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Emissions Race SSS vs. ROAD - Road versus Short Sea Shipping (SSS): updating the 2008 comparison of emissions between modes

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Abstract

In 2008, we compared emissions from road transport and SSS on specific routes in Vanherle (2010). The comparison of the three case studies showed how performance can differ depending on case specificities (ship type/size, route length,…), but also in what way performance was similar regardless of the differences of the 3 cases. We concluded SSS performed better than road transport in terms of CO_2 and vice versa for SO_2 and PM. In the past 8 years, various policies have come into effect to further reduce emissions from both modes. We find that on CO_2 both road and SSS have slightly improved performance in 2016 compared to 2008. Both modes have reduced emissions of other pollutants in 2016 compared to 2008; the improvement in SSS is significantly larger than road with dramatic improvements for SO_2 (up to factor 20 better), PM (up to factor 10 better) and NO_x (factor 3-4 better). SSS now scores better than road transport in terms of CO_2 emissions, equally well in terms of NO_x and PM emissions, and worse in terms of SO_2 emissions.

Keywords: Short Sea Shipping, transport emissions, emission regulation, SECA, NECA, EEDI.

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1. Introduction

In this paper, we compare 2 origin-destinations performed by road and Short Sea Shipping (SSS). In the first chapter, we first elaborate on the specific itinerary and equipment used. In the second section we elaborate on the methodology of the emission calculation. In the third section, we present the findings of the 2 new cases and compare with the 3 cases in the original paper of Vanherle (2010).

2. Two new cases

In this new study, we consider the following routes:

A. Kortrijk (BE) – Oslo (NO)

B. Amiens (FR) – Moscow (RUS)

Both routes have exactly the same origin and destination. This means that the emission calculation takes into account any hinterland road transport in the case of SSS and ferry transfers in the case of road. This mix of modes is also found in the original study and is even more pronounced for the routes chosen in this study (see below). We look at the selected routes in detail and elaborate on distance of legs and equipment used:

2.1. Kortijk (BE) – Oslo (NO) route

Table 1: breakdown of Kortrijk-Oslo road route and equipment used.

Origin	Destination	Distance	Equipment
Kortrijk (BE)	Antwerp (BE)	120km	Unknown
Antwerp (BE)	Travemunde (DE)	614 km	MAN TGX EURO V; load: 22 ton
Travemunde (DE)	Malmo (SE)	+/-260 km	Unknown ferry
Malmo (SE)	Oslo (NO)	565 km	MAN TGX EURO V; load: 22 ton

The road-trajectory is not "purely" executed via road given the Travemunde – Malmo ferry leg. However, most of the kilometers traveled are done by road mode: +/- 1300km on a total of 1560km. The first road section is divided into two parts, as the first part (Kortrijk - Antwerp) was carried out by another truck with no data available. For simplicity, we assume identical vehicle properties in the calculation.

Table 2: breakdown of Kortrijk-Oslo SSS route and equipment used.

Origin	Destination	Distance	Equipment
Kortrijk (BE)	Antwerp (BE)	120km	Unknown
Antwerp (BE)	Oslo (NO)	+/-1200 km	Container WES JANINE; GRT 10585 ton
Oslo (NO)	Oslo (NO)	22 km	SCANIA 580R EURO VI; load: 24.4 ton

This trajectory is a near "port-to-port" connection with only a limited amount of feeder and "last-mile" transport using road transport from origin to port of departure and from port of destination to final destination.

2.2. Amiens (FR) – Moscow (RUS) route

Table 3: breakdown of Amiens-Moscow road route and equipment used.

Origin	Destination	Distance	Equipment
Amiens (FR)	Kiel (DE)	996 km	Volvo FH 42T; EURO V; load 21.7 ton
Kiel (DE)	Klaipeda (LT)	+/-680 km	Ropax: Regina Seaways; GRT 25518 ton
Klaipeda (LT)	Moscow (RUS)	1481 km	Volvo FH 42T; EURO V; load 21.7 ton

Similar to the other case, the road trajectory includes a ferry leg. The SSS-trajectory is split in 3 legs:

Table 4: breakdown of Amiens-Moscow SSS route and equipment used.

