SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY

SPSD II

EMISSIONS OF CO_2, SO_2 AND NO_X FROM SHIPS (ECOSONOS)

F. MAES, P. VANHAECKE, J-P. VAN YPERSELE

PART 2

GLOBAL CHANGE, ECOSYSTEMS AND BIODIVERSITY

ATMOSPHERE AND CLIMATE
MARINE ECOSYSTEMS AND BIODIVERSITY
TERRESTRIAL ECOSYSTEMS AND BIODIVERSITY
NORTH SEA
ANTARCTICA
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Part 2:
Global change, Ecosystems and Biodiversity

FINAL REPORT

ECOSONOS
Emissions of CO_2, SO_2 and NO_x from Ships

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GLOSSARY

AE	Auxiliary Engine
AG	Auxiliary Generator
APICS	Database system of the Port of Antwerp
BLG	Bulk Liquids and Gases
Celine – Ircel	Interregional Environment Unit (for Belgium)
CO_2	Carbon dioxide
CH_4	Methane
CLRTAP	Convention of Long Range Transmission of Air Pollutants
CONCAWE	Conservation of Clean Air and Water in Europe
CORINAIR	Emission inventory of air pollutants in Europe
CF	Correction Factor
CRF	Common Reporting Format
DNV	Det Norske Veritas
EC	European Commission
EEA	European Environment Agency
EEZ	Exclusive Economical Zone
EMIS	Energie en Milieu Informatie Systeem (Energy and Environment Information System)
ENIGMA	Database system of the Port of Ghent
ENSOR	Database system of the Port of Ostend
EPA	Environmental Protection Agency (USA)
EMEP	Steering Body to the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe
EPER	European Pollutant Emission Register
EU	European Union
EUROSTAT	EU Statistical Agency
GHA	Gemeentelijk Havenbedrijf Antwerpen (Port of Antwerp)
GhG	Greenhouse Gas
GRT	Gross Registered Tonnage
GT	Gross Tonnage
HFC	Hydro fluorocarbon
HFO	Heavy Fuel Oil
IEA	International Energy Agency
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change
IVS – SRK	Informatie Verwerkend Systeem van de Schelde Radar Keten (VTS IT system for the Scheldt River and its estuary)
LNG	Liquid Natural Gas
MARPOL	International Convention for the Prevention of Pollution from Ships
MCR	Maximum Continuous Rate
MDO	Marine Diesel Oil
ME	Main Engine
MEPC	Marine Environment Protection Committee (IMO)
MGO	Marine Gas Oil
NFR	Nomenclature for Reporting
NIR	National Inventory Report
NIS	National Institute for Statistics

NMVOC	Non-methane volatile organic compound
NEC	National Emissions Ceiling
NO_x	Nitrogen oxides
N_2O	Nitrous oxides
OECD	Organisation for Economic Co-operation and Development
PFC	Per fluorocarbon
PM	Particle Matter
POP	Persistent Organic Pollutant
SBSTA	Subsidiary Body for Scientific and Technological Advice (UNFCCC)
SF_6	Sulphur hexafluoride
SNAP	Selected Nomenclature for Air Pollution
SO_2	Sulphur oxide
SECA	SO_x Emission Control Area
SSS	Short Sea Shipping
TSS	Traffic Separation Scheme
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VITO	Flemish Institute for Technological Research
VMM	Vlaamse Milieu Maatschappij (Flemish Environment Agency)
VOC	Volatile Organic Compound
VRIND	Vlaamse Regionale Indicatoren (Flemish regional indicators)
VTS	Vessel Traffic System
ZEDIS	Database system of the Port of Zeebrugge

ABSTRACT

The objective of this study is to quantify an estimate of ship's aerial emissions in the Belgian part of the North Sea, including the 4 most important Belgian ports: Antwerp, Ghent, Ostend and Zeebrugge and this for the period from April 2003 to March 2004. This quantification gives an overview of ship's aerial emission of CO_2, SO_2 and NO_x and can be used as an input to the discussions on regulating shipping emissions in the framework of combating air pollution and climate change.

First an overview is given of existing and upcoming international standards and reporting requirements; followed by the current emission inventories in use in Belgium. Next, a new method is used to estimate the emissions of shipping.

The method classifies ships into 15 classes and 2 different calculation methods, depending on the best available data: for 11 types of merchant ships, dredgers and tugs in non-operational condition and fishery (emissions by the Belgian fishing fleet in the Belgian part of the North Sea) a bottom-up approach is applied, for dredgers and tugs in operational condition a top-down approach is used. For LNG vessels we have to take the specific engine characteristics into account. Further, we also make a distinction between at sea and in port emissions, because of different sailing operations (whether cruising, at berth, manoeuvring or at anchor).

In the bottom-up approach, the engine loads are the most significant information and can be used to estimate the subsequent emissions, together with information on sailing times and emission factors. The top-down approach allows for a more simple calculation on the basis of fuel consumption and related emission factors.

When adding the total at sea and in port emission estimates from both the bottom-up and top-down approach we have the total estimate of ship's aerial emission in the Belgian part of the North Sea and the 4 most important ports. Unfortunately, a lack of data (due to a limited coverage of ship registration at the time) has not allowed to incorporate emissions from transit ships, passing the Belgian North Sea in the North bound Traffic Separation Scheme.

Key-words: emissions – shipping – North Sea – in port – at sea – air pollution – climate change – VTS – TSS – NO_x – SO_2 – CO_2

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1. INTRODUCTION: EMISSION QUANTIFICATION

1.1. INTERNATIONAL BACKGROUND

The issue of exhaust emissions in general, arises at the end of the 1960's. The first emission standard is the Clean Air Act of 1970, introduced by the Environmental Protection Agency (EPA) in the USA, to counter the growing motor vehicle pollution. These standards limit engine emissions but engine makers are free in how to achieve these limits. The emission reductions of the 1970's came about due to fundamental improvements in engine design, the addition of charcoal canisters to collect hydrocarbon vapours and exhaust gas recirculation valves to reduce nitrogen oxides. Over the course of years, standards have become tighter and manufacturers equip new engines with even more sophisticated emission control systems.

In the 1990's, several new provisions are introduced. EPA sets tighter emission limits and establishes fuel standards in the USA by provisions of the 1990 Clean Air Act. The European Union develops in 1991 the Euro 1 standard for passenger cars and in 1993 for light trucks, regulating five types of aerial emissions: CO, NO_x, HC, HC + NO_x and particle matter (PM). Since then, the Euro 2 (1996), Euro 3 (2000) and Euro 4 (2005) have reinforced the EU emission guidelines by reducing the maximum levels by 80% for CO and by 70% for NO_x. Together with the Euro 3 and 4 emission levels, the EU has established new standards for fuel quality regarding sulphur contents in diesel oil and gasoline.

The late 1980's are the beginning of a true revolution in emission reductions. Besides different local and national initiatives, the emission discussion moves to the international level. At first, acid rain and ozone depleting substances are dealt with through international cooperation. Later, the discussions on greenhouse gas emissions starts on the international level because of their global dispersion and effect as opposed to for example SO_2 emissions having local or regional effects. At COP 1 of the UN Framework Convention on Climate Change (UNFCCC – Berlin, March/April 1995), in a decision known as the Berlin Mandate, parties launched a new round of talks to decide on stronger and more detailed commitments for industrialized countries with the scope of limiting or reducing the greenhouse gas emissions. After two and a half years of intense negotiations, the Kyoto Protocol was adopted at COP 3 in Kyoto, Japan, on 11 December 1997, and entered into force on 16 February 2005. The protocol aims at reducing the emissions of industrialised countries (Annex I) with 5% compared to the 1990 baseline between 2008 and 2012. A possible post-Kyoto protocol will try to involve more states beyond annex-1 countries and to integrate new sectors like international aviation and shipping. The future of this protocol though rests upon political intentions of the different member states.

1.1.1. The maritime sector

On 27th September 1997, in the same period as the Kyoto protocol was negotiated, the IMO amended the MARPOL 73/78 regulations by the "1997 Protocol", which includes Annex VI: "Regulations for the Prevention of Air Pollution from Ships". Annex VI sets limits on NO_x and SO_2 emissions from ship exhausts and prohibits deliberate emissions of ozone depleting substances. The protocol is ratified in 2004 and entered into force on 19 May 2005.

This illustrates the marine sector limping behind in the field of regulating emission reductions. The emissions standards adopted in MARPOL Annex VI are not ambitious. The worldwide maximum percentage of sulphur in marine fuels is set at 4.5% while the average sulphur percentage in marine fuels distributed in European ports is estimated at 2.7% [*Whall et al, 2002*]. At this stage, only Europe has tightened its standards for shipping by introducing and ratifying special areas (1.5% sulphur limit in marine fuels) in Northern Europe (North Sea, English Channel, Baltic Sea) and proposing new and lower emission standards for the future. The USA (California) and Japan (Tokyo Bay) recently introduced proposals and guidelines for emission reduction from ships as well. Even with these extra measures, all efforts are situated in the field of reducing NO_x and SO_2 emissions and no rules concerning other GhG are set for the maritime sector. New and stricter measures concerning greenhouse gas emissions and concentrations will not come sooner than 2012. For the moment discussion on integrating emissions from international shipping in a post 2012 framework are being held to discuss the different options.

This reluctance can be explained by the fact that the shipping sector is an international business, a large part of the emissions happen in international waters and are not bound to national inventories and most of all merchant vessels are registered by flags of convenience that are not really interested in emission reductions. As most of these countries of convenience are developing countries, introducing a different target for (non-) Annex I countries would not work. Because of the international dimension of shipping and the technicalities it was decided to consult the IMO on these matters and to try and work out a solution between IMO and the UNFCCC.

1.1.2. Maritime emission quantification studies

Due to the international characteristic of shipping, estimating ship emissions is more difficult than with other types of emissions. They are less controllable and their reporting system is not as automated as in the aviation sector, however introducing AIS[1] has meant a great progress. This is one of several possible reasons why the research for ship emissions commenced only towards the end of the 1980's [*Lloyds Register, 1995*], as opposed to car and truck emissions that were studied from the 1970's onward. For

[1] Automatic Identification System (was introduced on 1 July 2002 by IMO under regulation 20 of the new SOLAS Chapter V)

example, the Lloyd's Register's Marine Exhaust Emissions Research Programme started at the end of 1989 largely in response to the initiation of discussions in the IMO.

The different ship emission studies consider various study areas, different types of exhaust gases and employ different methodologies. In general the study methods can be divided in three main classes. There are 1) top-down, 2) bottom-up approaches and 3) combinations of these two methodologies. Both approaches have specific advantages and disadvantages and are useful for different applications.

A top-down approach is the simplest method and does not require complex calculations. On the other hand is it a rough method and it does not allow for detailed geographical research. This type of methodology is largely suited for global studies or studies with large study areas (Europe, North-America, etc.). Though, due to its simplicity, it is a useful tool to detect certain tendencies on emission levels. The alternative methodology is the bottom-up approach. This requires more detailed data and complex calculations. This makes a bottom-up approach better fitted for smaller study areas. It is difficult to study tendencies but it offers other advantages: With data regarding ship positions and voyages, it is possible to allocate ship emissions in a more detailed way; and it is possible to link to a reliable diffusing scheme. If necessary, it is possible to increase the study scale and determine emissions per port or individual ship journeys. The combination of these two types of approaches is used in certain cases when the use of one methodology could not be applied for all shipping activities. For example, the examining of pleasure crafts demands a different study method than merchant vessels.

An overview and short description of earlier executed emission quantification studies is provided in annex 1.

1.2. In the Belgian Part of the North Sea

1.2.1. Study subject

The objective of this study is to quantify an estimate of ships' aerial emissions in the Belgian part of the North Sea. Due to the relative small study area it is possible to integrate a more precise calculation process regarding localisation, and, to develop optimal methodologies for study areas, activities or groups.

First, the Belgian part of the North Sea is categorised into areas according to primordial criteria for emission calculation. Three areas are specified: (1) sea area, covering the largest part of the Belgian part of the North Sea and including all shipping routes; (2) port areas, represented by the four largest Belgian ports situated at the Belgian part of the North Sea and land inward; (3) anchorage areas. These areas are shown in figure 1. The second phase identifies per area several types of activities, like: (1) cruising; (2) anchoring; (3) manoeuvring; (4) hauling; and (5) mooring.

Table 1 : Overview of ship classes and names as used in this study

Ship class	Ship type
1	**Oil tankers**
2	**Chemical tankers**
3	**Gas carriers**
4	**RoRo cargo**
5	**Dry bulk carriers**
6	**General cargo**
7	**Containers**
8	**Passenger**
9	**RoPax**
10	**Reefers**
11	**Other dry cargo**
12	**Towing/pushing**
13	**Dredgers**
14	**LNG**
15	**Fishery**
16	**Excluded**

The different study groups are subdivided per observation method, identifying (1) merchant shipping, (2) ferries, (3) dredgers, (4) tugboats and (5) fishery. In total we take 15 different ship types into consideration, 14 merchant ship types (including ferries and LNG vessels) and fishery (in this case the emissions of the Belgian fishing fleet in the Belgian part of the North Sea) (see table 1). Because of the specific design and engine characteristics of LNG vessels, this vessel type is taken separate from other gas carriers. Other categories like inland water vessels, naval vessels and recreational crafts are excluded from this report. Their contribution to ship emissions in the Belgian part of the North Sea is of minor importance.

Due to restraints in depth and dangerous currents caused by numerous sand banks, merchant shipping is restricted to certain shipping routes. Therefore, the largest portion of the maritime traffic is situated in the Westhinder and Noordhinder TSS (Traffic Separation Schemes) and the shipping lane to the Scheldt estuary and Zeebrugge port. The remaining routes are sailed by coastal vessels and ferries. The Belgian part of the North Sea also includes one anchorage area, located at the Westhinder TSS near the entrance of the obligatory pilotage area. The port areas include Ghent and Antwerp (situated inland) and Ostend and Zeebrugge (marked on figure 1).

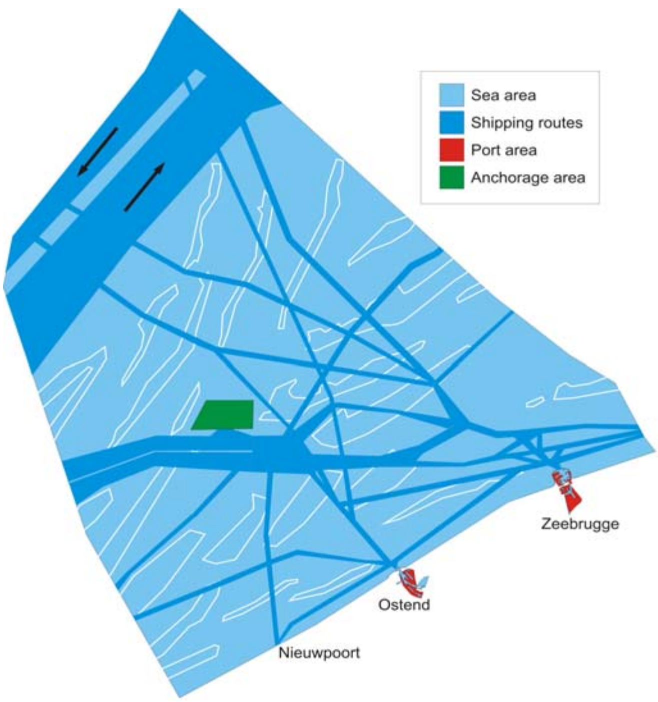


Figure 1 : Illustration of the different emission areas in the Belgian part of the North Sea

Vessels have different emission characteristics in port areas than "at sea".

When manoeuvring, hauling and berthing in port, a vessel handles variable engine loads and will burn different types of fuel. The surface of the total port area is limited in proportion to the Belgian sea area surface but has much denser shipping activities, responsible for an important amount of ship emissions in the Belgian territory.

1.2.2. Study period

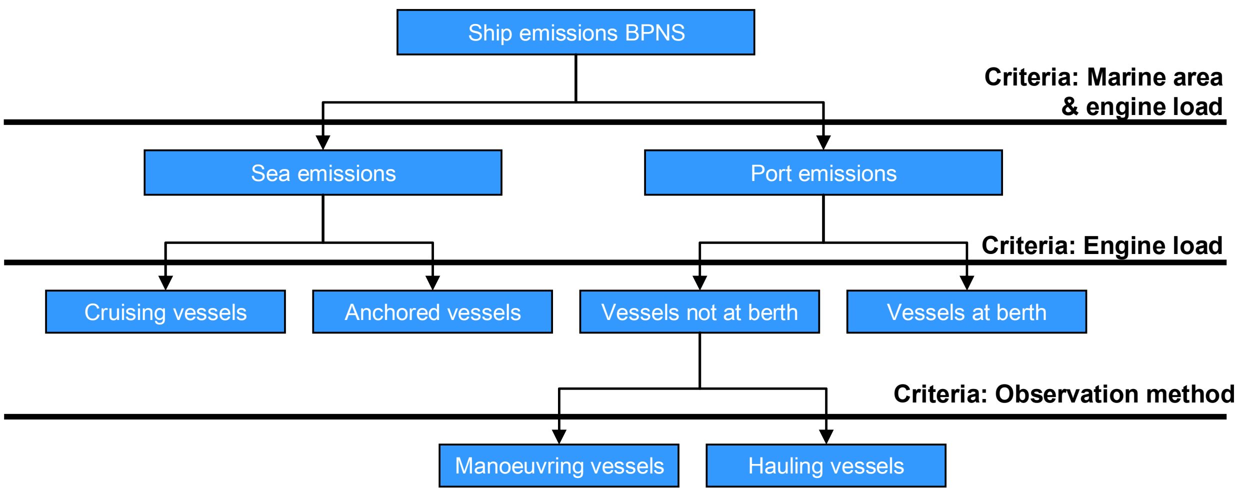
The Scheldt Vessel Traffic System (VTS) authority is the primordial data supplier for this study. Due to this dependence, we have to adapt our study period to the availability of the IVS-SRK[2] database. The Scheldt VTS-centre introduced their information processing system (IVS-SRK) in March 2003. Due to the fact that waiting for the 2004 data set would cause a serious delay in this study, we work with a data set covering a period of one year, starting at 1 April 2003 and ending at 31 March 2004.

1.2.3. The methodology

A different engine load indicates a divergent emission value. This implies that the engine load (of the main and auxiliary engines) is the most important factor in the calculation process of ships' emissions in combination with the different marine areas and observation methods. The different aspects of the methodology are presented in figure 2.

Two main classes are identified: (1) Sea emissions and (2) Port emissions. The sea emissions indicate all emissions from shipping in the Belgian part of the North Sea, as defined earlier. This class is subdivided into two types of activities that take place in the sea area (however with different engine load patterns), namely cruising and anchoring.

Figure 2 : Identification of the different aspects in the ECOSONOS methodology



2 IVS-SRK stands for "*het Informatie Verwerkend Systeem van de Schelde Radar Keten*" or the IT system, used by the Vessel Traffic Services controlling the river Scheldt and its estuary.

The second class (Port emissions) includes all emissions from vessels operating within port boundaries. The port area extends to the port entrances. In this area, two different engine load patterns are identified, namely berthing and not berthing. The vessels not at berth actually include all manoeuvring vessels but, in order to accentuate the difference in calculation method, two sub-classes are created: (1) the manoeuvring vessels containing all vessels entering or leaving the port and (2) the hauling vessels representing all vessels changing berth within one port stay. This structure is the basis for the ECOSONOS methodology. Each aspect is discussed in the following chapters.

1.2.3.1. Emission quantification

Depending on the best available data, two approaches of emission quantification are used in this study. For group 1 a bottom-up approach is used; it concerns all merchant vessels including dredgers and tugs in non-operational conditions (see figure 3). This group represents 96% of all emission calculations within this study. Group 2 represents dredgers and tugs in operational conditions; while dredging and towing respectively (see figure 4). For group 2 a top down approach is applied. Even though a top-down methodology is not as accurate on a local level, is it the single option to quantify and chart the emissions from these types of vessels during their operational periods. The group 2 methodology is applied for both the quantification of sea emissions (except for anchorage emissions) as port emissions by dredgers and tugs in operational condition.

The emission estimates for LNG vessels and fishery have been calculated in a separate way. For LNG vessels we have to take into account the specific engine characteristics. The estimates for fishery are also based on a bottom-up approach, but have been calculated in a separate study [*Goerlandt, 2006*].

The different results (group 1, group 2, LNG vessels and fishery) are added together to have the total amount of emissions from ships on the Belgian part of the North Sea.

Figure 3 : Group 1 ‘bottom-up’ approach

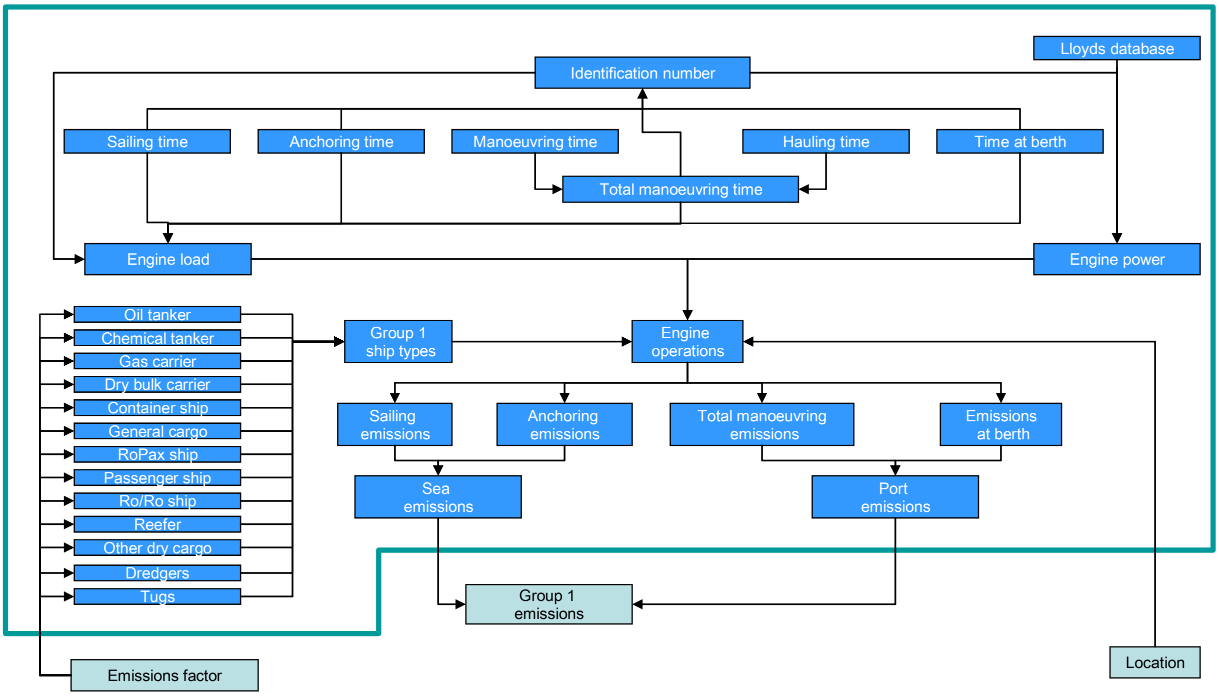
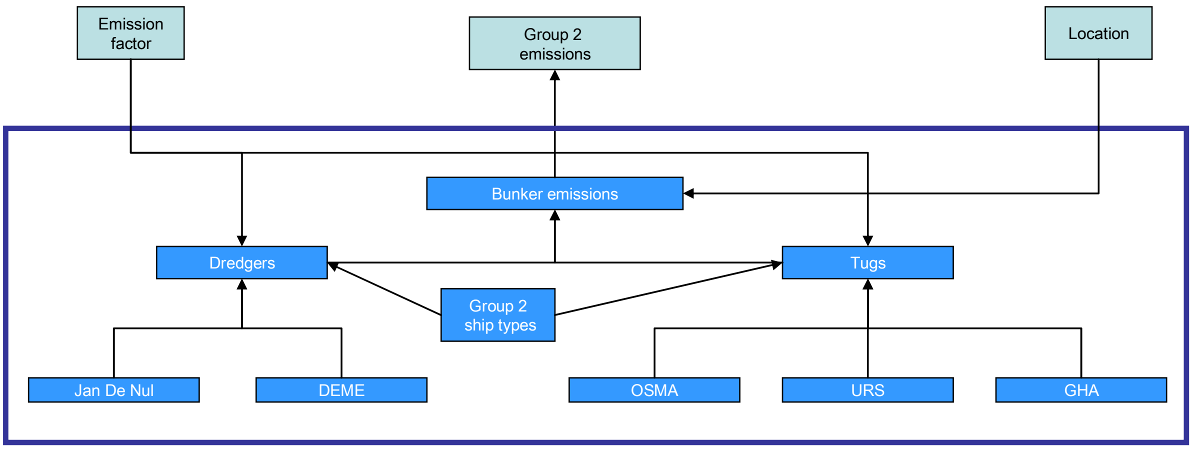


Figure 4 : Group 2 ‘top-down’ approach



2. IMO REGULATIONS, UNFCCC AND INTERNATIONAL REPORTING REQUIREMENTS

2.1. THE INTERNATIONAL MARITIME ORGANISATION (IMO)

In 1948 an international conference in Geneva adopts a convention formally establishing IMO (the original name was the Inter-Governmental Maritime Consultative Organization, or IMCO, but the name was changed in 1982 to IMO). The IMO Convention enters into force in 1958 and the new Organization meets for the first time the following year. The purpose of the Organization, as summarized by Article 1(a) of the Convention, is "to provide machinery for cooperation among Governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade; to encourage and facilitate the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships". The Organization is also empowered to deal with administrative and legal matters related to these purposes.

2.1.1. MARPOL Annex VI

2.1.1.1. History

Within IMO, the Marine Environment Protection Committee (MEPC) is among other topics responsible for the research and development of emission reduction control measures. This is agreed by the MEPC at its 39th session in March 1997. The Committee has prepared the text of a new Annex VI to the International Convention for the Prevention of Pollution from Ships (1973) as modified by the Protocol of 1978 relating thereto [*MARPOL 73/78, 1978*]. Annex VI contains measures to reduce air pollution from ships and ships' exhaust emissions [*MARPOL 73/78, 1997*].

Annex VI, covering the regulations for the Prevention of Air Pollution from Ships entered into force on 19 May 2005 and set limits on sulphur oxide (SO_x) and nitrogen oxide (NO_x) emissions from ship exhaust and prohibit deliberate emissions of ozone-depleting substances. It is applicable to every ship of 400 GRT or above and every fixed and floating drilling rig and other platforms. Under 400 GRT, the administration may establish appropriate measures.

2.1.1.2. Objectives

2.1.1.2.1. SO_x

Annex VI establishes a global cap of 4.5 percent by mass (% m/m) on the sulphur content of fuel oil. The sulphur content of fuel oil used onboard ships operating in a "SO_x Emission Control Area" (SECA) may not exceed 1.5% m/m or, alternatively, ships must fit an exhaust gas cleaning system or use other methods to limit SO_x emissions.

Initially, the Baltic Sea was the only ratified SECA, but MEPC 53 (July 2005) adopted the amendments related to the designation of the North Sea area as a SECA and the introduction of the Harmonized System of Survey and Certification into MARPOL Annex VI. The North Sea SECA, including the English Channel, will enter into force on 22 November 2007.

2.1.1.2.2. NO_x

In order to limit or reduce NO_x emissions, Annex VI develops the NO_x technical code. It applies to each diesel engine with a power output of more than 130 kW which is installed on a ship constructed on or after 1 January 2000 or which undergoes a major conversion on or after 1 January 2000. The technical code includes emission ceilings, exceptions and definitions. The operation of a diesel engine is permitted when equipped with an exhaust gas cleaning system or any other equivalent method.

2.1.1.2.3. Ozone-depleting substances

New installations which contain ozone-depleting substances shall be prohibited on all ships, except new installations containing HCFCs. These are permitted until 1 January 2020. With respect to measures against ozone-depleting substances and NO_x emissions, Annex VI makes no distinction between emissions "in port" or "at sea", nor between different seas.

2.1.1.2.4. Greenhouse emissions

During MEPC 48 in 2002, the committee developed a draft assembly resolution on greenhouse gas emissions from ships and invited members to submit comments on the draft. The committee agreed that policy issues on greenhouse gas emissions in the context of Article 2.2 of the Kyoto Protocol needed to be resolved before further action was taken on the draft resolution: "*2.2. The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively*."

In its draft form the resolution urges the MEPC to identify and develop the mechanism or mechanisms needed to achieve the limitation or reduction of Greenhouse Gas (GhG) emissions from international shipping, and, in doing so give priority to the establishment of a GhG emission baseline, the development of a methodology to describe the GhG-efficiency of a ship expressed as a GhG-index for that ship recognizing that CO_2 is the main greenhouse gas emitted by ships. It also calls for the establishment of guidelines by which the GhG emission index may be applied in practice. The guidelines would take into account related cost-benefit evaluations and verification procedures and be based on an evaluation of technical, operational and market-based solutions. They also call upon governments, in co-operation with the shipping industry, to promote and implement voluntary measures to limit or reduce GhG emissions from international shipping. The committee agreed that a CO_2 indexing scheme should be simple and easy to apply and should take into consideration matters related to construction and operation of the ship, and market based incentives. The MEPC recognized that IMO guidelines on greenhouse gas emissions have to address all six greenhouse gases covered by the Kyoto Protocol: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), hydro fluorocarbons (HFCs), per fluorocarbons (PFCs), and sulphur hexafluoride (SF_6). The draft was finalised during MEPC 49 (2003); MEPC 52 proposed guidelines on the CO_2 Indexing Scheme and urged members to carry out trials using the scheme; MEPC 53 approved interim guidelines for voluntary ship CO_2 emission indexing for use in trials.

The development of the GhG emission indexing scheme and reduction measures happens in close cooperation with the UN Framework Convention on Climate Change (UNFCCC). The main discussions within the MEPC concern how non-annex I countries (to the UNFCCC) are to be integrated into this scheme. The IMO philosophy prescribes that guidelines should apply equally to all IMO member states and stand opposite to the Kyoto principle with common but differential responsibilities meaning that only developed countries (annex I states) should pursue limitation or reduction of national GhG emissions.

2.1.1.3. Prospective

IMO is considered as the most appropriate way of implementing further improvements in air emissions from ships [*IMO, 2005a*].

Table 2 : Overview of IMO and EU emission reduction measures for shipping

Date	Action	Action zone	Legislation
19 May 2005	Entry into force of MARPOL Annex VI	Global	MARPOL
	NO_x technical code	Global	MARPOL
	Reduction Ozone-depleting substances	Global	MARPOL
	4,5% S in marine fuel oils	Global	MARPOL
19 May 2006	1,5% S in marine fuel oils	SECA Baltic Sea	MARPOL
	1,5% S in marine fuel oils	SECA Baltic Sea	EU Directive
11 August 2007	1,5% S in marine fuel oils	SECA North Sea	EU Directive
11 August 2007	0,1% S in MGO for AE's only	European ports	EU Directive
11 August 2007	1,5% S in marine fuel oils	Passenger ships on liner services to EU ports	EU Directive
22 November 2007	1,5% S in marine fuel oils	SECA North Sea	MARPOL

During the next MEPC meetings, the committee will undertake a review of Annex VI and the NO_x technical code with regards to revising the regulations to take account of current technology and the need to further reduce emissions from ships. The sub-committee on Bulk Liquids and Gases (BLG) was instructed to carry out the review by 2007. The committee and participating member states will evaluate the development of possible new SECAs in the future.

