EMISSION MODELS: A COMPARISON TO DETERMINE THE IMPACT OF MARITIME TRANSPORT ON EMISSIONS IN SW EUROPEAN SHORT SEA SHIPPING

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ABSTRACT

According to the mid-term review of the EU White Paper on Transport, Short Sea Shipping is expected to grow at a rate of 59% (metric tonnes) between 2000 and 2020. Even with Marpol Annex VI [1] in operation, the share of emissions from maritime transport can no longer be ignored because they would become increasingly important. There is an existing need to evaluate the impact of the maritime transport on air quality.

This paper analyses emissions of maritime transport in SW European Short Sea Shipping, considering actual routes and ships' particulars and presents the comparison of two emission models to calculate emissions from vessels, the REALISE [2] and the MOPSEA [3] emission models.

This paper will compare both methods and will conclude proposing some results that would justify the need to reduce atmospheric emissions from sea-going vessels to compete with road transport mode. Policy makers have to be aware of the results of such comparison and its effect on the current legislation for maritime transport.

KEY WORDS

1. Maritime transport 2. Emissions models 3. European Short Sea Shipping

INTRODUCTION

The European transport policy undertakes to enhance sustainability in transport in order to improve economic activities in the whole European Union. The reduction of pollutant emissions and a better equilibrium among modes of transportation to avoid road congestion are the pillars of the above policy. Although most developed countries boast a national network of roads to move freight despite road transport being the most expensive, pollutant mode, with the highest rate of fuel consumption per cargo unit, both public and private stakeholders have began to use the freight rail and maritime options more extensively in search for a better alternative.

Maritime transport was and still is an environmentally friendly and safe mode of transport, especially compared to congested road transport. Additionally, it contributes to the reduction of traffic congestion on European roadways. In particular, Short Sea Shipping is considered the fastest way to sustainability. However, there is still considerable scope for improvement, especially with regard to NOx and SO_2 emissions.

Most of the international environmental legislation excludes guidelines with regard to emissions from vessels. The only internationally applied convention, is the Marpol 73/78 Convention that covers prevention of pollution of the marine environment by vessels from operational or accidental causes. The International Maritime Organization (IMO, 2005) adopted in 1997 (and entered in force on May 2005) Annex VI "prevention of air pollution from vessels". With this annex, worldwide limits have been placed on sulphur dioxide (SO_2) and nitrogen oxide (NOx) emissions from vessels. Even with Marpol Annex VI in operation, the share of emissions from vessels will increase in the future as the exhaust emissions of other transport modes decrease even more. This is due to the more severe emission standards and fuel specifications for road transport, railway traffic and inland navigation that came into force during the last decade. Recently, on a European level, a new EU Directive to reduce atmospheric emissions from vessels entered in force on 11 August 2005 (EU Directive 2005/33/EC).

The present paper is divided into four sections. First, we briefly discuss the state of art of the existing emission models for the assessment of emissions maritime transport used. Second, we explain in detail REALISE and MOPSEA emission models, the data necessary and their methodology used in our calculations. In the next section, we calculate emissions from maritime transport in Mediterranean Short Sea Shipping context based on both models. Finally, we compare both methods and obtain the differences in results between both models and some conclusions of this study.

STATE OF THE ART OF EMISSION METHODS FOR MARITIME TRANSPORT

In this section we give an overview of the emission methods used for the assessment of maritime transport used in Europe. As far as environmental performance is concerned, several attempts have been made to estimate external costs in the transport sector. The most important results were obtained by some research projects, especially those within the 4th, 5th and 6th EU-framework programmes. Projects that conducted similar research are MEET (1999), RECORDIT (2001), ENTEC (2002), UNIT (2003), EMS (2003), TRENDS (2003), INFRAS (2004), ExternE (2005) REALISE (2005), MOPSEA (2006), EMMOSS (2007), EMSA (2007) and iTREN-2030 (2007), and IMO proposals.

MEET [4] stands for Methodologies for Estimating air pollutant Emissions from Transport. MEET is a methodology for calculating the emissions from maritime transport among the methodology for the other transport modes. RECORDIT [5] (and thus REALISE) results were expressed at emission factor costs.

ENTEC [6] is an analysis to quantify the ship emissions of SO_2, NO, CO_2 and hydrocarbons in the North Sea, Irish Sea, English Channel, Baltic and Mediterranean Sea. EMS [7] stands for Emission registration and Monitoring for Shipping had as target to map the different emissions from sea-going vessels and inland shipping for the

Netherlands. TRENDS [8] stands for TRasnport and ENvironment Database System. TRENDS is a methodology to determine the emissions from the four most important transport modes: road, rail, shipping and aviation.

