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Emissions of maritime transport: A European reference system

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ABSTRACT

Emissions from ships have recently received more attention since they have become a significant concern for air quality in harbours and port cities. This paper presents the methodology for a comprehensive maritime transport database of activity data, specific energy consumption, emission factors, and total emissions that have been developed within the European 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 handled (mainly based on 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 have used technology based emission factors to take into account the technological evolution of vessels.

To illustrate this new methodology, we present some results (emissions, fuel consumption and emission factors) for different countries. The overall methodology as well as the results and 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). Our results contribute to more accurate estimates of emissions and air quality assessments in coastal cities and ports.

1. Introduction

Following real reductions in the emissions of industrial sources of air pollution and extensive legislative work to reduce the emissions of road vehicles, attention of scientists and policy makers has recently turned to maritime sources. Maritime emissions have soared in parallel with the growth of international trade (Georgieva et al., 2007).

Emissions of ships have been shown to contribute substantially to air pollution in port cities (e.g. Saxe and Larsen, 2004) including increased concentrations of SO_2, NO_X, and different fractions of PM (ultrafines, sulphates and residual oil combustion particles) (Kim and Hopke, 2008). While the aerosol in many coastal cities contains fractions that are assumed to be harmless, such as sea salt, many of the suspected fractions (with respect to health effects) are related to the burning of residual oil. In addition coastal areas and port cities often have high population densities. Maritime emissions have therefore become an important new focus in attempts to safeguard public health.

Within the European EX-TREMIS (EXploring non road TRansport EMISsions in Europe) project we have developed a new reference system for emission factors, energy consumption, and total emissions for maritime sources as well as for rail and air transport.

One of the objectives of the EX-TREMIS project was to build a comprehensive maritime transport database of activity data, specific energy consumption, emission factors, and total emissions which would allow a better policy oriented assessment of emissions. In this paper we report the methodology used to construct the database which covers all 27 EU member states for the years 1980–2005 and includes projections up to the year 2030. The database covers all the classic pollutants CO_2, NO_x, SO_2, CO, HC, CH_4, NMHC, and 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 (Schrooten et al., 2008). Other models have 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. To be consistent with these recent developments in modeling ships' emissions, EX-TREMIS follows the bottom-up approach and derives information on ships' movements from a mixture of publicly available EUROSTAT and national data sources.

We have developed a new "activity based" emission model for sea-going ships engaged in the EU seaborne trade, also taking into account

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relevant factors like the technology evolution of maritime engines and the size of the vessels. The rationale of this approach is explained in Schrooten et al. (2008). The model is built upon three modules: the *fleet module* which defines the ship categories and their segmentation, the *transport activity module* which calculates the Origin-Destination (O/D) matrix of shipped tonnes and tonne-miles and converts such volumes into ship-equivalent traffic (in number of ships, ship-miles and hours of navigation for the different stages), the *emission module* which provides energy consumption and emission factors for the final calculation to come up with total energy consumption and emission figures. The flow chart (Fig. 1) describes the interaction of the modules and their main processes, and also presents the sources used for the model calibration.

2. Methods

2.1. Fleet module

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

The *loading capacity* of the different vessels is an important parameter to transform transported goods into ship-equivalents. The EUROSTAT Newcronos database (Eurostat, 2000) provides information on the number and gross tonnage (GT) of vessels calling at main ports by type (7 groups) and size of vessel (12 classes) for each EU country. From this collection we have derived information on the loading capacity and distribution of cargo 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 into average Deadweight (Dwt), which is a common 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) SeaWeb database. By using these same sources we finally converted the 12 cargo-based classes into 3 more appropriate "length" and emission-based classes.

We have defined the key parameters for the *engine characteristics* (main engines and auxiliaries) of a vessel that relate to their environmental characteristics. The combustion of fuel in marine engines causes emissions. The precise amount depends on the type of engine and the operation of the engine (which is closely linked to 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 in detail 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 the respective 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. In addition maritime experts were consulted to derive 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 (vintage year)* is an important parameter in the methodology for calculating emission and energy consumption figures. The age of the engines is the same as the age of the vessel for most vessels. 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.

Table 1
EX-TREMIS maritime fleet classification system.

