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Environmental Impact of Some Retrofit Options Applied to an Inland Vessel

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RESEARCH ARTICLE

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Abstract
The project MoVe IT! (www.moveit-fp7.eu), funded by the Seventh Framework Programme of the European Union, aims at a modernisation of inland waterway vessels with focus on retrofitting of existing vessels and technology transfer from new buildings and other transport modes. The topics of the project refer to the improvement of energy efficiency and environmental behaviour of inland waterway vessels, as well as the implementation of alternative energy sources to gasoil.
Environmental assessment of various retrofit options is one major objective of the MoVe IT! project. The analysis is carried out for five vessels, comprising a container vessel, three pushers and a motor cargo vessel being operated together with a lighter. In this paper only the analysis of this last vessel is presented. The effects of the different retrofit solutions to be applied in this vessel are taken into account by the resulting reduction of the fuel consumption or directly the respective emissions in per cent. To obtain a wider picture, the emissions referred to tkm are compared with the ones of road transport carried out with trucks complying with emissions standards EURO III up to Euro VI, as well as the East European emission standard (EE).

Keywords
inland navigation, retrofitting, emission, environmental impact

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1 Introduction

The emission reduction is a high priority scientific research field in transportation. Even the so called low emission transportation modes (like railway vehicles, aircrafts, ships) focus heavily on emission reduction research. For example in aircraft gas turbine design the theoretical (e.g. (Bicsák et al., 2012)) and experimental (e.g. (Beneda et al., 2013)) research is a key to reduce pollution.

Although the inland navigation is one of the lowest emission (related to the transport performance) transportation mode, the ship owners, designers and scientists pay special attention to the emission even by a ship reconstruction (retrofitting).

For this reason the MoVeIT! project investigated a variety of different retrofit solutions for improving the economic and environmental performance of inland waterway transport (IWT). Consultation with project member experts and (in particular) representatives of ship owners lead to a selection of retrofit solutions regarded as worth to be investigated further with respect to their practical implementation. These solutions were considered in detail in the project, comprising technical elaborations, as well as economic and environmental performance assessments. As improving the environmental performance of the MoVe IT! vessels is one major objective of the project, the environmental assessment plays an important role in the evaluation of the technologies developed.

It is difficult to determine the quantitative volume of pollutants of a vehicle during transportation, because lot of circumstance (fuel quality, load of engines, actual engine efficiency, environmental conditions, etc.) has influence on the momentary emission if pollutants. The researchers of different transportation modes worked out a lot of transport mode specific emission calculation method (e.g. (Rohács, 2013), (Van der Gon, 2010; VBD, 2001; Planco, 2007; HBEFA, 2010; Germanischer Lloyd, 2001), etc.), which try to simulate all emission affecting circumstances and operation modes of vehicles.

In MoVeIT! project the environmental assessment is carried out for five inland ships, comprising a container vessel, three pushers and a motor cargo vessel being operated together with a lighter. The vessels are being operated on the Rhine, the

Table 1 Emission factors for the specific vessel to be used in the environmental analysis, based on VBD, 2001

Vessel	Construction year of main engine	CO_2	NO_x	PM	HC	CO	SO_2	Source
		[g/kg fuel]	[g/kg fuel]	[g/kg fuel]	[g/kg fuel]	[g/kg fuel]	[g/kg fuel]	
Herso 1	1961		57	0.83	3.4	6.5	0.02	VBD, 2001
Herso 1, lower NO_X limit	1961		40	0.83	3.4	6.5	0.02	VBD, 2001 + CREATING measurement

Danube and the Seine. Full information on the operation of the vessels was made available by the ship owners, providing a real-life basis for the environmental assessment (MoVeIT, 2013a), (MoVeIT, 2013b). The emissions considered comprise the carbon dioxide (CO_2), nitrogen oxide (NO_X), particulate matter (PM), hydrocarbon (HC), carbon monoxide (CO) and sulphur dioxide (SO_2) emissions. The emissions are estimated using the fuel consumption recorded, as well as emission factors referred to the mass of fuel. The emissions are presented as yearly values, and values related to the transport performance in tonne kilometre (tkm). The effects of the different technologies to be applied in the vessels are taken into account by the resulting reduction of the fuel consumption or directly the respective emissions in per cent. The emissions referred to tkm are compared with the ones of road transport carried out with trucks complying with emissions standards EURO III up to Euro VI, as well as the East European emission standard (EE) (HBEFA, 2010).