Origin	Destination	Distance	Equipment
Amiens (FR)	Zeebrugge	243 km	MAN; EURO VI; load 21.7 ton
Zeebrugge (BE)	St-Petersburg (RUS)	+/-2400km	Container vessel Vohburg; GRT 7852 ton
St-Petersburg (RUS)	Moscow (RUS)	861 km	Volvo; EURO V; load 21.7 ton
Amiens (FR)	Zeebrugge	243 km	MAN; EURO VI; load 21.7 ton

Figure 1 below summarizes routes of both road and SSS for the 2 cases:

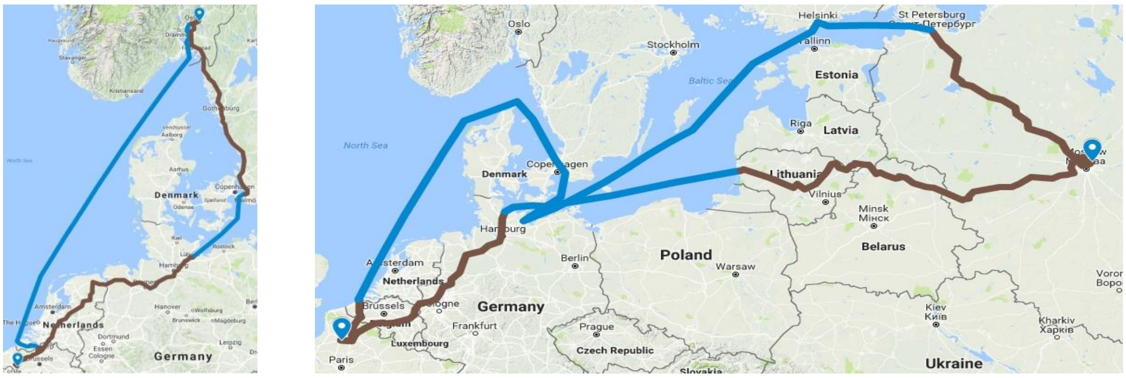

Fig. 1 routes by SSS and road for the Kortijk-Oslo case (left) and Amiens-Moscow case (right) – source: GoogleMaps

Note that the SSS route from Zeebrugge to St Petersburg also includes two stop-overs in Lubbeck and Helsinki. This somewhat "blurs" the pure comparison of SSS to road transport since the stop-overs are not productive for the route Zeebugge - St Petersburg as such and thus generate more emissions than strictly necessary. On the other hand, the stop-overs reflect the real operational pattern of SSS transport, where intermediate stop-overs are common. Therefore, we have chosen not to correct the emission calculations for these stop-overs.
The two trajectories have some specific characteristics that influence the emission calculations. In both cases, road transport and waterborne transport are combined. In both cases, we compare two options with a predominantly road component and a predominantly SSS component.

2.3. Details of ships deployed

The ships deployed on the SSS trajectory are similar: relatively small container ships commonly deployed in container feeder services. The participants of the SSS-trajectories were asked to disclose all specifications of the vessel used, which have an influence on the emission calculation. The data are summarized in the tables below.

Table 5: vessel details WES Janine (source: http://www.marinetraffic.com)

Property	Value
Lloydsnr°	9504073
YOB	2012
type	Container
Length	151.72 m
GRT	10585 ton
DWT	13000 ton
Main engine power	9000 kW
Main engine type	4stroke
Auxiliar engine power	620 kW
Auxiliar engine type	4stroke

Table 6: vessel details Vohburg (source: http://www.marinetraffic.com)

Property	Value
Lloydsn°	9287807
YOB	2005
type	Container
Length	140.68 m
GRT	7852 ton
DWT	9296 ton
Main engine power	8400 kW
Main engine type	4stroke
Auxiliar engine power	400 kW
Auxiliar engine type	4stroke

For the road sections, there is less variation in the type and size of the trucks; the trucks used typically fall into the 16-32 tonnes class and are representative for long distance road freight transport. Also, in terms of technology, there is similarity between the routes: the trucks are equipped with at least EURO V technology, in some cases with Euro VI technology, which has a direct impact on emissions. Compared to 2008, the emission factor estimation of the emission control technologies are further refined, distinguishing between exhaust gas recirculation (EGR) and selective catalytic reduction (SCR). The technology type applied in the trucks is not available, so we choose the technology that provides the "best fit" between calculated vs. reported fuel consumption.