Table 2 demonstrates that the EU follows the MARPOL Annex VI guidelines, taking them even a step further for ports from 1 January 2010 onwards [*EU, 2005*]. For example, the marine fuel oils consumed by the auxiliary engines in European ports, will then be restricted to a sulphur content of 0.1% by mass.

2.2. United Nations Framework Convention on Climate Change (UNFCCC)

2.2.1. Methodological issues regarding current reporting

2.2.1.1. The IPCC 2006 guidelines

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories were produced at the invitation UNFCCC to update the Revised 1996 Guidelines [*Houghton, 1996*] and associated good practice guidance [*IPCC, 2000*]. These updated guidelines were approved in April 2006.

The discussion of methodological issues regarding marine emissions in particular mainly focuses on CO_2, CH_4 and N_2O. As in the previous guidelines, the main categories are domestic and international navigation. The reporting methods are separated into tiers, the second tier involving a more detailed analysis. As before, in both tiers emissions are computed as fuel consumed (activity data) times emissions factors. Tier 1 uses "default" emission factors provided by IPCC for each fuel type. Tier 2 involves separate calculations with specific emission factors for different types of ships and engines, e.g. based on the EMEP[3]/Corinair Emission Inventory Guidebook [*EEA, 2004*]. The new guidelines require the use of tier 2 for CO_2 whenever the source is a "key source category" (i.e. an important source). Tier 1 can be used for CH_4 and N_2O if the fuel an emission factor data necessary to use tier 2 are not available [*Paciornik and Rypdal, 2006 (fig 3.5.1)*].

The separation of activity data in domestic and international components remains an important issue. International navigation is defined as the ensemble of journey segments that departs from one country and arrives in another. This is a simplification with regard to IPCC 2000 "good practice", as it is not required to distinguish between the types of intermediate stops (with or without dropping goods or passengers). It is recognised that the most feasible approach to obtain fuel use data depends on national circumstances. A list of data sources of decreasing typical reliability is provided, starting from national and IEA energy statistics, then including survey of shipping companies, equipment counts e.g. for pleasure crafts, import/export records, etc. The source of activity data should be reviewed and if possible compared to historical data.

2.2.1.2. Activities of UNFCCC / SBSTA

During the last years, discussions in the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA) mainly focused on methodological issues connected

[3] EMEP stands for "Steering Body to the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe"

with the current reporting requirements. The difficulty of separating domestic and international emissions was often mentioned, particularly in connection with the issue of drop-offs and pick-ups at stops in the same country, for which information is not required by the new IPCC guidelines anymore (see above). There were also discussions on the emissions factors, noting that most countries only use a tier 1 method, which is particularly inaccurate for CH_4 and N_2O. For these gases, it was noted by the UNFCCC secretariat following a meeting with IMO in 2004 that using engine emission data is desirable; by contrast, developing an emission profile for each ship voyage appeared expensive an complicated. It was also noted that the annex VI of MARPOL, which entered into force in May 2005, provides new data through the requirement of bunker receipts, with some indication of the national/international separation provided by the distinction of bunkers smaller/larger than 400 GT. In 2005, the EU submitted an analysis of data issues related to possible future inclusion of international bunker in overall GhG reporting, largely similar to a report from the Netherlands [*Wit et al, 2004]*, see section 2.2.2.

Since no conclusions where agreed upon at the previous meetings, the methodological issues of emissions estimates was again on the agenda of SBSTA 24 in may 2006. No clear progress has been achieved and the issue has been forwarded, once again, for further consideration to SBSTA 25 in Nairobi (November 2006).

2.2.1.3. Implications for reporting Belgian emissions

A distinction between fuel types is necessary to follow the guidelines, as it is used in both tiers. Further distinction between engine types is desirable, in order to use the tier 2 methodology, which is now required for CO_2 and if possible, other emissions. By contrast, the separation between domestic and international emissions should be simplified by the new guidelines, as it is not required to distinguish between types of intermediates stops anymore.

2.2.2. Methodological issues regarding reporting in view of future commitments

Following article 2§2 of the Kyoto Protocol, Annex 1 parties have to pursue limitation of greenhouse gas emissions from ships, working through the International Maritime Organisation. In 2003, the IMO adopted resolution A.963(23) that requires the Environment Protection Committee (MEPC) to develop mechanisms to limit or reduce GhG emissions. As explained in the section regarding to IMO, the Committee has designed "interim guidelines for voluntary Ship CO_2 emission indexing", currently adopted (in July 2005) only for use in trials. However, this should only be one of the component of an emission reduction strategy, since the aim of this indexing is only to provide a measure of the energy efficiency of individual ships (it provides g CO_2 / ton km, not absolute emissions).

At the time of adoption of the Kyoto Protocol, in 1997, the Conference of the Parties to the UNFCCC also urged the SBSTA to further elaborate on the inclusion of marine emissions in the overall greenhouse gas inventories of Parties. At that time, the SBSTA [*UNFCCC, 1996*] considered 8 options to allocate these emissions to the Parties, some of which have rapidly been discarded due to serious drawbacks, leaving the following: (1) no allocation, (3) allocation to the country where the fuel is sold, (4) allocation to the nationality of shipping companies, (5) allocation to the country of destination and/or departure of ship, (6) allocation to the country of departure and/or destination of passenger or cargo. Note that allocation according to emissions generated within each party's national space was discarded because of its inadequate global coverage, no emissions above international waters being allocated under this option.

The options considered by SBSTA where recently analysed in the framework of the Netherlands Research Programme on Climate Change [*Wit et al, 2004*]. The study concluded that none of the options currently satisfied a set of criteria for equity, risk of evasion and data availability. From the equity principle, the study regards option 4 and especially option 5 (departure/destination) as feasible. However, the report concludes that the necessary data is currently not available for any of the methods that may satisfy the other criteria. The system of bunker delivery notes introduced by IMO can be expected to provide comprehensive and reliable data on the total amount of bunker fuels tanked and consumed, for all vessels larger than 400 GT. However, even though bunker delivery notes may provide very valuable data on total bunker fuels tanked and consumed, they cannot be used to specify the fuel used on specific voyages, since it is common shipping practice for various voyages to be made between bunkering stops. Using the Lloyds Marine Intelligence Unit is also not sufficient since it does not record actual fuel consumption or parameters relevant to fuel efficiency such as speed and energy produced by auxiliary engines. The project thus concludes that research activities are necessary in order to arrive at accepted and robust bottom-up methodologies for calculating CO_2 emissions from ships.

2.3. INTERNATIONAL REPORTING REQUIREMENTS

To be able to meet the goals set forward by the different international conventions about air pollution, it is important to quantify the contribution of all possible emission sources. By drawing up an accurate inventory of ship emissions the impact of sea transport on the atmosphere can be evaluated. Therefore, national emission inventories are communicated to international institutes, conform a specific reporting format. On the basis of these emission reports, it is checked if Belgium meets the international goals for emission reduction for certain substances. Table 1 gives an overview of the international reporting requirements for Belgium.

Table 3 : List of official international reports

Emission reporting	Time of reporting	Format	Greenhouse gas	Air pollutants
UNECE CLRTAP/EMEP	15/2/year X	NFR		SO_x, NO_x, NH_3, NMVOC, CO, heavy metals, POP, PAC, TSP, PM10, PM2.5
UNFCCC	15/4/year X	CRF	CO_2, CH_4, N_2O, F-gas	SO_x, NO_x, CO, NMVOC,
EC/CO_2	31/12/year X	CRF	CO_2, CH_4, N_2O, F-gas	SO_x, NO_x, CO, NMVOC,
EC/NEC	31/12/year X	NFR		SO_x, NO_x, NH_3, NMVOC,

Two annual emission reporting formats are distinguished in Belgium, which contain information related to shipping:

- The *Common Reporting Format* (CRF) in which each region (Flanders, Walloon and Brussels Capital) establishes its own emission inventory in accordance with the UNFCCC guidelines. In Flanders, the emission inventory is set up by the Flemish Environment Agency (VMM). These are regional inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol. In Belgium the regional inventories are then combined into a national GhG inventory by the Interregional Environment Unit (CELINE-IRCEL), which is responsible for annual submissions of the national GhG inventory to the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) and to the European Commission (EC), under the Council Decision 1999/296/EU of 26 April 1999 for a Monitoring Mechanism of Community CO_2 and other greenhouse gas emissions.
- The *Nomenclature For Reporting* (NFR) is a standardized format for reporting estimates of emissions including activity data, projected activity data, projected emissions, etc. The information should be formally submitted on an annual basis by each Party of the Convention of Long Range Transmission of Air Pollutants (CLRTAP) to the United Nations Economic Commission for Europe (UNECE) secretariat and to the European Commission (EC), according to EU Directive 2001/81/EU of 23 October 2001 concerning the National Emission Ceilings for SO_2, NO_x, NH_3 and NMVOC, the so called NEC-directive [*EU, 2001*]. This data is also available on the EMEP web site.

Other emission reports which are published periodically are:

- The *National Inventory Report* (NIR) (2004) concerning the Belgian inventory of greenhouse gases for the period 1990-2002;
- The 2-yearly *questionnaire sent by the OECD* in collaboration with EUROSTAT about emissions of, for example SO_2, NO_x, NH_3, CO_2, metals;

- Reports concerning the implementation of European Pollutant Emission Register (EPER), (2000/479/EC).

2.3.1. Basic database system for reporting: Air Emission Inventory

As Flanders is the only Belgian region adjacent to the sea, the total amount of shipping emissions at sea can be attributed to the Flemish region.

One of the main documents used for the Flemish contribution to the Belgian greenhouse gas inventory (international reporting) is the Energy Balance Flanders. This independent energy and CO_2 emission balance of Flanders is drawn up by the Flemish Institute for Technological Research (VITO) in the framework of Energy and Environmental Information System (EMIS) for the Flemish region. The shipping emissions calculated from the Energy Balance Flanders are integrally incorporated in the Air Emission Inventory. The Air Emission Inventory includes the emissions of most of the air pollutants originating from industry, transport, agriculture and heating of buildings. All emissions of industrial and non-industrial sources in Flanders are collected and stored in detail in this central database system by the Flemish Environmental Agency [*VMM, 2004*]. One of the 4 main parts is transport with the sub-sector shipping.

The official figures used for the international report obligations (CRF, NFR) are the data from the Air Emission Inventory.

3. METHODOLOGY

3.1. GENERAL

To generate an emission inventory two approaches can be adopted, these being: the so-called "bottom-up" and "top down" approach.

The top-down approach, starts with data describing the total potential polluting activity throughout the whole geographical area of interest, for example the total marine fuel sales for a country. The fuel sold can then further be subdivided into different types of oil: residual bunker fuel oil (heavy fuel oil) and distillate fuel (gas oil and marine diesel oil), or other fuel types. A geographical break-down of the calculated emissions can then be performed when necessary.

The bottom-up method starts, with geographically disaggregated data, for example the number of ship movements on a shipping route. Emission data are calculated for each individual ship or per ship type. To obtain the total emissions for a geographical area the different contributions are summed up. This method requires detailed data and may be quite time consuming to perform.

3.2. METHODOLOGY EMISSION INVENTORIES USED IN BELGIUM

UNFCCC requires Parties to use the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories ("IPCC Guidelines") [*Houghton et al, 1996*]. Parties may use different methods ("tiers"), therefore giving priority to those methods which are believed to produce the most accurate estimates. Parties can also use national methodologies which they consider better able to reflect their national situation, provided, these methodologies are compatible with the IPCC Guidelines and are well documented [*UNFCCC, 1999*].

Parties of the CLRTAP should use the EMEP/CORINAIR Emission Inventory Guidebook [*EEA, 2004*] both as a reference book on good emission estimation practice and as a check-list to ensure that all relevant activities are considered and their emissions quantified. Parties should indicate where the Guidebook methodology has been used and where it has not. If another methodology has been used, Parties are requested to provide additional explanatory information.

Belgium, as a party to the UNFCCC and to CLRTAP, has chosen to develop its own methodology: in general emissions are calculated as the energy-use (fuel consumption) multiplied by the relevant emission factor for CO_2, NO_x and SO_2.

Emission = Energy-use x emission-factor

With respect to shipping emissions a distinction can be made in military navigation, national shipping, international shipping and sea fishery. The calculation of the energy-use will depend on the sector and will be discussed in the following paragraphs. The emission factors used for the Belgian calculations are the default emission factors from the Revised 1996 IPCC Guidelines [*Houghton et al, 1996*].

3.2.1. National shipping

The described methodology for national shipping is a bottom-up methodology. National shipping (domestic waterway transport) is subdivided into inland navigation on rivers and channels, and shipping between the Flemish sea harbours (coastal shipping). The latter includes the transport of sea ferries (excluding ferries crossing the English Channel) and the coasters. For both inland and coastal shipping a further distinction has been made between transport of goods or passengers.

As the ECOSONOS project is interested in the emissions on the Belgian Part of the North Sea, only the coastal shipping is of interest here.

The energy use of the transport of goods is estimated by multiplying the number of shipped ton kilometres with the average energy use per ton kilometre. The average energy use per ton kilometre is estimated in the framework of the "SUSATRANS" project by VITO for the period 1990-2003 [*Aernouts & Jespers, 2003*]. The average energy use per ton kilometre is based on yearly energy use of inland navigation only. The calculated value is however also used for the average energy use per ton kilometre for coastal shipping. The shipped ton kilometres are based on available statistics. As for the coastal shipping, they are calculated on the basis of the VRIND-statistics (cargo transported in ton). The cargo traffic in the harbour of Antwerp, Ghent, Zeebrugge and Ostend is taken into account [*VMM, 2004*]. To calculate the shipped ton kilometres the assumption is made by VITO that the average distance between two coastal harbours is 20 km.

Using this ship movement methodology, emissions from ships hotelling in port or at anchor awaiting a berth or awaiting orders, are excluded [*EEA, 2004*].

The fuel consumption for the transport of passengers is more difficult to estimate. Almost no figures are available. The following methodology is used:

- For *pleasure cruises for non-commercial purposes* the known number of sold waterway emblems ("vaarvignet") is multiplied with the average use per waterway emblem (per year). Waterway emblems are however only needed for inland navigation and not for coastal shipping. A ratio of 70/30 has been used to dedicate the total number of waterway emblems respectively to inland navigation and coastal shipping. The average use per waterway emblem is only based on inland navigation.
- For *commercial passenger shipping* no data are available and only rough estimates are made [*Aernouts & Jespers, 2003*]. The annual consumption is

estimated at 400,000 l gas- and diesel oil/year [*Danish questionnaire, 2002*]. The same ratio (70/30) has been applied to divide this annual consumption to inland and coastal shipping (ferries across the Channel are not included).

For the national emission estimations only distillate oil (gas oil) is taken into account. The amount of residual fuel oil (heavy fuel oil) used in local bunkering is included in the "international bunkering".

The calculated energy uses are further multiplied by the default IPCC emission factors.

The described methodology for coastal shipping is applied for the calculation of the CO_2, SO_2 and NO_x emissions and executed by VITO.

3.2.2. International shipping

International shipping is defined as all other transport at sea other than those described under national navigation. Flanders is the only Belgian region adjacent to the sea, so all federal marine bunkers are assigned to international transport at sea for Flanders.

The energy use is based on data collected by the Federal Energy Administration in the Federal Energy Balance (3.3.2). For the estimations of the international shipping emissions, both the fuel consumption classified under "international bunkers" and "local bunkers" (all fuels except gas oil) of the Federal Energy Balance are used.

The calculated energy uses are further multiplied by the default IPCC emission factors.

Currently only CO_2 emissions of international shipping are calculated and reported in the CRF document under "international bunkers". SO_2 and NO_x emissions of international shipping are not calculated. The IPCC reference approach (top-down) is followed for the marine bunkers [*Det Norske Veritas, 1999*].

3.2.3. Fishery

Fishery can be divided into 3 important groups: sea and coastal fishery, inland fishery and the cultivation of fish and crustaceans. Only the sea and coastal fishery are important for the estimation of shipping emissions at sea.

The calculation of CO_2 emissions from fishing vessels is also done by VITO. The energy use of fishery is based on the number of sea-days, the average use per type of fishing vessel and the average power (kW). Data are received from the Sea Fisheries Department of the Ministry of the Flemish Community. The calculated energy uses are further multiplied by the default CO_2 emission factors given by IPCC. The calculation of SO_2 and NO_x is done by the VMM.

3.2.4. Military navigation

Emissions from military navigation are outside the scope of the ECOSONOS project and will not be discussed further.

3.3. MAIN DATA SOURCES

The shipping emissions at sea are based on data collected by several authorities.

3.3.1. VITO: Energy Balance Flanders

The Energy Balance Flanders is set up by VITO in accordance with the IPCC guidelines (1996) for the development of a greenhouse gas emissions inventory. Information is received from statistical databases (e.g. VRIND, NIS) or from inquires taken by VITO from industrial and tertiary sectors. Energy uses (PJ) are calculated for different sectors.

The sectors related to marine activities are:

- International bunkers;
- National (domestic) market:
    - Inland navigation on channels;
    - Coastal navigation between the coastal harbours;
    - Sea fisheries.

The calculation of the energy use and the data sources are already discussed in 3.2.

3.3.1.1. Data problems

The basic shipping data used (ton kilometres) for cargo transport is reliable. However, some methodological problems exist concerning average use per ton kilometre and other assumptions made. They will be further discussed in 3.4.

3.3.2. Federal Energy Administration: Federal Energy Balance

The Federal Energy Administration compiles statistics of the movements and location of stocks of petrol and petrol derivatives by monthly reports to the National Institute for Statistics (NIS) from importers, exporters and refineries. This data allows for the separation of fuels between the domestic market and international marine bunker fuels. The three-monthly reports further specify between fuel supplies to various sectors.

The list of sectors includes separate categories for:

- International bunkers;
- National (domestic) market:
    - inland navigation: navigation on the channels;
    - local bunkers: sea ferries (excluding ferries crossing the English Channel) and coasters (without marine bunker contract);
    - sea fisheries.

For both markets (national and international) a distinction has also been made in the type of fuel:

- distillate fuel: gas oil (3 types);

- residual fuel oil: heavy fuel (4 types).

All the fuel data (metric tons) is converted into energy uses (PJ) and brought into the Federal Energy Balance, directly used by VITO for the estimations of the international shipping emissions (see further).

3.3.2.1. Data problems

The data are definitely not 100% reliable. There are a lot of inconsistencies in the data, depending on the data supplier, concerning the distinction of international and national shipping and of the type of oil. The reason for these inconsistencies is partly due to financial profits linked with certain types of oils.

3.3.3. Custom administration

Customs and excise regulations also require a follow-up of motor fuels used in aviation and navigation (bunker fuels). The information collected to assure this follow-up can be categorized according to: 1) the fiscal destination of the products concerned and 2) the nature of the products.

In the framework of customs and excise regulations three sector levels can be distinguished: 1) exported or re-exported goods are considered to be consumed on the international level. In theory two other levels can be distinguished: 2) inland navigation on the channels and 3) intra-EU consumption (Dutch: "communautaire vaart"). In practice no distinction can be made between the latter two destinations [*Danish questionnaire, 2002*].

As for fuels destined for shipping (national or international), no taxes (zero-tariff) have to be paid. The custom administration is not interested in more details like for example the different types of oil. As a consequence, no statistical details are available at the custom administration and they do not directly deliver data for the emission estimations.

3.3.3.1. Data problems

Despite the different typology (international, inland and intra-EU navigation), this difference is not correctly used in practice (inconsistencies in the data). It is for example hard to define if a ship bunkering in Antwerp and leaving for England is to be classified under inland navigation or intra-EU consumption.

Furthermore no distinction has been made in the following:

- Inland navigation, coastal navigation (sea ferries and bunkers) and sea fisheries for national shipping;
- Different types of oil.

3.4. METHODOLOGICAL PROBLEMS

Methodological problems connected to the collection of bunker fuel consumption data are:

3.4.1. Distinction between national and international transport

In accordance with the IPCC Guidelines for national greenhouse gas inventories and the UNFCCC reporting guidelines on annual inventories (see decisions 9/CP.2, 10/CP.2, 17/CP.8 and 18/CP.8), emissions from international marine transportation (also known as international bunker fuel emissions) should not be included in national totals. They should be calculated as part of the national greenhouse gas inventories of Parties, but reported separately.

In most countries, tax and custom dues are levied on bunkers for domestic consumption, where international consumption is free of such dues. This is however not the case for Belgium where all fuel destined for shipping is free of taxes and a distinction in national and international shipping on this base is not possible.

Belgium has therefore problems disaggregating domestic and international fuel from the total fuel sales. At the moment Belgium uses the following definitions for their reports:

- International shipping: emissions from international shipping include emissions from the 'international bunkers' and the 'local bunkers' (sea ferries & coasters) (non-gas oil fraction);
- National shipping: emissions from inland navigation on rivers and channels and coastal shipping (between harbours) (=local bunkers (gas oil)).

Furthermore there is no consistency in the terminology used by the Federal Energy Administration and the Custom Administration. As a consequence the data sources cannot be combined. Besides, the data gathered by the two former authorities include a lot of inconsistencies concerning this topic and are therefore not reliable. Depending on the data supplier the data are classified differently.

3.4.2. Sectoral approach

To be able to calculate national shipping emissions on the North Sea it is also important that within the national navigation a clear distinction between inland navigation and coastal shipping is made. Currently the coasters can not be found in a separate category and a clear well-defined description of inland navigation and coastal shipping is not available. Also attention should be paid to transit coasters (coasters departing in a Flemish harbour sailing for a foreign harbour).

Furthermore sea fisheries should be taken as a separate sector and not lumped under agriculture/forestry/fisheries.

Besides the general remark on a clear distinction within the national navigation for sea and channel traffic, more detailed information is needed to calculate the energy consumption, as listed below:

Emissions from ships hotelling in port, or at anchor awaiting a berth or awaiting orders should be included in the national emission estimations. They must be estimated using port statistics.

Currently, the average energy use per ton kilometre used in the calculation of the energy use of transports of goods is only based on inland navigation. Due to different tidal and current regimes taking place at sea the average energy use per ton kilometre can be expected to be different (higher) than in the case of inland navigation. A specific calculation of the average energy use per ton kilometre for transport of goods at sea is recommended.

Transport of passengers:

- The non-commercial coastal transport is based on the sold waterway emblems, while these are only needed for inland navigation and not for coastal shipping. Therefore the assumption was made that 30% of the vessels having such an emblem also navigate in the coastal waters. Still, the energy use per waterway emblem is based on information of inland navigation, while for coastal shipping it can be expected that the energy use will be higher due to stronger waves and tidal currents.
- For the commercial passenger transport no detailed information is available. Currently a general estimation of fuel consumption is used based on inland navigation data alone. The same ratio of 70/30 has been taken to get a division between inland and coastal shipping. More specific information is recommended.

For some vessels the statistics are not necessarily registering all fuel use. Fishing boats, in particular, may buy fuel abroad and therefore this fuel would not be registered in the national statistics [*EEA, 2004*]. As the sold fuel is the base for the Energy Balance Flanders this can lead to an underestimation of the national shipping emissions.

3.4.3. Distinction in fuel and engine type

As mentioned before, only one type of fuel (distillate fuel) is considered under national navigation. The residual fuel oil fraction (heavy fuel) of local bunkers (coastal shipping) has been allocated to international bunkering. So in other words, all distillate fuel (gas or marine diesel oil) is allocated to the national (domestic) navigation, while all heavy fuel (residual fuel oil) is allocated to the international navigation.

SO_2 emissions are related to the composition of fuels, not to combustion technologies. Therefore the sulphur and carbon content of fuels is an important factor. For estimating the SO_2 emissions of residual fuel oil (heavy fuel) and distillate fuel (gas or marine diesel oil) should be distinguished. Therefore, for SO_2 uncertainty depends on the variation of the sulphur content and fuel consumption which may be estimated to be within ± 5% [*EEA, 2004*]. CO_2 emissions are also fuel related but there is hardly any difference in carbon content between different types of fuel [*Whall et al, 2002*].

The emissions of NOx are dependent on the combustion process (engine type). Marine diesel engines are the predominant form of power unit within the marine industry for both propulsion and auxiliary power generation. Marine diesel engines are generally categorised into two distinct groups [*Lloyd's Register, 1993*]: slow speed and medium speed engines. For slow speed engines a longer period at higher temperatures occurs, which gives improved combustion efficiency but greater thermal fixation of nitrogen in the combustion air [*Whall et al, 2002*]. The emission factors for nitrous oxide [*Houghton et al, 1996*] are highly uncertain. NO_x emission factors for medium (57 kg/ton fuel) and slow speed engines (87 kg/ton fuel) differ significantly; a combined factor (72 kg/ton fuel) is provided for use in simpler methodology [*EEA, 2004*]. Uncertainties associated with estimates of NO_x should therefore be considered to be more than ± 20% [*EEA, 2004*].

3.4.4. Data deliverance

Some problems exist concerning the deliverance of data:

- Reports by industry to the Federal Energy Administration tend to be delayed for 1 to 2 months on average. There are currently no sanctions for untimely reporting, other than a non-committing reminder by the Administration;
- Generally, fiscal information collected by the Ministry of Finance is processed only to cater for the needs of the fiscal regulations it relates to. Data related to exports are globally available in electronic format, by firm and by NC code, but no distinction is made between 'bunkering' and other exports;
- Data related to products sold on the home market, with payment of excise duties, is globally available in electronic format, according to the fiscal category they belong to. Oil sold for shipping purposes are however exempt from excise duties. Data related to products brought on the home market, that are exempt from excise duties and products destined for re-exportation is not globally available. They are only available on a decentralized level, in the local offices of the Customs and Excise Administration and with the concerned economic agents. This data is not electronically processed;
- In the Flemish Region data collection is done on a strictly voluntary basis. For shipping, hardly any data is available. Marine transport is currently not covered by the regional energy statistics. In the regional energy statistics, fuel consumption by fishing vessels is included as a separate subsection under the 'agriculture' section;
- Due to competitiveness between the harbours it is not easy to obtain good and recent datasets;
- Due to terminology problems it is unclear what should be reported into the statistics;
- Not all data necessary for the calculation of shipping emissions is available on an annual basis;
- There are no sufficient quality control checks related to the available data.

3.5. Recommendations

3.5.1. Distinction between domestic and international navigation

It is clear that an unambiguous definition of domestic and international navigation is primordial. Different approaches are possible.

In accordance with the IPCC 1996 guidelines, Annex I Parties, such as Belgium, should make every effort to apply the IPCC good practice guidance definitions for separation between domestic (which are to be included in national totals) and international emissions and report emissions from international marine bunker fuels as a separate entry in their inventories[4].

The IPCC 1996 Good Practice guidelines recommend the following criteria for the distinction between international and domestic marine transport (Table 4). It is important to note that the criteria in this table are independent of the nationality or flag of the carrier:

Table 4 : Criteria for defining international or domestic marine transport (IPCC, 2000)

Journey Type	Domestic	International
Originates and terminates in same country	Yes	No
Departs from one country and arrives in another	No	Yes
Departs in one country, makes a 'technical' stop in the same country without dropping or picking up any passengers or freight, then departs again to arrive in another country	No	Yes
Departs in one country, stops in the same country and drops and picks up passengers or freight, then departs finally arriving in another country	Domestic segment	International segment
Departs in one country, stops in the same country and only picks up more passengers or freight and then departs finally arriving in another country	No	Yes
Departs in one country with a destination in another country, and makes an intermediate stop in the destination country where no passengers or cargo are loaded	No	Both segments international

Table 4 Table 4 relates to all water-borne vessels, whether they operate on the sea, on rivers or lakes. Although this table gives clear guidance, the approach is rather theoretical. In order to be able to apply these criteria, it is necessary to have sufficient statistical data (e.g. on passenger or cargo drop-off and pick-up). When this is not the case, a country may use another more feasible approach. This country is obliged to describe clearly the methodologies and assumptions that have been used.

Thus far Belgium has not used the IPCC Good Practice guidelines, but it recognizes the problem of inconsistencies due to unclear terminology. To overcome the problem the following attempts will be made in the near future:

- The use of the existing definitions of the International Energy Agency (IEA) and EUROSTAT for international and national shipping;

[4] Paragraph 24 of the guidelines attached to decision 18/CP.8; see FCCC/CP/2002/8 and FCCC/SBSTA/2004/8

- A clear fine-tuning of the terminology used by the Federal Energy Administration and the Custom Administration based on the different output documents for national and international shipping:
    - National (inland navigation + intra-European shipping): output document type ACC4;
    - International: output document type EX7.
- Standard documents for the data suppliers with clear definitions to avoid inconsistencies.

Furthermore it is worth mentioning that by using a bottom-up methodology based on shipped ton kilometres (VRIND-statistics) for the national shipping emissions this problem is already partly solved. Problems will still exist however for the calculation of the international shipping emissions if no clear definitions are defined.

3.5.2. Sectoral approach

The CORINAIR Technical Unit followed by the European Topic Centre on Air Emissions (ETC/AE) has been working closely with the IPCC/OECD/IEA to ensure compatibility between the joint EMEP/CORINAIR Emission Inventory Guidebook and reporting formats and the IPCC Guidelines and reporting formats. This was achieved by means of the preparation by ETC/AE of the revised SNAP97, distributed in 1998. 'SNAP' stands for the 'Selected Nomenclature of Air Pollution' and was developed as part of the CORINAIR project for distinguishing emission source sectors, sub-sectors and activities. SNAP97 is fully in line with the IPCC Guidelines (1996).

Within SNAP97 all shipping activities, whether at sea, in port or on inland waterways are included under sector 08 'Other mobile sources and machinery'. All ships, including fishing vessels, of more than 100 gross tonnes are covered. The emissions should be split as follows (EEA, 2004):

- Shipping activities (SNAP sub-sector 0804)
- National Sea Traffic (SNAP 080402)
- National Fishing (SNAP 080403)
- International Sea Traffic (SNAP 080404)
- Inland Waterways (SNAP sub-sector 0803).

The relationship between SNAP97, NFR and the CRF (IPCC) formats is included in table 5.

Currently VITO already makes a difference between international, national inland navigation, national coastal navigation and sea fisheries in its calculations. In this way the separate estimations are already available, but not always reported separately. Attention should go to a clear distinction between international and national marine activities and to more detailed methodologies based on high quality data specified for each sector (per engine type and fuel type).

In this way the lack of port emission estimates, the underestimation of fuel bought by fishing vessels, an insufficient detailed calculation of passenger transport emissions and a generalist approach of average energy use per kilometre can be avoided. This demands additional guidance regarding the fuel consumption data used for the inventory process and the estimation of emissions from fishing activities and non-commercial ships.