2 Methodology of emission calculation

The calculation of the emissions is based on monitored real-life quantities as far as possible. The total emissions per year, E_{Iyear}, are determined using the following equation:

$$E_{Iyear} = FC \cdot EF \tag{1}$$

where *FC* is the total fuel consumption per year in kg, and *EF* is the respective emission factor given in kg/kg fuel for the CO_2 emissions and g/kg fuel for the NO_X, PM, HC, CO and SO_X emissions, respectively.

The total yearly fuel consumption in litre is derived from reports of the shipping companies involved in the MoVeIT! project (MoVeIT, 2013a; 2013b). For completeness the fuel consumption is subdivided in the total yearly fuel consumption including empty trips and contributions from auxiliary engines, as well as the fuel consumption of the main engines only, including empty trips. The fuel consumption in kg is derived by multiplication of the fuel consumption in litre with the density of the fuel, $\rho = 0.835$ kg/litre.

The emission factors are obtained from various sources considered as appropriate for the analysis to be performed. In Table 1, the emission factors are based on (Planco, 2007), (VBD, 2001) and NO_X measurements carried out onboard a Danube pusher within the FP6 EU project CREATING (Kampfer et al., 2006).

In Table 1, the emission factors for particulate matter were corrected for the usage of low sulphur fuel with a maximum sulphur content of 10 ppm. The correction applied accounts for 17 %, corresponding to a reduction of the sulphur content of the fuel from 2000 ppm to 10 ppm. The emission factors for SO_2 correspond to the ones of fuel with 10 ppm sulphur content.

In Table 2, the emission factors for inland waterway vessels are given to be used alternatively in the environmental analysis of the Move it! vessels. The emission factors are based on a scientific research of TNO (2010) (Van der Gon, 2010). The transfer of the emission factors presented in g/kWh to factors given in g/kg fuel is performed on the basis of the specific fuel consumption and construction year of the engine listed in TNO (2010). The lower NO_X limit for the Herso 1 was obtained from onboard measurements within the FP6 EU project CREATING (see also Table 1). The emission factors of TNO (2010) are officially used in the creation of the emission inventory of the Netherlands. It has to be noted that the emission factors for

Table 2 Emission factors for the specific vessel to be used in the environmental analysis, based on TNO, 2010

Vessel	Construction year of main engine	CO_2	NO_X	PM	HC	CO	SO_2	Source
		[g/kg fuel]	[g/kg fuel]	[g/kg fuel]	[g/kg fuel]	[g/kg fuel]	[g/kg fuel]	
Herso 1	1961	$3.173 \cdot 10^3$	46	2.116	5.1	19	0.02	TNO 2010
Herso 1, lower NO_X limit	1961	$3.173 \cdot 10^3$	40	2.116	5.1	19	0.02	TNO, 2010 + CREATING measurement

particulate matter derived from TNO (2010) show significant deviations from the ones presented in Table 1. Reasons for the deviations may be the great uncertainty associated with particulate matter measurements, as well as the fact that the emission factors in Table 2 are average values over different power classes of engines, including the impact of high particulate matter emissions of engines with much lower power than the one of the engines of the Move it! vessels. The emission factors for particulate matter were corrected for the usage of low sulphur fuel with a maximum sulphur content of 10 ppm. The correction applied accounts for 8.5 %, corresponding to a reduction of the sulphur content of the fuel from 1000 ppm to 10 ppm.

The total yearly emissions are related to the yearly transport performance given in tkm. The transport performance is defined as average cargo load per voyage multiplied with the total distance sailed with cargo. The emissions are presented in g/tkm, allowing a comparison with other modes of transport.

The emission factors for road transport to be used in the ecologic comparison of road transport with the Move it! vessels are derived from HBEFA 3.1 (2010), which is considered to provide the most up-to-date information on this issue. The emission factors are presented in g/km. The total emissions, E, are derived from:

$$E = distance_{empty} \cdot EF_{empty} + distance_{loaded} \cdot EF_{loaded} \tag{2}$$

where $distance_{empty}$ and $distance_{loaded}$ are the total distances in km travelled without and with cargo. EF_{empty} and EF_{loaded} are the emission factors for an empty and a loaded truck.