Ship type categories	Size classes (length)	Main engine classes	Building year and type of fuel
Oil tanker	<150 m	2-stroke	<1974 (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 (HFO)
Containership			1990–1994 (HFO)
General cargo			1995–1999 (HFO)
Ferry/Ro–Ro (Ro–Ro, Ro–Pax, Con–Ro)			2000–2004 (HFO)
			>2005 (HFO)

MDO = Marine Diesel Oil, HFO = Heavy Fuel Oil.

2.2. 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 four main EUROSTAT collections: First, the total cargo tonnage handled in all ports of the reporting country,

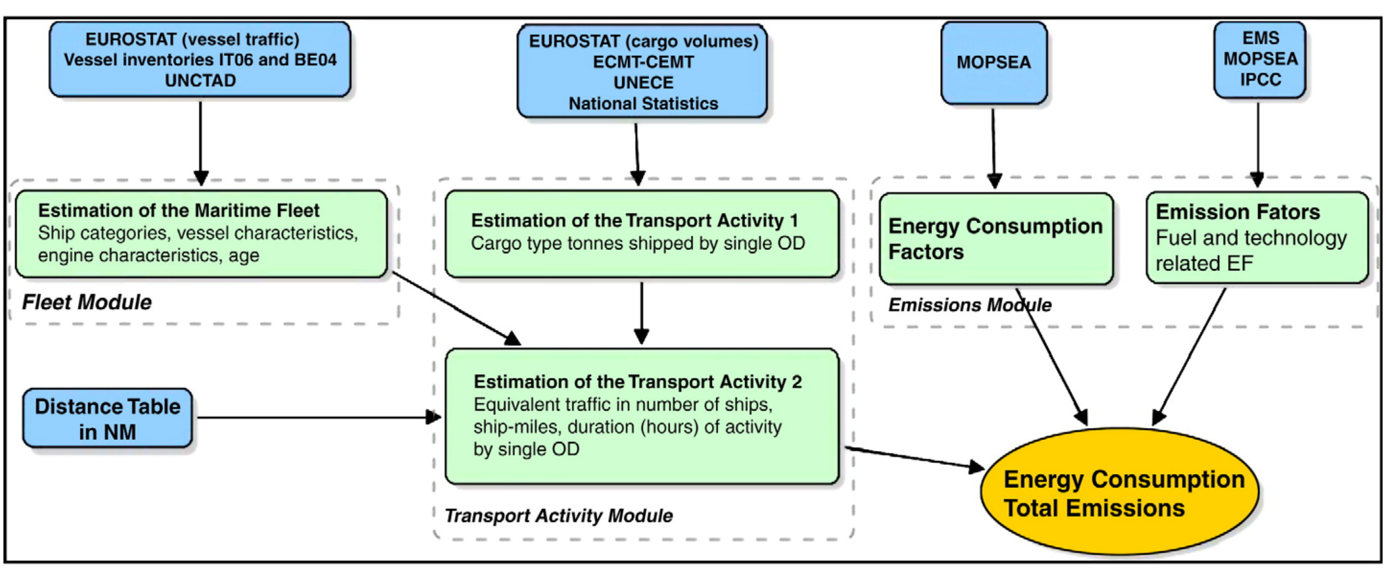

Fig. 1. Overview of the main modules and data sources used in EX-TREMIS.