It should be noted that none of the routes are pure road or SSS routes. In both cases, there is a transfer by ferry and specific data on the ferry type, engine technology, size,… are missing. For the Kiel-Klaipeda ferry we found the ship deployed on this specific route from public sources and could thus find relevant specifications of the vessel. Especially for the ferry Kiel-Klaipeda this is important given the relatively long leg of the ferry-transfer in the road section.

After examining the available ferry services on this route, we expect the vessel used it the Regina Seaways:

Table 7: vessel details Regina Seaways (source: http://www.marinetraffic.com)

Property	Value
Lloydsn°	9458535
YOB	2010
type	Ropax
Length	199 m
GRT	25518 ton
DWT	8400 ton
Main engine power	24000 kW
Main engine type	4stroke
Auxiliar engine power	unknown
Auxiliar engine type	4stroke
Load	2496 lane-meters

3. Emission calculation

3.1. Emissions from road transport

For the calculation of road freight emissions, we use COPERT, based on emission factors as a function of speed. The COPERT emission factors have been updated several times since 2008 and new emission factors for EURO VI technology are added to the library. COPERT distinguishes between different truck classes, engine technologies, load factors (empty, half full, full) and slope (0%, 2%, 4%, 6%).

For the calculations by truck type we select the "Articulated 34-40 tonnes" and "articulated 40-50 tonnes" types. We assume a load factor of 100% and we assume a 0% slope (i.e. uphill or downhill). The latter assumption is a simplification because certain sections will likely have an uphill or downhill slope. However, the required level of detail on road used is not available and the overall impact on emissions is small.

Regarding the technology, COPERT takes into account the EURO standard and also the technology used to meet the EURO standard: "exhaust gas recirculation" (EGR) and "selective catalytic reduction" (SCR). Data about the trucks used in the study lacks information on the emission abatement technology. As indicated earlier, we choose the technology that provides the "best fit" between the calculated vs. reported fuel consumption.

The speed-dependent emission functions are applied to all road sections. For the road trajectories, the participants were asked to collect distance driven and record the time for each leg, for different types of road (highway, road or city road) and traffic conditions (traffic congestion or free flow). We can thus determine the speed for each section. An example in table 8 below:

Table 8: Kortrijk-Oslo trajectory, summary of the road sections properties

Road type	Traffic conditions	Distance (km)	Time (h)	Speed (km/h)
motorway	free flow	95	1.15	82
motorway	congestion	4	0.3	13
motorway	free flow	515	7	73
motorway	free flow	565	10	56

The observed speeds, derived from the activity data were tested to speed data used in the TREMOVE model (De Ceuster, 2005). In case of significantly different result (e.g. lower speeds on road than on the highway), these were corrected with the default TREMOVE data.
With these speeds, the information on the truck type, load factor (fully loaded), the slope (arbitrary 0%) and technology (EURO V or VI, SCR or EGR) we determine the road freight emission factors (g/km).
The emissions are then calculated as the product of the emission factor and the distance traveled. After the calculation, we compare the calculated fuel consumption with the reported fuel consumption. The participants were asked to log the total fuel consumption for the entire trajectory as a validation test for the calculated fuel consumption. Table 9 below summarizes the deviation of calculated vs. reported fuel consumption for all sections:

Table 9: deviation calculated vs. reported fuel consumption road

Trajectory	Deviation
Kortrijk-Oslo ROAD	4.5%
Amiens-Moscow ROAD	1%
Amiens-Moscow SSS road sections	3.7%

We observe only limited deviations with typically marginally lower calculated vs. reported fuel consumption. The most likely explanation is idling of the engine while parked. In order to achieve an exact match of the calculated fuel consumption and the reported consumption, we scale the calculated emissions for all pollutants.