The emissions referred to tkm, E_{tkm}, are derived from:

$$Etkm = \frac{E}{cargo\,load \cdot distance\,loaded} \tag{3}$$

where *cargo load* is the amount of cargo transported by the truck in t. For all vessel cases, it is assumed that the goods are transported by a 34-40 t truck trailer with a cargo load of 25 t (except Carpe Diem: 19.6 t, and EE standard: 18.4 t). For the Dunaföldvár and the Herso 1, transportation using truck trailers of East European standard (EE) are considered additionally. The truck trailers of EE standard are slightly smaller and belong to the weight class of 28–34 t with a cargo load of 18.4 t. For the Carpe Diem, it is assumed that the 34-40 t truck trailer carries two TEUs with a total mass of 19.6 t according to the ones transported by the Carpe Diem. As the Carpe Diem is sailing always with cargo, it is assumed that the respective truck is also running always with cargo. For all other vessels, it is assumed that heavy goods are transported and the truck trailers are moving with cargo only in the same direction as the respective vessels. For the Dunaföldvár, it is assumed that the truck trailer is transporting iron ore in the upstream direction, and it is moving downstream empty, although the vessel itself is transporting e.g. grain in this direction. A vessel can be very flexibly used. A truck designed for the purpose of transporting e.g. iron ore cannot be used for another purpose, due to its particular design. The emissions and emission factors for road transport are given for EURO III, EURO IV SCR, EURO V SCR and EURO VI trucks. Additionally, for the Herso 1 and the Dunaföldvár the East European standard (EE) is considered. The emission factors for the Herso 1 and the Dunaföldvár are related to the ones derived for trucks moving on Austrian motorways. The emission factors for the Veerhaven X, the Inflexible and the Carpe Diem are related to the ones derived for trucks moving on German motorways, whereby for the Carpe Diem, emission factors for trucks moving on German urban motorways in saturated traffic situations are additionally considered, as the vessel is being operated in the Rotterdam area where saturated traffic situations are expected.

According to the statistics, the most common road transportation unit is the 34–40 t truck trailer of EURO V SCR standard, followed by EURO III.

For simplicity, it is assumed that the trucks are travelling the same distances as the vessels, which in reality can be different as the routes are different.

3 Environmental analysis of the HERSO 1

3.1 Description of the vessel

The inland navigation vessel MV "HERSO 1" belongs to the fleet of the Hungarian shipping company Plimsoll which is member of the MoVeIT! project. Plimsoll runs a couple of self-propelled dry bulk cargo vessels mainly on the Danube area.

The HERSO 1 is a self-propelled vessel of the EUROPA-type (CEMT Class IV), which is based on the so-called Johann Welker ship type. The vessel's machinery contains one main engine, two auxiliary engines, and an engine for the bow thruster, which is a built in 1989. Both engines use "Diesel EN590" as fuel. The engines neither comply with any emission standard nor have an emission reduction device.

One entire dry bulk hold with a length of 57.50 m reaches from the engine room front bulkhead to the forward hold bulkhead. The hold itself is covered with stackable hatch covers. The hold gives the vessel a 1382 t cargo capacity.

The vessel has a barge, "SL Leonie", which has a capacity of 1427 t at its maximum draught. If HERSO sails with barge, it always sails with Leonie. Regarding the resistance of the couple, it should be noted that unfortunately the barge is a bit wider than the vessel itself, this further increases the resistance – and hence the fuel consumption of the couple.

3.2 Available data and operational conditions

Upon consultation with the operator, data have been collected regarding the operating conditions of the vessel. The table below contains the yearly distance sailed, the yearly fuel consumption and the amount of cargo shipped per year. Based on these data, it is possible to determine the relative fuel consumption of the vessel.

Table 3 Emission factors for road transport to be used in ecologic com-parison of road transport and inland vessels based on HBEFA 3.1

