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EMISSIONS OF MARITIME TRANSPORT: A REFERENCE SYSTEM

L. Schrooten[1*], I. De Vlieger[2], L. Int Panis[3], C. Chiffi[4] and E. Pastori[4]

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Abatract

This paper presents the methodology for a comprehensive maritime transport database of activity data, specific energy consumption, emission factors and total emissions that has been developed within the EX-TREMIS project. The model is built upon 3 modules: the fleet module, the transport activity module and the emission module.

The *fleet module* defines the ship categories, the loading capacities and the engine characteristics of the different vessels by using EUROSTAT data, Sea Web Lloyd's database and international literature. The *transport activity module* transforms total cargo and passenger traffic (main source here are EUROSTAT data and CEMT statistics) into ship-equivalents. These ship-equivalents are further transformed into ship-hours. The *emission module* calculates energy uses and CO_2, NO_X, SO_2, CO, HC, CH_4, NMHC, PM emissions from the resulting maritime activities. We used technology based emission factors to take into account the technological evolution of vessels.

To illustrate, we present some results (emissions, fuel consumption and NO_X emission factors) for Spain. The overall methodology and results as the country specific energy consumption and emission factors per ship type and size class can be extracted from the EX-TREMIS website (www.ex-tremis.eu) in January 2008.

Key words: O/D matrix goods/passengers, ship-equivalent traffic, maritime emissions, fuel consumption, emission factors

[1]Researcher Flemish Institute for technological Research (VITO) NV, liesbeth.schrooten@vito.be, +3214335921, +3214321185, Boeretang 200 24000 Mol Flanders Belgium. [2]Researcher VITO NV, ina.devlieger@vito.be, +3214335933, +3214321185, Boeretang 200 24000 Mol Flanders Belgium. [3]Dr. Expert VITO NV, luc.intpanis@vito.be, +3214335887, +3214321185, Boeretang 200 24000, Mol Flanders Belgium. [4]Trasporti e Territorio (TRT), Italy.

* Corresponding author: liesbeth.schrooten@vito.be, +3214335921, +3214321185

INTRODUCTION

TRT Trasporti e Territorio and VITO (Flemish Institute for technological research) are developing a reference system on emission factors, energy consumption and total emissions for rail, maritime and air transport within the EX-TREMIS (Exploring non road TRansport EMISsions in Europe) project. The project is commissioned by the Institute for Prospective Technological Studies of the European Commission Directorate - General Joint Research Centre (JRC-IPTS).

One of the objectives of the EX-TREMIS project is to build a comprehensive maritime transport database of activity data, specific energy consumption, emission factors and total emissions covering the 27 EU member states for the years 1980-2005 and with projections for their development up to the year 2030. The database covers the pollutants CO_2, NO_X, SO_2, CO, HC, CH_4, NMHC, PM and presents detailed results for each EU country.

Most efforts to estimate ship emissions are currently based on bunker fuel sales (top-down approach). Bunker fuels are allocated to specific port cities and countries resulting in relatively high emission estimates for small countries hosting important sea ports. Other models used a bottom-up methodology based on vessel's characteristics, engine performances and, above all, real vessel traffic data provided by several government and private sector sources. Consistently with these recent developments in modelling ship's emissions, EX-TREMIS follows the bottom-up approach and derives information on ship's movements from a mixture of publicly available EUROSTAT and national data sources.