INFRAS [9] develops estimates of accidents, noise, air pollution, climate change risks, other environmental and non-environmental effects, and congestion for four modes (road, rail, air and water transport) in 17 European countries for 1995 and 2010 whereas ExternE [10] is a methodology, provides a framework for transforming impacts that are expressed in different units into a common unit –(monetary values).

The maritime transport emission model REALISE determines both SO_2, NOx, CO, nm-VOC y PM (local contamination), CO_2, CH_4 and S (global contamination) and pollution, accidents and noise. On the other hand, the maritime transport emission model MOPSEA accounts for the energy consumption as well as the carbon dioxide (CO_2), sulphur dioxide (SO_2) (based on technology of the engine) nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbons (HC) and particulate matter (PM) exhaust emissions (type of fuel) of transport activities from sea-going vessels.

EMMOSS [11] intends to determine emissions caused by railway, inland waterway and seagoing vessels, for transport of people as well as goods on Flemish territory, EMSA [12] treats about the revision of MarPol Annex VI in 2007 and finally, iTREN-2030 [13] is an analysis tool for transport in the European Union, covering transport, energy, environment and economy in 2030.

REALISE AND MOPSEA EMISSIONS METHODOLOGY

In this section we explain the REALISE and MOPSEA emission models, necessary data and their methodology. Our calculations are based on both models and consider shipping activities on Mediterranean territory, combined with individual vessel characteristics. We apply both models to study the effects of emissions from sea-going vessels in Mediterranean area.

REALISE Emission model

REALISE is a thematic network on Short Sea Shipping which provides prices of external costs from both sea and road transport. The REALISE project took the datasets in the EIG (2002), based upon the COPERT III calculation module, which were the most recent and complete available. The data are given in g/km. The air emission factors in g/kg fuel were calculated taking the fuel consumption into account. Since not all the pollutants were listed in the EIG report, additional information was extracted from the CBS database with regards to SO_2 and CO_2 emissions. We must note that the S has a negative cost impact value (i.e. a positive environmental impact). Its cost had to reflect this positive impact.

The following criteria are considered in our methodology based on REALISE project:

a) The cost categories are divided into two:

- Environmental external costs: local air pollution, global warming and noise pollution.

- Non-environmental external costs: accidents and traffic congestion.

b) To evaluate the impact of the evolution of transport emissions, the scenario considered is a future hypothetical improved condition where future stricter regulations are applied, resulting in a 10% decrease in all current emissions, except for S, SO_2 and NOx in maritime transport.

c) Cargo capacity was calculated dividing the ship's total linear capacity by 19.5 meters [14], including the number of trucks (assumed FEUs) that the ship is able to carry. The cargo is measured in FEU (very close to trailer length) as it is the common unit of freight in sea, assuming the container to be filled to 75% of its full capacity [15]. Thus, the maximum container payload of 25 tonnes (maximum total weight allowed is 40 tonnes) is limited to 18.5 metric tonnes on average.

d) For our purposes, we consider the hourly consumption of each ship on the basis of 200 g/kW per hour. Because almost all ships mentioned here are propelled by four-stroke diesel engines, the final consumption rate depends on the main engine output and working rate. Although the total fuel consumption rate depends on the engine's maximum output, the average power is assumed to be 85% of MCR (Maximum Continuous Rate) of installed power. However, the average main engine load and speed vary dramatically for different ship types. Some authors have reported an average load of 80% MCR based on statistical data. For example, bulk carriers tend to have slightly lower average values (72% MCR) than tankers (84% MCR). Accordingly, load can range from about 60% MCR up to 95% MCR for the analyzed ships [16]. For our purposes, the selected engine load was fixed to 80% of engine load when sailing, 40% of engine load when manouvering and 20% for time spent at ports due to operations [17].

e) The emission factors considered are taken from the REALISE database.

	Origin	**Destination**
Route		

Maritime distance (km)	

Ship's Name		
Linear meters		
Speed of ship (in knots and km/h)		
Ship's Power (kW)		
Number of FEU (theoretical)		
Load Factor (SHIP)		
Hours of navigation by SSS		
Type of ship		

			Manoeuvring	**Hotelling**
	Fuel consumption (kg/h) 100%	**Fuel consumption (kg/h) 80%**	**Fuel consumption (kg/h) 40%**	**Fuel consumption (kg/h) 20%**
Fuel consumption (kg/h) SHIP				

	Obligatory data
	Data obtained

Table 1: Calculation of initial data based on REALISE model

The above data allow assessment of the emissions for the maritime transport.

