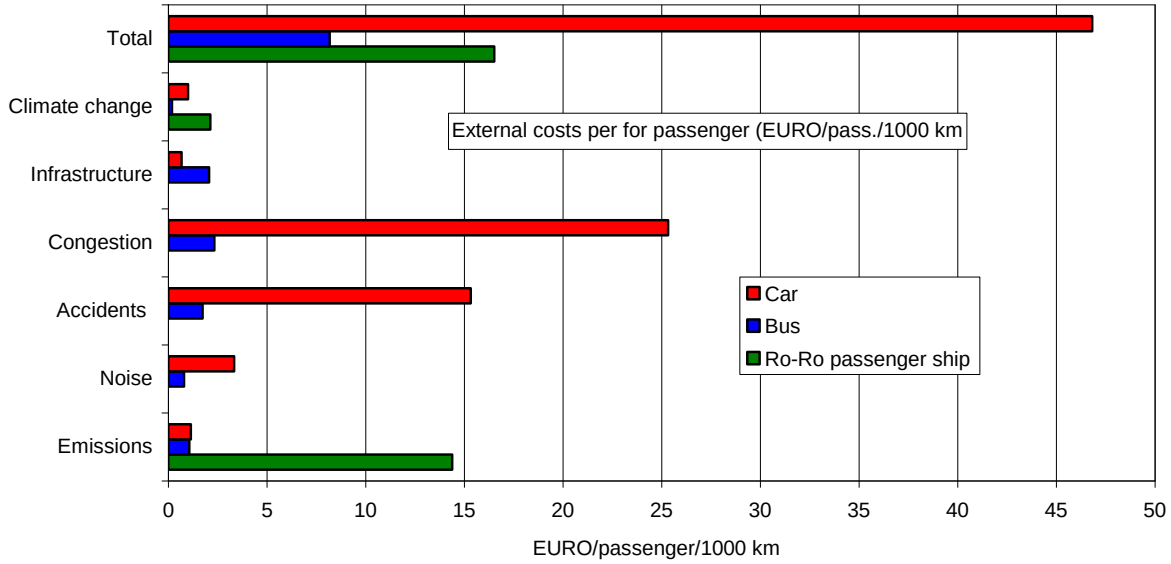
Emissions (g/passenger/km)

Ship		Car	
CO_2	200.1	CO_2	94.6
10 x NOx	7.7	10 x NOx	0.032
100 x SOx	13.1	100 x SOx	0.312
100 x CO	15.9	100 x CO	46.0
100 x HC	15.9	100 x HC	0.93
100 x Particulates	8.6	100 x Particulates	0.036

External costs (EURO/passenger/1000 km)

Ship		Car	
Emissions	14.39	Emissions	1.14
Noise	0.00	Noise	3.33
Accidents	0.00	Accidents	15.33
Congestion	0.00	Congestion	25.3
Infrastructure	0.00	Infrastructure	0.67
Climate change	2.13	Climate change	1.01
Total	**16.5**	**Total**	**46.8**