3.2. Emissions from SSS

For the calculation of emissions from maritime vessels, either in the SSS-sections or the ferry-sections in the road trajectory, we use the EMMOSS model (Vanherle, 2007). The emission calculation holds 3 steps:

1. Determination of energy consumption with the following formula:

$$Energy\ consumption\ (kWh) = time\ (h)\ X\ installed\ power\ (kW)\ X\ engine\ load\ (\%)$$

2. Determination of fuel consumption with the following formula:

$$Fuel\ consumption\ (kg) = energy\ consumption\ (kWh)\ X\ energy\ content\ (kg/kWh)\ X\ yield$$

3. Determination of emissions with the following formula:

$$Emissions\ (kg) = Fuel\ consumption\ (kg)\ X\ emission\ factor\ (kg/kg)\ X\ correction\ factor$$

The installed engine power, distinguishing between main and auxiliary power, and other indicators relevant for the emission factors can be derived from the ship's specifications. Apart from ship specifications, also the details of the journey are relevant to this calculation:

The EMMOSS-model distinguishes between 4 activities:

- At berth,
- maneuvering,
- sailing at reduced speed,
- sailing at cruise speed.

These activities differ in terms of engine load of the main and auxiliary engines. For example, while maneuvering, the auxiliary engine load is higher compared to sailing at reduced or cruise speed due to use of thrusters and other equipment. Although EMMOSS contains data on average engine load and duration of activity, variance of engine load can differ strongly in real world conditions. The calculation is more accurate when using specific activity data of the vessels used in the cases. Therefore, the participants were asked to collect this information along with the fuel consumption and the type of fuel used.

Table 10: summary of SSS activity for Amiens-Moscow case

Activity	time (h)	Main engine load (%)	Auxiliar engine load (%)	Fuel type and sulphur content
at berth port Zeebrugge	16.9	0	0.7	ULS HFO 0.0848% S
manoeuvring out of port Zeebrugge	0.5	0.25	0.45	ULS HFO 0.0848% S
sailing at reduced speed (Cast off - BOSP)	1.1	0.35	0.25	ULS HFO 0.0848% S
cruising speed (BOSP-EOSP)	48.5	0.85	0.25	ULS HFO 0.0848% S
reduced speed to port entrance Lubeck	1	0.3	0.25	ULS HFO 0.0848% S
manoeuvring in port Lubeck	0.5	0.2	0.45	ULS HFO 0.0848% S
at berth port Lubeck	20.8	0	0.7	ULS HFO 0.0848% S
at berth port Lubeck	20.8	0	0.7	ULS HFO 0.0848% S
manoeuvring out of port Lubeck	0.5	0.25	0.45	ULS HFO 0.0848% S
sailing at reduced speed (Cast off - BOSP)	1.3	0.35	0.25	ULS HFO 0.0848% S
cruising speed (BOSP-EOSP)	32.5	0.85	0.25	ULS HFO 0.0848% S
reduced speed to port entrance Helsinki	0.5	0.3	0.25	ULS HFO 0.0848% S
manoeuvring in port Helsinki	0.2	0.2	0.45	ULS HFO 0.0848% S
at berth port Helsinki	11	0	0.7	ULS HFO 0.0848% S
at berth port Helsinki	11	0	0.7	ULS HFO 0.0848% S
manoeuvring out of port Helsinki	0.2	0.25	0.45	ULS HFO 0.0848% S
sailing at reduced speed (Cast off - BOSP)	0.5	0.35	0.25	ULS HFO 0.0848% S
cruising speed (BOSP-EOSP)	11.7	0.85	0.25	ULS HFO 0.0848% S
reduced speed to port entrance Kronshtadt	1	0.3	0.25	ULS HFO 0.0848% S
manoeuvring in port Kronshtadt	0.5	0.2	0.45	ULS HFO 0.0848% S
at berth port Kronshtadt	12.7	0	0.7	ULS HFO 0.0848% S