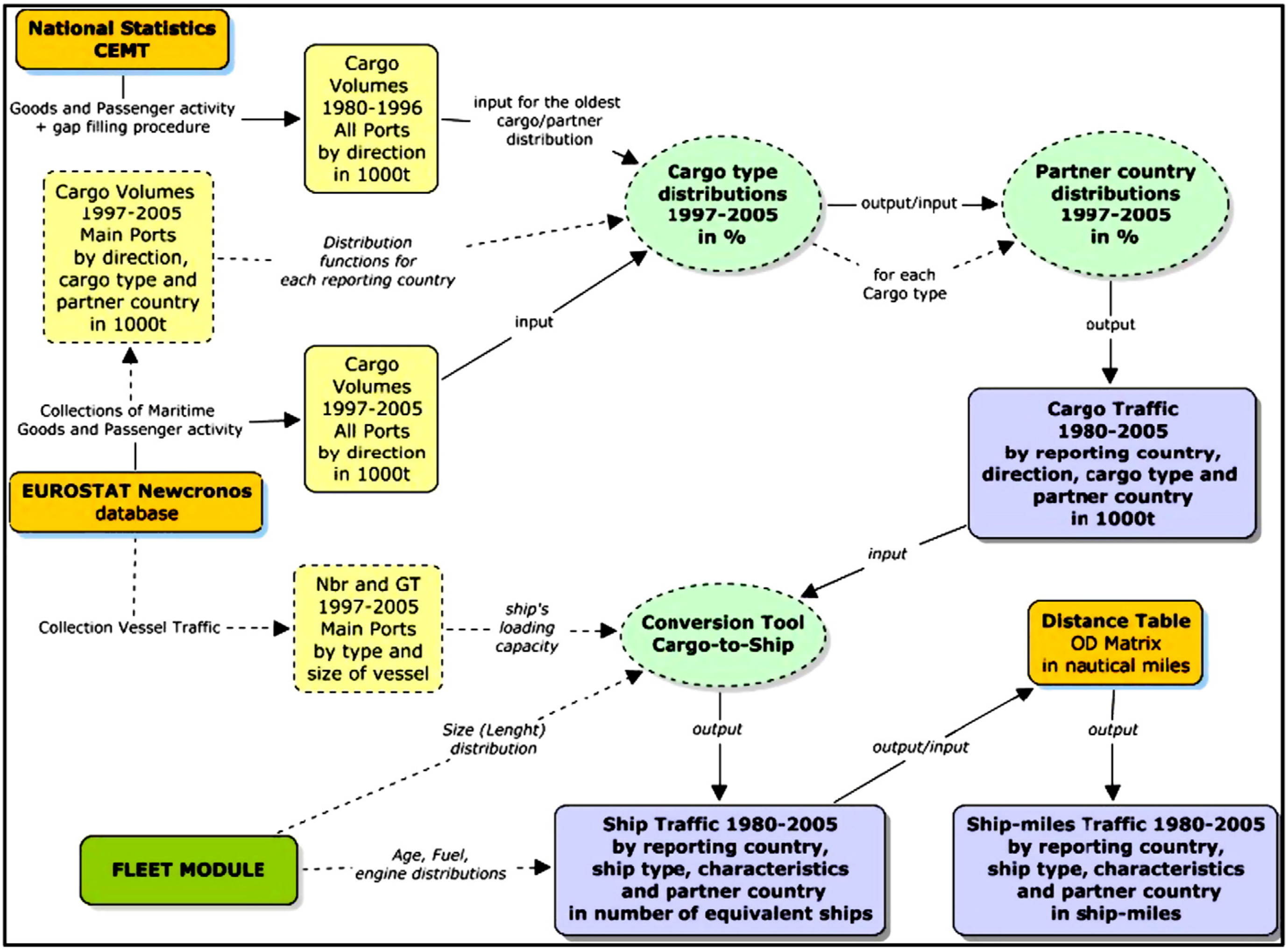

Fig. 2. Flow chart of the methodology for the estimation of maritime traffic.

second the detailed dataset of cargo tonnage handled in main ports of the reporting country by cargo type and partner entity, third the container cargo volumes handled in main ports or the reporting country by container size, loading status and partner entity, and finally the number and gross tonnage of sea-going vessels calling at main ports of the reporting country by type and size of vessels. National and CEMT statistics (ECMT-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 provide relevant parameters for converting cargo tonnes/volumes into numbers of (loaded) equivalent ships operating between each pair of countries (Fig. 2).

One of the main inconveniences 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 partner 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 first built a comprehensive database of total cargo tonnage or container cargo volumes handled in all the ports of each country using both EUROSTAT data and national statistics. Total volumes were afterwards split 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 transported by sea from each reporting country to each partner country/MCA (outwards) and *vice versa* (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 national average sailing distances.

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

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

intermediate stops. The same happens for the opposite flow. To derive the number of vessels required to ship the resulting cargo tonnage (or volumes), 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. This method seems more in line with the objective of attributing the responsibility for 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 considered 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. Port time periods are taken from the ENTEC database (2005).

2.3. 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 dependent 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 have 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. These figures are comparable with the figures for specific fuel consumption for main engines found in Endersen et al. (2003). The specific fuel uses for the auxiliaries were taken from a TNO study (Oonk et al., 2003).

The *energy use* is calculated by multiplying the power used and the duration. The used power depends on 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.

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 subsequently enforced by new 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 the findings of 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/tonne) 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.