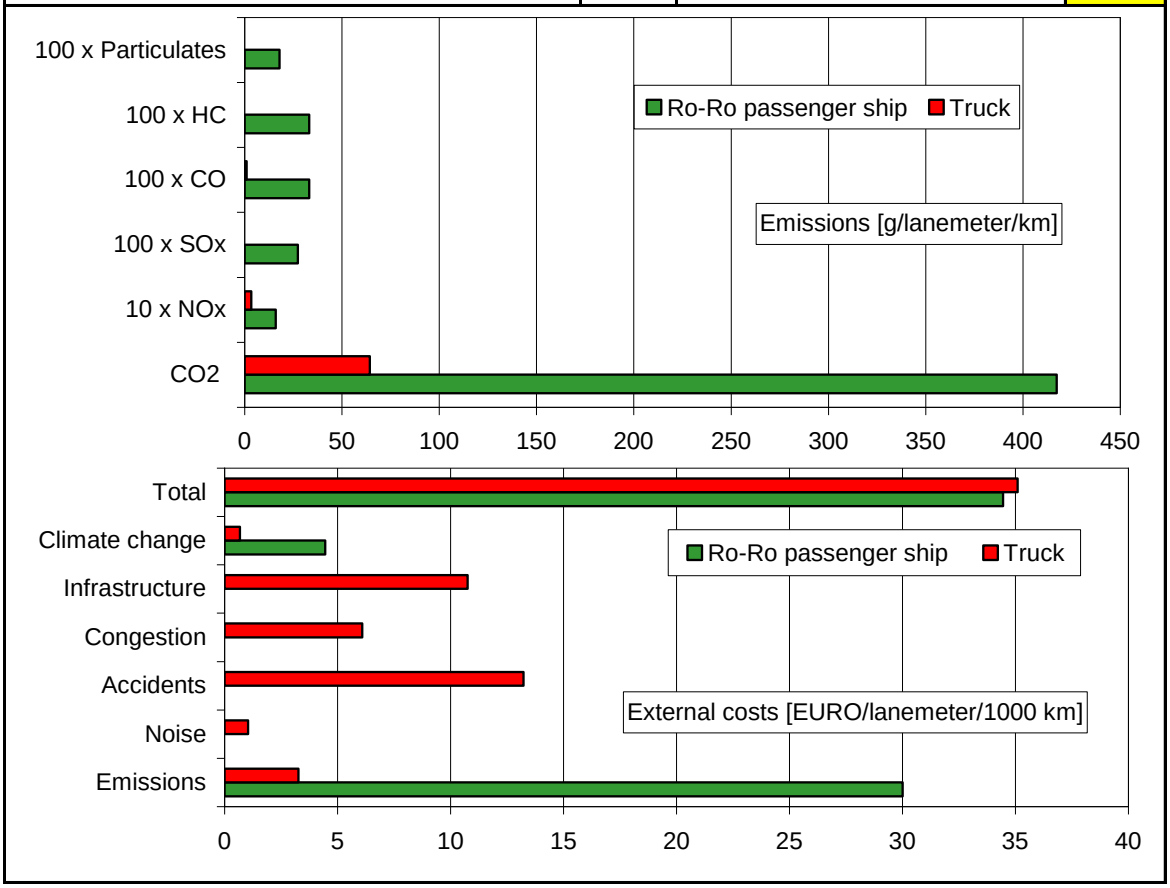


Total external costs for all transported items for a Ro-Ro passenger ship versus road (EURO/km)

By sea		**By road (trucks and cars only)**	
Area allocation method	EURO/km		EURO/km
Cargo	8.98	Cargo	23.46
Passengers	13.38	Passengers by car	23.41
Total	**22.36**	**Total**	**46.87**
Mass allocation method		**By road (trucks and busses only)**	
Cargo	19.21	Cargo	23.46
Passengers	3.15	Passengers by busses	4.09
Total	**22.36**	**Total**	**27.56**
Average allocation method			
Cargo	14.10		
Passengers	8.26		
Total	**22.36**		

Example No. 5: 2000 passenger Ro-Ro passenger ship loaded 300 passengers (15 %) and 25 % trucks, NO busses and 25 % cars (very poor utilization). Average allocation procedure

Ship data		Truck data	
Default ship (0) or ship alternative No. 1 or No. 2	0	Total weight of truck cargo (t)	18.0
Low cargo density (1) or high cargo density (2)	1	Truck weight (empty)	10.0
Passenger capacity (persons)	2000	Truck weight (loaded)	28.0
Actual number of passengers	300	Length of truck - total (m)	14.0
Total lanemeters (100 %) = LM	1337	EURO norm (2, 3, 4, 5 or 6)	4
Total number of cars (100 %)	450	Driving distance (km)	400
Actual payload/deadweight at maximum draught (pct.)	60	Driving percentage in city area	5
Rolling cargo lanemeters in pct. of total LM	25	**Car data (Euro Norm 6)**	
Bus lanemeters in pct. of total LM	0	Diesel (1) or petrol driven (2) car	2
Car and caravan lanemeters in pct. of total LM	25	Normal (1) or hybrid (2)	1
Occupied lanemeters	669	Engine volume (0.8 - 2.2 litres)	1.8
Normal speed (knots)	22.3	Number of passengers (max. 4)	2
Actual speed (knots)	22.3	**Bus data**	
Speed change (pct.)	0	EURO norm (3 - 6)	4
Pass. comfort class (1 = low, 2 = average or 3 = high)	2	Number of passengers (max. 45)	40
Suphur content of oil (%)	0.1	**External cost level**	
NOx emissions (IMO TIER 1, 2 or 3)	3	1 = Low, 2 = Mean, 3 = High	2
Slow speed (1) or medium speed main engine (2)	2	EURO/DKK exchange rate	7.50
Sailing percentage in harbour conditions	2.0	**Emission allocation method**	
Remaining draft reserve (m) - shall be positive !	0.59	Area (1), mass (2) or average (3)	3



Emissions (g/cargo lanemeter/km)

Ship		Truck	
CO_2	417.4	CO_2	64.4
10 x NOx	16.0	10 x NOx	3.52
100 x SOx	27.3	100 x SOx	0.04
100 x CO	33.3	100 x CO	1.00
100 x HC	33.3	100 x HC	0.15
100 x Particulates	17.9	100 x Particulates	0.20

External costs (EURO/lanemeter/1000 km)

Ship		Truck	
Emissions	30.01	Emissions	3.27
Noise	0.00	Noise	1.05
Accidents	0.00	Accidents	13.24
Congestion	0.00	Congestion	6.10
Infrastructure	0.00	Infrastructure	10.76
Climate change	4.45	Climate change	0.69
Total	**34.5**	**Total**	**35.1**

External costs (EURO/lanemeter/1000 km)

Ship		Truck	
CO_2	4.45	CO_2	0.69
NOx	11.28	NOx	2.48
SOx	7.64	SOx	0.01
CO	0.00	CO	0.00
HC	0.09	HC	0.00
Particulates	6.54	Particulates	0.09
Total	**30.01**	**Total**	**3.27**

Service allowance on ship power (%)	10

It is possible to scale the influence some of the external costs as follows:

Externality	Scaling (pct)
Noise	100
Accidents	100
Congestion	100
Infrastructure	100
Climate change	100

100 pct. means full implementation according to the quidelines by DTU/COWI (2016)

Emissions (g/passenger/km)

Ship		Bus	
CO_2	399.7	CO_2	17.9
10 x NOx	15.3	10 x NOx	1.1
100 x SOx	26.2	100 x SOx	0.1
100 x CO	31.9	100 x CO	2.0
100 x HC	31.9	100 x HC	0.1
100 x Particulates	17.1	100 x Particulates	0.1