Table 5 : Comparison codes used in SNAP97, CRF and NFR

Sector 08. Other mobile Sources and Machinery

SNAP97 code	Sub-Sector/ CORINAIR activity	UNFCCC/ CRF	LRTAP/ NFR2002	Reporting Detail
0801	Military	1A 5b	1A 5b	Other, mobile (including military)
0803	Inland waterways	1A 3d	1A 3dii	Transport-Navigation, National Navigation
080301	Sailing boats with auxiliary engines	1A 3d	1A 3dii	Transport-Navigation, National Navigation
080302	Motor- & workboats	1A 3d	1A 3dii	Transport-Navigation, National Navigation
080303	Personal watercraft	1A 3d	1A 3dii	Transport-Navigation, National Navigation
080304	Inland goods carrying vessels	1A 3d	1A 3dii	Transport-Navigation, National Navigation
0804	Maritime activities			
080402	National sea traffic	1A 3d	1A 3dii	Transport-Navigation, National Navigation
080403	National fishing	1A 4c	1A 4cii	Small combustion – Agriculture/forestry/fishing
080404	International sea traffic (international bunkers)	1A 3d	1A 3di	Transport-Navigation, International marine (bunkers)

3.5.3. Distinction in fuel and engine type

For both international and national shipping, statistical data should be collected per fuel type (distillate oil versus residual oil). The allocation of national residual oil from local bunkering to the international bunkers should be avoided. A differentiation of the data by fuel and engine type is desirable, especially for the estimations of SO_2 and NO_x emissions.

The average sulphur content may be obtained from national sources. Values may also be obtained from organisations such as CONCAWE, DNV or Lloyd's Register. In the absence of specific information on fuel sulphur content, the following default values may be used [*Lloyd's Register, 1995*]:

- 2.7% (by weight): residual fuel oil;
- 0.5% (by weight): distillate fuel.

Standard documents for the data suppliers should be drawn up to avoid inconsistencies in the data.

3.5.4. Data deliverance

With respect to data deliverance the following recommendations should be taken into account:

- Standardisation of documents for data gathering by suppliers;
- Orderly and easily accessible electronic databases on traffic patterns (ton kilometres cargo and passengers), fuel consumption, etc.;
- Quality control of the delivered data;
- Regular reporting without delay.

3.5.5. Other recommendations

Spatial and temporal division of the emissions is recommended. For example a higher activity of fishing and passenger cruises can be expected in the summer months. Spatial division is obtained by ship movement methodology.

4. DATA ANALYSIS

A bottom-up emission quantification study requires as much information as possible regarding ship movements, shipping routes and ship characteristics to obtain a predetermined accuracy level. This data is provided by several sources like national authorities, private companies, questionnaires and the internet. After analysis, adaptation and correction if necessary, all information is processed into calculation models. Due to analysis and comparison with other data sets, we are able to determine accuracy, advantages and disadvantages of each data source.

The IVS-SRK system is one of our main data sources next to the port databases, pilotage authorities, shipping companies, Lloyd's register, internet shipping schedules and seafarer questionnaires.

4.1. DATA SOURCES

4.1.1. IVS-SRK system

The IVS-SRK data system is the basis for the quantification of sea emissions and is provided by the Vessel Traffic System (VTS) administration. Data is delivered in an

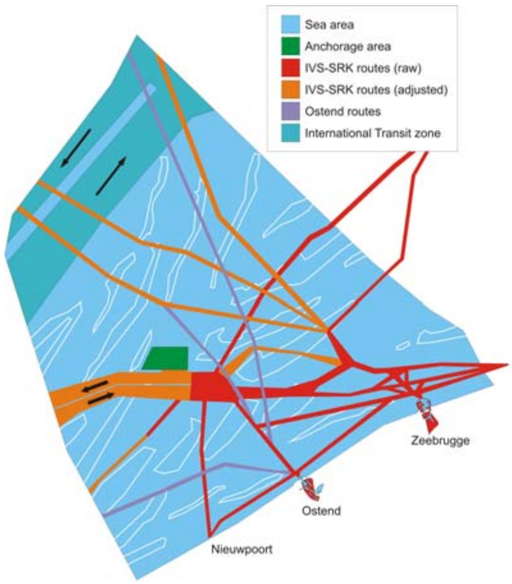
Access database format and is rather complex. Several steps are necessary in order to meet the goal of the project. During this process a number of problems have been encountered.

4.1.1.1. Geographical coverage of the IVS-SRK data system

The IVS-SRK data system covers the Belgian and Dutch part of the North Sea from Nieuwpoort at the western end till Domburg (Zeeland, Netherlands) in the north and the Scheldt river until the Kallo lock in the east. In the framework of this project, analysis of the IVS-SRK database is restricted to the Belgian part of the North Sea and all ship movements outside the Belgian part of the North Sea have been excluded from the database.

The IVS-SRK database also contains the ferry movements sailing to/from Zeebrugge (four ferry routes), but not the ones to/from Ostend. The ferry data (including the different ferry routes and their location) and the ship movements on the different ferry routes are collected additionally. Due to the fact that the ferry routes as indicated by IVS-SRK are too simplified and not accurate, corrections are necessary. For instance, based on information from the shipping companies and crews, the northerly ferry route to/from Zeebrugge is divided into three separate shipping lanes (Noordhinder (original), Westhinder and Westhinder Gap respectively), each covering a certain percentage of the original northerly route. The same type of information presents an overview of all ferry movements sailing to/from Ostend, which are not included in the IVS-SRK data system, identifying three additional routes (Buitenratel, Noordhinder and Westhinder Gap). Furthermore the ships on these routes are given a ship type code.

Figure 5 : Shipping lanes in the Belgian part of the North Sea



All ships from Ostend are identified as Ro/Ro (ship type 4) or RoPax (Ship type 9). For the two newly identified routes from Zeebrugge, the ships are divided equally between ship type 4 (Ro/Ro, car carriers), ship type 9 (RoPax) and ship type 8 (passenger ships).

The IVS-SRK data system does not cover the Noordhinder Traffic Separation Scheme (TSS) west-east northbound traffic route, with vessels sailing through the Strait of Dover to and from British or Northern European ports and passing through the northern part of the Belgian North Sea.

4.1.1.2. Screening for relevant tables and fields

The IVS-SRK database contains a lot of information that is relevant to the administration, but that is of minor use for the project. A selection of relevant tables has to be made, including the following: prediction point, vessel-voyage, dangerous-material, geo-point and block table.

- Prediction point: contains all passage points (prediction-points, geo-points or way-points) crossed by the ship during its voyage: every time a ship passes a prediction point a new record is introduced into the database. A (shipping) route segment is defined as the segment between 2 prediction points (e.g. NEAK-SWTH2). The table prediction-point of the original database (period of one year between April 2003 and March 2004) contains 1,572,765 records.
- Vessel-voyage table: information per voyage about anchorage and ship characteristics such as ship type, name agent, destination, double hull, dead weight tonnages, mast height, draught, etc…
- Dangerous-material table: information per voyage about dangerous material on board, the UN-number, IMO-code, material, quantity, etc… is given.
- Geo-point table: contains the different geographic points (abbreviation and geographical position of the several prediction points), distinguished by the IVS-SRK database.
- Block table: The IVS-SRK system divides its covered area in 26 blocks (e.g. RZ, CA, KN). Each block contains several geo-points. Geo-points situated inside a

block are called after the block. Geo-points located on the dividing line between two blocks are named after the two blocks separated by an oblique line (e.g. RZ/KN).

4.1.1.3. Adaptation of coordinates of route segments

Based on previously discussed tables (prediction-point, geo-point and block table) of the IVS-SRK database, existing route segments are assigned in GIS. In some cases, the geographical positions of some route segments have to be adapted as in the following examples:

Normally the route segments in opposite direction (e.g. OO-WN/OO2, WN/OO2-OO) are lying on top of each other, but there are some exceptions:

- The TSS in the block "Wandelaar": outward bound vessels are obliged to navigate in the northern part of the separation scheme, while inward bound vessels are obliged to navigate in the southern part of the separation scheme.
- For the route segments situated in the extended area of the separation scheme (area between A1 and SCH/Z) a distinction was made between the route segments of opposite direction.
- Two prediction points are not always connected by a straight line. The aim is to situate created route segments in the existing shipping routes and in the right direction;
- According to the bathymetry[5];
- The prediction points NP and OO are situated on land and have been moved into sea (port entrance of Nieuwpoort and Ostend respectively);
- The prediction point THBA is moved in NW-direction in order to coincide with the navigation route;
- Sometimes a prediction point is represented by the IVS-SRK by a line, with top and end coordinates of that line. In this case the coordinates of the centre of the line is taken;
- For the prediction points A1, WNP, WN/RZ4, WN/RZ3 two prediction points are distinguished, one for every direction.

4.1.1.4. Identifying classes and exclusion of data

For the emission quantification calculations, some distinctions have to be made:

Ship types: the ship type is represented in the database by a letter code with varying length. For some ships no data is available on the ship type or they can not be dedicated to a major ship type (e.g. dock, slipway, crane, pontoon, etc.). They are classified respectively as ship type 0 (ST0) and ship type 14 (ST14). Both ST0 and

[5] Characteristics of the sea-bed: bathymetry is the underwater equivalent for topography

ST14 are excluded from the analysis. 13 ship types (ST1 to ST13) are taken into account for further analysis.

Other excluded data from the database:

- route segments that deviate from the "normal" routes and where either impossible data (e.g. due to bathymetry) or where part of voyages are intermittent prediction points should be registered but are not present in the database;
- route segments with the same start and end point due to drift of the ship or returning of the ship (false loops).

4.1.2. Port databases

Every Belgian sea port keeps an individual database providing all time and ship data to agents. Except for APICS, they are all accessible by the internet but only exportable with permission of the port authorities. **APICS** is the ICT system of the Port of Antwerp like **ENIGMA** is for the Port of Ghent, **ENSOR** for the Port of Ostend and **ZEDIS** for the Port of Zeebrugge.

Because the database structure is less complex than the IVS-SRK database and the provided data is too raw to be employed in access files, we use Excel for the data processing. During these calculations several shortages are identified, such as errors and incomplete data. Obvious errors are excluded from further calculations but it is impossible to guarantee that all errors are identified and removed. By using large numbers of data, the total error rate is reduced maximally. For some ship types, with a limited amount of gathered data, results are compared to ship types in similar situations to estimate their probability. These data sets provide information regarding average and annual lay, hauling and manoeuvring times per ship type in every port. Time values are determined by calculating the sailed time between port entry/exit points and berths. Calculations could be very simple if the available data would be more correct. The four sea port databases employ a similar data system but have no common key code linking them to other databases, for example, the IVS-SRK data system. The LIS code, referring to the pilotage database linked to the IVS-SRK, is not used by all port databases.

4.1.3. Shipping companies

The IVS-SRK database covers about 80% of all vessel voyages in the Belgian part of the North Sea. It includes ferry movements except for Ostend ferries. The ferry movements for Ostend represent about 16% of the total number of ship movements in the Belgian part of the North Sea (9,048 ferry movements per year). Data concerning these ferries is accessible on the internet via the website of the port of Ostend[6]or via the

[6] Port of Ostend: http://www.portofostend.be

shipping companies themselves. Apart from exceptional circumstances these schedules are 100% correct.

The remaining percentage of ship movements (4%) include dredgers and tugboats and are mainly discussed in the group 2 methodology employing fuel consumption data. This data is provided by shipping companies or the coordinating organisation. The accuracy depends on the desired degree of detail.

4.1.4. Lloyd's Register of Shipping

This data set, providing ship characteristics of all vessels worldwide above 100 GT, enables us to determine the average installed engine power per vessel registered by the IVS-SRK system. The Lloyd's Register offers an excellent coverage of data with regards to main engines (average 98%) as opposed to auxiliary engines (average 19%) and auxiliary generators (average 48%). This lower availability has direct consequences for the error rate of the emission quantification study because the installed engine power is one of the major factors.

Table 6 : Data availability in the Lloyd's Register (not applicable for LNG vessels or fishery)

Ship type	ME	AE	AG
Oil tankers	99%	23%	52%
Chemical tankers	99%	25%	55%
Gas carriers	99%	13%	55%
RoRo cargo	93%	29%	76%
Dry bulk carriers	99%	12%	36%
General cargo	100%	16%	47%
Containers	100%	10%	57%
Passenger	97%	23%	36%
RoPax	100%	22%	39%
Reefer	99%	28%	57%
Other dry cargo	93%	13%	48%
Towing/pushing	94%	18%	35%
Dredgers	100%	9%	35%
Average availability	**98%**	**19%**	**48%**

4.1.5. Seafarer questionnaires

In order to obtain correct and detailed nautical information regarding navigational habits in the Belgian part of the North Sea we performed field research with a selection of seafarers and fishermen. These include experienced captains from different ferry operators, coastal or sea pilots and fishing boats. Second, the experts check the maps and results published in this report on nautical correctness and probability.

4.2. COMBINING DATABASES

Due to the lack of a common key code we are not able to link all provided data sets into one national database covering all ship movements in port and at sea. Each database is set up per authority without mutual consultations because every data system has its own objectives and customers.

The IVS-SRK database is identified as the most favourable central data set due to its extensive number of data. Other data sources are used to expand, to change or to add a degree of detail to the central database. For example, the routes presented in the IVS-SRK system are abstract and do not correspond to the reality. Therefore we can use the seafarer's questionnaires in combination with sailing schedules to complete and correct the IVS-SRK routes and their frequencies.

4.3. CONCLUSION

The Belgian part of the North Sea is not covered by an extended and available data set ready to perform emission quantification studies. The IVS-SRK data system is of primordial importance but does not cover the whole study area. For the reference period of the study, the IVS-SRK data system does not cover the Noordhinder TSS (Northbound route) and not all shipping activities are covered. Therefore, other data sets are compulsory to complete the IVS-SRK database and, at a later stage, to add corrections and more detail.

Nowadays, the AIS (Automatic Identification System) database, also operated by the Scheldt VTS centre, is able to provide more accurate information and for a more extended area than the IVS-SRK data system. Recent developments like AIS (private and public systems) and European cooperation regarding ship tracking systems[7] appear to provide promising data sources for future emission quantification studies in these regions.

[7] Safety @ Sea project and EMSA (European Maritime Safety Agency)

5. EMISSIONS AT SEA

5.1. DATA ACQUISITION

5.1.1. Study area

The total sea area of the Belgian part of the North Sea is estimated at 3,600 square kilometres. Only a small percentage is accessible for the major part of the world merchant fleet. These shipping lanes to the Belgian coast and the river Scheldt run through the Flemish Banks, a hazardous area for shipping in general. Therefore Belgian and Dutch authorities plan safe shipping routes, indicated by an impressive amount of beacons, and organise pilot services guiding foreign crews safely through this hazardous area.

The Belgian, French, Dutch and British authorities have taken the organisation of shipping in the southern North Sea and English Channel one step further by implementing a Traffic Separation Scheme (TSS) in order to improve safety at sea.

As a result of the pilot services and the TSS, all shipping is concentrated on a limited number of routes. This means that not all navigable areas in the Belgian part of the North Sea are used for merchant shipping and only smaller vessels, other than merchant ships, diverge from the provided route system.

Within the route system, between the TSS and the pilotage area, an anchorage zone is established south of the Westhinder Bank, named Westhinder anchorage. It is situated near Wandelaar pilot station and receives all vessels waiting to enter the final lap to their destination.

5.1.2. Data categories

As mentioned before, the Belgian part of the North Sea lies in one of the most trafficked areas in the world. This marine traffic is divided into four categories depending on data availability:

- Category 1: All seagoing merchant vessels, including dredgers and tugs in non operational conditions but excluding category 2 (IVS-SRK vessels)
- Category 2: The ferry lines sailing to and from Ostend (including passenger and cargo ferries) because these are not registered in the database of the radar chain along the Belgian and Dutch coast.
- Category 3: Local shipping, bound to one specific area or project such as sea dredgers.
- Category 4: All other vessels. It includes inland navigation, naval vessels and other seagoing specialised constructions such as hovercrafts, cranes, docks and pontoons. This category, however, is excluded within this study. The amount of extra work that the research in this ship category would require is outweighed by

the small portion of emissions that these vessels represent, i.e. the installed power of one large container vessel is equal to the entire Belgian fishing fleet (61.596 kW) [*FOD Mobiliteit en Vervoer, 2004*] and ship emissions are directly related to the engine power of a ship. (IMO, EU and UNFCCC also exclude naval and state owned vessels from all emission regulations or proposals for guidelines.) Because the data on fishery is available, it is decided to incorporate it any way.

Within category 1 there are two classes identified; all registered by the IVS-SRK database:

- All vessels berthing in a Belgian port or a port along the river Scheldt.
- All ferries[8] sailing to Zeebrugge, Ghent, Antwerp and Zeeland Seaports[9].

The data regarding category 2 and 3 is easy accessible. Ferries have fixed time schedules and routes that can easily be retrieved. Regarding category three, the total fuel consumption per year or per project is requested from the different companies and allocated for a port or project area. For example, tugboats are bound to one port and their emissions are included in the port emissions.

5.1.3. Data deficiency

The IVS-SRK database originally covers all ship activities on the eastern side of the Belgian part of the North Sea sailing to Zeebrugge, Ghent, Antwerp and Zeeland Seaports. Since 1 March 2005, with the activation of the Oostdyck radar post, the covered area is expanded to the total Belgian territorial sea and a part of the contiguous zone but this expansion is done too late to make use of in this study.

A dense shipping traffic passes the Belgian coast within the Belgian Exclusive Economical Zone (EEZ), more specific on the northbound fairway of the Noordhinder TSS. The southbound fairway is largely situated in the British part of the North Sea and partly on Belgian territory. This international TSS is monitored by the Belgian/Dutch (since 1 March 2005) and English VTS centres but no data on ship movements is registered. Recently the Lloyd's Register started its AIS-system, recording all ship movements in several areas, including the Noordhinder TSS. This system has not yet been operational during the ECOSONOS study period. Another option is the LMIU (Lloyd's Maritime Intelligence Unit) database that estimates ship frequencies per route based on information of shipping agencies. This data can complete our data on ship movements for the deep-sea marine traffic but is unfortunately too expensive.

Further west, at Dover Strait, this transit route is controlled closely by the VTS centres of Dover and Calais. A cooperation between British and French VTS authorities resulted in the MancheRep database. The French coastguard controls the northbound

[8] Definition: Ro/Ro and RoPax vessels sailing several times a week between two ports on a fixed time schedule.
[9] Zeeland Seaports is a union of the ports of Flushing and Terneuzen.

lane while the British monitor the southbound lane. With some adjustments it is possible to estimate the number of vessels sailing through the Belgian part of the Noordhinder TSS.

If we manage to compile a database, covering all shipping in the international TSS and the IVS-SRK area, we will have an accurate overview of all ship movements in the Belgian part of the North Sea. With this dataset it will be possible to perform emission quantification in the northern area of the Belgian part of the North Sea that is currently not included in the study.

5.2. Quantification of "sea emissions"

"Sea emissions" are divided into emissions from (1) cruising vessels, and (2) vessels at anchor; further two other types outside any category are identified: (1) fishery and (2) Liquid Natural Gas (LNG) vessels.

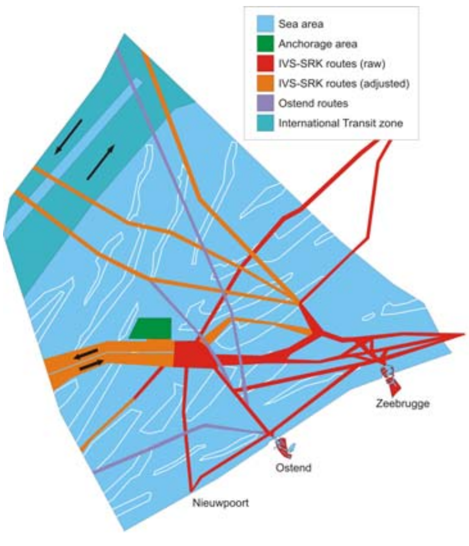
5.2.1. Emissions from cruising vessels

Cruising vessels represent all merchant ships including dredgers and tugboats that are 'under way'[10] or in non operational condition. The different categories of vessels require separate approaches for emission calculation. The categories are composed in accordance with the data source.

5.2.1.1. Ship categories

5.2.1.1.1. Category 1: IVS-SRK-vessels

Figure 6 : Overview of all regular shipping routes within the Belgian part of the North Sea



For category 1, covering largely all cruising vessels in the Belgian territorial sea, all data is provided by the IVS-SRK. This group also includes large ocean-going tugs as opposed to harbour tugs. Normally IVS-SRK also registers ferry movements, but during the ECOSONOS study period there is an insufficient coverage of the ferries sailing to and from Ostend.

Through analysing the results of the IVS-SRK data, we observe geographical inaccuracies. The routes are adjusted to reality by transposing within the beaconing system and extrapolating outside the covered area. Figure 6 shows all registered routes including the international transit zone.

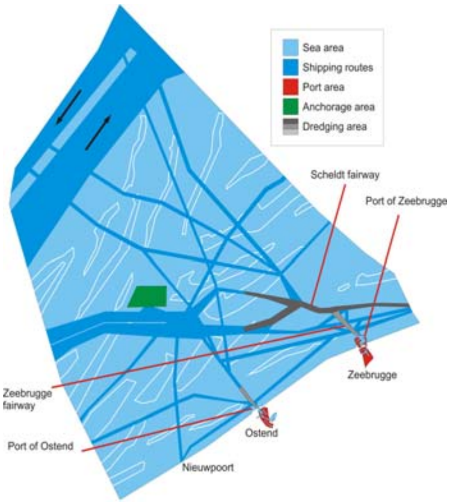
[10] Under way: a vessel that is not moored at any fixed construction or sea bottom and making speed through the water.

5.2.1.1.2. Category 2: Ostend shipping

The Ostend ferries are grouped in category 2. The emission quantification for this category is done on the basis of the time schedules from the Ostend ferry operators[11].

5.2.1.1.3. Category 3: Sea dredgers

Figure 7 : Dredging areas in the Belgian part of the North Sea



Category 3 determines by a top-down methodology the annual fuel consumption linked to a project, vessel or project area. This is the single available approach for this type of project-related vessels.

In the Belgian part of the North Sea, dredging areas are concentrated in the port fairways as shown by Figure 7. Next to these areas in the Belgian part of the North Sea, there are dredging activities more inland at the canal Ghent-Terneuzen and the Westerschelde.

5.2.1.1.4. Category 4: All excluded shipping

The study area of the ECOSONOS study is limited to merchant ships including ferries, dredgers, tugs and fishery. Certain types of vessels are not adopted in the study because there are no initiatives to incorporate these types into the international emission guidelines, such as (1) naval vessels; (2) state-owned vessels, built for other purposes than military and (3) recreational crafts.

5.2.1.2. Group 1 sea emissions

For sea emissions, a specific methodology is developed, based on the best available data with regards to the study area. The methodology is summarized in the following formula:

$$\sum \mathbf{SE_{1,st,rs}} = \sum \mathbf{(T_{st,rs} * P_{st,me} * EF_{st,rs} * LF_{st,me} / CF_{me})} + \sum \mathbf{(T_{st,rs} * P_{st,ae} * EF_{st,rs} * LF_{st,ae} / CF_{ae})}$$

Where:

$SE_{1,st,rs}$ sea emissions from ships determined according to group 1 approach per ship type and route segment;

$T_{st,rs}$ sailing time as acquired by an average speed value, multiplied with the sailed distance per route segment per ship type;

[11] Transeuropa ferries & Ferryways [http://www.portofoostende.be]

$\mathbf{P_{st,me/ae}}$	average installed main or auxiliary engine power per ship type;
$\mathbf{EF_{st,rs}}$	emission factors per ship type and activity, as determined by ENTEC [*Whall et al, 2002*] in g/kWh;
$\mathbf{LF_{st,me/ae}}$	load factor of the main or auxiliary engine, per ship type while sailing (% of MCR)
$\mathbf{CF_{me/ae}}$	a correction factor to compensate for loss of efficiency at reduced load (for main engines CF= 0.92 - for auxiliary engine CF= 0.88)

5.2.1.2.1. Sailing time

The sailing time is determined by multiplying an average speed value per ship type with the sailed distance per route segment. It is not possible to determine the speed of the vessels per route segment in the IVS-SRK database; therefore we have made an assumption of the employed speeds. This makes the assumed speed value an important factor that influences the total emission quantity. When assuming slower speeds for a ship, the sailed time and its related emissions will rise equally in this methodology. Three alternatives are identified: (1) a pilot inquiry; (2) EMEP speeds [*EEA,* 2004] and (3) ENTEC speeds [*Whall et al, 2002*].

5.2.1.2.1.1. The pilot inquiry

A questionnaire in cooperation with a number of coastal (3) and sea pilots (6) provides a clear view on speed policies per ship type and route segment. Larger, deeper and/or less manoeuvrable vessels tend to slow down in some parts of the Belgian part of the North Sea. Every route segment receives an average speed reduction expressed in percentage. Generally, a lower speed indicates lower aerial emissions for SO_2 and CO_2 but in the ECOSONOS methodology it increases sailing time and the total emission quantity. There is no international literature available concerning the change in emissions with regards to speed or engine load reduction. A Lloyd's study [*Lloyd's Register, 1995*] came close by studying this correlation but published the adapted emission factors in *kg/ton fuel*[12], lacking to integrate average fuel consumption patterns per ship type.

Even though we can not include these speed reductions in further calculations, they provide information on manoeuvring in the Belgian part of the North Sea. Two areas (route segments) are identified as general manoeuvring area: (1) Wandelaar Pilot station and (2) Westhinder Anchorage area. In these areas vessels are obliged to reduce their engine load with 50% or more. Because we use 'sea emission factors' for sailing vessels, 'port emission factors' for port operations and 'manoeuvring emission factors' for manoeuvring vessels, it is more accurate to employ the latter for the two identified areas.

[12] When adding a fuel consumption pattern, the emission factors are presented in *g/kWh*, which are used in the group 1 methodology.

5.2.1.2.1.2. EMEP & ENTEC speeds

EMEP publishes average speeds per ship type. These are in little detail but offer an average value for every ship type included in this study [*EEA, 2004*].

The ENTEC study [*Whall et al, 2002*] offers average ship speeds for 19 different ship types including the 13 ECOSONOS classes. The ENTEC values are less recent (2000) but employ a higher degree of detail. Both use the Lloyd's Register of Shipping as the source for statistical analysis.

Table 7 : Average ship speeds as published by the EMEP and ENTEC

Ship type	EMEP speeds (Kn)	ENTEC speeds (Kn)
Oil tankers	14	14.0
Chemical tankers	15	13.7
Gas carriers	16	16.8
RoRo cargo	18	15.4
Dry bulk carriers	14	14.3
General cargo	14	12.3
Containers	20	19.3
Passenger	20	20.8
RoPax	20	15.3
Reefers	20	16.9
Other dry cargo	15	13.5
Towing/Pushing	11	12.8
Dredgers	9	11.4

We can conclude that the ENTEC [*Whall et al, 2002*] values are preferable to use due to its degree of detail. On the other hand it is interesting to make parallel calculations with both speed indexes and to compare afterwards. So we do not choose one speed index but handle both, knowing that the ENTEC [*Whall et al, 2002*] values are preferable to use.

5.2.1.2.2. Average installed engine power

The engine power stands in direct relation to the amount of noxious gasses emitted by the engines. For every ship type, it is possible to determine a typical engine capacity and typical ratios between the main and auxiliary engines.

In order to calculate with more accurate data than the global values for the different ship classes, we determine average engine capacities, expressed as average installed engine power per ship type (both for main and auxiliary engine), of vessels actually sailing in the Scheldt estuary and Belgian part of the North Sea. A sample of one hundred ships (by Lloyd's number) per ship type is extracted at random from the IVS-SRK database. For these vessels, data regarding installed engine power - main and auxiliary engines - is exported from the Lloyd's database "Register of ships".

The Lloyd's Register of Ships provides 98% coverage of the installed main engine powers in our test samples, as opposed to the installed auxiliary engine power. Here the Lloyd's database provides an average coverage of just 19%. Per ship type, the highest availability we measure in our test sample is 29% for Ro/Ro cargo vessels against 9% for Dredgers. In order to render a correct average value for the auxiliary engine power of vessels in the Scheldt estuary and Belgian part of the North Sea, control test samples (one per ship type) of the auxiliary generators are extracted from the database. The power for an auxiliary generator is mostly supplied by the auxiliary engine and is estimated at on average 83% of the ships' auxiliary engine power. The auxiliary generators drawing power from the ships' main engine(s) are exempted from the test samples. Because the Lloyd's database offers a better coverage for the auxiliary generators (about 48%), it provides a good indirect indication of the accuracy of the auxiliary engine's average value.