A similar log was compiled for the second SSS route. Note that various ports were called in this specific case. These "detours" of course increase emissions, but also reflect how SSS transport is organized in real world.
With the information from the above log and the ship's specifications, all data is available to calculate emissions. Fuel consumption was also reported, allowing for a comparison between reported and calculated fuel consumption. As for the journeys by road, we use the difference between the reported and calculated fuel consumption as a validation for the calculations:

Table 11: deviation calculated vs. reported fuel consumption SSS

Trajectory	Deviation
Kotrijk-Oslo SSS	5.5%
Amiens-Moscow SSS	22%

For the Antwerp-Oslo route, there is a small deviation of 5.5%. For the SSS route Amiens-Moscow calculated emissions are 22% higher than reported. We suspect the cause is the reported engine load factor of the main engine during cruise of 85%, which is relatively high. If we apply a more common 65%, the calculated fuel consumption is 1% lower than reported. We maintain this 65% engine load factor for the calculation of emissions. Finally, emissions are then, analogous to road transport, scaled so that the calculated and reported fuel consumption matches.

We divide the estimated 19.5h travel time of the ferry Kiel-Klaipeda according to own estimates in different stages of the journey. In this case, there is no reported fuel consumption so we cannot validate the calculations.

To conclude, in the Kortrijk-Oslo road trajectory, there is a short ferry leg: Travemünde-Malmö about +/- 260km. These emissions should be calculated as well in order to make a fair comparison between the emissions of SSS and road transport. The ferry operator is not an active participant in this study and it was not possible to determine which vessel will be deployed on this route. Given the limited share of this ferry in the overall route, we use a simplified calculation of emissions. We scale the emissions from similar range Travemunde-Trelleborg from the original study, under the assumption that a similar ship is employed (TT-Line Peter Pan)

Table 12: vessel details TT-line Peter Pan (source: http://www.marinetraffic.com)

Property	Value
Lloydsn°	-
YOB	2001
type	Ropax schip
Length	190 m
GRT	36.468 ton
DWT	-
Main engine power	-
Main engine type	-
Auxiliar engine power	-
Auxiliar engine type	-

4. Results

Figures below summarize the results of the emission calculation. We've look into 4 pollutants: CO2, NOx, SO2 and PM. We first look into the results for CO2:

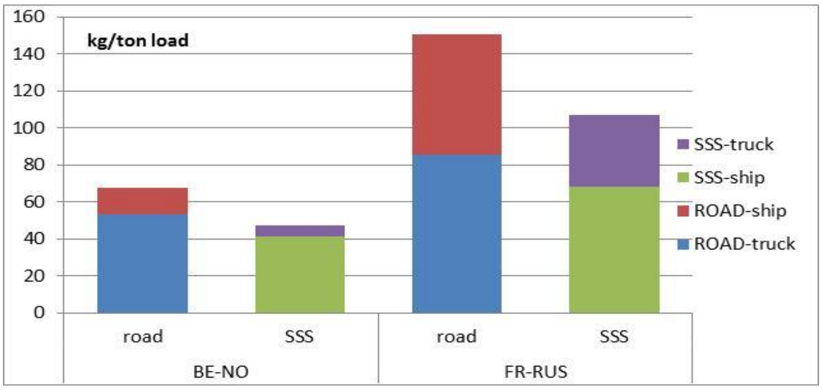

Fig. 2 CO2 emissions by road and SSS (in kg/ton load)

The results are expressed in kilograms per ton of cargo, allowing for a better comparison between SSS and road transport. For all trajectories, we add the distinction between the modes of transport used. The road trajectories in both cases include a (short) ferry leg and the SSS trajectory includes feeder and last-mile transport via road. In both cases, SSS performance better than the road section. The results for NOx:

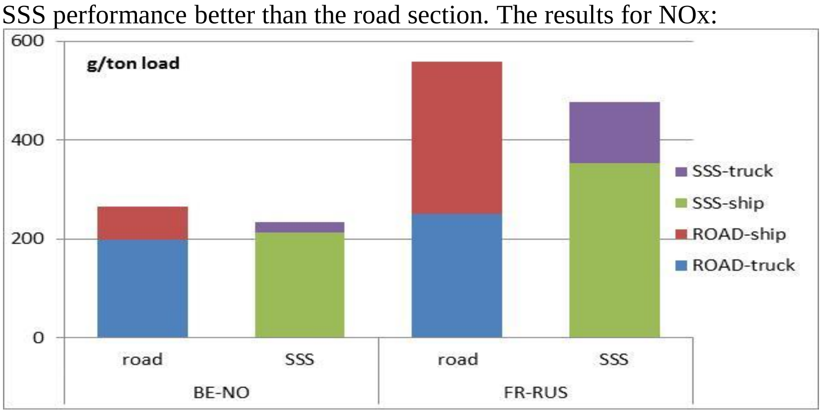

Fig. 3 NOx emissions by road and SSS (in g/ton load)

Both modes have about equal performance in both cases, with a small margin in favor of SSS. The emission standards for trucks, imposed by the European Commission regulate the emission of harmful gases. These so-called EURO standards have become more stringent in time. The most recent trucks, EURO VI emit five times less NOx than the Euro V. These EURO 5 trucks already emit 8 times less NOx than old trucks. The trucks used in the race are almost all equipped with EURO V and even VI technology in a few cases. Emissions standards for ships for NOx are imposed by the IMO. These NOx-emission standards are introduced in 3 stages and apply worldwide or in designated areas: "Emission Control Area's" (ECA):

Table 13: MARPOL Annex VI NOx Emission Limits (source: Dieselnet.com – n=RPM)

TIER	Date	NOx limit (g/kWh)		
		n<130	130<n<2000	n>2000
TIER I	2000	17.0	45 x n^-0.2	9.8
TIER II	2011	14.4	44 x n^-0.23	7.7
TIER III	2016	3.4	9 x n^-0.2	1.96

TIER I & II are applicable worldwide, TIER III applies in NECA's such as the North Sea and the Baltic Sea. The emission standards apply to new ships only so in principle only the WES JANINE is TIER II compliant. Although not confirmed by the operators, we've assumed a voluntary compliance of all ships involved to TIER II standards, which is achievable with engine performance optimization. Both modes have improved since the original study. The results for SO2:

Fig. 4 SO2 emissions by road and SSS (in g/ton load)

For SO2 SSS performs poorly, to such an extent that SO2 emissions from road transport are negligible relative to that of SSS. For the road trajectory, the only sections that are relevant to SO2 emissions of "road" are the ferry-sections. SO2 emissions are directly related to fuel sulfur content. Fuel for road transport has been regulated since the 90s; currently the standard of maximum 10 ppm sulfur (or 0.001%) applies. Fuel standards for marine fuel are less stringent. The North Sea is considered a "Sulphur Emission Control Area" (SECA) since 2007, capping the fuel sulfur content to 1.5%. From 2015 onwards, this is further reduced to 0.1%. Outside the SECA, there is a standard of 3.5%, though sulfur content well below the standard of 2.7% for heavy oil (HFO), and 1.5% for marine diesel oil (MDO) are common.