External costs (EURO/passenger/1000 km)

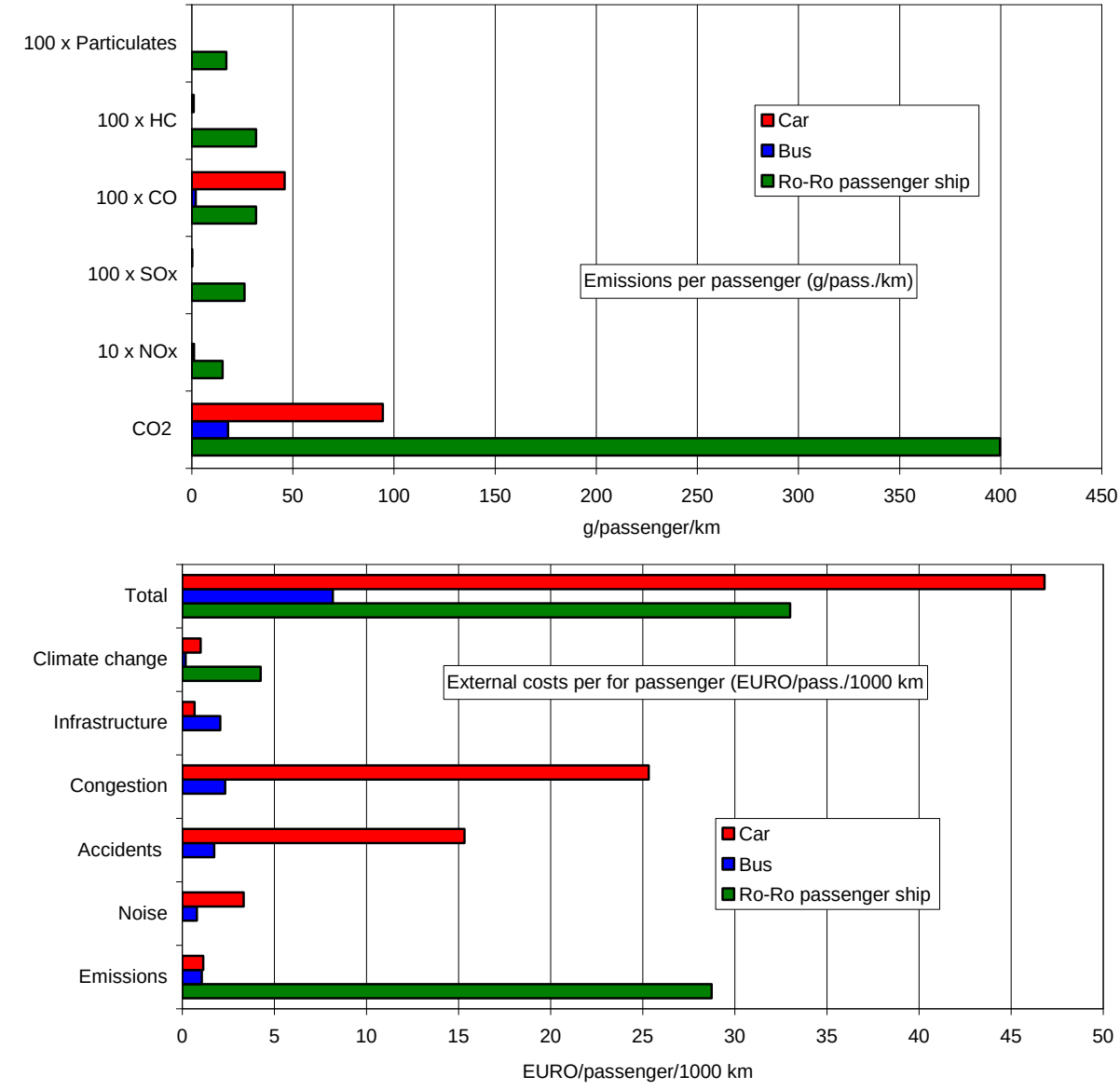
Ship		Bus	
Emissions	28.74	Emissions	1.06
Noise	0.00	Noise	0.80
Accidents	0.00	Accidents	1.73
Congestion	0.00	Congestion	2.33
Infrastructure	0.00	Infrastructure	2.07
Climate change	4.26	Climate change	0.19
Total	**33.0**	**Total**	**8.2**

Emissions (g/passenger/km)

Ship		Car	
CO_2	399.7	CO_2	94.6
10 x NOx	15.3	10 x NOx	0.032
100 x SOx	26.2	100 x SOx	0.312
100 x CO	31.9	100 x CO	46.0
100 x HC	31.9	100 x HC	0.93
100 x Particulates	17.1	100 x Particulates	0.036

External costs (EURO/passenger/1000 km)

Ship		Car	
Emissions	28.74	Emissions	1.14
Noise	0.00	Noise	3.33
Accidents	0.00	Accidents	15.33
Congestion	0.00	Congestion	25.3
Infrastructure	0.00	Infrastructure	0.67
Climate change	4.26	Climate change	1.01
Total	**33.0**	**Total**	**46.8**