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

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

3. Results

In the following tables and figures, the evolution in total emissions, emission factors, and energy consumption is briefly analyzed. Table 3 presents the emissions of all engines (main engines and auxiliaries) per country for the year 2005. Germany, Spain, the Netherlands, UK, Italy, Belgium, and France represent more than 80% of the presented emissions for maritime transport. This is in line with the total travelled ship-miles. Adding Greece, Sweden, Latvia, Denmark, and Portugal to the list, covers more than 90% of maritime transport emissions.

The cruising phase is the most important phase concerning total emissions. It represents about 99% of the emissions for main engines and about 80% of the emissions for auxiliaries. Manoeuvring emissions are negligible in the total emission picture, however this is not the case for local air quality and public health.

Fig. 3 presents the forecasts of total consumption of diesel and heavy fuel oil by main engines in maritime transport in Belgium for the time period 1980–2030. The overall fuel consumption by main engines is increasing because of the expected increase in transport activity: +183% of ship-miles in the period 1997–2030, with the largest increase foreseen for container ships (518%) and Ro–Ro vessels (395%).

Expected changes in the use of fuel type for port time and manoeuvring activities by vessels built before and after 1985 (change from diesel oil to heavy fuel oil) can be seen in the same figure. From 2010 on, a drop in heavy fuel oil consumption in favour of diesel oil consumption for the port time activities is expected due to the EC restrictions of a maximum sulphur content of 0.1 mass% for marine fuels used at berth (duration longer than 2 h).

Table 4 presents the total fuel consumption (specified for main engines and auxiliaries) of maritime transport for Spain. Similar figures for all other EU member states can be extracted from the EX-TREMIS website (www.ex-tremis.eu).

The main engines consume more than 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 used in auxiliaries is about 46% in the year 2000 and drops down to only 27% in 2010, due to the increased share of new vessels.

Detailed emission factors are used for the calculation of the emissions. The evolution in emission factors is mainly due to changes in fleet composition (age and size of the vessels) and the implementation

Table 3
Emissions (kton) per country for the year 2005.

kton	CH_4	CO	CO_2	VOC	NMVOC	NO_x	PM	SO_2
Belgium	0.187	20.88	6706	4.685	4.498	182.9	16.17	113.7
Bulgaria	0.012	1.34	418	0.306	0.293	10.9	0.87	7.0
Cyprus	0.004	0.41	132	0.090	0.086	3.6	0.33	2.3
Denmark	0.046	5.08	1657	1.140	1.095	39.4	2.80	27.8
Estonia	0.025	2.82	940	0.635	0.610	22.5	1.64	15.8
Finland	0.026	2.91	912	0.654	0.628	23.7	1.89	15.4
France	0.168	18.64	5967	4.193	4.025	165.5	14.77	102.0
Germany	0.300	33.55	11,021	7.503	7.203	295.2	25.61	188.7
Greece	0.067	7.44	2422	1.669	1.602	61.2	4.85	40.9
Ireland	0.025	2.75	899	0.618	0.593	22.5	1.74	15.2
Italy	0.227	25.16	8082	5.671	5.444	216.6	18.45	137.4
Latvia	0.051	5.65	1824	1.283	1.232	45.5	3.50	30.5
Lithuania	0.014	1.56	503	0.353	0.339	13.5	1.14	8.6
Malta	0.003	0.33	108	0.073	0.070	3.0	0.28	1.9
Netherlands	0.282	31.43	10,129	7.053	6.771	284.8	25.98	174.0
Poland	0.032	3.56	1153	0.806	0.774	29.5	2.34	19.4
Portugal	0.035	3.88	1242	0.873	0.838	33.9	2.96	21.2
Romania	0.018	2.00	639	0.455	0.437	17.1	1.44	10.8
Slovenia	0.009	1.04	328	0.236	0.226	8.9	0.75	5.5
Spain	0.299	33.31	10,801	7.464	7.165	295.0	26.02	184.8
Sweden	0.058	6.42	2053	1.447	1.390	52.0	4.04	34.6
UK	0.249	27.83	8958	6.232	5.983	246.9	21.98	153.5