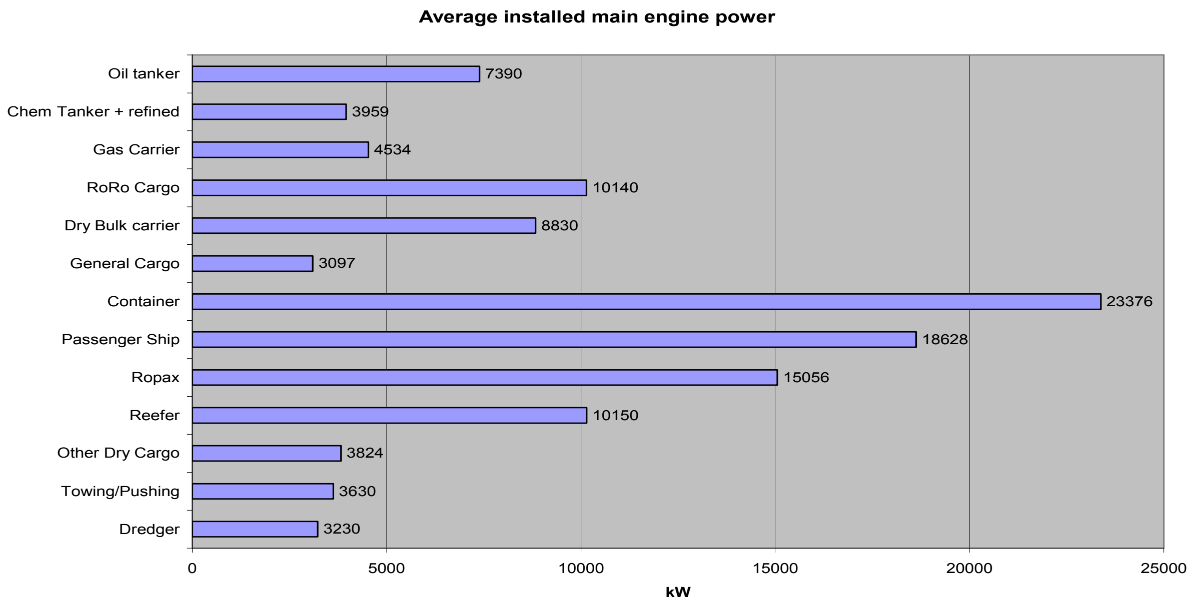


Figure 10 : The average installed main engine power (kW) for vessels in the Belgian part of the North Sea - from April 2003 to March 2004 (not applicable for LNG vessels or fishery)

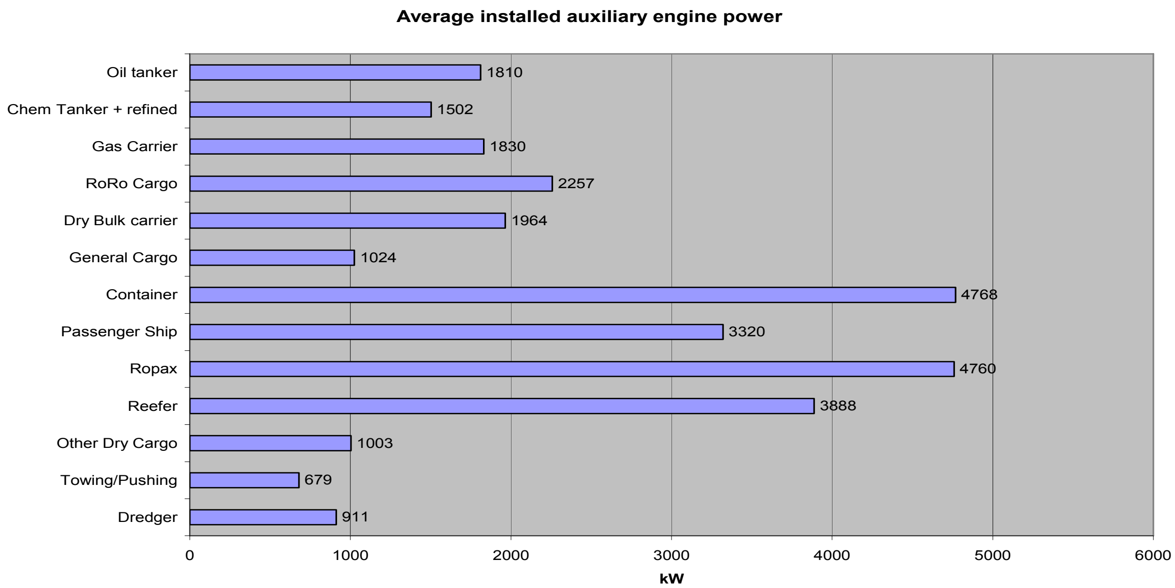


Figure 11 : The average installed auxiliary engine power (kW) for vessels in the Belgian part of the North Sea - from April 2003 and March 2004, as determined with the generator values (not applicable for LNG vessels or fishery)

We notice an important difference between the two estimates of average auxiliary engine power. The disadvantage of using the direct calculation of the average auxiliary engine power is the small number of values available in the test samples. For some ship types like tugs, RoPax and dredgers it is not possible to include more vessels in the sample because their number is limited in the Belgian part of the North Sea. The disadvantage of using the average value of the auxiliary generator, multiplied by a correction factor, is the limited accuracy of this factor.

5.2.1.2.3. Emission factors

After an extensive literary study, it is decided to employ the emission factors as published in the ENTEC study [*Whall et al, 2002*]. These are developed and based on older emission quantification studies and new statistical data. Future scenarios are incorporated producing extra emission factors per proposed guideline. At this moment, these are one of the most recent, detailed and complete emission factors published, and they give emission factors in *kg/ton fuel* as well in *g/kWh* (integrated fuel consumption pattern). This makes it possible to employ a combination of top-down and bottom-up approaches. Emission factors used in this study are developed only for the most frequently used ship types [*Whall et al, 2002*]. As a result, the ECOSONOS study is restricted to a limited number of ship types. Amongst the excluded ship types are: docks; grid-iron; marine railway; slipway; sailing (of minor importance to an emission study); factory ship; pontoon; research vessels; (semi) submersibles; hydrofoils; A.C.V (Air Cushioned Vessel); platforms; diving vessels.

Table 8 : Emission factors for 'at sea' operation regarding ship type [Whall et al, 2002] (g/kWh)

Ship type	NO_x	SO_2	CO_2
Oil tankers	14.9	11.7	689
Chemical tankers	16.5	11.0	645
Gas carriers	8.5	12.4	822
RoRo cargo	15.6	11.2	659
Dry bulk carriers	17.9	10.6	624
General cargo	16.3	10.9	644
Containers	17.5	10.7	631
Passenger	13.2	11.7	696
RoPax	13.3	9.8	686
Reefers	17.4	10.7	631
Other Dry cargo	11.1	12.9	757
Towing/pushing	13.7	10.8	673
Dredgers	14.1	11.4	674

5.2.1.2.4. Load and correction factors

The load factor (LF) and correction factor (CF) are necessary to adjust the ENTEC [*Whall et al, 2002*] emission factors to the specific situation in the Belgian part of the North Sea. The load factor compensates for a specific activity of the vessel. This implicates that the main or auxiliary engine is not always running on full capacity. For the main engine this will depend on whether the ship is cruising, manoeuvring,… For the auxiliary engine this mainly depends on the ship type. For instance, container vessels use auxiliary engines for powering refrigerated containers, while passenger ships need more electricity to provide services to the passengers. The specific load factors are mentioned in table 9. These figures have been discussed with experts [*pilots, harbour masters, Antwerp Maritime Academy*] and adjusted according to their advice.

A correction factor is introduced to compensate for the loss of efficiency at reduced load. This is only done in cases where the engine load is different than 80%, as this is considered as the most efficient load. While the relationship in reality is not linear, the figures where checked and this method was confirmed by expert advice *[L. Cappoen]*.

Table 9 : Load and correction factors at sea per ship type

	Load factor		Correction factor	
Ship type	**ME**	**AE**	**ME**	**AE**
Oil tankers	80%	30%	0.92	0.88
Chemical tankers	80%	30%	0.92	0.88
Gas carriers	80%	60%	0.92	0.88
RoRo cargo	80%	30%	0.92	0.88
Dry bulk carriers	80%	30%	0.92	0.88
General cargo	80%	30%	0.92	0.88
Containers	80%	50%	0.92	0.88
Passenger	80%	70%	0.92	0.88
RoPax	80%	70%	0.92	0.88
Reefers	80%	60%	0.92	0.88
Other Dry cargo	80%	30%	0.92	0.88
Towing/pushing	35%	10%	0.88	0.88
Dredgers	80%	10%	0.88	0.88

5.2.1.2.5. Results

The results of the 'sea emissions' as calculated in group 1 are shown in the table 10. It is interesting to remark that the results making use of the EMEP [*EEA, 2004*] speed assumptions are about 7% lower compared to using ENTEC [*Whall et al, 2002*] figures. However, both give the same tendency. The two main polluters are: Ro/Ro cargo and container vessels.

Table 10 : Group 1 estimated sea emissions in the Belgian part of the North Sea, per ship type and exhaust gas (kton/year)

	EMEP			ENTEC		
Ship type	**NO_x**	**SO_2**	**CO_2**	**NO_x**	**SO_2**	**CO_2**
Oil tankers	0.446	0.350	20.608	0.446	0.350	20.608
Chemical tankers	0.770	0.513	30.260	0.805	0.536	31.652
Gas carriers	0.303	0.443	29.346	0.297	0.433	28.717
RoRo cargo	6.703	4.813	283.168	7.390	5.305	312.165
Dry bulk carriers	1.289	0.763	44.919	1.275	0.755	44.458
General cargo	1.594	1.066	62.961	1.707	1.142	67.451
Containers	7.879	4.818	284.099	8.006	4.895	288.676
Passenger	0.079	0.070	4.173	0.078	0.069	4.115
RoPax	1.897	1.398	97.854	2.449	1.804	126.307
Reefers	0.946	0.581	34.289	1.013	0.623	36.739
Other dry cargo	0.072	0.838	4.916	0.076	0.089	5.214
Towing/Pushing	0.021	0.016	1.010	0.018	0.014	0.868
Dredgers	0.347	0.281	16.588	0.274	0.222	13.097
Total	**22.345**	**15.195**	**914.190**	**24.025**	**16.250**	**1008.493**

5.2.1.3. Group 2 sea emissions

In group 2, 'sea emissions' are determined by applying a top-down approach. Group 2 considers only two classes of vessels that are not fully covered by the IVS-SRK system. This includes dredgers / port maintenance vessels and harbour tugs[13] during operations (dredgers involved in a project, tugs towing or pushing a client vessel). When not involved in any operations, these types of vessels are also registered in the IVS-SRK system. Tracking ship movements of these vessels during operations would require a more accurate recording system. The methodology as employed in group 2 'sea emissions' is presented in the following formula:

$$\sum \mathbf{SE_{2,st,pa}} = \sum \mathbf{F_{st,pa}} * \mathbf{EF_{st}}$$

Where:

$SE_{2,st,pa}$ sea emissions from ships determined according to the group 2 approach per ship type and project area;

$F_{st,pa}$ fuel consumption as provided by ship or project operators per ship and project area;

EF_{st} emission factors per ship type as determined by ENTEC [*Whall et al, 2002*] and in kg/ton fuel;

Due to additional information regarding the different project areas, we are able to link the calculated emissions to certain geographical zone, i.e. dredgers to dredging areas

[13]Because harbour tugs largely operate within port boundaries, they are not included in the 'group 1 - sea emissions'

and port maintenance vessels and harbour tugs to port areas. It is not as accurate as employing a bottom-up approach, but it offers indications relative to project areas and other ship types, plus it gives us the possibility to divide 'group 2 emissions' into sea emissions and port emissions. Finally, the quantification of these emissions is important because of their proximity to port, residential and agricultural areas.

Group 2 sea emissions only involve dredgers and include two project areas: (1) Scheldt fairway and (2) Zeebrugge fairway (connection between port of Zeebrugge and Scheldt fairway).

Table 11 : Group 2 estimated sea emissions in the Belgian part of the North Sea, per exhaust gas (kton/year)

	NO_x	SO_2	CO_2
Zeebrugge fairway	0.222	0.245	14.417
Scheldt fairway	0.259	0.286	16.819
Total	**0.481**	**0.531**	**31.236**

5.2.2. Emissions from anchored vessels

Next to a couple of smaller emergency anchorage areas, the Belgian part of the North Sea offers one official anchorage zone. The Westhinder anchorage zone is used by all types of ocean-going vessels sailing to a Belgian port or Scheldt estuary. Waiting times depend on the availability of pilot services, cargo or berth in port. It is situated at the eastern end of the Westhinder TSS at Wandelaar Pilot Station. Vessels anchored in the Westhinder anchorage zone keep their main engine at 'standby' position, reducing main engine load to a minimum (±5%), to be able to react instantly in case of emergency (collision, dragging anchor, etc…). The load of the auxiliary engines remains the same as during cruising (±30%). All ships anchoring in the Westhinder area are controlled by the Belgian/Dutch VTS system and recorded in the IVS-SRK system. This data set allowed us to determine an average anchoring time and number of anchorages per ship type. The average anchoring time gives a distorted view of the anchoring times. Most vessels anchor for short periods but the average value becomes much higher due to vessels anchored for periods up to a week and more. Multiplying the average anchoring time and the number of anchored vessels, we obtain the anchoring time per ship type.

Table 12 : Assumptions regarding engine operation for the different activities and IVS-SRK data regarding the Westhinder anchorage during the study period (April 2003 – March 2004)

Ship type	% load of MCR for ME operation	% load of MCR for AE operation	Average anchoring times	# of vessels anchoring
Oil tankers	5%	30%	15:25	111
Chemical tankers	5%	30%	6:08	28
Gas carriers	5%	60%	13:20	81
RoRo cargo	5%	30%	7:19	25
Dry bulk carriers	5%	30%	11:09	105
General cargo	5%	30%	8:42	120
Containers	5%	50%	6:51	93
Passenger	5%	70%	No data	0
RoPax	5%	70%	No data	0
Reefers	5%	60%	8:57	16
Other dry cargo	5%	30%	No data	0
Oil tankers	5%	10%	2:35	1
Chemical tankers	5%	10%	0:19	1

The methodology to quantify the amount of emissions exhausted by vessel at anchor is summarised in following formula:

$$\sum AE_{1,st} = \sum (T_{st} * P_{st,me} * EF_{st,az,me} * LF_{st,me} / CF_{me}) + \sum (T_{st,az} * P_{st,ae} * EF_{st,az,ae} * LF_{st,ae} / CF_{ae})$$

Where:

- **$AE_{1,st}$** anchoring emissions from ships determined according to the group 1 approach per ship type;
- **T_{st}** anchoring time as acquired by the IVS-SRK database per ship type
- **$P_{st,me/ae}$** average installed main or auxiliary engine power per ship type;
- **$EF_{st,az,me/ae}$** emission factors per ship type and anchorage zone as determined by ENTEC [*Whall et al, 2002*] in g/kWh. For anchorage emission quantification we employ 'in port' emission factors for main engines and 'at sea' emission factors for auxiliary engines;
- **$LF_{st,me/ae}$** load factor of the main or auxiliary engine, per ship type when at anchor
- **$CF_{me/ae}$** a correction factor to compensate for loss of efficiency at reduced load

Table 13 : Estimated emissions for anchored vessels in the Westhinder anchorage area, per ship type and exhaust gas (kton/year)

Ship type	NO_x	SO_2	CO_2
Oil tanker	0.001003	0.000882	0.051947
Chemical tanker	0.000081	0.000059	0.003460
Gas carrier	0.000561	0.000846	0.056012
Ro/Ro cargo	0.000146	0.000118	0.006916
Dry bulk carrier	0.000908	0.000628	0.036931
General cargo	0.000345	0.000254	0.015034
Container	0.001723	0.001179	0.069428
Passenger ship	0	0	0
RoPax	0	0	0
Reefer	0.000320	0.000209	0.012348
Other dry cargo	0	0	0
Towing/Pushing	0.000000	0.000000	0.000003
Dredger	0.000000	0.000000	0.000021
Total	**0.005088**	**0.004175**	**0.252099**

We can conclude that vessels anchored produce a negligible contribution (less than 0.1%) of the sea emissions in the Belgian part of the North Sea.

5.2.3. LNG vessels

Liquefied Natural Gas (LNG) vessels use their cargo boil off for propulsion purposes instead of traditional marine fuel types. While natural gas is formed primarily of methane, it can also include some very small quantities of ethane, propane, butane and pentane. In its purest form, such as the natural gas that is delivered to your home, it is almost pure methane. This implies that LNG vessels consume a 'clean' fuel with regards to emissions of NO_x and SO_2. During MEPC 53 Admiral Robert C. North (Marshall Islands) presented emission calculations of one LNG tanker and 30 oil tankers, based on the actual fuel they consumed and on actual voyage data. Among other results, the data shows that the use of boil off on LNG tankers gives a very high CO_2 index: three to four times higher than on oil tankers with combustion engines for propulsion [*IMO, 2005b*].

5.2.3.1. LNG vessels sea emissions

The Belgian part of the North Sea counts two LNG vessels frequently sailing to Zeebrugge. During the study period, those two vessels performed 99 voyages. If we calculate emissions for these vessels according to the ECOSONOS group 1 methodology for gas carriers, we obtain the results in table 16. Though, following the LNG study presented during MEPC53 [*IMO, 2005b*], we must conclude that NO_x and SO_2 emissions should be practically zero, while CO2 emissions should be multiplied up to four times resulting in about 22 kton/year instead of 5.5 kton/year. For the estimations, we apply a factor 3.5 for CO_2 emissions; SO_2 and NO_x emissions are considered to be zero (table 17).

Table 14 : Theoretic emissions from LNG vessels in the Belgian part of the North Sea from April 2003 to March 2004 (ton per year) – using standard emission factors

	NO_x	SO_2	CO_2
Vessel A at sea	24.393	35.585	2,358.967
Vessel B at sea	28.355	41.364	2,742.059
Total sea emissions	**52.748**	**76.950**	**5,101.026**

Table 15: Estimated emissions from LNG vessels in the Belgian part of the North Sea from April 2003 to March 2004 (ton per year) – taking specific LNG specification into account

	NO_x	SO_2	CO_2
Vessel A at sea	0	0	8,256.385
Vessel B at sea	0	0	9,597.207
Total sea emissions	**0**	**0**	**17,853.59**

5.2.4. Fishery

Originally it was not foreseen to incorporate fishery emissions because of the limited combined engine capacity of the Belgian fishing fleet, but because of the data has become available it is decided to incorporate fishing emissions estimates. The estimate only takes into account the emissions of Belgian fishing vessels sailing and trawling in the Belgian part of the North Sea. Neither emissions from non-Belgian fishing vessels sailing in the Belgian part of the North Sea, nor emissions of Belgian fishing vessels outside the Belgian part of the North Sea are taken into account. Following, the methodology and results are briefly described. The whole report [*Goerlandt, 2006*] can be found in annex to this report.

5.2.4.1. Fishery methodology

In estimating the fishing emissions and because the fleet consists of a limited amount of vessels and consequently the data is rather limited it was possible to compare two different methodologies and compare the results with each other:

- Fuel consumption methodology
- Ship movement methodology

The fuel consumption methodology can be used for estimating the emissions of the Belgian fishing fleet without significant problems, as far as reliable data on the fuel consumption is available. Several paths were followed to determine the fuel use from individual vessels or vessel classes. A drawback using this method is that no distinction can be made between fishing and sailing activity, and that a spatial distribution of the emissions is not readily available. Therefore, this calculation shall be performed as a check on the results of the more thorough ship movement methodology.

The ship movement methodology is the most detailed procedure, as it can take into account the location of the vessel activity and the nature thereof. The distinction between sailing and trawling is important, as the fuel use, the used engine power and engine speed, and consequently some emission factors and emissions vary with these activities. It is this method that will lay at the basis of the emission estimates: the spatial distribution will be made using the ship movement data and one of the methods for determining the fuel consumption is directly linked to the duration of sailing and trawling activities, taking into account relevant characteristics of both main and auxiliary engines.

Concerning the comparison of the results obtained in this study with results available from VMM [*VMM, 2004*], it shows that for a number of pollutants, the estimates of both studies are within reasonable range. However, for other substances, the results differ quite considerably, leading to the conclusion that one of the estimates (or both, for that matter) is fundamentally wrong.

5.2.4.2. Fishery sea emissions

The fishery data is calculated for the Belgian fishing fleet. At the same time, there is made a spatial distribution of the emissions allowing attributing a specific percentage of the total emissions to the Belgian part of the North Sea. The rest is emitted outside the Belgian part and is therefore of no interest to this report, though the data can be consulted in the annex to this report. According to the calculations, 4.85% of total NO_x emission estimates and 4.98% of total CO_2 and SO_x emission estimates are emitted in the Belgian part of the North Sea. All fishery emissions are considered to take place at sea.

Table 14 provides figures for both vessel movement (VM) and fuel consumption (FC) method for the whole Belgian fishing fleet. Table 15 shows the estimated emissions in the Belgian part of the North Sea. In the final sum of all emissions the vessel movement data is selected as being the most accurate.

Table 16 : Total estimated fishery emissions for the Belgian fishing fleet (in kton/year)

	NO_x	SO_2	CO_2
VM method	3.938	0.261	212.316
FC method (SMED III)	4.087	0.284	210.956

Table 17 : Estimated fishery emissions in the Belgian part of the North Sea (in kton/year)

	NO_x	SO_2	CO_2
VM method	0.191	0.0129	10.573
FC method (SMED III)	0.198	0.0141	10.506

5.3. TOTAL SEA EMISSIONS

Table 18 : Total estimated sea emissions in the Belgian part of the North Sea, per ship type and exhaust gas (kton/year)

Ship type	NO_x	SO_2	CO_2
Oil tankers	0.447	0.351	20.660
Chemical tankers	0.805	0.537	31.655
Gas carriers	0.298	0.434	28.773
RoRo cargo	7.390	5.305	312.172
Dry bulk carriers	1.276	0.756	44.495
General cargo	1.708	1.142	67.466
Containers	8.008	4.896	288.745
Passenger	0.078	0.069	4.115
RoPax	2.449	1.804	126.307
Reefers	1.013	0.623	36.752
Other dry cargo	0.076	0.089	5.214
Towing/pushing	0.018	0.014	0.868
Dredgers	0.755	0.508	44.333
LNG	0	0	17.854
Fishery	0.191	0.013	10.500
Total	**24.511**	**16.541**	**1039.908**

The total sea emissions are the sum of cruising emissions and anchorage emissions, determined with group 1 methodology together with the emissions from fishery and LNG vessels at sea. For Dredgers and Towing/pushing this figure represent their estimated emissions for sailing activities at sea in non-operational condition; this is also calculated according to the group 1 methodology.

6. EMISSIONS IN PORT

6.1. INTRODUCTION

Exhaust emissions from ships in port areas originate from two sources: (1) manoeuvring and (2) activity at the ship's berth. Building on this, we can define port emissions as "all aerial emissions from merchant ships in port areas consisting of manoeuvring emissions and emissions generated at berth."

Manoeuvring emissions include all aerial emissions from ships when arriving at or leaving their berth through docks, locks and port fairways. Manoeuvring is more energy consuming than sailing the same distance at a steady, comparable, average speed due to turning, braking and accelerating [*Saxe and Larsen, 2004*]. Determining emissions from manoeuvring vessels is a complex calculation due to variable (main) engine loads. An accurate estimation of the average engine load is important because the main engines are responsible for the majority of marine emissions as main engines represent a much higher installed power than auxiliary engines. While being moored (the lay time) the vessel runs its auxiliary engines that are smaller sized diesel engines / generators to supply the vessel with electricity and to produce the required energy to run charging and discharging installations, if required (this depends on the ship type). Due to a smaller installed power and consumption of lighter and cleaner fuels, these engines produce relatively less emissions than the main engines.

Earlier studies reveal that at-sea emissions are responsible for the majority of the marine emissions [*Whall et al, 2002; IMO, 2000*]. The worldwide international marine bunker sales (for 1996) are estimated to be 138 million ton: divided into 38 million ton distillate fuel (MDO and MGO) and 100 million ton residual fuel (HFO) [*IMO, 2000]*. Because Belgium has a relative small sea area and four sea ports (including Antwerp, the second largest port in Europe) the proportion of port emissions will significantly higher, because ships don't need to cross a large sea area before entering the port and spend consequently a relatively long time in port.

6.1.1. SO_x emissions in port

Regarding emissions from marine fuels with high sulphur content, the Council of the European Union writes [*EU, 2002*]: "Emissions from shipping due to the combustion of marine fuels with high sulphur content contribute to air pollution in the form of sulphur dioxide and particulate matter. This damages the environment through acidification, as well as harming human health, property and cultural heritage, particularly around coastal areas and in ports."

The International Maritime Organisation estimates, "Sulphur emissions from ships' exhausts at 4.5 to 6.5 million tons per year - about 4 percent of total global sulphur emissions. Emissions over open seas are spread out and their effects moderate, but on certain routes emissions create environmental problems, including English Channel, South China Sea, and Strait of Malacca."

6.1.2. NO_x emissions in port

Regarding NO_x emissions, IMO estimates: "Nitrogen oxide emissions from ships … at around 5 million tons per year - about 7 percent of total global emissions. Nitrogen oxide emissions cause or add to regional problems including acid rain and health problems in local areas such as ports."

6.1.3. CO_2 emissions in port

Amongst all GhGs, CO_2 is the most important GhG produced by human activities. CO_2 has a global impact and exerts no local influences, for example in ports. Still, the emission quantification of CO_2 from shipping is important in the light of the UNFCCC, the Kyoto Protocol and future negotiations.

6.1.4. Consequences of Port emissions

In-port emissions are very concentrated in contrast with deep-sea emissions. Very often port areas are combined with heavy industry zones and situated close to residential and agricultural areas that are more vulnerable to harmful emissions. We can state that port emissions are becoming increasingly important – especially with regards to SO_2 and NO_x emissions – and justify detailed emission quantification studies in this field.

6.2. METHODOLOGY

The emission quantification method of 'port emissions' is similar to 'sea emissions'. We employ a combination of 'bottom-up' and 'top-down' approaches in group 1 and 2 methodologies respectively, but now specifically orientated towards port areas. Every port was studied separately in order to determine its characteristics and identify the available databases. Sometimes a combination of data from different data sets was necessary to obtain all required information, i.e. the port of Ghent where lay times were supplied by the Enigma port database and manoeuvring times by the IVS-SRK system.

6.2.1. Group 1 port emissions

The group 1 approach utilises a 'bottom-up' methodology, based on ship movements and ship characteristics, provided by several databases. Due to a lack of accuracy and completeness in the databases we are obliged to identify the usable records and to calculate average values. Nevertheless these values offer advantages with regards to future port emission quantifications.

In-port emissions are the sum of two types of port emissions: (1) emissions when berthed alongside the quay and (2) emissions when manoeuvring or hauling in a port area.

6.2.1.1. Emissions from berthed vessels

These emissions originate from vessels moored at their berth. During this period they mostly switch off their main engine, except for RoPax vessels that generally have short lay times (less than 3 or 4 hours). Auxiliary engines are used as electric power supply and drive all charging and discharging equipment on board like cranes, pumps, ventilation systems etc.

The methodology used for these calculations is shown in the following formula:

$$\sum BE_{1,st,p} = \sum (T_{st,p,be} * P_{st,me} * EF_{st,be} * LF_{st,be,me} / CF_{st,me}) + \sum (T_{st,p,be} * P_{st,ae} * EF_{st,be} * LF_{st,be,ae} / CF_{st,ae})$$

Where:

$BE_{1,st,p}$	port emissions from berthed vessels determined according to the group 1 approach per ship type and port (4 different ports);
$T_{st,p,be}$	lay time at berth as acquired by the specific port database per ship type and port;
$P_{st,me/ae}$	average installed main or auxiliary engine power per ship type;
$EF_{st,be}$	emission factors per ship type for 'activities at berth' as determined by ENTEC [*Whall et al, 2002*] in g/kWh;
$LF_{st,be,me/ae}$	load factor per ship type for the main or auxiliary engine per ship type at berth (% load of MCR)
$CF_{me/ae}$	a correction factor to compensate for loss of efficiency at reduced load

The methodology is largely similar to the calculation and the factors of the 'sea emissions' in the Group 1 approach. Only the time, emission factors and correction factors are different.

6.2.1.1.1. Lay time

Every Belgian sea port has its own database recording ship movements within its boundaries (Zeebrugge: Zedis; Ostend: Ensor; Antwerp: Apics and Ghent: Enigma). These include time data with regards to mooring and departure time. The time interval provides us with the 'lay time' per vessel. As mentioned earlier, the lack of data quality obliges us to work with average time values. These are determined per ship type and per port. Multiplying these values with the number of port visits, we obtained an annual lay time, also per ship type and per port.

6.2.1.1.1.1. Average lay time

Table 19 : The average lay time per ship type in the Belgian ports (between 1 April 2003 and 31 March 2004) in hours and minutes

Ship type	Zeebrugge	Ostend	Ghent	Antwerp	Total
Oil tankers	0:00	0:00	26:46	34:16	**59:56**
Chemical tankers	0:00	13:06	33:47	38:40	**167:23**
Gas carriers	26:41	0:00	0:00	25:02	**51:43**
Ro/Ro cargo	11:58	10:06	13:54	31:14	**67:13**
Dry bulk carrier	0:00	0:00	80:00	93:44	**173:45**
General cargo	30:38	18:27	37:09	64:35	**150:50**
Containers	15:24	0:00	0:00	24:16	**39:41**
Passenger	8:53	9:54	0:00	20:03	**38:51**
RoPax	10:23	5:50	0:00	0:00	**16:13**
Reefers	30:32	0:00	0:00	45:32	**76:10**
Other dry cargo	0:00	0:00	0:00	37:00	**37:00**

Because the ports' databases are developed for other purposes and not all data is correct or complete, a small margin of error must be taken into account. Most mistakes are obvious and can easily be corrected, but incomplete data has to be adapted by extrapolation. If data is found unrealistic and cannot be corrected, the data is exempted from further calculations. Obviously, the average value for a ship type with a limited number of port visits per month (for example passenger ships in Antwerp) will not be as accurate as for a ship type with a high visit frequency. Because of the huge amount and difficulties in processing this data, the average lay times (per month) for the ports of Zeebrugge, Ghent, Ostend and Antwerp are determined by calculating the average values for three different months, spread over one year, influenced by different seasons, namely November 2003, January 2004 and April 2004. Next to the average number of vessels visiting the Belgian ports during these three months, the total amount of port stay during the study year was noted per ship type and per port.

6.2.1.1.1.2. Annual lay time

In order to obtain the annual lay time in port, the average lay time values per month per ship type must be multiplied by the total number of vessels per ship type, visiting the port during the study period.

The coastal ports of Zeebrugge and Ostend are specialised in Short Sea Shipping (SSS), primarily Ro/Ro cargo vessels, followed by the Container and RoPax branch. Though not indicated, Ostend disposes of container traffic by general cargo vessels and this is of major importance for the Ostend port. The in-land ports – Ghent and Antwerp – put the emphasis on other markets. In these ports, the general cargo vessels and bulk carriers already have a major share in port visits, and because of their longer average lay times their presence is accentuated even more in these statistics. Antwerp also represents a significant lay time for container vessels and chemical tankers.

Table 20 : The total number of vessels per ship type visiting the Belgian ports between 1 April 2003 and 31 March 2004

Ship type	Zeebrugge	Ostend	Ghent	Antwerp	Total
Oil tankers	0	0	513	532	**1045**
Chemical tankers	0	64	19	2195	**2278**
Gas carriers	120	0	0	1019	**1139**
Ro/Ro cargo	4499	1330	454	1377	**7660**
Dry bulk carrier	0	0	337	757	**1094**
General cargo	235	262	1570	5592	**7659**
Containers	718	0	0	3092	**3810**
Passenger	45	7	0	12	**64**
RoPax	640	2588	0	0	**3228**
Reefers	113	0	0	712	**825**
Other dry cargo	0	0	0	49	**49**

The annual lay time for the four Belgian ports show a majority for the general cargo vessels (46%), followed at great distance by Ro/Ro (12%), dry bulk carriers (10%), container ships (9%) and chemical tankers (9%). Other ship types are of minor importance.

Table 21 : The annual lay time per ship type in Belgian ports (hours)

Ship type	Zeebrugge	Ostend	Ghent	Antwerp	Total	%
Oil tankers	0	0	13738	18236	**31974**	**4**
Chemical tankers	0	838	642	84874	**86354**	**9**
Gas carriers	3203	0	0	25509	**28712**	**3**
Ro/Ro cargo	53884	13433	6317	43012	**116646**	**12**
Dry bulk carrier	0	0	26965	70967	**97932**	**10**
General cargo	11518	4833	58346	361214	**435911**	**46**
Containers	11059	0	0	75080	**86139**	**9**
Passenger	400	69	0	240	**710**	**1**
RoPax	6648	15096	0	0	**21745**	**2**
Reefers	0	0	0	32427	**32427**	**4**
Other dry cargo	0	0	0	1813	**1813**	**1**
Total	**86712**	**34269**	**106008**	**713372**	**940361**	**100**
%	**9**	**4**	**11**	**76**	**100**	

Due to its larger part in the shipping industry, the port of Antwerp represents the largest portion of lay time per year in Belgium. Ghent is second followed by Zeebrugge and Ostend.