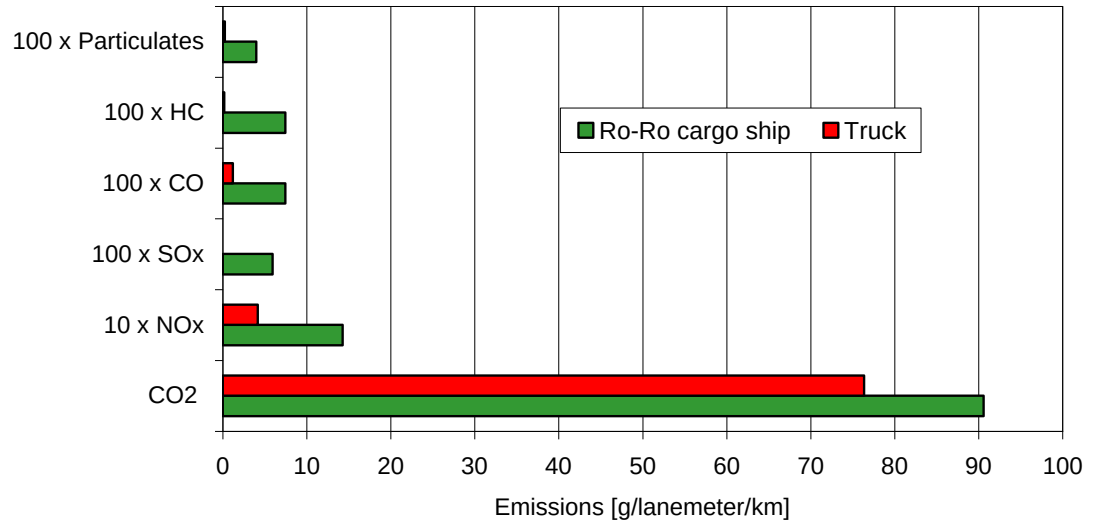
Total external costs for all transported items for a Ro-Ro passenger ship versus road (EURO/km)

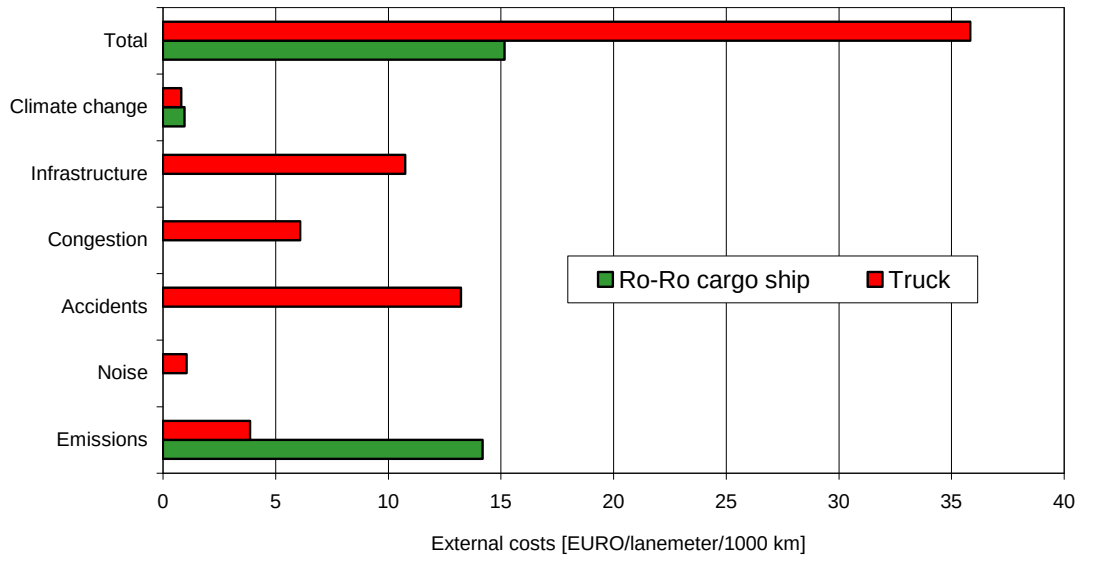
By sea		**By road (trucks and cars only)**	
Area allocation method	EURO/km		EURO/km
Cargo	6.53	Cargo	11.73
Passengers	14.89	Passengers by car	14.04
Total	**21.42**	**Total**	**25.78**
Mass allocation method		**By road (trucks and busses only)**	
Cargo	16.51	Cargo	11.73
Passengers	4.91	Passengers by busses	2.46
Total	**21.42**	**Total**	**14.19**
Average allocation method			
Cargo	11.52		
Passengers	9.90		
Total	**21.42**		

Appendix D Calculation examples of emissions and external costs with SHIP-DESMO for a Ro Ro cargo ship

Example No. 1: 4000 lanemeter Ro-Ro cargo ship 100 % loaded

Ship data		Truck data	
Cargo capacity (length of cargo lanes)	4000	Number of containers per truck	2
Payload/deadweight at design draught (%)	70	Weight per container (t/TEU)	14
Lanemeter capacity utilization (pct.)	100	Truck weight (empty)	10
Deadweight per lanemeter (t/lm)	3.9	Total weight of truck cargo (t)	28
Default max. deadweight per lanemeter (t/lm)	5.1	Truck weight (loaded)	38
Rolling cargo load per lanemeter	2.0	Length of truck - total (m)	14
Normal speed (knots)	21.2	EURO norm (2, 3, 4, 5 or 6)	4
Speed change (pct.)	0.0	Suphur content of oil (%)	0.001
Actual ship speed (knots)	21.2	Driving distance (km)	400
Suphur content of oil (%)	0.1	Driving percentage in city area	5
NOx emissions (IMO TIER 1, 2 or 3)	2	EURO/DKK exchange rate	7.50
Slow speed (1) or medium speed main engine (2)	2	**External cost level**	
Sailing percentage in harbour conditions	2	1 = Low, 2 = Mean, 3 = High	2
Normal deadweight ship (1), Low deadweight ship (2) or high deadweight ship (3)			3