Table 14: MARPOL Annex VI SO2 SECA fuel standards (source: Dieselnet.com)

Date	Sulfur limit in fuel (% m/m)	
	SOx ECA	Global
2000	1.5%	4.5%
2010.07	1.0%	4.5%
2012	1.0%	3.5%
2015	0.1%	3.5%
2020	0.1%	0.5%

All shipping routes in this race occur in a SECA and therefore fuel with max 0.1% sulfur is used. While this is already a considerable improvement compared to 2008, this is a factor of 100 worse than the fuel for road transport. The results for PM:

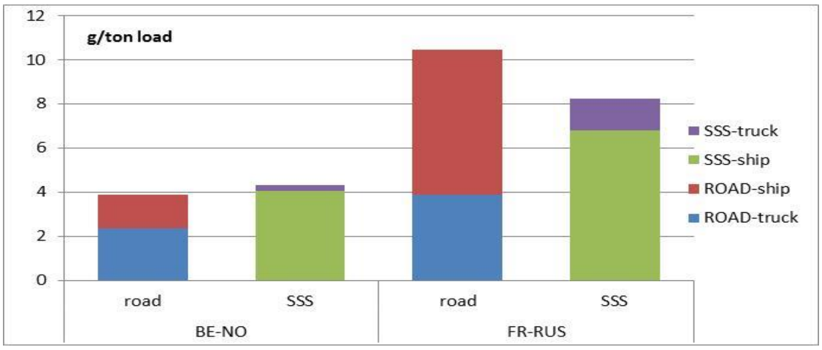

Fig. 5 PM emissions by road and SSS (in g/ton load)

Both modes have similar performance. As with NOx, particulate matter emissions from road transport are regulated by the EURO standards. Trucks equipped with Euro V and Euro VI technology have PM emissions 15 times lower than trucks from the pre-Euro era. For maritime shipping there is no direct regulation of emissions of particulate matter. PM emissions are associated with the sulfur content of the fuel. Given the strong reduction of the sulfur content of fuel, there is also an effect on PM emissions. (Alfoldy 2013) estimates a correlation between sulfur fuel and the PM emission factor that we have applied here. The PM emissions thus decrease by a factor of +/- 5.5 for fuels with 0.1% compared to 1.5% sulfur.

5. Trends

This study is an update of a similar survey in 2008. The conclusion was that SSS scored well for CO2, but that there was a need for SSS to catch up for the pollutants NOx, SO2 and PM. The legislation in the making at that time has now been implemented. We examine in this chapter whether this new legislation has indeed been effective. The figure below summarizes the emissions per tonne-kilometer, averaged for the three cases of the original study in 2008 for the road and SSS, versus the two new cases examined in this study