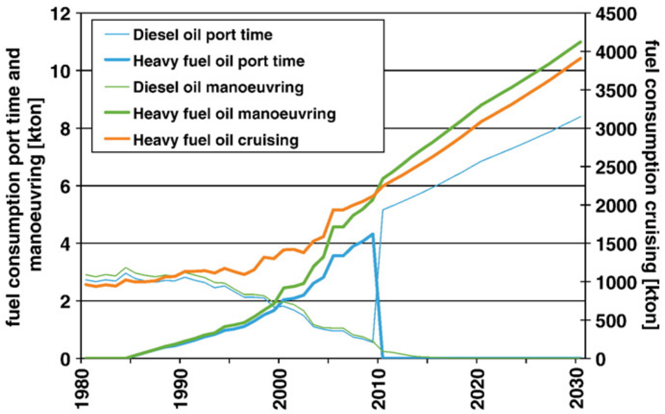

Fig. 3. Fuel consumption figures (1980–2030) for main engines for Belgium.

of legislation in future years (IMO and EC regulation). The model can also calculate aggregated emission factors by ship type and size class, separately for the main engines and auxiliaries. As an example we present for Spain the aggregated NO_x emission factors for the main engines in Table 5. These aggregated emission factors are derived from the emission (g) and energy (kWh) calculations in the model by ship type and size class.

The fleet NO_x emission factors have increased up to 1990. Indeed, main engines built before 1975 emit about 25%–33% less NO_x than main engines built between 1985 and 1989. However, after 1990, the main engines were designed to gradually emit less NO_x, resulting in the foreseen decrease of the fleet NO_x emission factor. For Spain, the fleet NO_x emission factor equals 15.5 g/kWh in 1980 to increase up to 16.7 g/kWh in 1990. After 1990, the fleet NO_x emission factor for Spain gradually decreases towards 13.8 g/kWh in 2030. The decrease is even more explicit after 2007 because of the restrictions on the NO_x emission level of main engines built after 1999 (IMO regulation).

The expected effect of the IMO and EC regulation on the maximum sulphur content in fuels used in "Sulphur Emission Control Areas" (SECA) is well seen in Fig. 4 from 2007 onwards (drop to 55% of the fleet SO_2 emission factor). The decrease in the fleet main engine SO_2 emission factor for Spain and France is less than those for other SECAs. Emission calculations for Spain and France are made per MCA, which means that for France a different SO_2 emission factor was used for maritime transport incoming from and leaving to the Atlantic Ocean/North Sea and for maritime transport incoming from and leaving to the Mediterranean Sea. For Spain the same is true for respectively the Atlantic Ocean (North) and the Mediterranean Sea/Atlantic ocean (South).

There is an evident increase in the fleet PM emission factors starting from around 1985—average increase of 18% between 1980 and 2010—because of a change in fuel use for the auxiliaries built from that period on. Until the beginning of the eighties, the majority of the new auxiliaries use diesel oil as fuel type, whereas auxiliaries built at the end of the eighties use heavy fuel oil.

Due to the limited sulphur content in fuels used at berth that should be guaranteed from 2010 on (EC regulation), a drop in the fleet PM emission factor is expected because of the use of diesel oil at berth instead of heavy fuel oil. However, the percentage of port time compared to the total time (port time, manoeuvring, and cruising) is the main influencing parameter for the decrease in fleet PM emission factor foreseen in the next years. The fleet PM emission factor would decrease with about 8% for Belgium and 22% for Malta in 2010 as the port time in these countries represents 18% and 50% respectively of the total time. The further slight decrease of the fleet PM emission factors after 2010 is due to lower PM exhaust emissions of auxiliaries that run on diesel from 1990 onwards.

Table 6 illustrates the expected effect for SO_2 and PM emissions (EU27) of the IMO and EC regulations on the maximum sulphur content in marine fuels for SECAs from 2007 on and the effect of the EC regulation on the maximum sulphur content in marine fuels used at berth from 2010 on.

The overall methodology and results as well as the specific energy consumption and emission factors per ship type and size class can be extracted from the EX-TREMIS website (www.ex-tremis.eu) for all 27 member states (in fact 22 member states with a coastal area).

4. Discussion and conclusion

A new model to calculate air pollution emissions of maritime transport was developed. The model is based on a fleet module, a

Table 4
Emissions (kton) per country for the year 2005.