Emissions (g/lanemeter/km)

Ship		Truck	
CO_2	90.6	CO_2	76.4
10 x NOx	14.3	10 x NOx	4.17
100 x SOx	5.93	100 x SOx	0.05
100 x CO	7.44	100 x CO	1.19
100 x HC	7.44	100 x HC	0.18
100 x Particulates	4.00	100 x Particulates	0.24

External costs (EURO/lanemeter/1000 km)

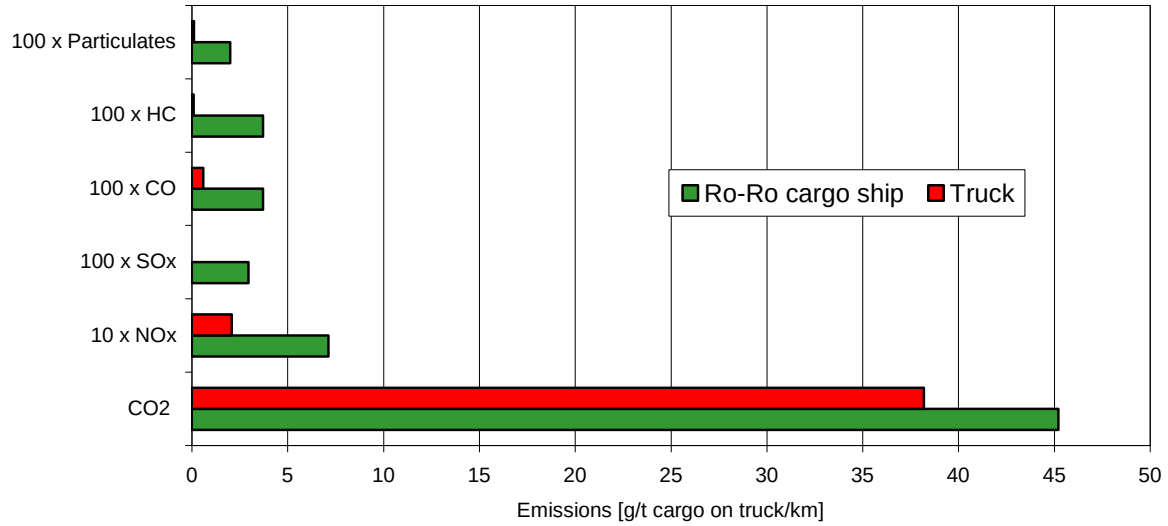
Ship		Truck	
Emissions	14.20	Emissions	3.88
Noise	0	Noise	1.05
Accidents	0	Accidents	13.24
Congestion	0	Congestion	6.10
Infrastructure	0	Infrastructure	10.76
Climate change	0.97	Climate change	0.81
Total	**15.2**	**Total**	**35.8**

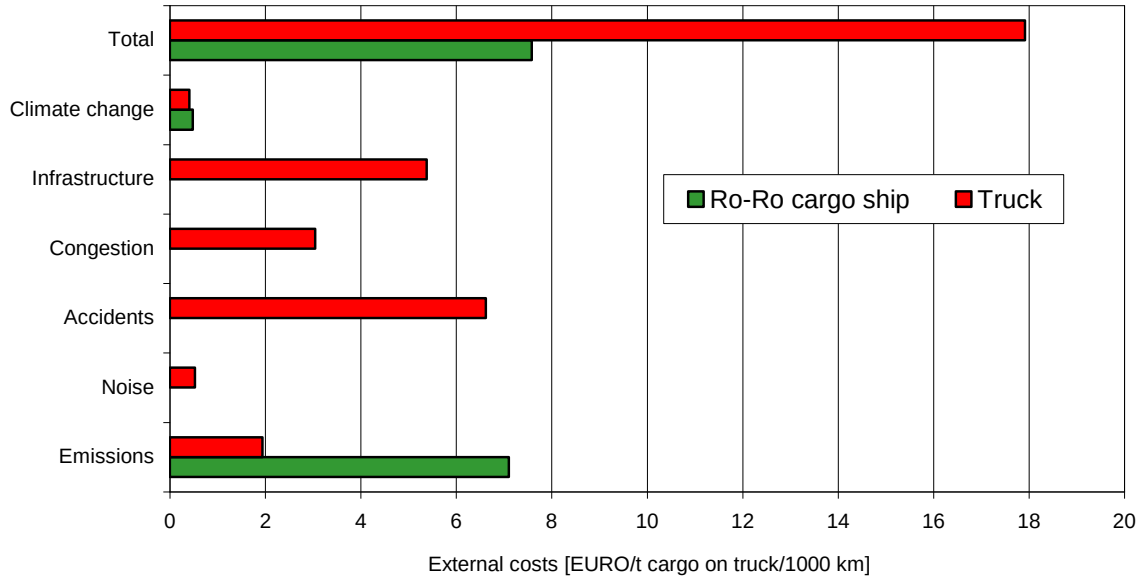
External costs (EURO/lanemeter/1000 km)