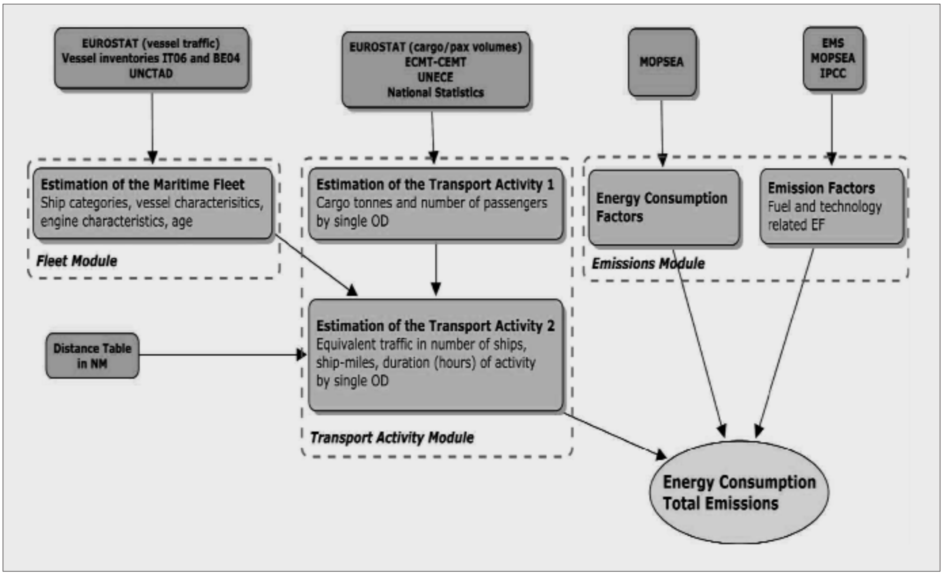

Figure 1: Overview of the main modules and sources in EX-TREMIS

We have developed a new "activity based" emission model for sea-going ships engaged in the EU seaborne trade, also taking into account relevant factors such as the technology evolution of maritime engines and the size of the vessels. The model is built upon three modules: the *fleet module* defines the ship categories and their segmentation, the *transport activity module* calculates the Origin-Destination (O/D) matrix of shipped cargo tonnes and passengers and converts such volumes in ship-equivalent traffic (in number of ships, ship-miles and hours of navigation for the different stages), the *emission module* provides energy consumption and emission factors for the final calculation to come up with total energy consumption and emission figures. The flow-chart (figure 1) describes the interaction of the modules and their main processes, and presents also the sources used for the model calibration.

METHODS

Fleet module

Ship categories for EX-TREMIS (table 1) are chosen according to the developed methodology for the estimation of emissions and energy consumption. The classification depends also on the availability of detailed EUROSTAT (2000) data.

Ship Type categories	Size classes (Length)	Main Engine classes	Age classes (Building year) and type of fuel
Oil Tanker	< 150 m	2-stroke	< 1974 (*Marine Diesel Oil - MDO*)
Chemical Tanker	150 – 250 m	4-stroke	1975-1979 (*MDO*)
LG Tanker (LPG and LNG Tanker)	> 250 m	Steam turbine	1980-1984 (*MDO*)
Bulk Carrier			1985-1989 (*Heavy Fuel Oil – HFO*)
Containership			1990-1994 (*HFO*)
General Cargo			1995-1999 (*HFO*)
Ferry (Ro-Ro Cargo, Ro-Pax, Con-Ro Ship)			2000-2004 (*HFO*)
Passenger Ship (Hi-speed Craft, Fast-Ferry)			> 2005 (*HFO*)

Table 1: EX-TREMIS maritime fleet classification system.

The *loading capacity* of the different vessels is an important parameter to transform transported goods/passengers into ship-equivalents. The EUROSTAT Newcronos database Eurostat (2000) provides for each EU country information on the number and gross tonnage (GT) of vessels calling at main ports by type (7 groups) and size of vessel (12 classes). From this collection we derive information on the loading capacity and distribution of cargo and passenger vessels visiting the country by calculating the average gross tonnage for each size class and group of ships. To convert the resulting average gross tonnage parameters in average Deadweight (Dwt), which is a measure of the loading capacity of a vessel, we have calculated a list of differentiated conversion factors based on available visiting vessel inventories for

Italy and Belgium and extractions from the Lloyd's Register Fairplay (LRF) Sea-Web database. By using the same sources we finally convert the 12 cargo-based classes into 3 more appropriate "length" and emission-based classes.

We defined the key parameters for the *engine characteristics* (main engines and auxiliaries) of a vessel. The combustion of fuel in both types of marine engines causes emissions and their operation depends on the stage of navigation. There are three types of main engines in the model: 2-stroke engines, 4-stroke engines and steam turbines. We looked at the characteristics of the vessels visiting Belgium in 2004 and Italy in 2006 . The movements data per ship type and size class were provided by Port Authorities. Data from ship characteristics like the average installed main engine power (per ship type, size class and engine type) and the distribution between 2-stroke and 4-stroke engines, were extracted from the LRF SeaWeb database. Experts were consulted for the average auxiliary power used for air conditioning, ventilation and preheating of heavy fuel oil and the type of fuel used in the engines based on type and age.

The *vessel's year of building* is an important parameter in the methodology for calculating emission and energy consumption figures. The age of the engines is for most vessels the same as the age of the vessel. The UNCTAD secretariat UNCTAD (2007) compiled the age distribution of the world merchant fleet by types of vessels on the basis of data supplied by Lloyd's Register-Fairplay. The percentages of total are expressed in terms of Dwt. We applied the relative age distribution for each year of the time span 1980-2005.