6.2.1.1.2. Emission factors

After an extensive literary study, the decision is made to employ the emission factors as published in the ENTEC study [*Whall et al, 2002*]. They are developed based on older emission quantification studies and new statistical data. Also future scenarios are incorporated producing extra emission factors per proposed guideline. At this moment, these are one of the most recent, detailed and complete emission factors published; they give emission factors in kg/ton fuel as well in g/kWh (integrated fuel consumption pattern). This makes it possible to employ a combination of top-down and bottom-up approaches.

Table 22 : Emission factors for 'in port' operation regarding ship type [Whall et al, 2002] (g/kWh)

Ship type	NO_x	SO_2	CO_2
Oil tankers	12.1	12.8	754
Chemical tankers	13.3	12.1	710
Gas carriers	7.5	13.4	884
Ro/Ro cargo	13	12.3	723
Dry bulk carrier	13.8	12	706
General cargo	13.3	12.1	716
Containers	13.7	12.1	710
Passenger	11.6	12.6	750
RoPax	11.3	11.2	746
Reefers	13.5	12.1	714
Other dry cargo	11.8	12.9	761

6.2.1.1.3. Load and correction factors

The load factor (LF) and correction factor (CF) are necessary to adjust the ENTEC [*Whall et al, 2002*] emission factors to the specific situation in the Belgian ports. The load factor compensates for a specific activity of the vessel. This implicates that the main or auxiliary engine is not always running on full capacity. For the main engine this will depend on whether the ship is hotelling, manoeuvring,… For the auxiliary engine this mainly depends on the ship type. For instance, container vessels use auxiliary engines for powering refrigerated containers, while RoRo vessels use auxiliary engine to power ventilators to air the cargo bay. The specific load factors are mentioned in table 23. These figures have been discussed with experts [*pilots, harbour masters, Antwerp Maritime Academy*] and adjusted according to their advice.

A correction factor is introduced to compensate for the loss of efficiency at reduced load. This is only done in cases where the engine load is different than 80%, as this is considered as the most efficient load. While the relationship in reality is not linear, the figures where checked and this method was confirmed by expert advice *[L. Cappoen]*.

Table 23 : Load and correction factors while mooring, per ship type

	Load factors		Correction factors	
Ship type	ME	AE	ME	AE
Oil tankers	20%	60%	0.92	0.88
Chemical tankers	0%	60%	0.92	0.88
Gas carriers	0%	70%	0.92	0.88
Ro/Ro cargo	0%	70%	0.92	0.88
Dry bulk carrier	0%	10%	0.92	0.88
General cargo	0%	10%	0.92	0.88
Containers	0%	20%	0.92	0.88
Passenger	0%	60%	0.92	0.88
RoPax	10%	70%	0.92	0.88
Reefers	0%	10%	0.92	0.88
Other dry cargo	0%	10%	0.92	0.88

6.2.1.1.4. Emissions from berthed vessels - Results

Table 24 : Estimated emission from berthed vessels, per ship type and exhaust gas (kton/year)

Ship type	NO_x	SO_2	CO_2
Oil tankers	1.099	1.163	68.483
Chemical tankers	1.176	1.070	62.788
Gas carriers	0.313	0.560	36.947
Ro/Ro cargo	2.722	2.576	151.410
Dry bulk carrier	0.302	0.262	15.431
General cargo	0.675	0.614	36.319
Containers	1.279	1.129	66.274
Passenger	0.019	0.020	1.204
RoPax	1.351	1.339	89.171
Reefers	0.193	0.173	10.229
Other dry cargo	0.002	0.003	0.157
Total	**9.131**	**8.909**	**538.413**

The most significant ship types are oil tankers, Ro/Ro Cargo, RoPax and container vessels. This can be explained by the fact that Ro/Ro and RoPax vessels keep their engines running when berthing because of the short lay-times. Oil tankers use their own engines for unloading. Container vessels represent an important share of visiting ships and consequently represent a significant share of emissions at berth.

6.2.1.2. Emissions from manoeuvring and hauling vessels

The second type of operations producing emissions in port areas are manoeuvring and hauling. Hauling is an operational condition very similar to manoeuvring but it concerns vessels changing between berths within the same port area, while manoeuvring vessels actually enter or leave the port. Each requires a different calculation method. This means that the time calculations are done separately. For the emission quantification we handle the same emission factors for both operational conditions. Vessels entering/leaving their berth require variable duration to travel the distance from or to the port boundaries. During manoeuvres, vessels employ variable engine loads resulting in higher emission levels. This implies the establishment of the port boundaries as an important factor in the emission calculation process. We must estimate a realistic but fictive line where vessels start or end their manoeuvres. This is studied per port because every sea port has specific characteristics regarding its accessibility or port entrance fairway (sea entrance, canal, river, etc.).

The employed methodology for manoeuvring operations is summarised in the following formula:

$$\sum \mathbf{MA_{1,st,p}} = \sum (\mathbf{T_{st,p,ma} * P_{st,me} * EF_{st,ma} * LF_{st,ma,me} / CF_{st,me}}) + \sum (\mathbf{T_{st,p,ma} * P_{st,ae} * EF_{st,be} * LF_{st,ma,ae} / CF_{st,ae}})$$

Where:

$\mathbf{MA_{1,st,p}}$	port emissions from manoeuvring vessels determined according to the group 1 approach per ship type and port (4 different ports);
$\mathbf{T_{st,p,ma}}$	manoeuvring time as acquired by the specific port database per ship type and port;
$\mathbf{P_{st,me/ae}}$	average installed main or auxiliary engine power per ship type;
$\mathbf{EF_{st,ma}}$	emission factors per ship type for 'manoeuvring activities' as determined by ENTEC [*Whall et al, 2002*] in g/kWh;
$\mathbf{LF_{st,ma,me/ae}}$	load factor per ship type for the main or auxiliary engine per ship type at berth (% load of MCR)
$\mathbf{CF_{me/ae}}$	a correction factor to compensate for loss of efficiency at reduced load

Due to incompleteness and inaccuracy in the port databases, we are not able to locate the manoeuvring emissions as good as the moored emissions, where we dispose of all berth numbers and the annual lay times. When optimising these data sets, a similar allocation method can be employed as completed for 'group 1 sea emissions'. At this moment, the allocation is limited to port areas.

6.2.1.2.1. Average manoeuvring time

In order to determine the average manoeuvring time of a vessel we need to categorize all visiting ships. Per port, every type of vessel has specific berths and specific manoeuvring routes. Only ship types with a minimum frequency of five passages per month have been examined. If the number of port visits of a certain ship type is too low, this type was compared to another similar type, based on the position of berths and manoeuvring characteristics. In this way we were able to eliminate unreliable manoeuvring values for rare ship types.

Due to the fact that every port is different we have to calculate an average value for each port specifically. For every port we use a different approach according to its specific characteristics.

6.2.1.2.1.3. Port of Zeebrugge

In Zeebrugge it is possible to derive all necessary information from one database: ZEDIS. It registers all time data of visiting vessels from the moment they enter the outer port. This data includes the point in time of mooring/leaving its berth and sailing out of port. In Zeebrugge the outer boundary of the port is fixed by a fictive line between the new breakwaters.

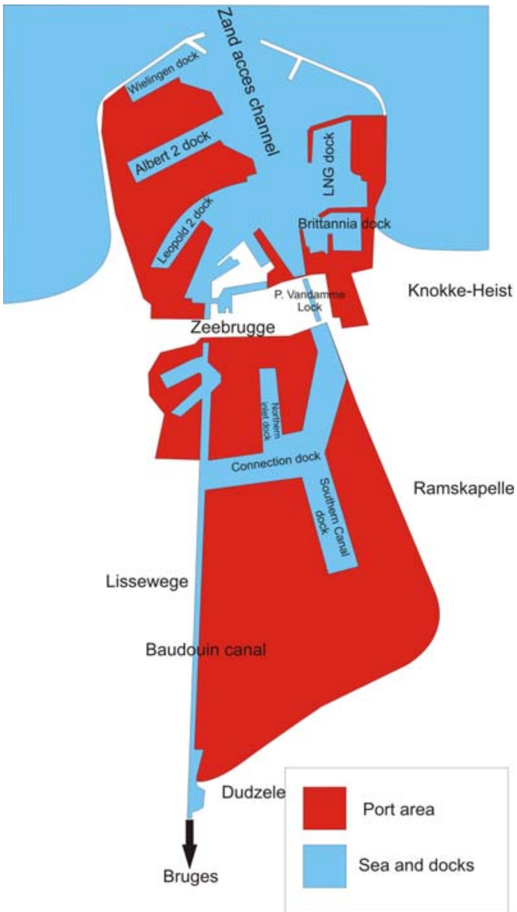


Figure 8 : Port of Zeebrugge

The manoeuvring time is calculated per ship type. Because of the tidal lock, vessels berthing in the inner port have manoeuvring times that are one up to three hours higher than vessels berthing in the tidal outer port. RoPax, container, passenger vessels and gas carriers are ship types that only berth in the outer port. General cargo vessels generally berth in the inner port. Ro/Ro vessels moor as well in the outer as in the inner port. In order to determine a realistic value, the proportions of vessels going to each port area are respected. Of all Ro/Ro vessels, 73,3% berth in the outer port and 26,3% sail trough the tidal lock, berthing in the inner port. This explains why Ro/Ro vessels have a higher manoeuvring time than ship types that always moor in the outer port, despite the fact that Ro/Ro vessels avail of better manoeuvring characteristics than container or gas carriers.

6.2.1.2.1.4. Port of Ostend

In Ostend all information is retrieved from the ENSOR database. The situation in Ostend is similar to the port of Zeebrugge. Vessels entering the port are registered when passing the roadstead in the entrance of the port. In combination with the time data - registered when berthing and leaving the quay - the manoeuvring time for each ship can be calculated per ship. Most of the vessels berth in the outer port, resulting in a low average manoeuvring time compared to other ports. Ostend is the smallest port of the four ports covered in the study. All berths in the outer port are situated nearby the port entrance, directly accessible from the central fairway ('havengeul').

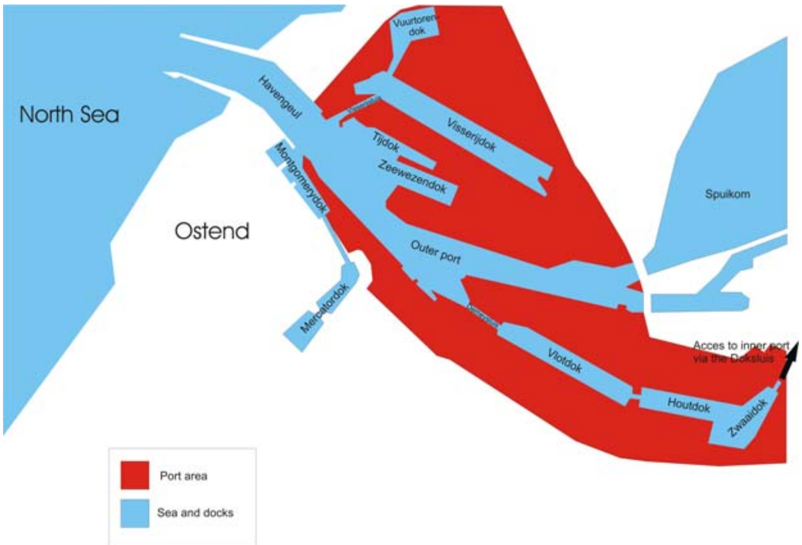


Figure 9 : the port of Ostend.

Only general cargo ships regularly manoeuvre to the inner port. The inner port is accessible via the 'Demeysluis' (connecting to the 'Vlotdok'). Between the inner port and the quays at the canal Ostend-Bruges, ships must also pass the 'Doksluis'. As a result of this infrastructure, vessels sailing to the inner port spend much longer manoeuvring times. For all vessels berthing in the outer port, the manoeuvring time is mainly determined by manoeuvring characteristics and length. These are of great importance when making turns in port.

6.2.1.2.1.5. The port of Ghent

The port of Ghent is situated on the sea canal Ghent-Terneuzen that connects the port area with the river Scheldt. Just the southern part of the canal is situated on Belgian territory. Because a canal is manoeuvring area, the limit of the manoeuvring area was easily determined by the Belgian-Dutch border. The canal has berths along the canal and several docks in the south, as shown on the figure.

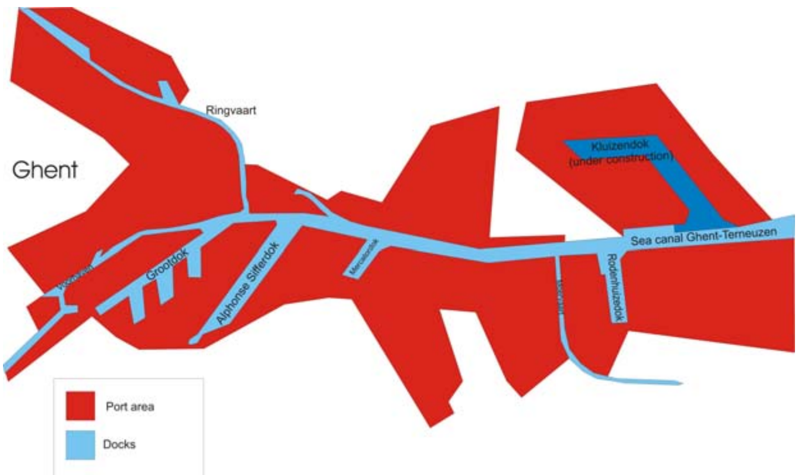


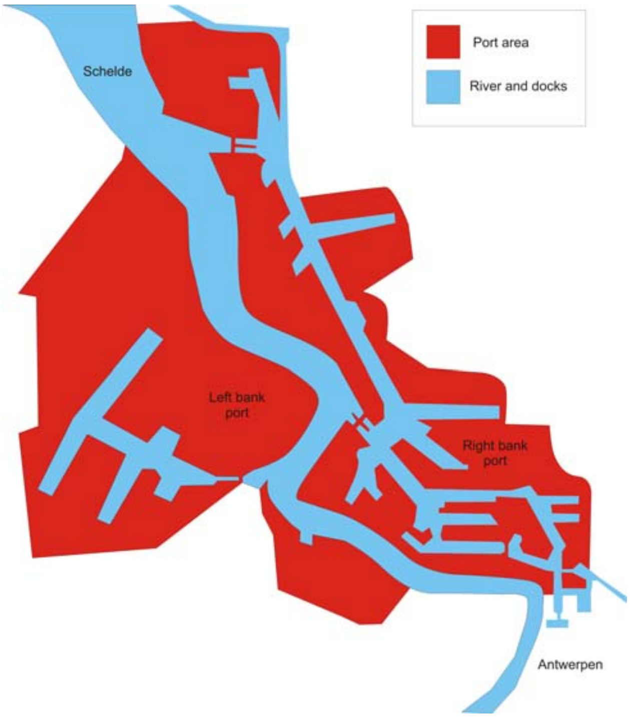
Figure 10 : The port of Ghent

The data for manoeuvring times is derived from the IVS-SRK database. Because there is no lock between the port of Ghent and its sea access route (the sea canal), the manoeuvring times of the different ship types are very similar. The lock connecting the sea canal with the river Scheldt is located on Dutch territory. Factors influencing the manoeuvring time are only limited to manoeuvrability and distance from berth to Belgian/Dutch border.

6.2.1.2.1.6. The port of Antwerp

The data to determine the average manoeuvring times in the port of Antwerp are derived from two data sets: (1) The IVS-SRK database that registers all ship movements on the river Scheldt and (2) The APICS database, set up by the port of Antwerp and registering all ship movements in the docks (behind the locks). These data sets provide us with the average Scheldt manoeuvring time and the average port manoeuvring time respectively. These two data sets are complementary.

Figure 11 : The port of Antwerp



From the IVS-SRK database all sailing times per voyage are extracted. Due to the fact that the sailing time inbound is not equal to the sailing time outbound - usually the sailing time outbound is 20% shorter – an average duration for in- and outbound voyages is calculated per ship type, logically assuming an equal number of inbound and outbound ships. The total average sailing time per ship type on the river is determined by adding the average inbound and outbound values. From the moment a vessel passes one of the tidal locks separating the river Scheldt and the docks, all ship movements are covered by the APICS database instead of the IVS-SRK system.

The port manoeuvring time of a vessel is the average time interval between mooring in a lock and mooring at its berth for inbound ships. For outbound ships it is the time interval between leaving its berth and leaving the lock. The results present a clear correlation between average manoeuvring time and the distance from lock to berth. The tidal terminals along the river Scheldt are taken into account by research on the proportion of tidal to non-tidal berthing per ship type. Adding the average Scheldt and average port values provides us with the total manoeuvring time for the port of Antwerp, in the most realistic possible way.

6.2.1.2.1.7. Average manoeuvring times - Results

Table 25 : Average manoeuvring time per ship type in the Belgian ports between 1 April 2003 and 31 March 2004 (hours and minutes)

Ship type	Zeebrugge	Ostend	Ghent	Antwerp
Oil tankers	0:00	0:00	0:34	6:21
Chemical tankers	0:00	13:06	2:34	5:46
Gas carriers	1:09	0:00	0:00	5:01
Ro/Ro cargo	1:16	10:06	1:44	5:28
Dry bulk carrier	0:00	0:00	0:50	6:32
General cargo	3:31	18:27	0:36	5:44
Containers	1:07	0:00	0:00	3:23
Passenger	1:01	9:54	0:00	2:13
RoPax	0:52	5:50	0:00	0:00
Reefers	3:31	0:00	0:00	6:16
Other dry cargo	0:00	0:00	0:00	6:58

Notice the higher manoeuvring values for the port of Antwerp due to its inland location.

6.2.1.2.2. Annual manoeuvring time

Table 26 : The annual manoeuvring time per ship type in the Belgian ports from April 2003 to March 2004 (hours)

Ship type	Zeebrugge	Ostend	Ghent	Antwerp	Total	%
Oil tankers	0	0	1,070	3,381	**4,451**	**4.48**
Chemical tankers	0	38	19	12,660	**12,717**	**12.79**
Gas carriers	138	0	0	5,128	**5,266**	**5.29**
Ro/Ro cargo	5,728	1,108	1,136	7,535	**15,507**	**15.60**
Dry bulk carrier	0	0	915	4,956	**5,872**	**5.91**
General cargo	892	672	3,246	32,152	**36,962**	**37.19**
Containers	805	0	0	10,497	**11,302**	**11.37**
Passenger	45	12	0	26	**84**	**0.08**
RoPax	563	1,466	0	0	**2,030**	**2.04**
Reefers	398	0	0	4,465	**4,863**	**4.89**
Other dry cargo	0	0	0	341	**341**	**0.34**
Total	**8,569**	**3,296**	**6,386**	**81,141**	**99,395**	**100.00**

The annual manoeuvring time was determined separately per ship type and per port, by multiplying the average manoeuvring time values, as determined above, and the total number of vessels visiting the Belgian ports during the study period.

6.2.1.2.3. Average hauling time

Table 27 : The average hauling time per ship type in Belgian ports between 1 April and 31 March 2004 (hours and minutes)

	Zeebrugge	Ostend	Ghent	Antwerp
Oil Tanker	0:00	0:00	0:09	0:16
Chemical Tanker	0:00	0:00	0:13	0:37
Gas Carrier	0:02	0:00	0:00	0:08
Ro/Ro	0:02	0:00	0:00	0:05
Dry Bulk Carrier	0:00	0:00	0:27	0:35
General Cargo	0:00	0:00	0:11	0:31
Container Ship	0:07	0:00	0:00	0:34
Passenger Ship	0:00	0:00	0:00	0:00
RoPax	0:00	0:00	0:00	0:00
Reefer	0:00	0:00	0:00	0:14
Other Dry Cargo	0:00	0:00	0:00	0:13

Hauling time is the specific time that a vessel needs to manoeuvre from one to another berth within the same port area. Vessels changing berths by being towed along the quay are not included in the hauling time. A vessel will produce as much emissions during the hauling period as during a manoeuvring period. These two periods are both characterized by a variable engine load and both use the emission factors for manoeuvring operations. The reason for distinction between these two similar types of operation is because not every ship hauls during its port stay, as opposed to manoeuvring in or out a port. Due to this separated approach, we are able to determine an average hauling time per ship type, regardless of its effective hauling time. This way, the operational time of a small percentage of vessels is distributed over the total number of vessels visiting these ports and it is possible to apply these average values for future studies without analysing port databases. This implies that a high average hauling time does not necessarily indicate a high percentage of hauling ships, but could also indicate a low percentage of hauling ships with individual high hauling times.

Ships haul to another quay for reasons like bunkering, different charging and discharging berths, etc… Some vessels haul up to five times during one port stay. For instance RoPax vessels have low hauling percentages, in contrast with chemical tankers and bulk carriers. In the port of Ostend, no hauling was recorded.

We should note that these values depend on variable factors and no patterns could be identified. This implies that even with a detailed study of a dataset with a time period of one year, variations remain possible. However, the presented values are as accurate as possible and provide a good indication of the real situation. Generally the calculated values correspond to the expected results. On the other hand, there is no need for a more profound study concerning this issue because hauling times represent just a minor part in the total manoeuvring time of a port, about 7.4%.

6.2.1.2.4. Annual hauling time

The average hauling time is determined per ship type. In order to obtain the annual hauling time per ship type, this average hauling time must be multiplied by the total number of vessels visiting the port during the study period.

Table 28 : The annual hauling time per ship type in the Belgian ports (hours)

	Zeebrugge	Ostend	Ghent	Antwerp	Total	%
Oil Tanker	0	0	78	146	**225**	**2.84**
Chemical Tanker	0	0	4	1,373	**1,377**	**17.39**
Gas Carrier	4	0	0	140	**144**	**1.82**
Ro/Ro	198	0	1	129	**328**	**4.14**
Dry Bulk Carrier	0	0	154	443	**597**	**7.54**
General Cargo	3	0	298	2,896	**3,198**	**40.38**
Container Ship	94	0	0	1,776	**1,870**	**23.61**
Passenger Ship	0	0	0	0	**0**	**0**
RoPax	3	0	0	0	**3**	**0.04**
Reefer	1	0	0	166	**168**	**2.12**
Other Dry Cargo	0	0	0	10	**10**	**0.13**
Total	**304**	**0**	**536**	**7,080**	**7,920**	**100**

Because of the limited dimensions of the port of Ostend and its main shipping types it can be concluded that the number of hauling manoeuvres is very limited. In fact, no hauling manoeuvres are registered.

General cargo ships (40.4%) represent the largest part of the hauling time, considering all Belgian ports together. In second place come the container ships (23.6%), followed by chemical tankers (17.4%) and dry bulk carriers (7.5%). All other ship types represent together less than 12% of the total.

6.2.1.2.5. Total manoeuvring time

The total manoeuvring time is the sum of the manoeuvring and hauling time. The annual manoeuvring time covers 92.6%, the annual hauling time 7.4%.

As expected, the larger part of the total manoeuvring time is represented by the general cargo vessels (37.4%). The second largest share is taken by the Ro/Ro cargo sector (14.8%) followed by the chemical tankers (13.1%) and the container ships (12.3%).

The total manoeuvring time is dominated by the port of Antwerp: For most ship types, Antwerp represents the largest manoeuvring time, for example, general cargo, container, Ro/Ro cargo vessels and chemical tankers; in total, the port of Antwerp represents a share of more than three quarters of the total manoeuvring time in Belgium. This is mainly due to its magnitude, receiving a large amount of vessels, and the inland location of the Antwerp port.

Table 29 : The total manoeuvring time per ship type in the Belgian ports (hours)

Ship type	Zeebrugge	Ostend	Ghent	Antwerp	Total	%
Oil tankers	0	0	1,148	3,528	**4,676**	**4.36**
Chemical tankers	0	38	24	14,034	**14,096**	**13.13**
Gas carriers	142	0	0	5,268	**5,410**	**5.04**
Ro/Ro cargo	5,926	1,108	1,137	7,665	**15,836**	**14.76**
Dry bulk carrier	0	0	1,069	5,400	**6,469**	**6.03**
General cargo	896	672	3,544	35,049	**40,161**	**37.42**
Containers	899	0	0	12,273	**13,172**	**12.27**
Passenger	45	12	0	26	**83**	**0.08**
RoPax	567	1,466	0	0	**2,033**	**1.89**
Reefers	400	0	0	4,631	**5,031**	**4.69**
Other dry cargo	0	0	0	352	**352**	**0.33**
Total	**8,875**	**3,296**	**6,922**	**88,226**	**107,315**	**100**
%	**8.27**	**3.07**	**6.45**	**82.21**	**100**	

6.2.1.2.6. Emission factors

Table 30 : Emission factors for 'manoeuvring operations' per ship type [Whall et al, 2002] (g/kWh)

Ship type	NO_x	SO_2	CO_2
Oil tankers	12.0	12.8	754
Chemical tankers	13.3	12.1	710
Gas carriers	7.4	13.5	887
Ro/Ro cargo	12.5	12.3	724
Dry bulk carrier	14.3	11.7	688
General cargo	13.1	12.0	709
Containers	14.0	11.8	696
Passenger	10.7	12.9	764
RoPax	10.6	10.8	754
Reefers	13.9	11.8	697
Other dry cargo	9.3	14.0	821

After an extensive literature study, the decision is made to employ the emission factors as published in the ENTEC study [*Whall et al, 2002*]. These are developed based on older emission quantification studies and new statistical data. Also future scenarios were incorporated producing extra emission factors per proposed guideline.

6.2.1.2.7. Load and correction factors

Table 31 : Load and correction factors for manoeuvring operations, per ship type

	Load factors		**Correction factors**	
Ship type	**ME**	**AE**	**ME**	**AE**
Oil tankers	20%	40%	0.92	0.88
Chemical tankers	20%	40%	0.92	0.88
Gas carriers	20%	70%	0.92	0.88
Ro/Ro cargo	20%	40%	0.92	0.88
Dry bulk carrier	20%	40%	0.92	0.88
General cargo	20%	40%	0.92	0.88
Containers	20%	60%	0.92	0.88
Passenger	20%	75%	0.92	0.88
RoPax	20%	75%	0.92	0.88
Reefers	20%	70%	0.92	0.88
Other dry cargo	20%	40%	0.92	0.88

The load factor (LF) and correction factor (CF) are necessary to adjust the ENTEC [*Whall et al, 2002*] emission factors to the specific situation in the Belgian ports. The load factor compensates for a specific activity of the vessel. This implicates that the main or auxiliary engine is not always running on full capacity. For the main engine this will depend on whether the ship is hotelling, manoeuvring,… For the auxiliary engine this mainly depends on the ship type. For instance, container vessels use auxiliary engines for powering refrigerated containers, while RoRo vessels use auxiliary engine to power ventilators to air the cargo bay. The specific load factors are mentioned in table 23. These figures have been discussed with experts [*pilots, harbour masters, Antwerp Maritime Academy*] and adjusted according to their advice.

A correction factor is introduced to compensate for the loss of efficiency at reduced load. This is only done in cases where the engine load is different than 80%, as this is considered as the most efficient load. While the relationship in reality is not linear, the figures where checked and this method was confirmed by expert advice *[L. Cappoen]*.

6.2.1.2.8. Emissions from manoeuvring and hauling vessels - Results

We can conclude that container vessels produce the major share (+/- 34%) of manoeuvring emissions due to their high engine powers, followed by Ro/Ro cargo (+/- 16%) and general cargo vessels (+/- 14%), due to their high number of port visits.

Manoeuvring emissions in ports regarding tugs and dredgers are studied in 'group 2 port emissions'.

Table 32 : Total estimated emissions from manoeuvring vessels (hauling and manoeuvring), per ship type and exhaust gas (kton/year)

Ship type	NO_x	SO_2	CO_2
Oil tankers	0.148	0.158	9.288
Chemical tankers	0.289	0.263	15.444
Gas carriers	0.098	0.178	11.715
Ro/Ro cargo	0.639	0.629	37.033
Dry bulk carrier	0.260	0.213	12.515
General cargo	0.599	0.549	32.422
Containers	1.537	1.295	76.391
Passenger	0.006	0.008	0.448
RoPax	0.161	0.164	11.458
Reefers	0.371	0.315	18.579
Other dry cargo	0.004	0.006	0.371
Total	**4.112**	**3.778**	**225.665**

6.2.1.3. Group 1 port emissions - Results

The results for group 1 port emissions are the sum of emissions from berthed, manoeuvring and hauling vessels. These are presented per ship type or per port.

$$\sum PE_{1,st,p} = \sum (BE_{1,st,p} + MA_{1,st,p})$$

Group 1 port emissions represent the major portion of emissions of the four main sea ports in Belgium (Ostend, Zeebrugge, Antwerp and Ghent) compared to tugs and dredgers, discussed under 'group 2 port emissions'.

Table 33 : Estimated port emissions from berthed, manoeuvring and hauling vessels (Group 1), per ship type and exhaust gas (kton/year)

Ship type	NO_x	SO_2	CO_2
Oil tankers	1.247	1.320	77.771
Chemical tankers	1.465	1.333	78.233
Gas carriers	0.411	0.738	48.662
Ro/Ro cargo	3.362	3.205	188.444
Dry bulk carrier	0.562	0.475	27.945
General cargo	1.274	1.163	68.741
Containers	2.815	2.425	142.665
Passenger	0.025	0.028	1.652
RoPax	1.512	1.503	100.629
Reefers	0.564	0.488	28.808
Other dry cargo	0.007	0.009	0.528
Total	**13.243**	**12.687**	**764.078**

Table 34 : Estimated port emissions from berthed, manoeuvring and hauling vessels (Group 1), per port and exhaust gas (kton/year)

Port	NO_x	SO_2	CO_2
Antwerp	8.482	8.049	478.515
Ghent	0.980	0.969	57.095
Ostend	4.445	1.419	91.980
Zeebrugge	2.336	2.250	106.032
Total	**13.243**	**12.687**	**733.623**

It clearly identifies the port of Antwerp as the largest polluter. This is considered logic due to its share in Belgian shipping and receiving vessels. Looking back at the emissions of berthed vessels one can notice that these represent more than 60% within the 'group 1 port emissions'. This indicates that a reduction of port emissions by means of shore power, for example, can represent a significant impact.

6.2.2. Group 2 port emissions

Group 2 is a collective term quantifying emissions from all vessel movements that can not be determined in a bottom-up approach due to insufficient data availability. The solution is to introduce a simpler and not as detailed top-down approach. Regarding port areas, two ship types were selected for the group 2 methodology: tugboats (specifically harbour tugs) and dredgers. In order to avoid redundancies and overlaps in 'port emission' calculations no data concerning these ship types were taken into account in the 'group 1' calculations, as opposed to 'sea emissions' calculations.

The methodology is summarised in following formula:

$$\sum PE_{2,st,p} = \sum (F_{st,p} * EF_{st})$$

Where:

$PE_{2,st,p}$ port emissions from ships determined according to the group 2 approach per ship type and port;

$F_{st,p}$ fuel consumption as provided by ship or project operators per ship and port. The defined study period was respected as much as possible, but in some cases we were obliged to use annual fuel consumption statistics for the period 2003-2004.