Ship		Truck	
CO_2	0.97	CO_2	0.81
NOx	10.09	NOx	2.95
SOx	1.66	SOx	0.013
CO	0.00009	CO	0.00002
HC	0.020	HC	0.00049
Particulates	1.46	Particulates	0.10
Total	**14.20**	**Total**	**3.88**

Service allowance on ship power (%)	10

Ship data		Truck data	
Cargo capacity (length of cargo lanes)	4000	Number of containers per truck	2
Payload/deadweight at design draught (%)	70	Weight per container (t/TEU)	15
Lanemeter capacity utilization (pct.)	100	Truck weight (empty)	10
Deadweight per lanemeter (t/lm)	3.9	Total weight of truck cargo (t)	30
Default max. deadweight per lanemeter (t/lm)	5.1	Truck weight (loaded)	40
Rolling cargo load per lanemeter	2.1	Length of truck - total (m)	14
Normal speed (knots)	21.2	EURO norm (2, 3, 4, 5 or 6)	4
Speed change (pct.)	0.0	Suphur content of oil (%)	0.001
Actual ship speed (knots)	21.2	Driving distance (km)	400
Suphur content of oil (%)	0.1	Driving percentage in city area	5
NOx emissions (IMO TIER 1, 2 or 3)	2.0	EURO/DKK exchange rate	7.5
Slow speed (1) or medium speed main engine (2)	2.0	**External cost level**	
Sailing percentage in harbour conditions	2.0	1 = Low, 2 = Mean, 3 = High	2
Normal deadweight ship (1), Low deadweight ship (2) or high deadweight ship (3)			3





Emissions (g/t cargo on truck/km)

Ship		**Truck**	
CO_2	45.2	CO_2	38.2
10 x NOx	7.13	10 x NOx	2.085
100 x SOx	2.96	100 x SOx	0.024
100 x CO	3.71	100 x CO	0.596
100 x HC	3.71	100 x HC	0.089
100 x Particulates	2.00	100 x Particulates	0.119

External costs (EURO/t cargo on truck/1000 km)

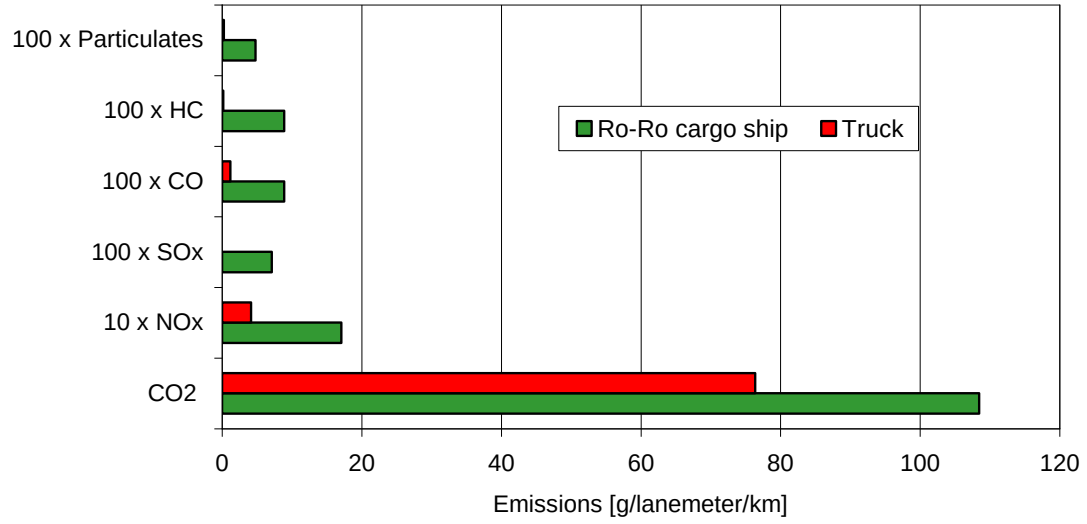
Ship		**Truck**	
Emissions	7.10	Emissions	1.94
Noise	0	Noise	0.52
Accidents	0	Accidents	6.62
Congestion	0	Congestion	3.05
Infrastructure	0	Infrastructure	5.38
Climate change	0.48	Climate change	0.41
Total	**7.58**	**Total**	**17.9**