Truck	Cargo	Distance	Co_2	No_x	PM	HC	CO	SO_2	Cargo	Distance	Co_2	No_x	PM	HC	CO	SO_2
Motorway	[t]	[km]	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]	[t]	[km]	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]
Carpe Diem																
EURO III	19.6	50000	850.3784	7.438496	0.143624	0.272376	1.166976	0.0046112								
EURO IV SCR	19.6	50000	832.1608	3.167912	0.017488	0.023488	1.41824	0.004568								
EURO V SCR	19.6	50000	828.1304	1.973464	0.016704	0.023488	1.409776	0.0044896								
EURO VI	19.6	50000	838.3728	0.344688	0.003	0.023704	0.758536	0.004568								
Urban area, city motorway, saturated traffic																
EURO III	19.6	50000	849.4336	7.978968	0.152632	0.290296	1.643448	0.004568								
EURO IV SCR	19.6	50000	830.3728	3.696592	0.02976	0.025272	1.696968	0.0045248								
EURO V SCR	19.6	50000	828.9184	2.433152	0.02976	0.025272	1.72476	0.0045248								
EURO VI	19.6	50000	835.2432	0.31096	0.003784	0.024488	0.870448	0.0045248								
Inflexible																
Motorway																
EURO III	0	20000	595.5	5.052	0.135	0.281	1.058	0.0032	25	20000	920.6	8.096	0.146	0.27	1.197	0.005
EURO IV SCR	0	20000	552.9	2.997	0.012	0.018	1.234	0.003	25	20000	909.1	3.215	0.019	0.025	1.469	0.005
EURO V SCR	0	20000	551.3	2.055	0.012	0.018	1.242	0.003	25	20000	904.4	1.951	0.018	0.025	1.456	0.0049
EURO VI	0	20000	564.6	0.3	0.003	0.019	0.677	0.003	25	20000	913.8	0.357	0.003	0.025	0.781	0.005
Veerhaven X																
Motorway																
EURO III	0	46822	595.5	5.052	0.135	0.281	1.058	0.0032	25		920.6	8.096	0.146	0.27	1.197	0.005
EURO IV SCR	0	46822	552.9	2.997	0.012	0.018	1.234	0.003	25	46822	909.1	3.215	0.019	0.025	1.469	0.005
EURO V SCR	0	46822	551.3	2.055	0.012	0.018	1.242	0.003	25	46822	904.4	1.951	0.018	0.025	1.456	0.0049
EURO VI	0	46822	564.6	0.3	0.003	0.019	0.677	0.003	25	46822	913.8	0.357	0.003	0.025	0.781	0.005
Dunaföldvár																
Motorway																
EURO III	0	17000	585.7	5.308	0.135	0.282	1.267	0.004	25	17000	937.9	8.382	0.16	0.274	1.591	0.0065
EURO IV SCR	0	17000	544.6	3.263	0.017	0.019	1.321	0.0038	25	17000	927.1	3.606	0.026	0.027	1.539	0.0064
EURO V SCR	0	17000	543.1	2.317	0.017	0.019	1.329	0.0038	25	17000	923.7	2.232	0.026	0.026	1.538	0.0064
EURO VI	0	17000	553.9	0.351	0.003	0.019	0.694	0.0038	25	17000	931.1	0.393	0.004	0.026	0.808	0.0064
EE standard	0	17000	611.9	10.465	0.493	1.253	2.002	0.0042	18.4	17000	889	15.97	0.641	1.156	2.307	0.0061
Herso 1																
Motorway																
EURO III	0	17269	585.7	5.308	0.135	0.282	1.267	0.004	25	18713	937.9	8.382	0.16	0.274	1.591	0.0065
EURO IV SCR	0	17269	544.6	3.263	0.017	0.019	1.321	0.0038	25	18713	927.1	3.606	0.026	0.027	1.539	0.0064
EURO V SCR	0	17269	543.1	2.317	0.017	0.019	1.329	0.0038	25	18713	923.7	2.232	0.026	0.026	1.538	0.0064
EURO VI	0	17269	553.9	0.351	0.003	0.019	0.694	0.0038	25	18713	931.1	0.393	0.004	0.026	0.808	0.0064
EE standard	0	17269	611.9	10.465	0.493	1.253	2.002	0.0042	18.4	18713	889	15.97	0.641	1.156	2.307	0.0061

The vessel sails typically between Regensburg, Germany and Constanta, Romania. The home port is Dunaújváros, Hungary. The vessel makes nine round trips a year between Dunaújváros and Regensburg, and nine round trips between Dunaújváros and Constanta. The cargo transported is typically bulk cargo (mostly agricultural products), in some cases general cargo is also transported. One barge is attached to the ship in order to provide additional capacity in most of the trips. The total cargo capacity of the convoy is approximately 2000 t. Due to the frequently occurring low water level on Danube, the average mass of cargo transported is significantly less than the maximum (approx. 60%).