MOPSEA Emission model

MOPSEA is an activity-based emission model to determine emissions from sea-going vessel. In this section we have developed an emission model based on MOPSEA Project for our calculations.

The following criteria are considered:

a) Is designed to calculate emissions and energy consumption for the different stages of navigation for every voyage and hotelling period. The percentage of MCR is dependant of the stage of navigation. For our purposes, the selected engine load was fixed to 85% of engine load for the cruise speed stage, 40% of engine load for the reduced speed stage, 20% for the manoeuvring stage [18].

b) Provides two different types of main engine: 2-stoke engine and 4-stoke engine. The model uses different methodology for 2-stoke engine, 4-stoke engine and auxiliaries engines and is dependant of the year of construction of the engine.

c) The used power of the main engines is dependent on the speed of the vessels and on rates of flow. This is taken into account through the combination of duration and used power for every stage of navigation.

d) The model makes a distinction between technology related emissions and fuel related emissions.

Characteristics of the sea-going vessels
Ship type
Length (m)
Main engine type
Fuel type
Power main engine (kW)
Date of building
RPM Main engine
Speed (knots)
Power auxiliary engine (kW)
Date of building auxiliary engine
Auxiliary engine type

Characteristics of the route
Distance (km)
Duration of the total voyage
Cruising speed time (h)
Reduced speed time (h)
Manoeuvring time (h)
Hotelling time (h)

Table 2: Calculation of initial data based on MOPSEA project

The above data allow assessment of the emissions for the maritime transport.

CALCULATION OF THE EMISSIONS BASED ON BOTH METHODS IN SW MEDITERRANEAN EUROPEAN SHORT SEA SHIPPING CONTEXT

Table 3 gives an overview of what is considered in our calculation and the differences between both methods:

<table>
<tr><th></th><th>REALISE model</th><th>MOPSEA model</th></tr>
<tr><td>Routes</td><td colspan="2">Actual routes in Mediterranean Short Sea Shipping between Spain and Europe.</td></tr>
<tr><td>Vessels</td><td colspan="2">Actual Ro-Ro (and Ro-Pax) in Mediterranean Short Sea Shipping between Spain and Europe.</td></tr>
<tr><td>Stages of navigation</td><td>- Cruise speed
- Manoeuvring
- Hotelling.</td><td>- Cruise speed
- Reduction speed
- Manoeuvring
- Hotelling</td></tr>
<tr><td>Emission parameters</td><td>- Local pollution:
SO_2, NOx, CO, nm-VOC and PM.
- Global pollution:
CO_2, CH_4 and S.</td><td>- Technology of the engine: CO_2 and SO_2.
- Type of fuel:
NOx, CO, HC, PM.</td></tr>
<tr><td>Engine</td><td>- Main engine:
Power.</td><td>- Main engine:
Type, fuel, power, rpm and date of building).
- Auxiliary engine:
Type, power and date of building).</td></tr>
</table>

Table 3. Parameters and differences considered in both methods

As we can see in the above table 3, MOPSEA model uses more accurate parameters for the calculation of the emissions compared with REALISE model. We have selected a total of 16 routes between Spain and Europe obtained in a previous research [19] carried out by TRANSMAR Research Group. These are the actual (May 2009) Mediterranean Short Sea Shipping routes and all of them leave from Spanish ports and have different destinations in Western Europe (Table).

Route 1	Barcelona-Civitavecchia
Route 2	Barcelona-Genoa
Route 3	Barcelona-Fos Sur Mer
Route 4	Barcelona-Livorno
Route 5	Valencia-Salerno
Route 6	Valencia-Livorno
Route 7	Valencia-Palermo
Route 8	Tarragona-Salerno
Route 9	Tarragona-Livorno
Route 10	Tarragona-Civitavecchia
Route 11	Vigo-Livorno
Route 12	Barcelona-Marseilles
Route 13	Valencia-Marseilles

Route 14	Valencia-Pireus
Route 15	Barcelona-Koper
Route 16	Barcelona-Pireus

Table 4. Routes selected in our analysis

These 16 selected routes are served, in May 2009, by a total of 35 Ro-Ro and Ro-Pax vessels. The selected Ro-Ro and Ro-Pax vessels' particulars are shown in Table 5:

Vessels	Speed (knots)	Length (m)	Linear Meters	Power ME (kW)	Type ME	FO/DO-GO ME	Year ME
Cruise Roma	27.5	225	3060	55440	4T	DO	2008
Eurostar Barcelona	32	211.9	1900	50424	4T	DO	2001
Eurostar Roma	27	173.7	1700	31680	4T	DO	1995
Majestic	23	188,2	1850	36000	4T	DO	1993
Splendid	23	214.14	2259	36000	4T	DO	1994
Excellent	23	202,83	2000	25952	4T	DO	1998
Excelsior	24	202	3000	28944,8	4T	DO	1999
Fantastic	23	188	1850	36000	4T	DO	1996
La Surprise	20	141.25	1500	12960	4T	DO	2000
Florencia	23	186	2700	21600	4T	DO	2004
Eurocargo Valencia	20	195	2550	12510	4T	DO	1999
Eurostar Salerno	24	186.4	2100	18900	4T	DO	2003
Eurostar Valencia	24	186.4	2200	18900	4T	DO	2003
Setúbal Express	17.8	169.4	2350	9720	2T	DO	1992
Salerno Express	16	140.11	770	4487	2T	DO	1982
Malta Express	18	126.5	1150	11032	4T	DO	1980
Sorrento	24	186.4	2200	18900	4T	DO	2003
L'Audace	20	142	1500	12960	4T	DO	1999
Arroyo Frío Dos	14	107.91	984	4796	4T	DO	1985
Arabian Breeze	18	164	307	7943	4T	DO	1983
Yohjin	18	164	307	7943	4T	DO	1983
Carlo Morace	18	135	1260	11032	4T	DO	1981
Neptune Okeanis	20	164.4	1705	12600	4T	DO	2005
Neptune Thelisis	20	164.4	1705	12600	4T	DO	2006
Grand Benelux	20.1	176.7	3100	11060	4T	DO	2001
Neptune Hellas	15.7	105.54	510	3884	4T	DO	1979
Valmont Express	17.5	122.8	1375	7356	4T	DO	1982

Table 5. Ro-Ro and Ro-Pax vessels' particulars selected in our analysis

Some of these routes are served for different vessels, and some of these vessels sails in different routes. The main mean values of these vessels are described in the next table:

Power main engine	14039 kW
Speed	19.9 knots
Number of FEU	153.3 FEU/ship

Table 6. Mean values from ships in our analysis (Source: Análisis de la aplicación del ecobono, en los tráficos marítimos españoles, una propuesta basada en los costes externos generados, Martínez de Osés and Castells, 2009)

The following are the results for Route 1, i.e. between Barcelona port and Civitavecchia port with Cruise Roma Ro-Pax vessel considering both emission methods:

Maritime and Transhipment	
Emissions of air pollution (in Tm)	
SO_2	4.780
NOx	6.929
CO	2.185
nm-VOC	0.579
PM	0.630
Emissions of global warming (in Tm)	
	406.152

Table 7. Emission parameters in selected route based on REALISE model

Emissions Technology of the engine (Tm)	
Cruise speed stage	
HC	0.393
CO	3.469
NOx	10.363
PM	0.232
Reduced speed stage	
HC	0.023
CO	0.205
NOx	0.611
PM	0.014
Manoeuvring stage	
HC	0.006
CO	0.051
NOx	0.153
PM	0.003
Hotelling stage	
HC	0.002
CO	0.009
NOx	0.048
PM	0.004

Emissions Type of fuel (Tm)	
Cruise speed stage	
CO_2	538.70
SO_2	0.70
Reduced speed stage	
CO_2	31.76
SO_2	0.04
Manoeuvring stage	
CO_2	7.94
SO_2	0.01
Hotelling stage	
CO_2	0.86
SO_2	0.00

Table 8. Emission parameters in selected route based on MOPSEA model

	Air pollution (in Tm)	Global warming (in Tm)	Total (in Tm)
Maritime	12.83	406.13	418.96
Transhipment	2.27	0.02	2.29
Total	15.10	406.15	**421.26**

Table 9. Global Emission in selected route based on REALISE model

Cruise speed stage	
Emissions Technology of the engine (Tm)	14.46
Emissions Type of fuel (Tm)	539.40
Reduced speed stage	
Emissions Technology of the engine (Tm)	0.85
Emissions Type of fuel (Tm)	31.80
Manoeuvring stage	
Emissions Technology of the engine (Tm)	0.21
Emissions Type of fuel (Tm)	7.95
Hotelling stage	
Emissions Technology of the engine (Tm)	0.06
Emissions Type of fuel (Tm)	0.86
Total Emissions (Tm)	**595.59**

Table 10. Global Emission in selected route based on MOPSEA model

The results in the below tables allow estimation of the total emission with a vessel in one Mediterranean Short Sea Shipping route by comparing both models above mentioned.