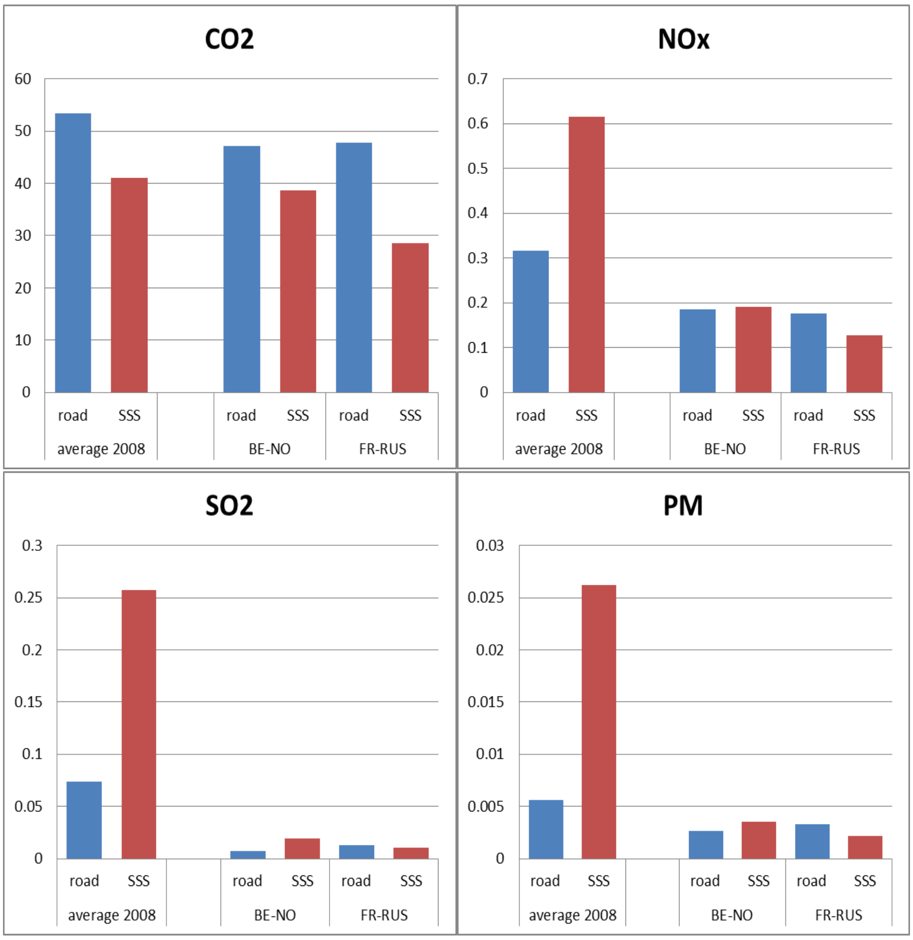

Fig. 6 evolution of performance road vs SSS; 2008 – 2016.

We assess the trends for the 4 pollutants:

On **CO2**, both road and SSS show slightly improved performance in 2016 compared with 2008. SSS retains the advantage of lower CO2 emissions that it has relative to road transport. The "lead" averaged 25% in 2008; for the two examined trajectories in this race SSS leads 20% (BE-NE) or 40% (FR-RUS).
For **NOx**, there is a clear improvement noticeable in both modes. The improvement in SSS is greater than for road. Both modes are approximately equivalent in emissions, while emissions of SSS were on average twice as high in 2008 than for road.
Regarding **SO2**, the emissions of SSS in 2016 also remain higher than road. Moreover, the emissions from the

ferries in the road-trajectory represent the majority of the emissions for the "road"-routes. Although still higher than road, there is a strong decrease in SO2 emissions of SSS since 2008 as a result of the use of low sulfur fuel. For **PM**, we observe a similar trend as with SO2, with the difference that the sharp decline in PM emissions from SSS emissions have led to an environmental performance on par with road. The emissions of road have also further decreased, but the spectacular improvement in the performance of SSS (an indirect result of the use of low-sulfur fuel) is much greater.

6. Conclusions

The CO2, NOx, SO2 and PM emissions from road transport and SSS were compared for two specific cases and compared with the performance in the initial 3 cases from the 2008 study.

There is (again) no clear winner in this study; SSS scores better than road transport in terms of CO2 emissions, similar in terms of NOx and PM emissions, and worse in terms of SO2 emissions. CO2 has an impact on climate change; this is a global problem. NOx, SO2 and PM have an impact on regional air quality, which may affect the human health (PM, ozone due to NOx) and the environment (acid rain by SO2, ozone due to NOx).

Both modes have improved in 2016 in comparison with 2008; the improvement in SSS is significantly larger than road with dramatic improvements for SO2 (up to factor 20 better), PM (up to 10 times better) and NOx (factor 3-4 better). The conclusion of the study in 2008 confirms that SSS had to "catch-up" in terms of environmental performance. From this study we can conclude this "catch-up" has indeed materialized.

Both the European Commission and the IMO have been working on environmental regulation. In April 2008, the IMO decided to strengthen the existing global treaty on ship emissions, Marpol Annex VI, to reduce emissions of SO2 and NOx from ships. The SECA regulations, applicable in the Baltic Sea and the North Sea, have lowered the maximum sulfur content of marine fuels initially to 1% in 2010 to 0.1% in 2015. The results for SO2 and PM emissions are clear. Tier I, II and III standards for NOx emissions are just beginning to bear fruit. The impact of Tier III NOx standards are not yet visible in the analysis of this report, as they have only come into effect since 2016 for new ships. Therefore, there is still a large emission reduction potential available for maritime shipping. If the trend of improving environmental performance in shipping continues, it is likely that SSS in the future will "win" this race.

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