The crew contains a master and three engineers / crew members.

Fig. 1 MV HERSO 1 at Port of Dunaföldvár

Fig. 2 MV HERSO 1 at Port of Dunaföldvár

Table 4 Main particulars of MV "HERSO 1"

Particular		Value
	Building year	1962
L_{OA}	Ship length over all	84.95 m
L_{PP}	Length between perpendiculars	83.50 m
L_{WL}	Length of waterline	84.50 m
D	Depth	2.90 m
T_{empty}	Empty draught	0.81 m
T_{max}	Maximum draught	2.70 m
$B_{moulded}$	Breadth moulded	9.5 m
v	Speed of the vessel – with barge fully loaded	11 km/h
Depl	Displacement at T_{max}	1977.5 t
LSW	Light ship weight	596.0 t
$Cargo_{max}$	Cargo capacity at T_{max}	1381.5 t
$Cargo_{2.5}$	Cargo capacity at $T_{2.5\ m}$	1185.0 t
$Cargo_{2.0}$	Cargo capacity at $T_{2.0\ m}$	813.0 t
$Cargo_{1.6}$	Cargo capacity at $T_{1.6\ m}$	520.0 t
	Weight of supplies & outfitting	130.8 t
	Main engine power (Deutz RBV 8M 545)	780 kW
	Maximum engine RPM	393 1/min
	Propulsion configuration	directly driven
	Propeller	5 bladed FPP
	Propeller diameter	1.55 m
	Auxiliary engines (2xDeutz 912)	2x30 kW
	Bow thruster engine (DAF 1160)	212 kW

Table 5 Main particulars of barge "SL Leonie"

	Particular	Value
L_{OA}	Ship length over all	70.75 m
$B_{moulded}$	Breadth moulded	10.44 m
T_{max}	Maximum draught	2.47 m
$Cargo_{max}$	Cargo capacity at T_{max}	1427 t

The prime mover of the vessel is a diesel engine of type Deutz RBV 8M 545 with output power of 780 kW each. The engine was built in 1961 and has no emission standard clas-si-fications. Last revision was made in 2011. The majority of time the engine is used at an average revolution speed between 320 and 380 rpm, with the fuel consumption ranging from 130 l/h to 190 l/h, providing a speed of 9–11 km/h (supposing still water). Fast streaming operation is used only temporarily, for not more than 30 minutes, when sailing upstream at the following places: Austrian – Slovakian border (DEVEN), near the Vienna Airport (East Vienna), Schönbühel an der Donau (near Melk) and Isar (junction between Danube and Isar). Under fast streaming operational conditions, the fuel consumption is 260 l/h and the speed is 13 km/h. The type of fuel used is EN590.

The ship is equipped with a bow thruster of type DAF 1160 with a performance of 212 kW. The auxiliary engine that drives the bow thruster was constructed in 1989. The auxiliary engine has no emission standard classification. The bow thruster is used for manoeuvring, sailing in ports and near locks.

Neither the main engines, nor the auxiliary engines are fitted with emission reduction devices. The remaining economic lifetime of the ship and the equipment is estimated to be 50 years.

The average speed of the vessel is 10–12 km/h. A round trip to Regensburg takes 12 days of sailing, while a round trip to Constanta takes 24 days of sailing. Loading and unloading lasts 2 days apiece, and waiting time is often added to the duration of a trip. The mass of fuel consumed by the main engines and auxiliary equipment is approx. 310 t yearly. The cargo performance is 36.3 Mio tkm. The cargo performance–specific fuel consumption is 8.5 g/tkm.

Table 6 Operational data of HERSO 1

Vessel:	Herso 1
Reference year	2012
Cargo per voyage	1 939 t
Distance sailed with cargo	18 713 km
Transport performance per year	36 284 507 tkm
Total amount of annual fuel consumption	370 295 litre
Total amount of main engines annual fuel consumption	342 935 litre
Total amount of annual fuel consumption	309 196 kg
Total amount of main engines annual fuel consumption	286 350 kg
Relative fuel consumption	8.52 g/tkm
Relative fuel consumption of main engines	7.89 g/tkm

3.3 Description of technological improvements

Based on the MoVeIT research for HERSO1, the following retrofit options were considered by the owner (MoVeIT, 2013c):

- Option No. 1: Improved propulsion, using the Ship Studio solution
- Option No.2: Lengthening by 20%
- Option No.3: Application of 'trapezes' for sailing in coupled formation

Calculations were made to find the effect of the various retrofit options for each vessel. These are summarised in the following table.