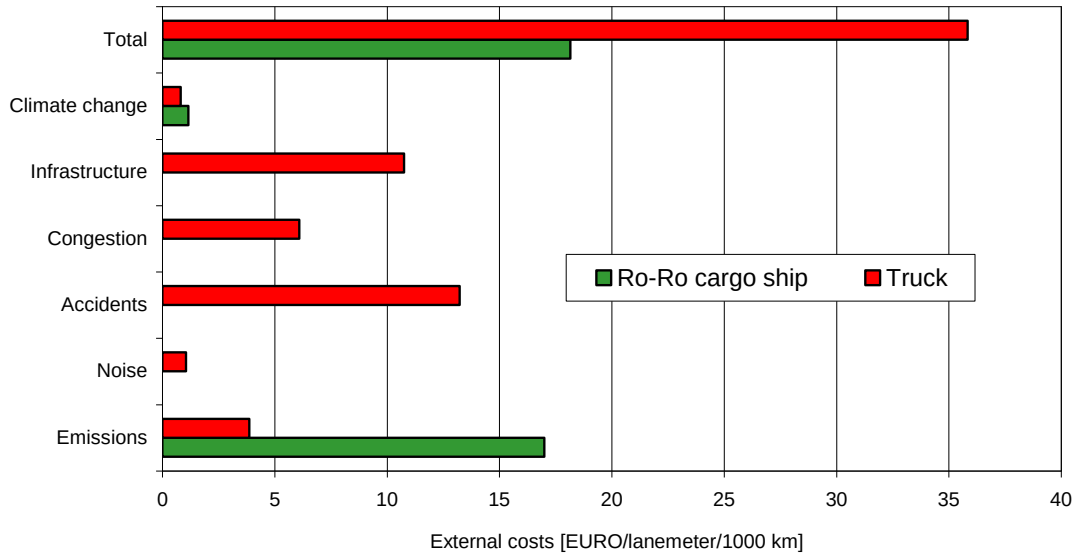
External costs (EURO/t cargo on truck/1000 km)

Ship		**Truck**	
CO_2	0.48	CO_2	0.41
NOx	5.05	NOx	1.47
SOx	0.83	SOx	0.007
CO	0.00005	CO	0.00001
HC	0.010	HC	0.0002
Particulates	0.73	Particulates	0.05
Total	**7.10**	**Total**	**1.94**

Example No. 2: 4000 lanemeter Ro-Ro cargo ship 75 % loaded

Ship data		Truck data	
Cargo capacity (length of cargo lanes)	4000	Number of containers per truck	2
Payload/deadweight at design draught (%)	70	Weight per container (t/TEU)	14
Lanemeter capacity utilization (pct.)	75	Truck weight (empty)	10
Deadweight per lanemeter (t/lm)	2.9	Total weight of truck cargo (t)	28
Default max. deadweight per lanemeter (t/lm)	5.1	Truck weight (loaded)	38
Rolling cargo load per lanemeter	2.0	Length of truck - total (m)	14
Normal speed (knots)	21.2	EURO norm (2, 3, 4, 5 or 6)	4
Speed change (pct.)	0.0	Suphur content of oil (%)	0.001
Actual ship speed (knots)	21.2	Driving distance (km)	400
Suphur content of oil (%)	0.1	Driving percentage in city area	5
NOx emissions (IMO TIER 1, 2 or 3)	2	EURO/DKK exchange rate	7.50
Slow speed (1) or medium speed main engine (2)	2	**External cost level**	
Sailing percentage in harbour conditions	2	1 = Low, 2 = Mean, 3 = High	2
Normal deadweight ship (1), Low deadweight ship (2) or high deadweight ship (3)			3





Emissions (g/lanemeter/km)

Ship		Truck	
CO_2	108.5	CO_2	76.4
10 x NOx	17.1	10 x NOx	4.17
100 x SOx	7.11	100 x SOx	0.05
100 x CO	8.90	100 x CO	1.19
100 x HC	8.90	100 x HC	0.18
100 x Particulates	4.79	100 x Particulates	0.24

External costs (EURO/lanemeter/1000 km)

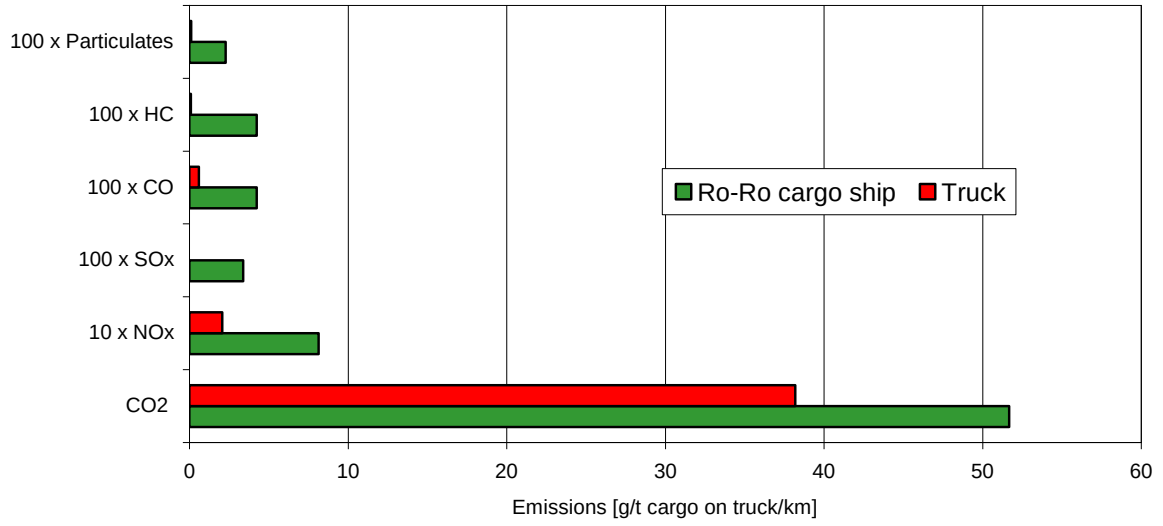
Ship		Truck	
Emissions	17.00	Emissions	3.88
Noise	0	Noise	1.05
Accidents	0	Accidents	13.24
Congestion	0	Congestion	6.10
Infrastructure	0	Infrastructure	10.76
Climate change	1.16	Climate change	0.81
Total	**18.2**	**Total**	**35.8**