EF_{st} emission factors per ship type as determined by ENTEC [*Whall et al, 2002*] and in kg/ton fuel for 'manoeuvring operations';

Tugs and dredgers are considered to turn their engines out when berthed, so these emissions are zero.

6.2.2.1. Towing/pushing

Because tugs are not registered in any port database, an alternative data source was required. In the Belgian seaports three towing companies supply towing services. URS[14], OSMA[15] and the port authority of Antwerp (GHA)[16]. OSMA is active in the port of Ostend, while URS works in the ports of Zeebrugge, Ghent and Antwerp. In the port of Antwerp their services are limited to the Scheldt River; in the docks GHA provide all towing services. Every company registers the annual/monthly fuel consumption of their fleet and per operation area and provides this data. The overview in combination with emission factors provides us with the annual emission levels for harbour tugs per port.

Logically, the port of Antwerp turns out to provide the largest share of tug emissions.

Table 35 : Estimated emissions from harbour tugs, per port and exhaust gas (kton/year)

	NO_x	SO_2	CO_2
Antwerp	0.489	0.519	32.361
Ghent	0.053	0.057	3.537
Ostend	0.000	0.000	0.005
Zeebrugge	0.113	0.120	7.489
Total	**0.655**	**0.696**	**43.392**

6.2.2.2. Dredgers

The ship category of dredgers includes several classes: (1) split hopper barges; (2) trailing suction hopper dredgers; (3) cutter suction dredgers; and (4) backhoe dredgers. The latter two only operate within port boundaries as opposed to the first two types that operate both inside ports and at sea. When dredging inside ports the dredged substances are often dumped in special dedicated areas outside port boundaries. Due to difficulties in allocating these voyages outside port areas, all emissions of these projects are assigned as generic port emissions.

The operators of dredging projects in Belgian ports provide data regarding annual fuel consumption – whether per vessel or per project. Using the emission factors, emission levels can be determined for dredgers, per port.

[14] Unie van Redding- en Sleepdiensten (http://www.urs.be)
[15] Oostendse Sleepvaart Maatschappij, a part of the URS group.
[16] Gemeentelijk Havenbedrijf Antwerpen (GHA), (http://www.portofantwerp.be)

Table 36 : Estimated emissions from port dredging projects, per port and exhaust gas (kton/year)

	NO_x	SO_2	CO_2
Antwerp	0.287	0.316	18.603
Ghent	0.031	0.034	1.981
Ostend	0.030	0.033	1.920
Zeebrugge	0.133	0.147	8.650
Total	**0.480**	**0.529**	**31.156**

6.2.2.3. Emission factors

Table 37 : Emission factors for 'manoeuvring' operations per ship type (kg/ton fuel) [Whall et al, 2002]

	In kg/ton fuel		
Ship type	**NOx**	SO_2	CO_2
Towing/pushing	48	51	3,179
Dredging	49	54	3,179

6.2.3. Fishery

All emissions from fishery are considered to take place at sea.

6.2.4. LNG vessels

The specifics of LNG vessels have been discussed earlier in 5.2.4. For port emissions, the same factor 3.5 is used and NO_x and SO_2 emissions are considered to be 0.

6.2.4.1. LNG vessels port emissions

Table 38 presents the theoretical port emissions according to the general top-down methodology. Though, as described in the LNG vessels sea emissions (5.2.3), these vessels have specific engine characteristics, requiring a different calculation. Table 39 gives the correct estimates, taking the engine specifications into account, for both LNG vessels calling on the port of Zeebrugge.

Table 38 : Theoretic emissions from LNG vessels in port (ton per year) – using standard emission factors

	NO_x	SO_2	CO_2
Vessel A in port	1.807	3.253	214.281
Vessel B in port	2.086	3.602	237.259
Total port emissions	**3.893**	**6.855**	**451.540**

Table 39: Estimated emissions from LNG vessels in port (ton per year) – taken specific LNG specification into account

	NO_x	SO_2	CO_2
Vessel A in port	0	0	749.984
Vessel B in port	0	0	830.407
Total port emissions	**0**	**0**	**1,580.39**

6.2.5. Total port emissions

Total port emissions are the sum of the two methodology types, group 1 bottom-up approach and group 2 top-down approach. Both methods have been adapted in order to avoid redundancies.

Table 40 : Total estimated port emissions, per ship type and exhaust gas (kton/year)

Ship type	NO_x	SO_2	CO_2
Oil tankers	1.247	1.320	77.771
Chemical tankers	1.465	1.333	78.233
Gas carriers	0.411	0.738	48.662
Ro/Ro cargo	3.362	3.205	188.444
Dry bulk carrier	0.562	0.475	27.945
General cargo	1.274	1.163	68.741
Containers	2.815	2.425	142.665
Passenger	0.025	0.028	1.652
RoPax	1.512	1.503	100.630
Reefers	0.564	0.488	28.808
Other dry cargo	0.007	0.009	0.528
Towing/pushing	0.655	0.696	43.392
Dredger	0.480	0.529	31.156
LNG	0	0	1.580
Total	**14.379**	**13.912**	**840.207**

It appears that Ro/Ro cargo and Container vessels represent the largest share of port emissions followed by RoPax and Oil tankers. Oil tankers are ranked relatively high: they produce more than three times as much emissions in port as at sea due to the use of main engines for pumping during port operations.

7. RESULTS

Table 41 : Total estimated emissions from ships in the Belgian part of the North Sea and the ports, per ship type and exhaust gas (kton/year - %)

Ship type	NO_x		SO_2		CO_2	
Oil tankers	1.693	4.35 %	1.671	5.44 %	98.431	5.24 %
Chemical tankers	2.270	5.84 %	1.870	6.09 %	109.888	5.85 %
Gas carriers	0.709	1.82 %	1.172	3.82 %	77.436	4.12 %
Ro/Ro cargo	10.752	27.65 %	8.511	27.72 %	500.615	26.63 %
Dry bulk carrier	1.838	4.73 %	1.231	4.01 %	72.441	3.85 %
General cargo	2.981	7.67 %	2.304	7.51 %	136.206	7.25 %
Containers	10.823	27.83 %	7.321	23.85 %	431.410	22.95 %
Passenger	0.103	0.26 %	0.097	0.32 %	5.767	0.31 %
RoPax	3.961	10.18 %	3.307	10.77 %	226.936	12.07 %
Reefers	1.577	4.06 %	1.111	3.62 %	65.560	3.49 %
Other dry cargo	0.083	0.21 %	0.098	0.32 %	5.742	0.31 %
Towing/pushing	0.673	1.72 %	0.710	2.31 %	44.260	2.35 %
Dredger	1.236	3.18 %	1.283	4.17 %	75.487	4.02 %
LNG	0	0 %	0	0 %	19.434	1.03 %
Fishery	0.191	0.49 %	0.013	0.04 %	10.500	0.56 %
Total	**38.890**		**30.699**		**1,880.113**	

CO_2 gas is the principal emitted exhaust gas from marine engines. NO_x represents the second largest quantity, but is about 50 times smaller. SO_2 has the smallest share of the calculated types of aerial emissions.

We see that the difference in results for the EMEP speed-assumptions is about 4% (table 42) lower than in case one applies ENTEC speed assumptions. It offers a good insight in the influence of speed assumptions in emission quantification methodologies. New technologies like AIS with real-time speed data are possible solutions to provide higher accuracy.

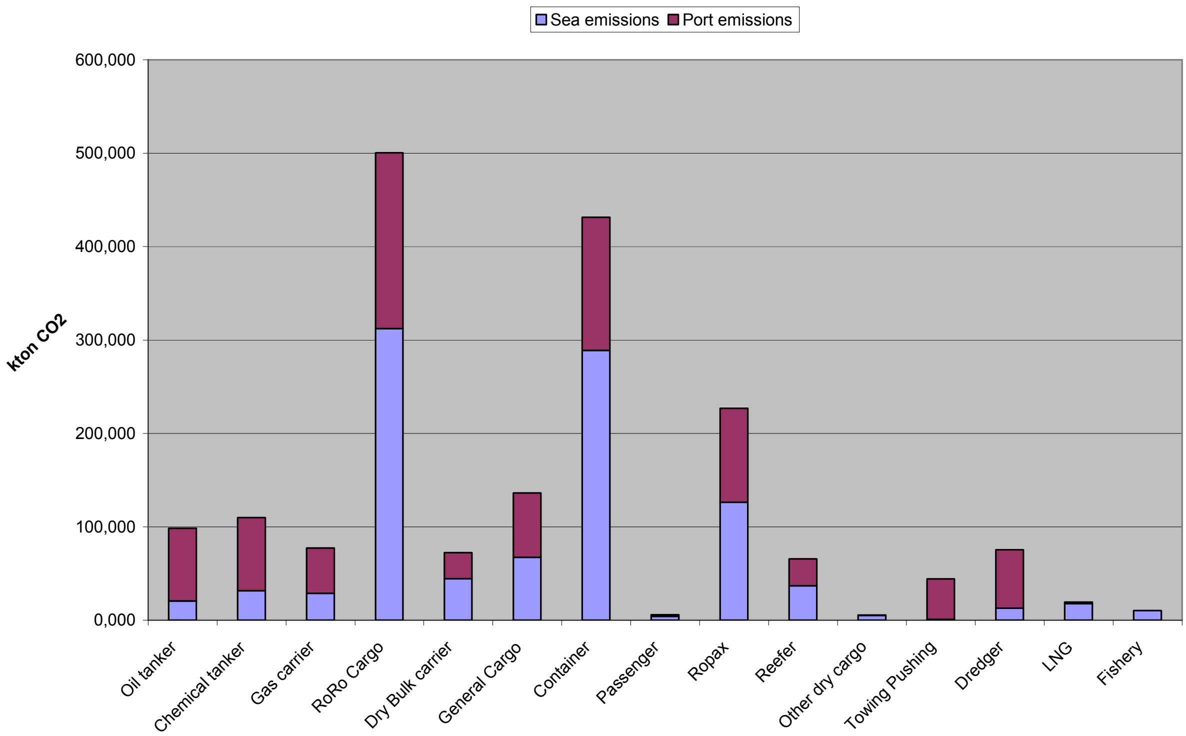
Container and Ro/Ro cargo vessels are considered to be the main contributors to the emissions from ships in the Belgian part of the North Sea. Certainly, the high portion of container vessels is remarkable despite only representing 14% of all entries in the IVS-SRK system as opposed to Ro/Ro cargo vessels at 26%; this is due to the high installed power levels of container vessels. On the other hand general cargo vessels represent about 18% of all entries but produce only about 8% of all emissions; this ship type largely consists of smaller and less powerful vessels. Clearly, installed engine power is a primordial factor influencing the emission quantities of ship types.

7.1. Conclusion and Remarks

7.1.1. Ratio Port-Sea emissions

Port emissions represent about 38% (for NO_x), 46% (for SO_2) and 45% (for CO_2) of all ship emissions in the Belgian part of the North Sea and the Flemish ports. This is explained by the high density of seaports in comparison to a small sea surface. Vessels in Belgian seaports spend on average 34.61 hours in port (at berth: 29.55h; manoeuvring: 4.80h and hauling: 0.26h). The transit time for the most important traffic in the Belgian part of the North Sea (Knokke-Westhinder TSS) is about 2.71h (distance: 40.69Nmi and average speed: 14 knots). Back and forth, the result is 5.42 hours. This is only 16% of all time spent in the Belgian part of the North Sea that was subject to this study. But a vessel does not consume as much fuel in port as at sea due to a smaller power level, except for oil tankers that use main engines to power their discharge pumps. Tugs and dredgers are anomalies in this theory because they are supposed to be in active operation, both in port or at sea. Of course, this ratio excludes all vessels transiting the Belgian part of the North Sea by the Noordhinder TSS or the deep-sea transit zone.

Figure 12 : Ratio Port-Sea emissions for CO2



7.1.2. ENTEC or EMEP speed table

When looking back at the EMEP speed tables one would get the following result (table 42). The difference between both options is about 3%, indicating the importance of accurate speed data. Probably both EMEP and ENTEC speeds will include some errors so we can assume that the correct result is situated somewhere in between.

Table 42 : Comparison between EMEP and ENTEC speed assumptions (total estimated emissions)

	EMEP (in kton/year)			ENTEC (in kton/year)		
Ship type	**NO_x**	**SO_2**	**CO_2**	**NO_x**	**SO_2**	**CO_2**
Oil tankers	1.693	1.671	98.431	1.693	1.671	98.431
Chemical tankers	2.235	1.846	108.496	2.270	1.870	109.888
Gas carriers	0.715	1.182	78.064	0.709	1.172	77.436
Ro/Ro cargo	10.065	8.018	471.618	10.752	8.511	500.615
Dry bulk carrier	1.851	1.239	72.901	1.838	1.231	72.441
General cargo	2.868	2.228	131.717	2.981	2.304	136.206
Containers	10.696	7.243	426.833	10.823	7.321	431.410
Passenger	0.104	0.098	5.825	0.103	0.097	5.767
RoPax	3.409	2.901	198.484	3.961	3.307	226.936
Reefers	1.510	1.070	63.110	1.577	1.111	65.560
Other dry cargo	0.079	0.093	5.444	0.083	0.098	5.742
Towing/pushing	0.676	0.712	44.402	0.673	0.710	44.260
Dredger	1.309	1.340	78.980	0.755	0.752	44.251
LNG	0	0	19.434	0	0	19.434
Fishery	0.191	0.013	10.500	0.191	0.013	10.500
Total	**37.401**	**29.654**	**1,814.238**	**38.409**	**30.168**	**1,848.877**

7.1.3. Comparison to national emission statistics

The national methodology employs different data sources (bunker statistics) and applies other emission factors (one emission factor per gas per fuel type in contrast with this study that applies different emission factor for 13 ship types and three types of exhaust gases) leading to a raw top-down approach without much detailed information. This explains the huge differences with the ECOSONOS results presented above.

Table 43 : Comparison between national and ECOSONOS results (in kton/year)

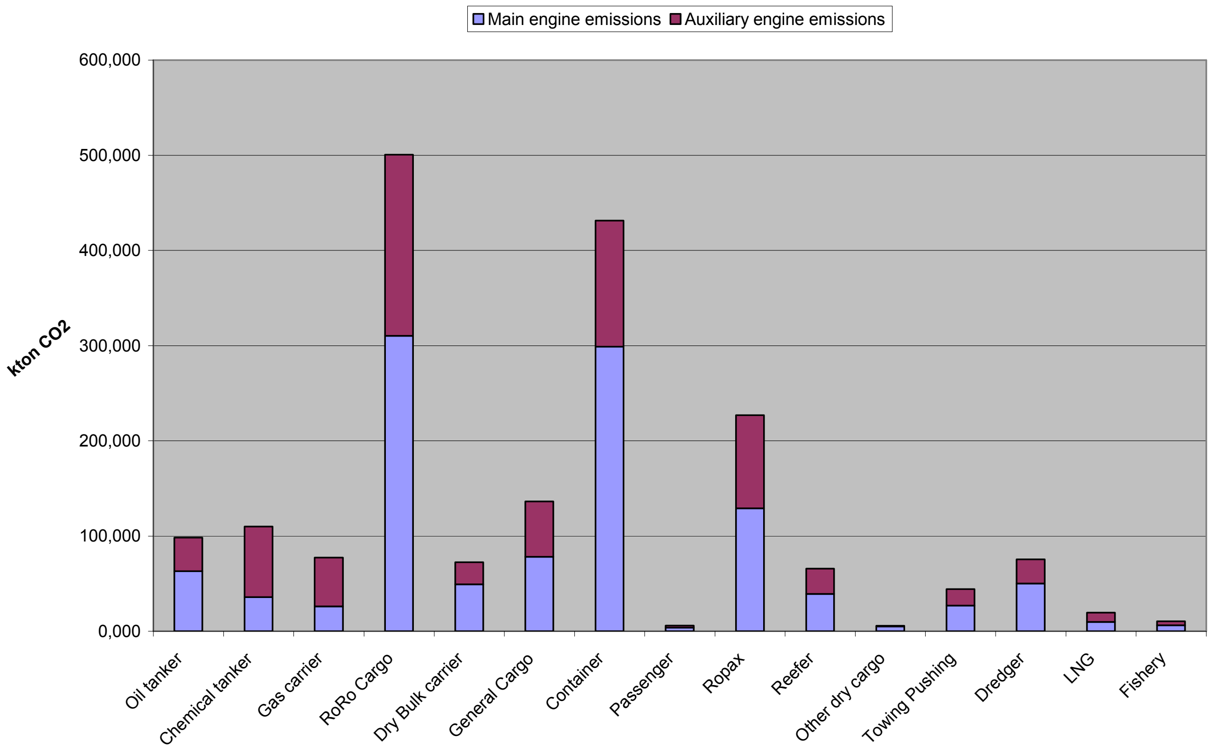
	NO_x	**SO_2**	**CO_2**
National navigation emissions	3.96	0.40	342.67
International navigation emissions	No data	No data	22,753.57
ECOSONOS national emissions (ENTEC-speeds)	38.409	30.168	1,848.877

Notice the remarkable differences between the two approaches. The national approach largely depends on the chosen emission factors (standard IPCC factors) and the definition and separation of national and international bunkers. The latter is almost impossible in Belgium. Almost every ship bunkering in a Belgian port leaves for a foreign port because of the limited surface of the Belgian part of the North Sea.

7.1.4. Ratio Main-Auxiliary engines

When looking at the ratio between main and auxiliary engines, it is obvious that main engines represent the largest part of shipping emissions. The fact that emission estimates from auxiliary engines represent a relative big share can be explained by the specific circumstances of the Belgian part of the North Sea, as mentioned before.

Figure 13 : Ratio Main and Auxiliary engine emissions for CO_2



7.2. FUTURE SCENARIOS

7.2.1. Shipping growth

Introducing a vision of the future we must take into account a growth/reduction scenario for shipping in the Belgian waters. This is different from the annual growth in shipping movements for future years as presented by a recent publication [*IMO, 2000*]. IMO estimates a growth between 1.5% and 3% per annum in vessel movements for the period 2000 to 2010. For Belgium it is important to perform calculations based on the frequency of ship types visiting Belgian ports because of specific emission characteristics per type. For instance, an increase in general cargo vessels will have a much smaller impact on emissions in the Belgian part of the North Sea as opposed to an increase in container vessels. The deepening of port entrances also means the arrival of larger vessels with higher engine powers. If this goes hand in hand with a decrease in number of vessels (because of a higher loading capacity) it is possible it causes a decrease in emissions. There are recent studies[17] indicating all possible

[17] Whall et al (2002); Stavrakaki (2005); IMO (2000); Davies et al (2000); Howard & Nikolas (2001).

methods to reduce emissions from ships and to find the optimal ship dimensions in relation to aerial emissions. The result is very similar to an optimal cost efficiency calculation.

7.2.2. Emission regulations

Looking at the future we must take into account new emission guidelines and proposals. During the ECOSONOS study period (1 April 2003 – 31 March 2004) and thereafter regulations have changed. MARPOL Annex VI regarding the reduction of NO_x, SO_x and ozone depleting substances entered into force on 19 May 2005. We have emission factors at our disposal considering subsequent phases in emission policy [*Whall et al, 2002*]. These emission factors are applied on the baseline study presented here, without taking predictions on the future shipping traffic into account. This shows the potential for reducing shipping emissions while it will be interesting to include growth figures in subsequent scenarios.

The base year figures are the ones estimated according to the ECOSONOS methodology for the period April 2003 – March 2004.

For fishery and LNG vessels this will have a very limited or no impact. So, these two classes are exempt from the future scenarios.

7.2.2.1. Scenario 1

A first scenario considers the implementation of a SO_x Emission Control Area (SECA) in the North Sea as planned by MARPOL Annex VI in 2006. A SECA makes the use of residual fuel with low sulphur content (max 1.5% S) compulsory.

The implementation of a SECA would cause a total reduction of about 43% of SO_2 emissions from vessels, as calculated from 1 April 2003 to 31 March 2004. The reduction for Towing/Pushing is not as strong, because they do not sail on heavy fuel. The other exhaust gasses are not influenced.

Table 44 : Comparison of SO_2 emissions to the implementation of a North Sea SECA (in kton/year and as % compared to the base year).

Ship type	Base year	Scenario 1	Difference (%)
Oil tanker	1.671	0.927	-44.524
Chem Tanker + Refined	1.870	1.036	-44.599
Gas carrier	1.172	0.658	-43.857
Ro/Ro cargo	8.511	4.709	-44.672
Dry Bulk Carrier	1.231	0.681	-44.679
General Cargo	2.304	1.265	-45.096
Container	7.321	4.086	-44.188
Passenger Ship	0.097	0.054	-44.329
RoPax	3.307	1.835	-44.512
Reefer	1.111	0.620	-44.194
Other Dry Cargo	0.098	0.054	-44.898
Towing/Pushing	0.710	0.704	-0.845
Dredger	0.752	0.711	-5.452
Total	**30.168**	**17.340**	-42.522

7.2.2.2. Scenario 2

Table 45 : Comparison of NO_x, SO_2 and CO_2 emissions from ships due to the implementation of a North Sea SECA + the use of MGO with maximum 0.2% Sulphur content inside ports (only for auxiliary engines) (in kton/year and as % compared to the base year)

	NO_x			SO_2			CO_2		
Ship type	**Base year**	**Scen 2**	**Diff (%)**	**Base year**	**Scen 2**	**Diff (%)**	**Base year**	**Scen 2**	**Diff (%)**
Oil tanker	1.693	1.690	-0.177	1.671	0.904	-45.901	98.431	98.273	-0.161
Chem Tanker + refined	2.270	2.253	-0.749	1.870	0.956	-48.877	109.888	109.534	-0.322
Gas carrier	0.709	0.705	-0.564	1.172	0.633	-45.990	77.436	77.310	-0.163
Ro/Ro cargo	10.752	10.668	-0.595	8.511	3.955	-53.531	500.615	496.427	-0.837
Dry Bulk Carrier	1.838	1.829	-0.490	1.231	0.609	-50.528	72.441	72.047	-0.544
General Cargo	2.981	2.956	-0.839	2.304	1.098	-52.344	136.206	135.293	-0.670
Container	10.823	10.777	-0.425	7.321	3.769	-48.518	431.410	429.636	-0.411
Passenger Ship	0.103	0.103	0.000	0.097	0.051	-47.423	5.767	5.749	-0.312
RoPax	3.961	3.944	-0.429	3.307	1.719	-48.019	226.936	226.196	-0.326
Reefer	1.577	1.570	-0.444	1.111	0.558	-49.730	65.560	65.216	-0.525
Other Dry Cargo	0.083	0.083	0.000	0.098	0.053	-45.918	5.742	5.738	-0.070
Towing/Pushing	0.673	0.673	0.000	0.710	0.710	0.000	44.260	44.260	0.000
Dredger	0.755	1.236	63.709	0.752	0.711	-5.452	44.251	75.489	70.593
Total	**38.409**	**38.484**	**0.195**	**30.168**	**15.724**	**-47.879**	**1848.877**	**1841.168**	**-0.417**

Scenario two considers the reduction of SO_2, NO_x and CO_2 emissions due to the introduction of a SECA and an compulsory use of Marine Gas Oil (MGO) with a maximum sulphur content of 0.2% inside ports (only for auxiliary engines). This measure will only have consequences on the reduction of SO_2 in the Belgian part of the

North Sea, and is slightly larger than scenario 1. The reductions for CO_2 and NO_x are negligible.

7.2.2.3. Scenario 3

A third scenario takes a look at an extension of scenario two by introducing 0.2% MGO fuel use inside ports for auxiliary and main engines.

Because main engines are of greater importance than auxiliary engines for ship emission in ports because of their higher capacities, the use of 'clean' fuels as MGO (with 0.2% Sulphur content) for main engines has a much larger effect, especially regarding SO_2 emissions; the effect on CO_2 and NO_x emissions is limited. In order to obtain similar reductions as for SO_2 emissions, different approaches requiring technical adjustments need to be considered. Therefore we refer to more detailed studies such as the ENTEC study [*Stavrakaki, 2005*] and the IMO study performed by MARINTEK and DNV (2000).

Table 46 : Reduction of NO_x, SO_2 and CO_2 emissions from ships due to the implementation of a North Sea SECA + the use of MGO with maximum 0.2% Sulphur content inside ports for auxiliary and main engines (in kton/year and as % compared to the base year)

	NO_x			SO_2			CO_2		
Ship type	**Base year**	**Scen 3**	**Diff. (%)**	**Base year**	**Scen 3**	**Diff. (%)**	**Base year**	**Scen 3**	**Diff. (%)**
Oil tanker	1.693	1.676	-1.004	1.671	0.796	-52.364	98.431	97.612	-0.832
Chem Tanker + refined	2.270	2.235	-1.542	1.870	0.828	-55.722	109.888	108.773	-1.015
Gas carrier	0.709	0.699	-1.410	1.172	0.548	-53.242	77.436	76.808	-0.811
Ro/Ro cargo	10.752	10.632	-1.116	8.511	3.653	-57.079	500.615	494.636	-1.194
Dry Bulk Carrier	1.838	1.813	-1.360	1.231	0.505	-58.976	72.441	71.410	-1.423
General Cargo	2.981	2.919	-2.080	2.304	0.833	-63.845	136.206	133.739	-1.811
Container	10.823	10.678	-1.340	7.321	3.132	-57.219	431.410	425.795	-1.302
Passenger Ship	0.103	0.102	-0.971	0.097	0.047	-51.546	5.767	5.728	-0.676
RoPax	3.961	3.929	-0.808	3.307	1.576	-52.344	226.936	225.420	-0.668
Reefer	1.577	1.546	-1.966	1.111	0.404	-63.636	65.560	64.283	-1.948
Other Dry Cargo	0.083	0.083	0.000	0.098	0.050	-48.980	5.742	5.720	-0.383
Towing/Pushing	0.673	0.673	0.000	0.710	0.710	0.000	44.260	44.260	0.000
Dredger	0.755	1.216	61.060	0.752	0.201	-73.271	44.251	75.489	70.593
Total	**38.409**	**38.201**	**-0.54**	**30.168**	**13.282**	**-55.973**	**1848.877**	**1829.673**	**-1.039**

7.3. Error margin

In fact is the maritime sector dependent on numerous circumstances, varying from weather conditions to economic and local aspects. Still, scientific research is needed to determine a value representing an average situation, tempering extreme conditions in order to simplify future recalculations. It is impossible to reproduce a perfect simulation but we are able to reduce the error margin to a minimum. We provide these margins in order to assure an insight in data reliability.

7.3.1. Emission factors

It is of great importance to assess the level of uncertainty associated with the emission factors [*Whall et al, 2002*]. This uncertainty arises primarily from:

- The number and representation of the measurements used in deriving the emission factors in comparison to the total number and types of marine engines in use;
- Measurement uncertainties within the emission factor data set that vary for different measurement techniques and relevant pollutants, and even activities;
- Assumptions made in assigning the factors for a given activity, e.g. main engine operation in port;
- The applicability of a universal factor for a given ship category (i.e. uncertainty will increase for inventories covering a smaller number of ship categories).

By considering the above, and bearing in mind uncertainty calculations for accredited marine emission measurement methods, an attempt has been made to determine uncertainty levels for the presented emission factors. Following guidelines presented by Eurochem, uncertainty is expressed as a relative percent at the 95% confidence interval. It should be noted that these uncertainties are for consideration of a large shipping fleet. On a much smaller scale, for example a minor port with only a few ships hotelling, considerably greater uncertainty can be expected, arising mainly from ships having machinery and fuel atypical of the ship category in general and their main engine use in port (both operation time and load).

Table 47 : Estimated uncertainties at the 95% confidence interval given as relative percent of the ENTEC emission factors (g/kWh or kg/ton fuel) [Whall et al, 2002

	At sea	Manoeuvring	In port
NO_x	± 20%	± 40%	± 30%
SO_2	± 10%	± 30%	± 20%
CO_2	± 10%	± 30%	± 20%

ENTEC identifies "the estimation of emission from vessels whilst undertaking in-port operations due to an unknown degree of variation regarding exact engine load levels and durations in particular operation modes" as the greatest contribution to uncertainty. We must remark that the ECOSONOS study improves the ENTEC emission factors considerably by applying specific load and correction factors per ship type and per operational activity. This will reduce the ENTEC uncertainty level in a positive but incalculable way.

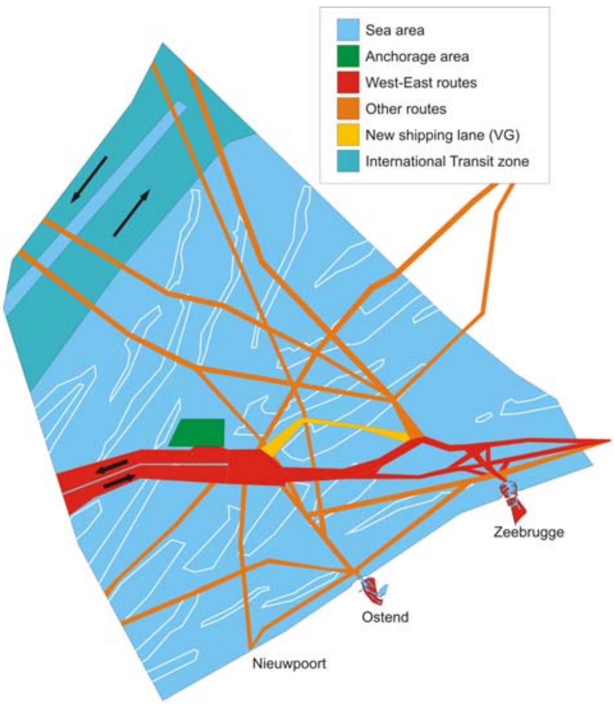
7.3.2. Ship movement data sets

For this study several databases are used to obtain an optimal coverage of the Belgian part of the North Sea and Belgian seaports. Every database suffers from the same inaccuracy and incompleteness problems causing analytical and processing difficulties. Incorrect data is exempted when obvious but it is impossible to eliminate or to correct all possible errors. Errors are compensated as much as possible by the application of average values.

The routes within the Belgian part of the North Sea are determined in cooperation with the Belgian pilot association and provide an accurate plan of all shipping lanes or routes. Ninety-nine percent of all vessels will navigate within the presented boundaries except for the smallest merchant vessels or because of distress situations.

The principal deficiency within this study arises from the lack of data regarding deep-sea ship movements in the Noordhinder TSS. The number of vessels transiting the Belgian part of the North Sea by this route is unknown due to the lack of radar or AIS coverage at the time of the data collection and the considerable cost of purchasing LMIU data. For future projects AIS will create a cheap and more accurate alternative to the expensive LMIU databases. The amount of vessels sailing and transiting the Belgian part of the North Sea in the Noordhinder TTS is estimated to double at least the Belgian part of the North Sea emissions.