Table 7 Retrofit options of the vessel HERSO 1 and their effects

Herso1	Retrofit option	Fuel consumption change	Cargo carrying capacity change
Option No.1	Lengthening 20%	6–9% increase	14% increase
Option No.2	Trapezes	7–11% reduction	
Option No.3	New propulsion: Ship Studio solution	10–11% reduction	

In general, it can be stated that Ship Studio solution and the application of trapeze have similar effect, as both reduce the yearly fuel consumption of the vessel. As a result, the emissions will be reduced as well with the same ratio. For Ship Studio solution and for trapeze application, a 10–11% and 7–11% reduction were estimated, respectively. Since emissions are calculated on the basis of the fuel consumption and the emission factors (in kg/kg fuel) it is obvious, that a 10–11% and 7–11% emission reduction can be expected.

In the case of lengthening, the situation is a bit more complicated. With lengthening the vessel not only the annual fuel consumption changes, but cargo carrying capacity is increased significantly as well. The change in fuel consumption is a 6-9% increase which results also more emissions in absolute manner. Taking only this into account would mean that this option is not desirable from the environmental point of view. However, due to the increased cargo carrying capacity, the relative values (kg emission/tkm) can be much better than without retrofitting. This can make this option more favourable and more environmentally-friendly as well.

3.4 Assessment of emissions

The assessment was carried out according to the methodology given in Chapter 2. In the next tables the results are summarised. The annual fuel consumptions of the retrofitted vessels are calculated on the basis of the operational data with the values of fuel consumption change indicated previously.

Then the annual emissions are calculated for each option. In the following tables, both absolute and relative to tkm values are provided. For a better overview, graphs are also plotted for every retrofitting option.

Table 8 Annual fuel consumptions and transport performance of HERSO 1

Retrofit option	Annual fuel consumption		Annual total fuel consumption		Annual transport performance	Total amount of fuel consumed	
	main engine [kg]	aux. engine [kg]	[kg/year]	[%]	[tkm/year]	[g/tkm]	[%]
Without retrofitting	286 350.7	22 845.6	309 196.3	100	36 284 507	8.521	100
Option No.1 Lengthening 20%	297 088.9	22 845.6	319 934.5	103.47	41 383 800	7.731	91
Option No. 2 Trapezes	273 464.9	22 845.6	296 310.5	95.83	36 284 507	8.166	96
Option No. 3 Ship Studio solution	256 283.9	22 845.6	279 129.5	90.28	36 284 507	7.693	90

Table 9 Annual emissions of HERSO 1 in kg

Retrofit option	Calculation source	CO_2	NO_X	PM	HC	CO	SO_2
		[kg/year]	[kg/year]	[kg/year]	[kg/year]	[kg/year]	[kg/year]
Without retrofitting	VBD	981 698	17 624	257	1 051	2 010	6.18
	TNO	981 080	14 223	654	1 577	5 875	6.18
Option No.1 Lengthening 20%	VBD	1 015 792	17 276	266	1 088	2 080	6.40
	TNO	1 015 152	14 717	677	864	3 775	6.40
Option No. 2 Trapezes	VBD	940 786	16 001	246	1 007	1 926	5.93
	TNO	940 193	13 630	627	800	3 496	5.93
Option No. 3 Ship Studio solution	VBD	886 236	15 910	232	949	1 814	5.58
	TNO	885 678	12 840	591	1 424	5 303	5.58