Transport activity module

The *transport activity module* derives national and international (both intra and extra-EU) maritime traffic in terms of number of equivalent ships, ship-miles and hours of navigation stages. The processing is conducted on two main EUROSTAT collections: the total cargo and passenger traffic in all port of the reporting country and the detailed dataset of maritime traffic in main ports of the reporting country by cargo type and partner entity. National and CEMT statistics (CEMT, 1997) were collected in order to cover the whole time span 1980-2005. The *fleet module* and the further EUROSTAT collection of vessel traffic provides relevant parameters for converting cargo tonnes and number of passengers in number of (loaded) equivalent ships operating on each country pair.

One of the main inconvenient of seaborne trade statistics is that we have information about the commodities shipped by sea but not on how they are transported. Detailed maritime statistics on the Newcronos database are instead collected since 1997 according to the cargo type, so that the functional link between the type of cargo and the type of ship engaged in its transportation is direct and clear. In addition, for the main ports of each reporting country, EUROSTAT identifies the part-

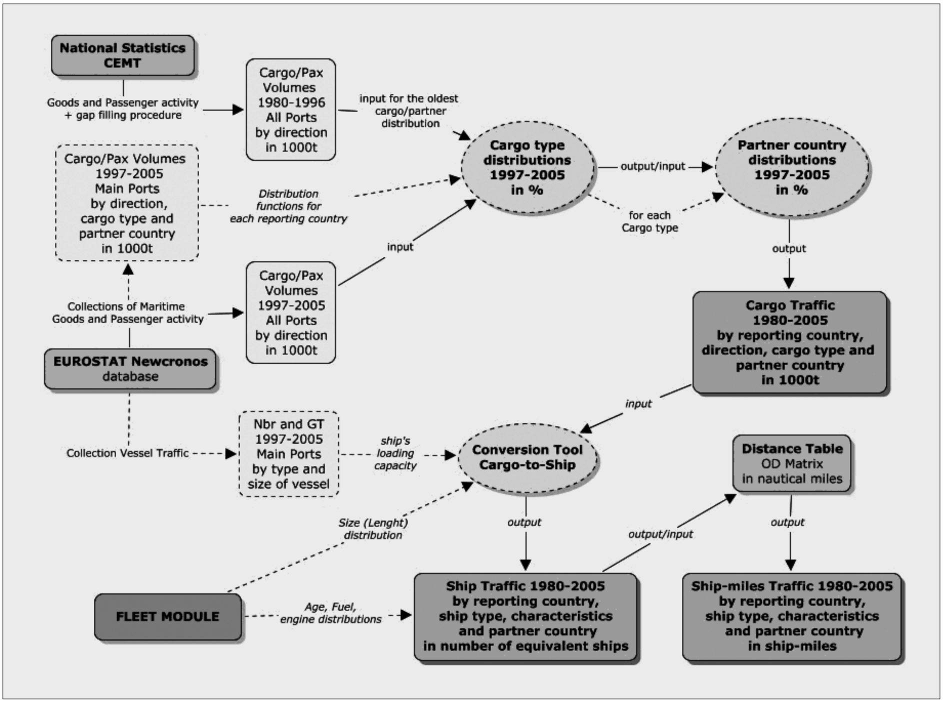

Figure 2: Flow chart of the methodology for the estimation of maritime traffic.

ner country and its relevant Maritime Coastal Areas (e.g. in Spain it identifies the MCA Mediterranean and the MCA Atlantic) plus the direction of the flow.

We have firstly built a comprehensive database of total passenger and cargo tonnage handled in all the ports of each country using both EUROSTAT data and national statistics. Total volumes were afterwards splitted using distributions (by cargo type and partner entity) extracted from the detailed Newcronos collection. The final result of this process is the provision of a complete O/D matrix of cargo type volumes (in tonnes) and number of passengers transported by sea from each reporting country to each partner country/MCA (outwards) and *viceversa* (inwards). Missing years (1980-1996) were added to the process according to the oldest available EUROSTAT cargo type and partner distributions.

In order to derive figures in terms of ship-miles we created a country based O/D table of sailing distances expressed in nautical miles (NM). The distance table is built on a detailed maritime network, which includes bulk shipping, container (liner) routes and ferry links among NUTS2 coastal zones in Europe. For each reporting country or MCA we associated one reference port. The distance table includes all EU country/MCA pairs, all EU-Non EU pairs in the Mediterranean and the Baltic

Sea plus Iceland) and connections with 13 relevant Overseas Zones[1]. In order to calculate the mileage for national maritime traffic (*cabotage* or regular feeder services) we created a table with average sailing national distances. The mileage of Ferries and Passenger ships were calculated using a country specific ferry network which includes as well information on the frequency of services.