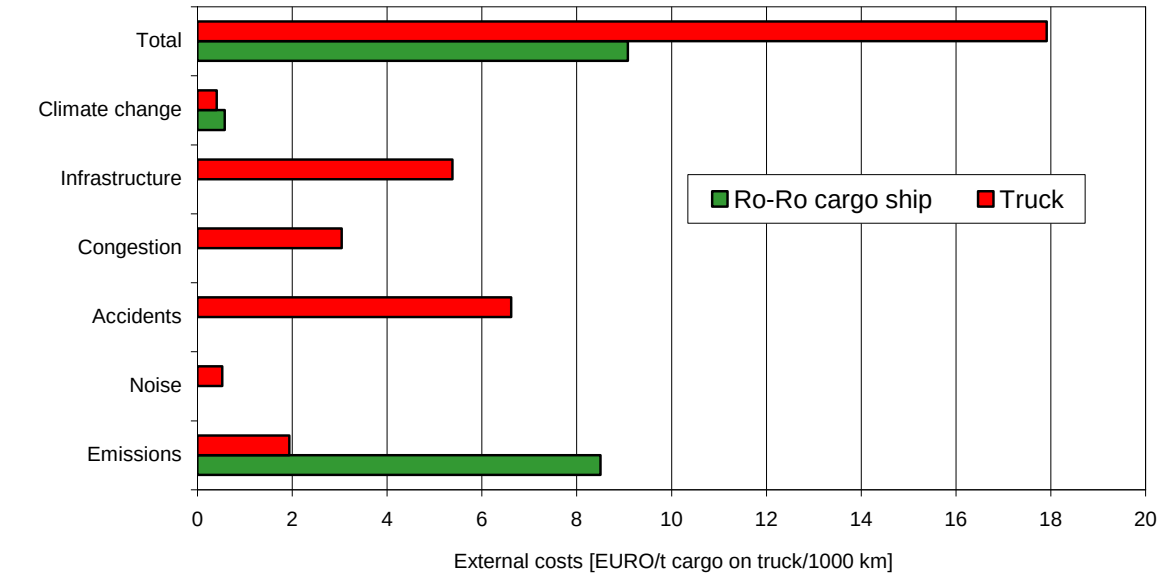
External costs (EURO/lanemeter/1000 km)

Ship		Truck	
CO_2	1.16	CO_2	0.81
NOx	12.08	NOx	2.95
SOx	1.99	SOx	0.013
CO	0.00011	CO	0.00002
HC	0.024	HC	0.00049
Particulates	1.75	Particulates	0.10
Total	**17.00**	**Total**	**3.88**

Service allowance on ship power (%)	10

Ship data		Truck data	
Cargo capacity (length of cargo lanes)	4000	Number of containers per truck	2
Payload/deadweight at design draught (%)	70	Weight per container (t/TEU)	15
Lanemeter capacity utilization (pct.)	75	Truck weight (empty)	10
Deadweight per lanemeter (t/lm)	2.9	Total weight of truck cargo (t)	30
Default max. deadweight per lanemeter (t/lm)	5.1	Truck weight (loaded)	40
Rolling cargo load per lanemeter	2.1	Length of truck - total (m)	14
Normal speed (knots)	21.2	EURO norm (2, 3, 4, 5 or 6)	4
Speed change (pct.)	0.0	Suphur content of oil (%)	0.001
Actual ship speed (knots)	21.2	Driving distance (km)	400
Suphur content of oil (%)	0.1	Driving percentage in city area	5
NOx emissions (IMO TIER 1, 2 or 3)	2.0	EURO/DKK exchange rate	7.5
Slow speed (1) or medium speed main engine (2)	2.0	**External cost level**	
Sailing percentage in harbour conditions	2.0	1 = Low, 2 = Mean, 3 = High	2
Normal deadweight ship (1), Low deadweight ship (2) or high deadweight ship (3)			3





Emissions (g/t cargo on truck/km)

Ship		**Truck**	
CO_2	51.7	CO_2	38.2
10 x NOx	8.14	10 x NOx	2.085
100 x SOx	3.39	100 x SOx	0.024
100 x CO	4.24	100 x CO	0.596
100 x HC	4.24	100 x HC	0.089
100 x Particulates	2.28	100 x Particulates	0.119

External costs (EURO/t cargo on truck/1000 km)

Ship		**Truck**	
Emissions	8.50	Emissions	1.94
Noise	0	Noise	0.52
Accidents	0	Accidents	6.62
Congestion	0	Congestion	3.05
Infrastructure	0	Infrastructure	5.38
Climate change	0.58	Climate change	0.41
Total	**9.08**	**Total**	**17.9**

External costs (EURO/t cargo on truck/1000 km)

Ship		**Truck**	
CO_2	0.58	CO_2	0.41
NOx	6.04	NOx	1.47
SOx	0.99	SOx	0.007
CO	0.00006	CO	0.00001
HC	0.012	HC	0.0002
Particulates	0.88	Particulates	0.05
Total	**8.50**	**Total**	**1.94**