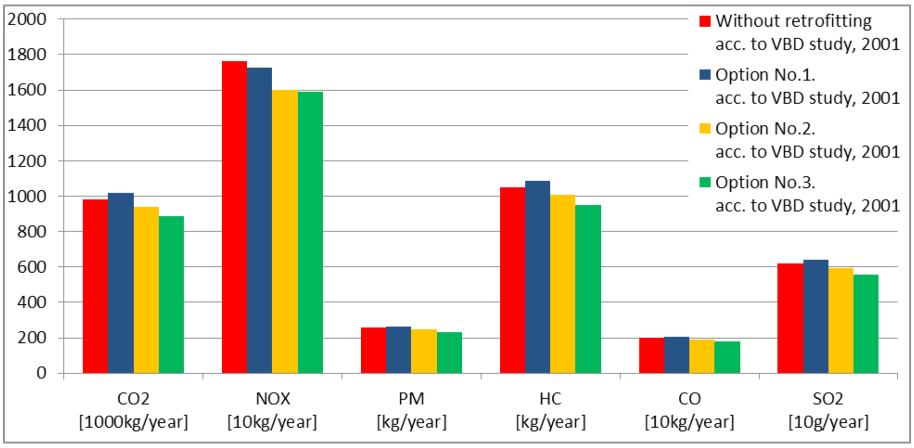

Fig. 3 Annual emissions of HERSO 1 in kg

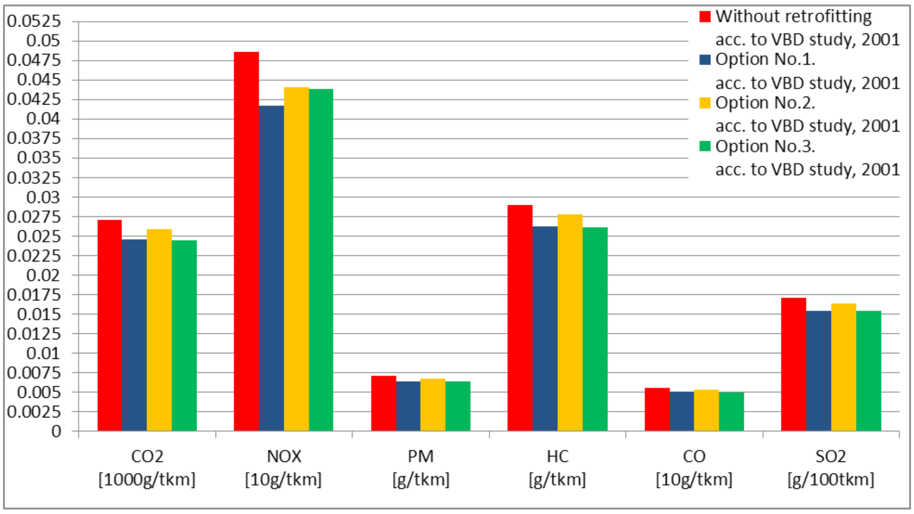

Fig. 4 Emissions in g/tkm of HERSO retrofit options

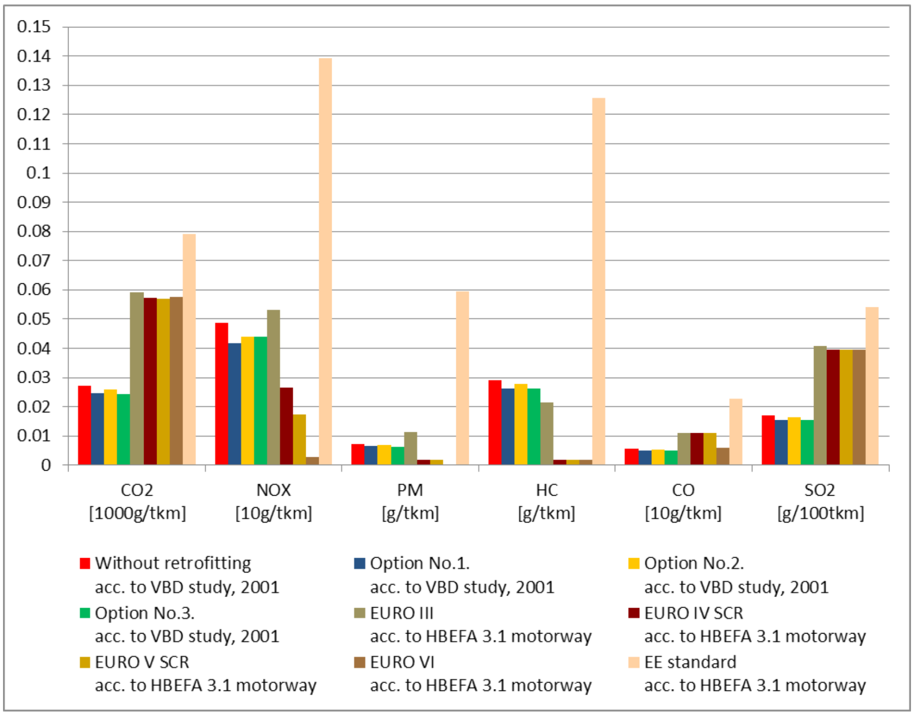

Fig. 5 Comparison of HERSO 1 emissions with different truck emissions

Table 10 Emissions in g/tkm of HERSO retrofit options

Retrofit option	Calculation source	CO_2 [g/tkm]	NO_X [g/tkm]	PM [g/tkm]	HC [g/tkm]	CO [g/tkm]	SO_2 [g/tkm]	Annual transport performance [tkm/year]
Without retrofitting	VBD	27.06	$4.86 \cdot 10^{-1}$	$7 \cdot 10^{-3}$	$2.9 \cdot 10^{-2}$	$5.5 \cdot 10^{-2}$	$1.7 \cdot 10^{-4}$	36 284 507
	TNO	27.04	$3.92 \cdot 10^{-1}$	$1.8 \cdot 10^{-2}$	$4.3 \cdot 10^{-2}$	$1.62 \cdot 10^{-1}$	$1.7 \cdot 10^{-4}$	
Option No.1 Lengthening 20%	VBD	24.55	$4.17 \cdot 10^{-1}$	$6 \cdot 10^{-3}$	$2.6 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$1.55 \cdot 10^{-4}$	41 383 800
	TNO	24.53	$3.56 \cdot 10^{-1}$	$1.6 \cdot 10^{-2}$	$2.1 \cdot 10^{-2}$	$9.1 \cdot 10^{-2}$	$1.55 \cdot 10^{-4}$	
Option No. 2 Trapezes	VBD	25.93	$4.41 \cdot 10^{-1}$	$7 \cdot 10^{-3}$	$2.8 \cdot 10^{-2}$	$5.3 \cdot 10^{-2}$	$1.63 \cdot 10^{-4}$	36 284 507
	TNO	25.91	$3.76 \cdot 10^{-1}$	$1.7 \cdot 10^{-2}$	$2.2 \cdot 10^{-2}$	$9.6 \cdot 10^{-2}$	$1.63 \cdot 10^{-4}$	
Option No. 3 Ship Studio solution	VBD	24.43	$4.38 \cdot 10^{-1}$	$6 \cdot 10^{-3}$	$2.6 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$1.54 \cdot 10^{-4}$	36 284 507
	TNO	24.41	$3.54 \cdot 10^{-1}$	$1.6 \cdot 10^{-2}$	$3.9 \cdot 10^{-2}$	$1.46 \cdot 10^{-1}$	$1.54 \cdot 10^{-4}$	

Table 11 Truck emission in g/tkm by the same travel distance with cargo as HERSO 1