7.4. THE NEW SHIPPING LANE



For the study period the VTS centre provides us the data on ship movements in the Belgian part of the North Sea but for the study period the IVS-SRK system does not take a new shipping lane that recently is introduced into account. This new shipping lane offers an alternative deep-water route between the Wandelaar pilot station and the Ribzand fairway entrance. This route is introduced in 2002 but the IVS-SRK system has only been adapted to this new shipping lane in 2005.

Figure 14 : Location of the new shipping lane "Nieuwe vaargeul"

The ECOSONOS emission charts do not show this new shipping lane because it is impossible to determine the exact ratio between vessels taking the 'old' route or the new alternative. Still, with data samples for 2005 we are able to calculate an indicative ratio. The old A1 route represents 96.03% of all ship movements between Wandelaar and Ribzand as compared to 3.97% for the new route. Because this route is situated within the pilotage area we can assume pilots will choose the new route more often in the future when they become more familiar with it. For the study period – April 2003 to March 2004 – the percentage of ships using the new route is estimated at less than 4%.

7.5. ECOSONOS-MOPSEA: explaining the differences in result

Introduction

Belgian Science Policy (BELSPO) financed under the Scientific Support Plan for a Sustainable Development Policy (SPSD II)) two related projects: **ECOSONOS** (Emissions from CO_2, SO_2 and NO_X from Ships) and **MOPSEA** (MOnitoring Programme on air pollution from SEA-going vessels). Eventually, it was decided that both projects would work out their estimates independently. This is an interesting way to proceed, as both projects can validate each others results. Though, at the end of both projects, the results differ significantly. A number of meetings have been organised to discuss these differences and to try and find an explanation. Hopefully, this can contribute to future modelling efforts for shipping emissions in Belgium and abroad.

On 15th September 2006 a workshop was organised by both research teams. This workshop brought 4 international experts and the national stakeholders who were also involved in both ECOSNOS and MOPSEA steering groups together. The conclusions of this workshop are available on the website: www.maritieminstituut.be.

On 16th February 2007 a final meeting was organised and it was decided that this joint note on possible explanations and assessments of the different results would be added to the final reports of both studies.

Main differences

In preparation of the workshop both teams consulted each other and had several meetings to identify a number of issues that can explain the differences. These where also presented at the workshop. Unfortunately, some differences can only be judged from a qualitative perspective, and can not be compared in a quantitative way. Therefore, it is not clear which of these issues is the most important. Each of these issues contributes to a certain (non calculable) extent to the difference and the sum of these differences equals to the final difference.

Table 48 : overview of main differences

	ECOSONOS	**MOPSEA**
Ship types	Sea-going vessels Towing/pushing Dredgers Fishery	Sea-going vessels
(Un)loading activities	Included	Excluded
Activity data	Aggregated, per ship type	Detailed calculations, per individual ship
Vessel characteristics	Aggregated, per ship type	Detailed data, per individual ship
Stages of navigation	1. cruising 2. reduced speed / manoeuvring 3. hotelling 4. anchoring	1. cruising 2. reduced speed 3. manoeuvring lock / mooring / bridge 4. hotelling 5. anchoring
Emission factors	Taken from ENTEC (CO_2, SO_2, NO_X,) Per ship type	Taken from EMS Age dependent Fuel related (CO_2, SO_2) Technology related (NO_X, PM, CO)

The *first* difference between both projects is the **type of vessels** included. ECOSONOS investigated sea-going vessels, towing/pushing, dredgers and fishery, whereas the aim of the MOPSEA project was to investigate sea-going vessels only. For the latter, only the CO_2, SO_2 and NO_X emissions of the sea-going vessels have been compared. Table 2 presents the final estimated emissions for sea-going vessels for both projects. The figures show a difference of about factor 2.5.

Table 49 : ECOSONOS and MOPSEA final estimated emissions for sea-going vessels (kton / year)

	ECOSONOS (kton)			**MOPSEA (kton)**		
	NO_X	**SO_2**	**CO_2**	**NO_X**	**SO_2**	**CO_2**
Sea-going vessels	38.4	30.2	1849	16.9	10.9	720

The *second* main difference is that ECOSONOS takes into account **loading and unloading activities of ships in port**, while MOPSEA does not. This leads to significant differences in the assumptions for the use of auxiliary power. For ECOSONOS, the assumptions for the use of auxiliary power can be found in the different tables in the ECOSONOS report. The MOPSEA model only foresees the energy use for air conditioning, ventilation, hotel requirements, preheating of heavy fuel oil. … by auxiliaries. Based on expert opinion this energy use has been assumed to be between 250 and 500 kW depending on the ship type. In the end, this contributes to higher port emission estimates for ECOSONOS. An extra assessment was made to compensate the MOPSEA figures for the loading and unloading activities (table 3) based on ECOSONOS figures. The remaining difference in emissions of sea-going vessels - ECOSONOS/MOPSEA - is decreased to a factor 1.8.

Table 50 : MOPSEA emissions for sea-going vessels with estimated loading and unloading emissions(kton / year)

	NO_X	SO_2	CO_2
MOPSEA	16.9	10.9	720
Loading and unloading	4.3	5.1	265
TOTAL	**21.2**	**16.0**	**985**

There is also a difference in how the **activity data** for the different ship types or individual ships were calculated.

Taking *sailing times in the North Sea*, ECOSONOS determines the distance between every way-point of the IVS-SRK registration and multiplies this with an average speed (taken from ENTEC), depending on the ship type. Multiplying the registered number of ships per ship type and the sailed distance with the average speed at sea per ship type, ECOSONOS estimates the total sea time, per ship type. MOPSEA on the other side, uses per individual ship the times registered in the IVS-SRK system.

For the *activities in ports*, both projects started from the same data sets, provided by the different ports. The ECOSONOS team carried out a random sample survey to come up with average activity data per ship type, while the MOPSEA team calculated the activity data for each individual vessel. The hotelling times and the sailing times are respectively 1.2 and 1.3 times higher in the ECOSONOS project compared to the MOPSEA project.

In addition, two other important groups of parameters in the emission models are:

- **vessel characteristics**, more specific the installed engine power;
- **different stages of navigation**, more specific the load factor (% of engine power that is being applied).

The *installed main engine* power of the different ship types in ECOSONOS is based on a sample of one hundred ships per ship type, whereas MOPSEA takes into account the real main engine power for every ship separately based on Lloyd's register Fairplay data. The different approach leads to higher emissions in the ECOSONOS study compared to MOPSEA.

The *used auxiliary power* during sailing times differs greatly between the two models, factors up to seven – ECOSONOS compared to MOPSEA - for the most important vessel types.

MOPSEA used a more detailed method, taking into account more stages of navigation. ECOSONOS estimated port activity times per ship type on an aggregated level and more simple way.

Of course the use of different **emission factors/functions** influences the emission figures. For the purpose of sensitivity analysis the MOPSEA model has been run with the widely used ENTEC (2005) emission factors. Emissions for the year 2004 have been calculated by using the ENTEC average emission factors per ship type instead of the detailed EMS emission factors per individual ship. This resulted in emissions figures which are higher than those calculated with the EMS emission factors, namely 13% for CO_2, 25% for SO_2, 3% for NO_X. One can conclude that the use of different emission factors in the MOPSEA and ECOSONOS studies explain the differences in emissions to a small extent.

More results from the workshop:

When comparing both projects conceptually, the conclusion is that MOPSEA performed a very detailed calculation of shipping activity and related atmospheric emissions for the year 2004. Performing similar inventory work every year again would be very time consuming. ECOSONOS on the other side used more aggregate assumptions that could be used for a number of consecutive years. This approach is more suitable for a yearly update.

It would also be interesting to collect and test data over several years and see whether this way, one can distil more accurate average manoeuvring / hauling / berth times per ship type for each port and more accurate sailing times for activities at sea.

Some general conclusions from the workshop:

There is an urgent need to improve the available data:

- How to deal with missing data
- Make the data sets more reliable
- Implementation and use of AIS-data (Automatic Identification System)

When reporting the data it will be important to do so in a consistent and comparable way in all countries. It was suggested to present the results in the following way:

- Total ship km travelled in the Belgian part of the North Sea
- Emissions per ship km
- Number of port calls (per year)
- Emissions per port call

Confidentiality of data does not always allow such detailed reporting. A task for researchers and policy makers in the future, is to convince data suppliers of the importance of this issue for environmental studies.

Furthermore, more research needs to be performed on the engine loads during different shipping activities (stages of navigation).

Final conclusions:

Obviously, it is the first time that an extensive exercise of estimating / calculating shipping emissions in the Belgian part of the North Sea and the seaports was performed. This was an interesting learning process and by comparing both projects, a number of issues can be identified that need to be taken into account in the future.

Data collection is one of these issues. Most likely, AIS-data can bring a solution to this, as it will allow future researcher to have very detailed and accurate activity data.

Furthermore, some more work can be performed to identify the exact load factor at different stages of navigation: full speed at sea, reduced speed at sea when approaching a port, entering a port, manoeuvring and hauling. The same can be performed for (un)loading activities in port and for engine loads when mooring.

For future emission data from shipping activity in the Belgian ports and in the Belgian part of the North Sea, it will be interesting to combine the strengths of both projects and find a solution for the weaknesses. While MOPSEA performed a very detailed inventory, ECOSONOS focused more on producing a conceptual model. With the information from MOPSEA, the model can probably be better fine tuned to take into account the specific characteristics of shipping traffic in the Belgian ports and in the Belgian part of the North Sea.

Finally, we would like to warn the reader not to try and make an average number out of both projects. For the moment no one can judge where exactly the exact figure is to be found. Both projects each have there strengths and weaknesses.

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SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY (SPSD II)

Part 2:
Global change, Ecosystems and Biodiversity

ANNEXES

ECOSONOS
Emissions of CO_2, SO_2 and NO_x from Ships

EV/44

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GLOSSARY

AMVER	Automated Mutual-assistance Vessel Rescue system
As	Arsenic
AUX	Auxiliary Engine
BFC	Bromine-Fluoro-Carbon
BOIL	Boilers
CAFÉ	Clean Air For Europe
$CaSO_4$	Calcium Sulphate
Cd	Cadmium
CFC	Chlorine Fluor Carbon
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
COADS	Comprehensive Ocean-Atmosphere Data Set
CONCAWE	Conservation of Clean Air and Water in Europe
Cr	Chrome
Cu	Cupper
DNV	Det Norske Veritas
EEZ	Exclusive Economic Zone
EIA	Energy Information administration (USA)
EMEP	Steering Body to the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe
EU	European Union
FPS	Federal Public Service
GRT	Gross Registered Tonnage
GT	Gross Tonnage
HCy	Hydrogen Cyanide
HFC	Hydro-Fluoro-Carbon
HFO	Heavy Fuel Oil
He	Helium
Hg	Mercury
IMO	International Maritime Organisation
ISO	International Standards Organisation
kW	kilo watt
LMIU	Lloyd's Maritime Intelligence Unit
LS	Large Segment
MARPOL	International Convention for the Prevention of Pollution from Ships

MCR	Maximum Continuous Rate
MDO	Marine Diesel Oil
ME	Main Engine
MEPC	Marine Environment Protection Committee (IMO)
MGO	Marine Gas Oil
Ne	Neon
NH_3	Ammonia
Ni	Nickel
NMVOC	Non-methane volatile organic compound
NEC	National Emissions Ceiling
NOx	Nitrogen oxides
N_2O	Nitrous oxides
OECD	Organisation for Economic Cooperation and Development
PAH	Polycyclic Aromatic Hydrocarbons
Pb	Lead
PFC	Poly Fluor Carbon
PM	Particle Matter
POP	Persistent Organic Pollutant
RNA	Ribo Nucleic Acid
Rpm	rotation per minute
Se	Selenium
SF_6	Sulphur Hexafluoride
SO_2	Sulphur oxide
SO_X	Sulphur Oxides
SO_x ECA	SO_x Emission Control Area
SS	Small segment
TS	Territorial Sea
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile Organic Compound
VTS	Vessel Traffic System
Zn	Zinc

1. ANNEX 1 : LITERATURE STUDY ON INTERNATIONAL EMISSION QUANTIFICATION METHODOLOGIES

1.1. MARINTEK [BREMNES, 1990]

This early and significant emissions inventory roughly estimates vessel movements and patterns, and resulting emissions of NO_x and SO_2 in the North Sea, the English Channel and the Baltic Sea. The study estimates broad ship movement patterns based on information presented in the United Nations' International Seaborne Trade Statistics Yearbook (1984-85), categorising the study in the bottom-up approach class. However, trade figures are a fairly coarse method of estimating shipping patterns, a fact which may have something to do with the apparently significant degree of underestimation of emissions in the study.

The MARINTEK emissions inventory is significant as, for a number of years it was the basis for the European Monitoring and Evaluating Programme's (EMEP) estimates of the contribution made by shipping to European trans-boundary acidification. This despite its incompleteness, i.e. the fact it only estimated emissions from international trade and excluded passenger ships, service vessels and non-carrying vessels as well as ships hotelling or at anchor [Davies et al., 2000].

1.2. CONCAWE [LYNE ET AL, 1994]

The CONCAWE report presents a detailed analysis of the impact of sulphur emissions (SO_2) from ships within the heavily trafficked southern North Sea and English Channel as a contribution to the debate on the need to limit the sulphur content of bunker fuels. The study is based on a bottom-up approach and seems to be the first emissions study to rely on actual ships movement data from Lloyd's Maritime Intelligence Unit (LMIU) along with data from ferry operators. During the study period – 1992 - approximately 204,000 non-ferry vessel movements and 80,900 ferry movements are estimated to have taken place. These figures exclude ships below 250 GRT as well as fishing and pleasure crafts.

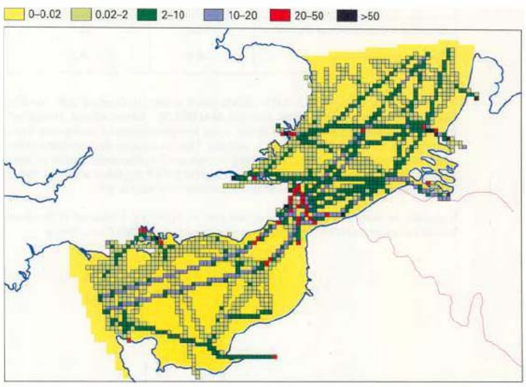


Figure 1 : Emissions (t($S0_x$)/km^2/year) mapped onto shipping lanes and ports [Lyne et al, 1994].

UK land areas were modelled on a 20x20 km grid scale and continental land areas on a 25x25 km grid scale. This provides significantly more detailed data than available from the 150x150 km grid scale of EMEP. The study clearly identifies in port emissions as a significant source of ship aerial emissions in the study area, representing 26% of the total emissions from ships. Because of the proximity to land, it is assumed to be more cost effective to reduce in port emissions to achieve a given reduction in deposition on land.

The application of a dispersion model allows calculating the contributions of these emissions to the annual mean SO_2 concentrations. CONCAWE compares results with the MARINTEK [Bremnes, 1990] study: For the same study area the MARINTEK inventory calculated 25% less sulphur emissions than the CONCAWE study, in the southern North Sea this even amounts to a difference of 50%.

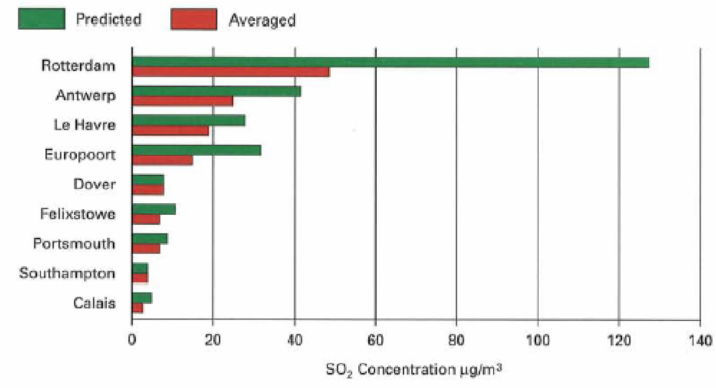


Figure 2 : Near source annual mean concentrations of SO2 in port [Lyne et al, 1994]

1.3. LLOYD'S REGISTER [LLOYD'S REGISTER OF SHIPPING, 1995]

The Lloyd's "Marine Exhaust Emissions Research Programme" estimates the amount of energy converted for marine transport purposes in the area of interest and transforms it into emission levels by using emission factors. These are determined by tests with several vessels in service as opposed to other studies that determine the emission factors based on exhaust emissions from test bed engines.

This research determines emission factors for medium and slow speed diesel (main) engines in terms of both kg pollutant per ton of fuel and gram pollutant per kWh. Secondly, the difference between emissions generated under steady state (for NO_X, CO, HC, CO_2 and SO_2) and transient conditions (for HC, CO, NOX and particulate exhaust emissions) are examined. Subsequently, the developed emission quantification methodology is tested on a local scale (Flushing port).

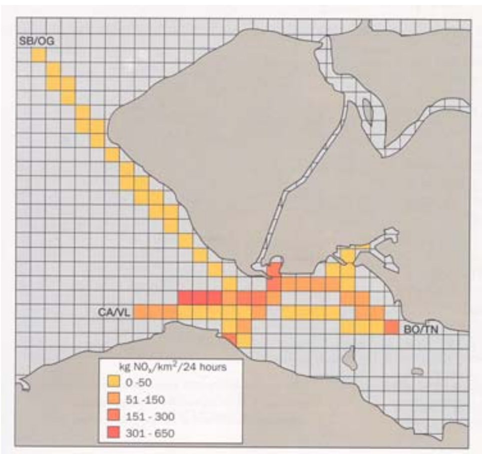


Figure 3 : Spatial distribution of NOx emissions from shipping in the Wester Scheldt. Data relates to August 1992 [Lloyd's Register of Shipping, 1995]

Later on, it is adapted to enable a quantification study on a regional scale, namely the North-Eastern Atlantic Ocean including the North Sea, the English Channel, the Irish Sea and the Norwegian Seas. This study area of approximately 23.2 million square km is equivalent to the EMEP area, except that it excluded the Baltic and Mediterranean Seas. Within this area Lloyd's estimates a total of 625,000 shipping movements during 1990; extrapolated from the 37,145 vessel movements provided by LMIU and 10,919 ferry movements listed in operators' schedules or international timetables.

	Area	SO_2	NOx
Lloyd's	English Channel & southern North Sea	162	227
CONCAWE	English Channel & southern North Sea	152	-
MARINTEK	English Channel & southern North Sea	122	-
Lloyd's	NE Atlantic	1371	1935
DNV	NE Atlantic	590	780
EMEP	NE Atlantic	490	541

Table 1 : Comparative evaluation of SO_2 and NO_x emission estimates for the study area (kton) [Lloyd's Register of Shipping, 1995]

Naval vessels, small crafts and fishing vessel movements are generally excluded from the study. The results for NOx, SO2, CO and HC are presented in a GIS format with a grid scale of 50 x 50 km.

The Lloyd's study compares its results with estimates from earlier published studies. This comparison shows a considerable higher number for the Lloyd's study, especially for the NE Atlantic where the amount of aerial emissions doubled or more.

1.4. MEERI [MEERI, 2004]

The MEERI model is developed by the Finnish government and calculates annually the amount of emission and energy consumption caused by waterborne traffic in Finland. The system includes sea and inland water traffic, recreational boating, fishing and icebreaker traffic; Finnish naval vessels are not included.

MEERI is a sub model of the LIPASTO project, covering emission calculations from all different types of transport. Thanks to this traffic emission inventory, Finland is able to compare the different transport sectors like road traffic (LIISA), rail traffic (RAILI), air traffic (ILMI) and maritime traffic (MEERI).

The model entered into force in 1995 and calculates the emission levels for six emission compounds: carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X), particles (PM), sulphur dioxides (SO_2) and carbon dioxide (CO_2).

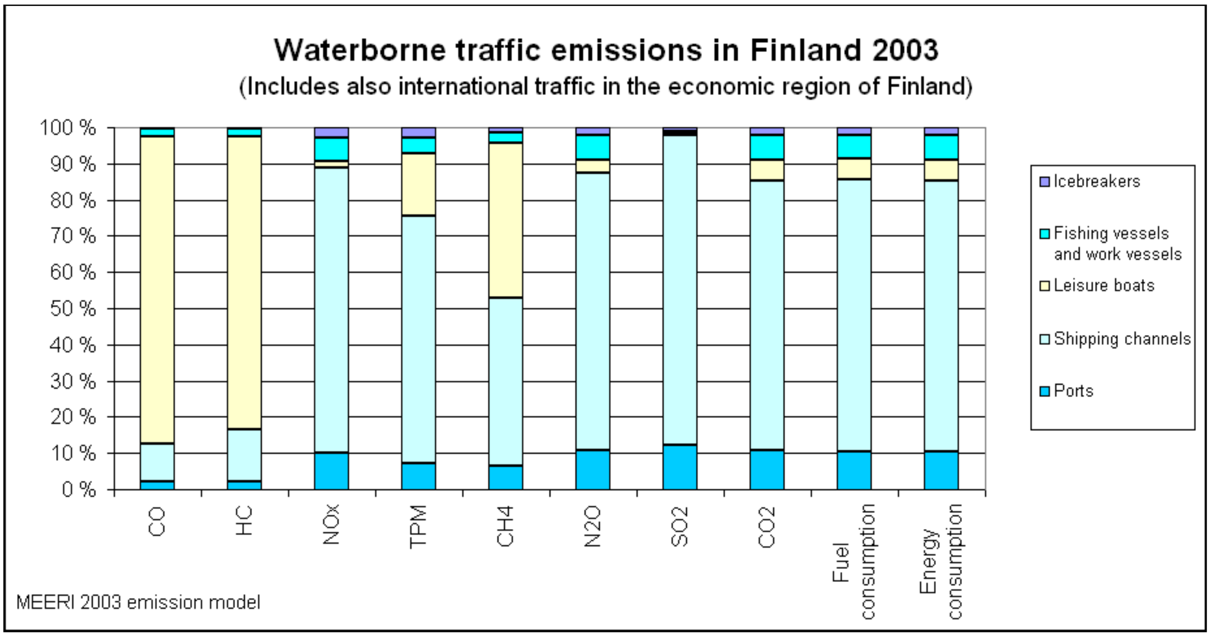


Figure 4 : Waterborne traffic emissions in Finland 2003 (includes also international traffic in the economic region of Finland) [MEERI, 2004]

The methodology is based on port Vessel Traffic Services (VTS) and determines the level of aerial emissions and energy consumption caused by waterborne traffic in shipping channels or lanes and in ports during a period of one year. The data is specified per ship type, its VTS area (domestic traffic, international traffic), its origin (Finnish, international) and its tonnage.

The employed approach depends on the type of vessel: The emission quantification of merchant vessels is executed by a bottom-up approach as opposed to the top-down calculation of emissions from leisure crafts that is based on their number and on annual operating rates (h/year/boat). The same approach is applicable for fishing and work vessels where the calculation is based on their number and on their annual fuel consumption (kg/year/boat).

	CO	**HC**	**NO_x**	**TPM**	**CH_4**	**N_2O**	**SO_2**	**CO_2**
Ports	621	225	7,236	154	30	10	2,376	354,348
Shipping	3,201	1,544	56,452	1,471	212	70	16,668	2,474,441
Leisure crafts and boats	25,457	8,768	1,427	367	196	3.1	81	198,572
Fishing and work vessels	653	208	4,643	99	12	6.2	133	222,192
Icebreakers	77	49	2,068	58	6.6	2.1	233	73,375
Total	30,009	10,795	71,825	2,150	458	91	19,491	3,322,928

Table 2 : The Finnish water-borne traffic emissions for 2003 (tons) [MEERI, 2004].

The MEERI model produces estimations concerning the evolution of the ship emissions from the base year 1980 to 1995 and from 2003 to 2023.

1.5. LOWLES AND APSIMON [LOWLES AND APSIMON, 1996]

This study looks at the English Channel and the southern North Sea. It reports more than 290,000 ship movements annually within its study area. It is not clear however, whether this is an independent count or one that relies on CONCAWE [Lyne et al, 1994], see 1.2 [Davies et al., 2000].

1.6. TECHNE SRL [TROZZI, CARLO AND RITA VACCARO, 1998]

TECHNE srl reviews marine emission factors and develops an inventory methodology on behalf of the European Commission in the so-called MEET project (Methodologies for Estimating Air Pollutant Emissions from Transport). In addition, other researchers have used these emission factors and methodology for inventory work for instance in the Turkish Straits [Kesgin and Vardar (2001); Whall et al (2002)]

The detailed methodology of Trozzi and Vaccaro (1998) to characterize ship activity assumes that the emission factor per ton of fuel is higher while the cargo ship is in the harbour because of the non-optimal engine load (the higher emission factor is compensated by the reduced fuel consumption during the harbour stay). Parameters for six types of engines are derived: gas turbines, three diesel engines (high, medium and slow speed engines) and two types of steam oil engines (residual oil and distillate oil).

Trozzi and Vacarro (1998) develop emission quantification methodologies for several phases in shipping: (a) cruising in international waters; (b) cruising in national x-miles zone; (c) approaching the port (by a river or a canal); (d) docking in port; (e) hotelling in port; (f) departing from port (by a river or a canal); (g) cruising in x-miles zone; (h) cruising in international waters (as referred to in the EMEP Emission Inventory Guidelines 5.2.1).

Phase (c) starts when the ship's deceleration begins and ends at the moment of the docking, while phase (f) starts with departure from the berth and ends when cruising speed has been reached. From a consumption and emissions point of view, there are three manoeuvring phases (c, d, f), one hotelling phase (e) and four cruising phases (a, b and g, h). After its arrival in harbour, a ship continues to emit at the dockside while in the hotelling phase (e).

1.7. LLOYD'S REGISTER [LLOYD'S REGISTER OF SHIPPING, 1999]

On behalf of the European Community Directorate General for Environment Lloyd's Register undertook a marine exhaust emission quantification study for the Mediterranean and Black Sea. The quantification of emission levels of NO_x, CO, SO_2 and Hydrocarbons (HC) are based on a bottom-up approach, making use of data supplied by Lloyd's (LMIU and Register of Ships), including ship movements and ships' particulars for two periods in 1990. Ferry movements for the relevant periods are derived from operators' schedules or international timetables. Ships hotelling in port, at anchor, awaiting a berth or awaiting orders, were not adopted in the study. The same goes for naval and fishing vessels.

The results were quantified in a grid matrix, covering the Mediterranean and Black Sea and equating to the 50 x 50 km grid system by EMEP.

The year 1990 is chosen as the base year for the emission estimates in this study as it is the year other Lloyd's Register emission quantification studies were based upon [Lloyd's Register of Shipping, 1995]. The emissions from this study are estimated at approximately 85 – 90% of the total emissions for the north-eastern Atlantic region.

1.8. CORBETT ET AL [CORBETT ET AL, 1999]

The objective of this study is the development of global emissions inventories of nitrogen and sulphur emissions from international maritime transport for use in global atmospheric models. 'Corbett et al' (1999) employ a top-down methodology using the international bunker fuel information reported in the USA Energy Information Administration's 'World Energy Database' in combination with the LMIU, providing data on engine profiles for registered commercial vessels of 100 GRT and greater and with marine exhaust emission test data by Lloyd's Register. The study estimates the 1993 global annual NO_x and SO_2 emissions from ships at 3.08 Teragrams (Tg) N and 4.24 Tg S, respectively.

	Nitrogen from ships, Tg/yr	Sulphur from ships, Tg/yr
Global ship emissions	3.08	4.24
Northern Hemisphere	2.63	3.62
North Atlantic	1.61	2.22
North Pacific	0.82	1.14
North Indian	0.18	0.25
North of Russia	0.01	0.02
Southern Hemisphere	0.45	0.62
South Atlantic	0.13	0.17
South Pacific	0.23	0.32
South Indian	0.09	0.13

Table 3 : Regional summary of ship emissions [Corbett et al, 1999].

To break down the global ship emissions geographically, the study uses data from the "Comprehensive Ocean-Atmosphere Data Set" (COADS) observation patterns. COADS is considered as the most extensive collection of surface marine data available for the world oceans over the past century and a half [Woodruff et al., 1993] and consists of a large database of location and weather observations made by merchant and naval mariners.

This study concludes that nitrogen and sulphur emissions from international shipping are larger than they previously were considered to be. These emissions are largely situated within potential transport distance of land regions. About 70% of all ship emissions occur near coastal areas. Additionally, seasonal characteristics for ship traffic represent significant variability in overall volume distribution. Another interesting conclusion of this study is the fact that approximately 70% of the world's nitrogen and sulphur emissions from shipping are emitted by transport ships.

1.9. MARINTEK [IMO, 2000]

The study is commissioned by IMO and examines the possibilities to reduce greenhouse gas emissions through different technical, operational and market-based approaches; the establishment of an emission inventory is not considered as the major aspect of the study.

This report estimates several types of aerial emissions from ships (CO, CO_2, NMVOC, CH_4, N_2O, SO_2 and NOx) for the year 1996 and employs two different types of emission models, both top-down approaches: (1) a fuel consumption methodology and (2) a statistical emission model.

In the fuel consumption methodology, the specific emission rates for NO_x, SO_2, CO_2, CO and NMVOC are calculated by the following general equation, adopted from the MARINTEK/DNV study [Klokk, 1996] and [DNV, 1998]:

$$M_{(g)} = B \cdot \sum_{i=1}^{n} (E_{i(g)} \cdot \alpha_i)$$

Where:

i = For NO_x calculation: engine type (1 = slow speed, 2 = medium speed, 3 = other); for SO_2, calculation: fuel type (1=residual, 2= distillate); for CO_2, CO, and NMVOC calculation: fuel type (1=residual+ distillate).

g = Individual exhaust gas component (NO_x, SO_2, CO_2, CO, and NMVOC).

$M_{(g)}$ = Emissions rate (kg pollution) for the individual exhaust gas component g.

$E_{i(g)}$ = Fuel- or engine-based emission factors (kg pollution per kg fuel).

B = Annual international marine bunker consumption (kg fuel).

a_i = For NO_x calculation: fraction of total installed engine effect world-wide with a specific engine type (slow =1, medium=2, other=3); for SO_2 calculation: fraction distillate and residual fuel; for CO_2, CO, and NMVOC calculation: equals 1.

Table 4 : Comparison of global inventories for ship emissions

Source	Year	C[1] (Mton)	SO_2 (Mton)	NO_X (Mton)
Present study, fuel based	1996	117 (138)	5.8 (5.2-7.8)	10.3 (10.1-11.4)
Present study, statistical model[2]	1996	112	5.5	9.8
UNFCCC, 1997	1994	109	7.5-11.5	9.3
Corbett, 1999	1992/1993	123.6	8.5	10.12
Corbett, 1999/EDGAR[3]	1990	149.2	-	-
Range		**109-149**	**6.1-11.5**	**9.3-11.9**

The statistical emission methodology divides the world fleet into different ship types and only includes propelled sea-going merchant ships of 100 GT and above. The model estimates the fuel consumption (annual, 1996) to about 132 Mton (main engine(s)).

Using the assumption that auxiliary engines consume 10% of the main engines(s), the total commercial consumption is about 145 Mton, which is approximately the same as the value calculated by EIA[4] fuel data.