Spain	kton	1980	1990	2000	2010	2020	2030
Main engine	Diesel oil	24	21	14	25	32	40
Auxiliaries	Diesel oil	133	123	86	68	77	93
Total	Diesel oil	157	144	99	93	109	133
Main engine	Heavy fuel oil	3478	3581	4249	7427	10,039	12,514
Auxiliaries	Heavy fuel oil	0	25	99	188	260	316
Total	Heavy fuel oil	3478	3607	4348	7615	10,298	12,830

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

NO_x (g/kWh)	Size	2000	2005	2010	2020	2030
Bulk carrier	<150	15.7	15.4	14.5	13.7	13.1
Bulk carrier	150 – 250	17.3	16.6	15.8	14.9	14.2
Bulk carrier	>250	17.3	16.6	15.8	14.9	14.2
Chemical tanker	<150	14.5	14.3	13.4	12.8	12.3
Chemical tanker	150 – 250	16.6	16.0	15.4	14.5	13.9
Chemical tanker	>250	17.3	16.4	15.7	14.7	14.1
Container ship	<150	14.2	14.1	13.0	12.6	12.6
Container ship	150–250	16.6	15.7	14.8	14.2	14.1
Container ship	>250	16.6	15.8	14.8	14.3	14.2
General cargo	<150	14.3	14.6	14.1	13.1	12.2
General cargo	150–250	17.6	17.5	17.1	15.6	14.1
General cargo	>250	17.6	17.6	17.1	15.6	14.1
LG tanker	<150	14.2	14.2	13.3	12.6	12.2
LG tanker	150–250	17.3	16.5	15.8	14.9	14.2
LG tanker	>250	17.3	16.5	15.8	14.9	14.2
Oil tanker	<150	14.5	14.2	12.8	12.4	12.5
Oil tanker	150–250	17.1	16.0	14.8	14.2	14.1
Oil tanker	>250	17.2	16.1	14.9	14.3	14.2
Ro–Ro cargo	<150	14.1	14.1	13.2	12.5	12.1
Ro–Ro cargo	150–250	14.4	14.5	13.9	13.4	13.0
Ro–Ro cargo	>250	13.5	13.7	13.1	12.6	12.4

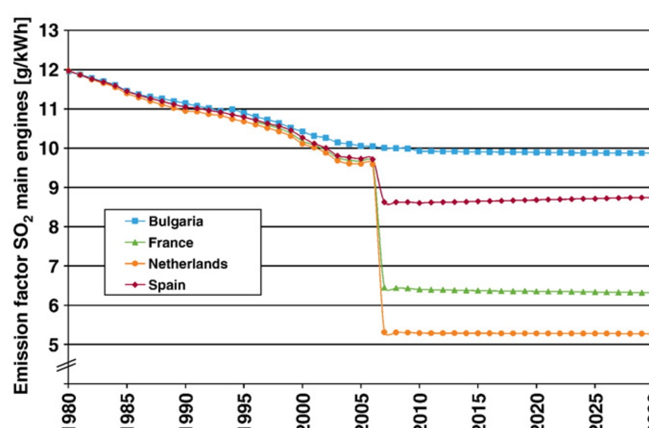

Fig. 4. Fleet SO_2 emission factors for the main engines for Bulgaria, France, Netherlands and Spain.

Table 6
Total EU27 SO_2 and PM emissions up to 2030.

EU27 (kton)	2005	2010	2015	2020	2030
SO_2	1311	997	1127	1276	1500
PM	180	195	217	244	285

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

The development of such a new detailed bottom-up emission model was necessary to provide both national and European policy makers with environmental data in such a format that well targeted reduction strategies can be developed or bilateral agreements drafted. This model enables such agreements because maritime emissions are attributed to specific EU member states in a completely new way and are no longer based on sales of bunker fuels (which has obvious disadvantages for small coastal states) nor on the emissions in the national sea territory (e.g. Schrooten et al., 2008) which privileges small states.

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. Similar results were obtained for other member states. 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. Emissions of auxiliary engines are more important while mooring. Ex-TREMIS can be used to estimate emissions but it also enables more detailed modeling of pollutant concentrations in coastal areas with specific emphasis on pollutants that are relevant to public health.

5. Future work

Updating the new methodology for maritime transport with cargo tonnage and container volumes handled on a per port basis would increase the accuracy of the activity module. However this is a time consuming job, the activity module based on more detailed data can also give input to spatial models, for instance STEEM. STEEM uses an empirical waterway network based on shipping routes revealed from observed historical shipping routes revealed from observed historical ship locations over 20 years to allocate emissions. STEEM underestimates European emissions estimates compared to regional inventories (Wang et al., 2007). Cargo ships voyages of shorter duration among or within nations in a region—short sea shipping—are probably the cause of this underestimation. STEEM can be updated with regional traffic patterns obtained through the updated Ex-TREMIS methodology.

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