The concept of equivalent-ship traffic means that we calculate the number of equivalent (full) vessels loaded to transport by sea the total amount of a given cargo type to a specific partner country, from one sample departure port of the reporting country and without intermediate stops. The same happens for the opposite flow. To derive the number of vessels required to ship the resulting cargo tonnage, we used the country specific distribution of visiting vessels resulting from the *fleet module* (by type, cargo size, length, engine type and age) and considered a *load factor* of 90% to obtain a fairer measure of the real capacity and thus take into account a percentage of the empty trips. The difference between the real traffic and this "country generated" traffic should not be huge, because in practice it represents a redistribution of traffic on a straight line and country-to-country. This method seems more in line with the objective of linking the responsibility of emissions to a specific country and its commercial partners without having to reproduce the real port rotation planned by the shipping companies for a single voyage. In terms of country's emission responsibility, we consider the 50% of the sailing distance. Ships are multiplied by the relative sailing distances to obtain ship-mile values and these values are transformed into ship-hours for cruising and manoeuvring. Hotelling periods are taken from the ENTEC database (2005).

Emission module

The emission module calculates energy consumption figures, fuel related emissions (i.e. CO_2, SO_2) and technology related emissions (i.e. NO_X, PM, CO, HC).

The *specific fuel use* is dependant on the engine type, percentage of maximum continuous rate and the age of the engine. The specific fuel use takes into account the caloric value of the fuel and the efficiency of the engine. The range of specific fuel uses that we integrated into the model are presented for the different engine types in table 2. The assumptions for the main engines were made in close consultation with ship owners, pilots and harbour masters. The specific fuel uses for the auxiliaries were taken from a TNO study (Oonk et al., 2005).

The *energy use* is calculated by multiplying the used power and the duration. The used power is dependant of the maximum installed power and the percentage of maximum continuous rate. The fuel use is the combination of the energy use and the specific fuel consumption.

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[1] Black Sea, Arabian Gulf, Red Sea, Indian Sub Continent, Australasia, Far East - China & Japan, South & East Africa, West Africa, US Atlantic & Canada - Great Lakes, Central America – Caribbean, South America – Atlantic, US & Canada – Pacific, South America – Pacific.

	Specific fuel use (g/kWh)
2-stroke engine	157 – 218
4-stroke engine	185 – 235
Steam turbine	290 - 510
Auxiliary	200 - 235

Table 2: Range of specific fuel use for the vessel engines.

The *CO_2 emission factors* are based on IPCC data (IPCC, 1997) and the *SO_2 emission factors* are based on the sulphur content in the fuels used in the past and in legislation (EC, 2002; MARPOL Annex VI convention, 2005/33/EC Directive). Fuel related emissions are calculated by multiplying the fuel use with the corresponding emission factor.

The *technology related emission factors* for HC, CO, NO_X and PM for 2-stroke and 4-stroke engines are those of the project EMS (AVV et al., 2003). They are modeled as a combination of a basic emission factor (g/kWh) and correction factor for the technology (age of the engine and the NO_X regulation) and the percentage of the maximum continuous rate (MCR). The percentage of maximum continuous rate for the main engines depends on the stage of navigation. The figures from ENTEC (2005) are used in the model. The technology related emission factors for HC, CO, NO_X and PM for steam turbines are based on findings from a TNO study by Scheffer and Jonker (1997). Different emission factors for different percentages of maximum continuous rates were put into the model. The *technology related emission factors* for HC, CO, NO_X and PM for *auxiliaries* are those of the project EMS (EC, 2002). They are modeled as a combination of a basic emission factor (kg/ton) and a correction factor for the technology (age of the engine). Technology related emissions are calculated by multiplying the energy use with the corresponding emission factor.

DEVELOPMENT

Database prototype country: Spain

Here we present the results, in terms of estimated total energy consumption, emission factors and emissions from sea-going ships, for a chosen prototype country (Spain).

kton	2000	2001	2002	2003	2004	2005
CO	20,3	28,9	30,5	34,5	38,6	40,2
CO_2	6 222	8 829	9 298	10 931	12 297	12 938
VOC	4,84	6,80	7,10	7,94	8,71	8,99
NO_X	174	250	266	311	349	365
PM	15,4	22,3	23,8	28,3	31,9	33,5
SO_2	105	150	158	187	211	222

Table 3: Emissions for Spain (in kton).