RESULTS FROM THE ANALYSIS

This section compares the environmental impact for sixteen routes. We have considered different vessels, using data from REALISE and MOPSEA models. The selected target routes all leave from Iberian Peninsula ports and have different destinations in Mediterranean Europe.

Routes	Vessel	MOPSEA RESULTS (Tm)	REALISE RESULTS (Tm)
Barcelona - Civitavecchia	Vessel 1	595.59	421.26
	Vessel 2	470.95	329.15
	Vessel 3	346.6	245.16
Barcelona - Genoa	Vessel 1	372.25	262.31
	Vessel 2	372.25	262.31
	Vessel 3	267.19	189.1
	Vessel 4	286.7	202.17
	Vessel 5	370.66	262.31
Barcelona - Fos Sur Mer	Vessel 1	85.49	57.3
Barcelona - Livorno	Vessel 1	244.62	173.22
Valencia - Salerno	Vessel 1	295.04	216.98
	Vessel 2	375.09	273.31
	Vessel 3	375.09	273.31
	Vessel 4	232.35	121.41
	Vessel 5	120.04	97.25
Valencia - Livorno	Vessel 1	50.06	38.79
	Vessel 2	121.13	84.8
	Vessel 3	158.08	109.15
Valencia - Palermo	Vessel 1	335.65	243.47
	Vessel 2	207.71	168.69
Tarragona- Salerno	Vessel 1	307.76	226.11

Tarragona - Livorno	Vessel 1	96.45	69.46
Tarragona - Civitavecchia	Vessel 1	205.88	149.02
Vigo - Livorno	Vessel 1	389.73	288.63
	Vessel 2	389.73	288.63
	Vessel 3	540.92	400.86
Barcelona - Marsella	Vessel 1	83.13	55.7
	Vessel 2	83.13	55.7
Valencia - Marsella	Vessel 1	146.21	103.42
	Vessel 2	146.21	130.42
Valencia - Pireo	Vessel 1	497.91	369.47
	Vessel 2	497.91	369.47
	Vessel 3	435.04	322.7
Barcelona - Koper	Vessel 1	205.15	151.95
Barcelona - Pireo	Vessel 1	311.94	230.36

Table 11. Emission results (in Tm) using data from REALISE and MOPSEA

CONCLUSIONS AND FURTHER RESEARCH

The data of SW Mediterranean Short Sea Shipping fleet and traffic in May 2009 between Spain and Europe is based on project “Análisis de la aplicación del ecobono, en los tráficos marítimos españoles” carried out for the TRANSMAR research group in the Department of Nautical Science and Engineering of the Universitat Politècnica de Catalunya in 2009.

Table 11 shows the results of emissions of vessels for the year 2009 in Mediterranean Short Sea Shipping routes considering two emission models, REALISE and MOPSEA models. Emissions calculated with MOPSEA model are on average 27,7% bigger than emissions calculated with REALISE model. As we can see in table 3, MOPSEA model uses more accurate parameters for the calculation of the emissions compared with REALISE model. A more in deep analysis should be carried out.

In both cases, emissions from maritime shipping become important and emission reductions from maritime transport and in harbours are to be considered. These results would justify the need to reduce atmospheric emissions from sea-going vessels to compete with road transport mode. Policy makers have to be aware of the results of such comparison and its effect on the current legislation for maritime transport.

Data obtained can be used for further research, affording prediction of emissions in the near future by keeping in mind the traffic and fleet evolution and the existing legislation.

ENDNOTES

[1] MarPol 73/78 Convention is the main international convention that covers prevention of pollution of the maritime transport. The International Maritime Organization adopted in 1997 Annex VI, prevention of air pollution from vessels.

[2] REALISE Project: Regional Action for Logistical Integration of Shipping across Europe. (2005). AMRIE. [http://www.realise-sss.org]

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[14] Trailer length is considered 19.5 meters, as stated by the EC Directive 2002 of 18th February 2002 as maximum length for an articulated trailer of 16.5m, 1.5 meters being added between trucks.

[15] Data obtained from the Emission Inventory Guidebook (EIG) on the COPERT III calculation model (2002).

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[17] On page 15 of the above paper, Endresen, O. explains that the fuel consumed by auxiliary engines in ports and at sea may amount to less than 10% of installed power.

We adopt a 20% figure in view of the greater amount of electric power required by a Ro/Pax ship as that considered in our study.

[18] These assumptions are taken from the project EMS, November 2003.

[19] Análisis de la aplicación del ecobono, en los tráficos marítimos españoles carried out for the TRANSMAR research group in the Department of Nautical Science and Engineering of the Technical University of Catalonia. Project funded by the Ministry of Spanish Public Works (2009)

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