Truck engine standard	Calculation source	CO_2 [g/tkm]	NO_X [g/tkm]	PM [g/tkm]	HC [g/tkm]	CO [g/tkm]	SO_2 [g/tkm]
EURO III	HBEFA 3.1 (2010) motorway	59.136	0.531	0.0114	0.0214	0.110	$4.08 \cdot 10^{-4}$
EURO IV SCR		57.187	0.265	0.0017	0.0018	0.110	$3.96 \cdot 10^{-4}$
EURO V SCR		56.996	0.175	0.0017	0.0017	0.111	$3.96 \cdot 10^{-4}$
EURO VI		57.690	0.029	0.0003	0.0017	0.058	$3.96 \cdot 10^{-4}$
EE standard		79.004	1.393	0.0596	0.1257	0.226	$5.42 \cdot 10^{-4}$

Finally, the relative-to-tkm emissions of trucks are given in tabular form.

A comparison of HERSO 1 solutions with road transport by different kind of trucks is shown in the next diagram.

4 Summary and conclusions

From Fig. 4 one can conclude that in spite of that the first retrofit option (lengthening) increases the fuel consumption, its performance-specific emissions are rather good due to the positive influence on the cargo carrying capacity.

In case of other options, the emissions change proportionally with the fuel consumption.

From Fig. 5 it can be seen that HERSO 1 solutions always perform better than EURO III and EE standard trucks and in case of CO_2, CO and SO_2 emissions IWT is better than any of the trucks. The reason for this is that the relative fuel consumption of the vessel is always better than that of trucks and hence, in case of those emissions that depend on nothing else but the amount and type of fuel consumed, this advantage can be copied.

Regarding NO_x, PM and HC unfortunately no retrofit options can compete with modern engines only with the EE standard engines.

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