Table 3 presents the total emission figures for Spain calculated by means of the developed methodology. The fuel combustion in the main engines is responsible for more than 90% of the overall emissions.

The cruising phase represents about 99% of the emissions for main engines and about 80% of the emissions for auxiliaries. Manoeuvring emissions are negligible in the total emissions picture, however not negligible when looking to the human impacts of the emissions.

Table 4 presents the total fuel consumption (main engines and auxiliaries) of maritime transport for Spain.

kton	2000	2001	2002	2003	2004	2005
Diesel oil	58	69	66	53	53	47
Heavy fuel oil	1 943	2 770	2 924	3 462	3 901	4 113
Total	**2 001**	**2 839**	**2 990**	**3 515**	**3 954**	**4 160**

Table 4: Fuel consumption for Spain (in kton).

The main engines consume about 95% of the total fuel and more than 99% of the fuel used is heavy fuel oil. This is somewhat different for the auxiliaries. The share of diesel oil is about 45% in the year 2000 and drops down to 22% in 2005 due to the increased share of new vessels. Improvements in technology made it possible for auxiliaries built at the end of the eighties to use heavy fuel oil.

Detailed emission factors are used for the calculation of the emissions. The model can also calculate aggregated emission factors by ship type and size class,

NO_X (g/kWh)	Size	2000	2001	2002	2003	2004	2005
Bulk carrier	< 150 m	15,7	15,7	15,8	15,5	15,4	15,4
Bulk carrier	150 - 250 m	17,3	17,3	17,2	16,9	16,7	16,6
Bulk carrier	> 250 m	17,3	17,3	17,2	16,9	16,7	16,6
Chemical tanker	< 150 m	14,5	14,6	14,5	14,7	14,7	14,7
Chemical tanker	150 - 250 m	16,7	16,7	16,6	16,8	16,6	16,7
Chemical tanker	> 250 m						
Container ship	< 150 m	14,0	14,2	14,3	14,0	14,0	14,1
Container ship	150 - 250 m	16,6	16,5	16,5	16,0	15,8	15,7
Container ship	> 250 m	16,7	16,6	16,6	16,0	15,9	15,8
General Cargo	< 150 m	14,4	14,5	14,5	14,6	14,6	14,7
General Cargo	150 - 250 m	17,6	17,7	17,6	17,6	17,6	17,6
General Cargo	> 250 m						
LG tanker	< 150 m	14,3	14,5	14,4	14,6	14,6	14,6
LG tanker	150 - 250 m	17,4	17,4	17,3	17,4	17,2	17,2
LG tanker	> 250 m						
Oil tanker	< 150 m	14,5	14,5	14,5	14,5	14,4	14,2
Oil tanker	150 - 250 m	17,2	17,1	16,9	16,6	16,3	16,0
Oil tanker	> 250 m	17,1	17,0	16,9	16,6	16,3	16,0
RoRo cargo	< 150 m	14,0	14,2	14,2	14,3	14,4	14,4
RoRo cargo	150 - 250 m	15,1	15,2	15,1	15,3	15,3	15,3
RoRo cargo	> 250 m	15,7	15,7	15,8	15,5	15,4	15,4

Table 5: NO_X emission factors per vessel type and size class for Spain (in g/kWh).

separately for the main engines and auxiliaries. As an example we present in table 5 the aggregated NO_X emission factors for the main engines. These aggregated emission factors are derived from the emission (g) and energy (kWh) calculations in the model by ship type and size class.

The overall methodology and results as the country specific energy consumption and emission factors per ship type and size class can be extracted from the EXTREMIS website (www.ex-tremis.eu) in January 2008.

CONCLUSIONS

A model to calculate emissions of maritime transport was developed. The model is based on a fleet module, a transport activity module and an emissions module. The model can also calculate aggregated emission factors by ship type and size class, separately for the main engines and auxiliaries.

The case-study of Spain shows that the fuel combustion in the main engines is responsible for more than 90% of the overall emissions, the cruising phase represents about 99% of the emissions for main engines and about 80% of the emissions for auxiliaries. Manoeuvring emissions are negligible in the total emissions picture. The main engines consume about 95% of the total fuel and more than 99% of the fuel used is heavy fuel oil. This is somewhat different for the auxiliaries.

A transparent and easy to use model is made available on-line (www.ex-tremis.eu).

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