The estimated amount of emissions in this study is compared to several other global emission inventories. It seems that the estimated amount of emitted gases corresponds well, even with a limited number of studies. Only the SO_2 emissions vary, but this effect is explained by the chosen sulphur content per fuel type, the relationship between residual and distillate fuel consumption and the amount of fuel burned.

The employed methodologies have documented weaknesses due to uncertainties related to statistical data material and emission factors: The emission inventory for ships in international trade is established for the year 1996 with data collected from energy databases published by EIA and UNFCCC; the different data sources are found inconsistent and indicate a number of errors in the system for reporting the consumption of marine bunkers.

1.10. BMT [Davies et al, 2000]

The BMT study considers, analyses and recommends policy options to sustain the objective of reducing the harmful environmental impact of emissions of SO_2 and NO_x from ships operating in European waters. These are divided in four different sea areas:

[1] Emitted amounts of carbon, approximately 85% (carbon content by weight) of marine fuel consumption

[2] Only main engine(s), not included in "range" (last row)

[3] Reported in Corbett (1999), based on Olivier et al (1996) (Emissions Database for Global Atmospheric Research (EDGAR), rep. 771060 002, National Institute on Public Health and Environment (RVIM) Bilthoven, Netherlands, 1996).

[4] Energy Information Administration, see website: http://www.eia.doe.gov

(1) the Baltic Sea, (2) the North and Irish Sea plus the English Channel, (3) the Mediterranean Sea and (4) the NE Atlantic Ocean.

The report estimates the share of SO_2 and NO_X emissions from ships in European Waters at 30% - 40% of the planned total of EU aerial emissions in 2010. The effects of the entry into force of MARPOL Annex VI are positive, but because of the very modest requirements for both SO_2 and NO_x, it will hardly contribute to emission reduction in European waters. For SO_2, the recent adoption of the North Sea as a SO_x Emission Control Area will have a positive effect, reducing the base level emission, against which the study has made its assessments, by 5-7%.[5]

The BMT study is based on the methodology developed by Corbett et al (1999). The data set is supplied by COADS, covering nearly 1.5 million ship observations during the period 1992-96. Still the COADS data set has two weaknesses: First, because COADS observations are generally made at six-hour intervals, it is unlikely that vessels on short and busy voyages, particularly ferries, are included. Second, ships in port will not make COADS observations either. This will cause an underestimation of emissions in marine areas having an above average concentration of ferry transit and port activities, e.g. the English Channel. The net effect of shipping in European waters was estimated at 1.9 million tonnes of SO_2 and 2.3 million tonnes of NO_X per annum.

1.11. H.O. Holmegaard Kristensen [Holmegaard Kristensen, 2000]

This study reports on the energy consumption and exhaust emissions for various types of marine transport compared with trucks and private cars. It is based upon theoretical calculations, and confronted with existing data from road transport studies.

The consumption patterns of bulk and container vessels were calculated in equivalent units of MJ/ton fuel or TEU[6]/ton fuel. This way, the emissions are decreasing when the capacity of the vessel is growing. These ship emissions are mostly inferior to emissions of road transportation. Only on smaller container vessels (less than 500 TEU), it is possible that the amount of NO_x emissions is superior to the same amount of TEUs transported by road modes.

The most surprising results are found for Ro/Ro cargo vessels: First, there is a substantial growth of the specific consumption proportional to the capacity of the vessel. Second, the specific consumption is higher than the specific consumption for road transport, certainly when the vessel transports trains as well, but less when it transports just trailers, without the trucks.

[5] This study was performed before the entry into force of Annex VI –Marpol. Therefore, the authors could only estimate the effects.

[6] TEU is a measurement for containers: Twenty feet Equivalent Unit (6.21m). 1 TEU stands for a container of 20 feet long, 2 TEU stands for a container of 40 feet or 2 containers of 20 feet,…

1.12. ENTEC [WHALL ET AL, 2002]

This study is commissioned by the European Commission, executed by "ENTEC UK limited" and published in July 2002. It quantifies ship aerial emissions of SO_2, NO_X, CO_2 and HC in the North Sea, English Channel, Baltic Sea, Black Sea and Mediterranean, as well as in-port emissions of these pollutants and PM. The study area roughly corresponds to the BMT area, but also includes the Black Sea.

The study employs a bottom-up approach, analysing all vessel movements and determining emissions for all vessels as well as separately for each vessel type and flag state (EU-state or not). It takes the effects of the MARPOL Annex VI agreement and alternative future scenarios into account, principally concerning SO_2 and particles. Additionally, the study undertakes a market survey of low sulphur marine distillates and investigates the feasibility of ships storing and using multiple grades of marine distillates.

The ship data is provided by the LMIU and covers 608,942 vessel movements over 4 months spread over the year 2000. The data is structured to identify the vessel, the vessel type, the engine type, the vessels size, the flag and the travelled routes. The emission estimates are shown in a GIS representation of the EMEP domain with grid squares of 50 x 50 km.

The 2001 BMT estimates are significantly lower than those derived by ENTEC for 2000, which indicates the large error ranges reported for ship emissions.

1.13. ENDRESEN ET AL [ENDRESEN ET AL, 2003]

This report presents detailed model studies of changes in the atmospheric composition of pollutants and greenhouse gases due to emissions from cargo and passenger ships in international trade. The model is based on a global emission inventory of NO_x, SO_2, CO, CO_2 and volatile organic compounds (VOC), developed by a bottom–up approach.

The model takes the world fleet data of cargo and passenger ships above or equal to 100 GT [Lloyd's Register of Shipping, 1995, 1999] as the main statistical source for the calculations. The data is combined with emission factors (kg per ton fuel) in order to determine the amount of emissions per grid section.

Auxiliary engines are recognised to contribute to the total exhaust gas emissions, but only emissions from main engines are included in the equation. The paper estimates a global fuel consumption of 152 and 166 Mton for 1996 and 2000 respectively, and assumes that in-port emissions range between 2 and 6% of these total emissions [Streets et al, 2000; Whall et al, 2002].

The global emission inventories are distributed geographically based on global ship reporting frequencies collected by the (1) Comprehensive Ocean-Atmosphere Data Set

(COADS), (2) PurpleFinder[7] and (3) Automated Mutual-assistance Vessel Rescue system (AMVER). The study evaluates each distribution system and concludes that the AMVER fleet best reflects the international cargo fleet by vessel types, size, and reporting frequency, followed by PurpleFinder. The reporting frequency weighted by the ship size is only available from the AMVER data.

Regarding the global distribution of emissions, the majority of the emissions seem to occur in the Northern hemisphere within a fairly well-defined system of international sea routes. Secondly, model calculations show that the response in the atmospheric chemical composition from ship emission is rather complex, and does not reflect the pattern of emissions. Further, the study concludes that solutions to problems with acidification and climate change seem to require different approaches. The impact on ozone, from a climate point of view, can be reduced by lowering the NO_x emissions in oceanic background regions, while NO_x reduction is much less effective in reducing ozone in the coastal areas with high background NO_x levels like in the North Sea. The situation is opposite for the acidification problem where reductions in coastal and in port areas are more important than reductions in open sea.

1.14. CORBETT AND KOEHLER [CORBETT AND KOEHLER, 2003]

As opposed to their earlier publication, Corbett and Koehler use for this study a bottom-up approach to develop a global ship emission inventory.

The study produces own emission factors in g/kg fuel, where the former study of Corbett et al (1999) uses emission factors from the Lloyd's Register. The emission factors are based on many parameters like engine type, size, speed and load. Other factors are the type and specification of the fuel, engine design (in-line or V-type), mode of operation (constant speed or propeller law), and number of cylinders. These fuel-based emission factors are very similar to the ones used by ENTEC [Whall et al, 2002].

The first Corbett study [Corbett et al, 1999] derives international shipping traffic densities from voluntarily reported, ship-based weather observations (COADS). This update study considers other approaches for assigning locations to international ship activities on a global scale and concludes that the Automated Mutual-assistance Vessel Rescue system (AMVER) provides the most representative international shipping distribution, in correspondence with Endresen [Endresen et al, 2003].

The study concludes that the annual emissions from ships (particularly NO_X: 6.87 Tg, SO_X: 6.49 Tg and CO_2: 249 Tg) are significantly greater than previously considered. The main remark that arises from these new (doubled) values for global ship emissions is the question why there is such a large discrepancy between fuel statistics and actual

[7] a Web-based solution that can be used to locate, communicate with and monitor fixed or mobile assets, from the largest Ultra-Large Crude Carrier tankers to small leisure craft, from Heavy Goods Vehicles to motorbikes, from remote silos to remote security systems, all on a global scale. [http://www.purplefinder.com/Wiki.jsp]

fuel usage by internationally registered ships. One possible answer is that a certain amount of vessels, registered as international shipping actually operates on fuel included in domestic inventories. Assuming this, only about 13% of world domestic residual consumption would be necessary to account for the discrepancy between international fuel statistics and the estimates of this study. Another interesting conclusion of this study is the fact that heavy fuel oil represents nearly 80% of the fuel consumed by these engines.

1.15. GERMANISCHER LLOYD [IMO, 2005A]

This report is based on information available from the FAIRPLAY database. The emission characteristics are performed for main engines only and are based on design values taking the deadweight as indicator for the transport capacity. The results are used for interpretation of the fuel related emissions (i.e. CO_2) of energy supply by means of diesel engines only.

The investigation is carried out for container, dry cargo ships, bulk carriers, tankers and passenger ferries. CO_2 emissions are calculated from the total fuel consumption of main and auxiliary engines. If applicable the differences in emission characteristics of each fuel type are taken into account.

The study concludes that operational results can only be discussed for the respective ship type and the available operational results of only a few ships and short observation times can lead to wrong conclusions, depending on their situation in comparison to all the other ships of the same type. For a fair indexing, the calculation of average values should be based on observations carried out over a sufficiently long period of time; for the indexing of new ships a methodology to calculate a first specific value near to what will be the result of operation is required.

Fuel type	kg CO_2 / kg fuel
HFO	3.11
LFO	3.15
MDO	3.17
MGO	3.17

Table 5 : emission factors per fuel type

A solution must be found to distribute the ship emissions between passengers and/or different types of cargo. This would require calculating with different reference values.

1.16. MARINTEK [IMO, 2005B]

As a study object, three sister ships operating in the same trade are selected to provide data sets covering fuel consumption, voyage data and cargo information. The fuel consumption is subdivided into port and sea patterns and for main and auxiliary engines and boilers.

First, initial analyses are conducted to consider the impact of alternative definitions of fuel consumption.

Ship	1	2	3
ME+AUX	2%	0%	1%
ME+AUX+BOIL	4%	4%	9%

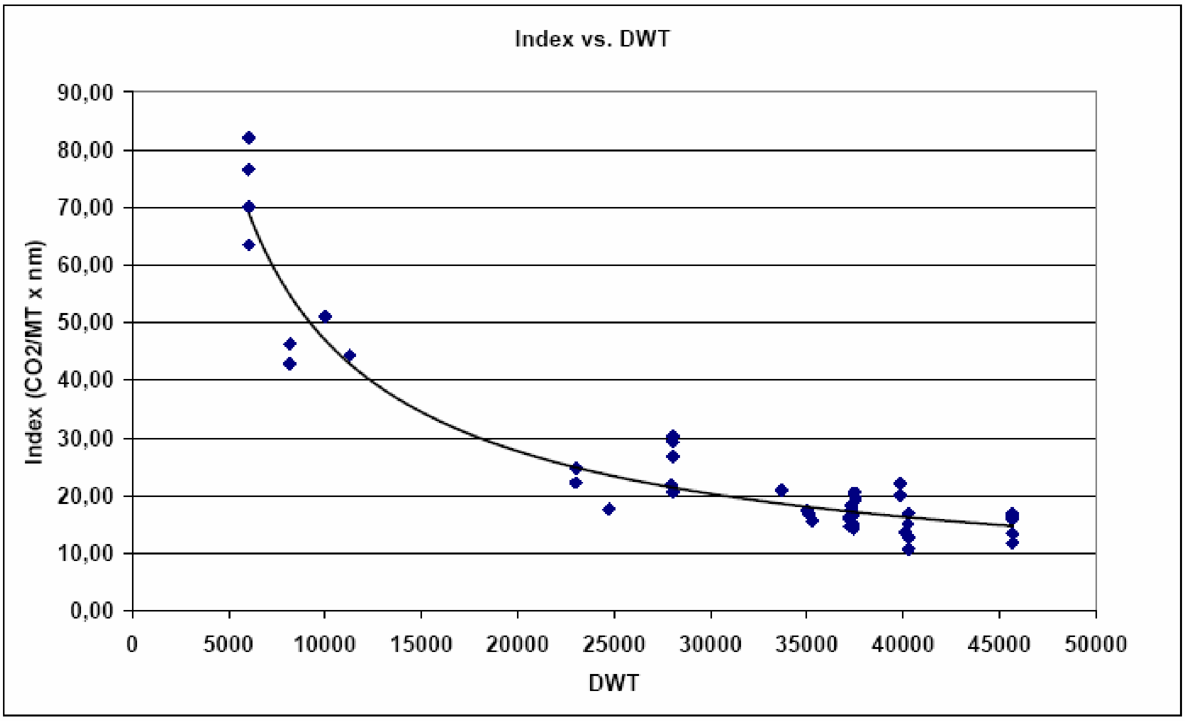
Table 6 : Relative increase in index with alternative definition of fuel consumption at sea. Increase compared to values if only main engine fuel consumption is considered.

Ship	1	2	3
ME	4%	2%	2%
ME+AUX	10%	9%	8%
ME+AUX+BOIL	14%	13%	12%

Table 7 : Relative increase in index with alternative definition of fuel consumption at sea and in port. Increase relative to values excluding fuel consumption in port.

As shown in the table the impact of including the fuel consumption by auxiliary engines and boilers has a slight variation for the three ships, and it is confirmed by the calculation that the main engine fuel consumption alone represents approximately 86-88% of the overall fuel consumption for the ships considered.

Figure 5 : Variation of index value for a fleet of same ship type, with associated trend line.



While an in-depth analysis of the properties of the index is performed for a few ships, annual average indexes are established for a fleet of vessels of the same ship type as the three ships analysed above. Due to variation in ship size, the variation in corresponding index value is found to be significant.

The figure shows that it is possible to develop an expected value for the index as a function of ship size for a given ship type (trend line).

Following remarks are made: First, the size of the data set significantly affects the index calculation, and a minimum number of observations should be included to ensure a statistically robust result for the index. Second, the index stabilizes at a given level when the number of observations increases and an accumulated index applying data over more than one year seems to converge towards a ship specific value. An index based on data for one year operation appears to represent a stable figure, but with likelihood of variation between different years (annual index).

1.17. ENTEC [STAVRAKAKI ET AL, 2005]

This report, ordered by the European Commission and a continuation to an earlier ENTEC study [Whall et al, 2002], made preliminary assignments of ship emission to European Countries including the following geographical areas: Baltic Sea, Black Sea, North Sea, Irish Sea, English Channel, Mediterranean Sea and North-East Atlantic.

Seven different methods were applied to assign five types of emissions to every EU25 member states plus Bulgaria, Romania, Turkey and Croatia:

method A: assignment according to location of emissions – ship emissions estimated in each country's inland waterways, ports, 12 and 200-mile zones;

method B: assignment according to flag of ship – ship emissions estimated for the flagged fleet of a country;

method C: assignment according to industry fuel sales estimates – ship emissions estimated for each country based on industry fuel sales estimates and reported fuel consumption and generic emission factors for the fuel;

method D: assignment according to reported fuel consumption - ship emissions estimated for each country based on industry fuel sales estimates and reported fuel consumption and generic emission factors for the fuel;

method E: assignment according to freight tons loaded – total ship emissions of the 29 countries estimated based on method A (for 200-mile zones) and split among the countries based on their relative share of freight tons loaded;

method F: assignment in proportion to national emissions – total ship emissions of the 29 countries estimated, based on method A (for 200-mile zones) and split among the countries based on their relative share of national emissions; and

method G: assignment according to country of departure/destination – ship emissions estimated as in method A but assigned to countries based on port of departure and destination.

These methods are a selection of "top-down" and "bottom-up" methodologies. An overall multi-criteria analysis presents a detailed assessment of each of the methods. The following criteria are considered: (1) costs to calculate assigned emissions; (2)

simplicity and transparency of assignment method; (3) data sources and quality, consistency and accuracy; (4) degree of influence for countries on key variables; and (5) fairness and appropriateness.

Method A is considered to be the most advantageous offering a relatively good potential accuracy and consideration of location. It also appears to be consistent with assignment of land based emissions under the NEC Directive [EU, 2001] and the 'sulphur in marine fuel' directive [EU, 2005] already sets a precedent for sea area based emission controls with the SO_x Emission Control Areas (SO_x ECAs) covering member states' territorial seas, exclusive economic zones and pollution control zones.

While methods B (assignment by flag) and method F (assignment in proportion to national emissions) are considered as unfavourable, other methods such as C (assignment by fuel sale), D (fuel consumption), E (freight tons) and G (departure/destination) are identified to have specific advantages. The former methods are considered worthy of further investigation.

An interesting conclusion is the ranking of Belgium regarding ship emissions within the EU25 + four candidates for each method, summarized in the following table:

	A – 12 mile zone	A – 200 mile zone	B	C	D	E	F	G
Belgium	11	13	22	3	3	6	14	7

Table 8 : Ranking based on the emissions allocated to each country under the different assignment methods (1 = most allocated emissions).

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2. ANNEX 2: THE BELGIAN FISHING FLEET'S EMISSIONS OF CO_2, SO_X, NO_X AND OTHER SUBSTANCES. [GOERLANDT, 2006]

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2.2. INTRODUCTION & PURPOSE

As is widely recognised, environmental protection is an important mission for modern day societies. However, air pollution has relatively late been given the attention it deserves. Issues as acid rain, climate change and a number of health problems are broadly accepted to be closely linked to air pollution. The general public is ever more aware that the matter is serious and that it is necessary to act. Scientific research is being executed in varying fields of study to better understand and diminish the harmful effects related to this form of pollution.

One of the difficulties with air pollution is that the effects often reach beyond national borders. Because of this, international cooperation is required. This is reflected in the overwhelming number of international bodies and councils acting on this matter. A number of treaties has been adopted, binding nations to minimise emissions of several key substances. Other treaties prescribe maximum levels of pollutants in the atmosphere in order to minimise effects on human health. Consequently, it is of great importance to obtain reliable estimates of the immission and emission quantities of the noxious substances. Several treaties have been adopted on this matter as well.

This work is to be seen against the background of this legal framework. The main goal of this study is to obtain a dependable estimate of the emissions of the Belgian fishing fleet for substances for which such a legal framework exists. This is done for 2005.

First, a brief overview of international reporting requirements is given in 2.3. Closely related to this, in 2.44 a concise description of the pollutants which are studied shall be given. With these background topics outlined, the actual study is commenced by giving an overview the Belgian fishing fleet in 2.55. It's evolution and current composition is discussed, and it is briefly compared to the European fleet in order to get an idea of its relative importance. 2.66 is the most comprehensive part of this study, discussing in detail the calculation procedures which are used to obtain the emission estimates. The results of the different methodologies are summarized and compared to one another and to results from the literature, giving attention to the accuracy of the estimates. The final results are presented and compared to emissions of other shipping activities. Recommendations are made on which methodologies should be used in future studies on the emissions of the Belgian fishing fleet.

Finally, a general conclusion is presented.

2.3. LEGAL FRAMEWORK: INTERNATIONAL REPORTING REQUIREMENTS

In this chapter, a concise overview is given of international reporting requirements Belgium has to comply with. The purpose is to show why this study is performed.

Other international law regarding to environmental protection, such as regulations of the International Maritime Organisation (IMO) and the United Nations Framework Convention on Climate Change (UNFCCC), are not discussed.

2.3.1. UNITED NATIONS

2.3.1.1. UNECE EMEP/LTRAP

The consequences of transboundary air pollution were first examined during the late 1960ies [34]. Acidification of water and soil were linked to increasing fish mortality and damage to forests. Recognising the problem of air pollution in large areas in Europe resulted on 13 November 1979 in the Convention on Long-Range Transboundary Air Pollution (CLTRAP) [61].

The already existing European Monitoring and Evaluation Program for Long Range Transported Air Pollutants (EMEP) was integrated in the Geneva Convention [68]. This program has from hence forward been an important instrument in the development of scenarios for emission reduction and in the negotiations concerning emission control laws between the parties. Belgium has ratified the Geneva convention on 15 July 1982. As a consequence, the emissions of a number of pollutants is annually reported to the United Nations Economic Commission for Europe (UNECE).

The EMEP/LTRAP reporting originally contained annual emission estimates of SO_2, NO_x, NMVOC and CO, broken up into various sources. Through the years, information was asked on heavy metals, POPs, total dust, PM10 and PM2.5 as well. The Nomenclature for Reporting, a standardised format for reporting estimates of emissions, was adopted. This encompasses a comprehensive description of the methodologies used in compiling the inventory, the data sources, the institutional structures and quality assurance and control procedures [19].

The Belgian fishing fleet's emissions are listed in the category "Agriculture, Forestry and Fisheries".

2.3.1.2. UNFCCC

In the framework of the climate agreement, IPPC (Intergovernmental Panel on Climate Change)-guidelines have been established for determination of greenhouse gases [34]. Countries that are party to the convention are required to report anthropogenic emissions of greenhouse gases, in casu CO_2, CH_4, N_2O and certain F-gases (SF_6 , CFC's and PFC's), and NO_x, CO and NMVOC.

The IPCC-guidelines state very clearly that all emission sources should be considered and classified under one of the categories. Emissions from fisheries are listed under "Transportation". The reporting format is the Common Reporting Format, in which each region (Flanders, Walloon and Brussels Capital) establishes its own inventory according to UNFCCC guidelines. It encompasses a series of standardized data tables, containing mainly numerical information and is submitted electronically [78].

2.3.2. Organisation for Economic Co-operation and Development

By the OECD [76], a biannual survey is submitted to the member states, in cooperation with Eurostat, the Statistical Bureau of the European Union [34]. Member states are asked to provide information on emissions of the pollutants SO2, NOx, NH_3, dust, CO, N_2O, NMVOC, CH_4, CO_2, Pb, Hg, Cd, HFC's and BFC's.

In June 2000, the first emission reports were gathered. The following reports were not effectuated as Eurostat could make use of other international emission reports. The emissions of the Belgian fishing fleet are listed under "Other Mobile Sources".

2.3.3. European Union

2.3.3.1. Reporting of CO_2 and Other Greenhouse Gases

Under Council Decision 93/389/EEC, as amended by Decision 1999/296/EC, each member state is required to communicate the emissions of CO_2 and other greenhouse gases [34] [46] [47]. Article 3, paragraph 2 states that »Member States shall each year, not later than 31 July, report to the Commission their anthropogenic CO2 emissions and CO2 removal by sinks for the previous calendar year«.

2.3.3.2. National Emissions Ceiling

For the battle against acidification, eutrophication and the formation of ozone, the European Union is implementing its own strategy [34]. An important tool is the EC-directive 2001/81/EC, establishing for each member state national emissions ceilings, which are to be achieved by 2010 [49]. Belgium has committed itself to reach following limits:

- SO_2: 99 kilotonnes;
- NO_x: 176 kilotonnes;
- NMVOC: 139 kilotonnes;
- NH_3: 74 kilotonnes.

Article 8, paragraph 1 states: »Member States shall each year, by 31 December at the latest, report their national emission inventories and their emission projections for 2010 […] to the Commission and the European Environment Agency. They shall report their final emission inventories for the previous year but one and their provisional emission inventories for the previous year. […]«

It is important to note here that according to the scope of the directive (Article 2), all emissions on the territory of the member states and their exclusive economic zones are to be considered, with exemptions for certain activities, e.g. international maritime traffic.

For the study of the emissions of the Belgian fishing fleet, this implies that a distinction will have to be made between national and international voyages and emissions in

Belgian waters and outside of these. Concluding, only emissions from national voyages in Belgian waters (which will prove to represent only a small fraction of the total amount) are to be taken into account.

The directive 2001/81/EC is to be evaluated in a wider context, the CAFE-program (Clean Air For Europe). The data which is to be reported is not only used for assessing the feasibility of the national ceilings. It also serves as input-data for model calculations of the CAFE-baseline scenario. This model allows to understand how the air quality in Europe will presumably evolve by 2020 based on present policy measures, showing what the impact of new measures would be.

2.4. EMISSIONS AND AIR POLLUTION

In this chapter, a brief introduction to various type of noxious substances shall be given, discussing their effects on the environment. The discussion will be limited to the pollutants to be estimated in 2.6. First, some general thoughts on air pollution and emissions will be given.

2.4.1. AIR POLLUTION, COMBUSTION AND EMISSIONS

As is widely known, air is a mixture of numerous gases [6]. The most important elements are nitrogen (N_2, 78.1 %), oxygen (O_2, 20.9 %) and argon (Ar, 0.9 %). In addition to these, air contains a rather large number of elements in small fractions, e.g. water vapour (H_2O), carbon dioxide (CO_2), neon (Ne), helium (He), methane (CH_4),…

The World Health Organisation [44] [82] considers air as polluted when the well-being of man is adversely affected or when damage is inflicted to his property. Well-being is to be interpreted in the broadest sense, namely the optimal state of physical, mental and social. Air pollution can be harmful for both fauna and flora and for materials.

The EU-directive 84/360/EC of 28 June 1984 [45] assumes the following definition of air pollution: »The introduction by man, directly or indirectly, of substances or energy into the air resulting in deleterious effects of such a nature as to endanger human health, harm living resources and ecosystems and material property and impair or interfere with amenities and other legitimate uses of the environment«.

In Belgian law, following definition is found [54]: »Air pollution is the discharge into the air, irrespective of the origin of the gases, liquids of solid substances, which can affect the health of man, can be detrimental for fauna and flora of can inflict damage to goods and natural and municipal beauty«.

The combustion of fossil fuels results in exhaust gases that contribute to air pollution [14]. The Belgian fishing vessels, which are mobile sources of air pollution, rely exclusively on fossil fuels for their propulsion. The emissions caused by burning fuel in engines are largely dependent on the quality of the fuel: certain fuel types contain more impurities such as sulphur or heavy metals. In the combustion process, all the sulphur for instance is converted into sulphur dioxide. Other substances are not as such present in the fuel, but are created during combustion. The formation of nitric oxides (NO_x) for instance is also dependent on the combustion temperature and the shape of the combustion chamber.

2.4.2. DESCRIPTION OF THE SUBSTANCES ESTIMATED IN THIS WORK

In this section, a short description of the pollutants which will be estimated in 2.6 is given. The purpose is to make clear why legal rules have been laid down for the emission of these substances [69], [70], [74], [75], [80].

2.4.2.1. NITROGEN OXIDES (NOx)

Nitric oxide (NO) and nitrogen dioxide (NO_2), collectively called NOx, are two of the most serious pollutants attributed to combustion sources [14] [5] [42]. Usually, only NO is emitted, but in the atmosphere, this will react to create NO_2. These nitrogen oxides will, by a similar mechanism to SO_x, form acid rain. NOx will also participate in the formation of solid particles during smog periods. At ground level and under sunlight, NO_2 will release one oxygen atom causing the formation of ozone (O_3), which is very irritating for the respiratory system.

Nitric oxide is formed in combustion processes by three mechanisms:

- Fuel NO: certain fuels contain up to 2 % nitrogen (N_2). During combustion, up to 50 % of this nitrogen reacts with hydrocarbon radicals, forming hydrogen cyanide (HCy), which reacts to NO;
- Prompt NO: quite similarly to the above mechanism, nitrogen in the air will react with hydrocarbon radicals forming HCy, leading to NO;
- Thermal NO: the formation of NO depends on the amount of O_2 and N_2 and on the temperature. The thermal equilibrium is shifted to NO-creation to an important extend for temperatures higher than about 1500 °C as the chemical reaction is relatively slow to the combustion process. Hence, shortening the residence time at high temperatures, the final quantity of NO emissions is decreased.

There are various techniques for reducing the amount of the NO-emissions [14]. The most widely applied method is the reduction of the residence time of the gas mixture in the cylinder, which decreases the amount of thermal NO. Other techniques encompass exhaust treatment systems.

2.4.2.2. CARBON MONOXIDE (CO)

Incomplete combustion of fossil fuels results in the formation of CO [14]. This is an extremely dangerous gas, which can cause death if inhaled in large concentrations. The formation depends on a number of factors: the mixing of fuel and combustion air, flame quenching close to the cylinder walls and the residence time in the cylinder. Certain catalysts can reduce the emission of CO by oxidating it to CO_2 before the discharge into the environment. In general, this gas is emitted in rather insignificant quantities at high-power operating conditions. When the power use is low, the combustion process is inefficient and the concentration of CO will be much higher.

2.4.2.3. NON-METHANE VOLATILE ORGANIC COMPOUNDS (NMVOC)

Non-methane volatile organic compounds include hydrocarbons such as propane, butane and ethane [5]. Along with NO_x, these substances participate in the formation of tropospheric ozone and other photochemical oxidants. Emissions of NMVOC are function of the amount of hydrocarbons passing unburnt through the engine. This condition depends amongst others upon the engine and fuel type. Emissions are generally highest at lower speeds.

Certain substances have serious adverse effects on human health, e.g. benzene [28]. Breathing very high levels of benzene can result in death. Exposure to high concentrations can cause amongst other dizziness and headaches. In the long term, it affects the bone marrow and the blood, causing a decrease in red blood cells, leading to anaemia.

2.4.2.4. SULPHUR OXIDES (SOx)

When fuels containing sulphur are burnt, all of the sulphur will be oxidised in the flame, forming SO_2 and SO_3 [14] [23]. One major problem with this is that these SO_x dissolve in clouds to form sulphuric acid, which can subsequently be deposited to earth by rain. This phenomenon is widely known as "acid rain", and has caused deforestation in Europe and North America [32]. Furthermore, it has caused serious damage to structures. Sulphur oxides also have a negative impact on human health: it is a respiratory irritant and in large concentrations can cause death.

The quantity of the discharged sulphur dioxides is directly linked to the sulphur content of the fuel. Therefore, a number of standards are created, setting limits to this percentage. There are post-combustion treatment techniques of the exhaust gases. In most cases, this technique is based on scrubbing: the exhaust gases are mixed with water droplets containing limestone, forming calcium sulphate ($CaSO_4$). In practice, this technique is however used only for large installations.

2.4.2.5. AMMONIA (NH3)

Ammonia is a colourless, toxic gas with a pungent odour [28]. It affects the mucous membranes and the respiratory system, and it is severely irritating for the eyes.

For the environment, ammonia serves a double role. On the one hand, NH_3 is basic, being transformed in ions of NH_4^+ when it comes in contact with water particles. By so doing, it can neutralise sulphuric acid, thus having a positive environmental effect. On the other hand, when NH_3 or NH_4^+ is precipitated to the soil, it can be converted into nitric acid by bacterial activity. This way, it contributes to acidification. The net effect is found to be acidification.

2.4.2.6. CARBON DIOXIDE (CO2)

All the carbon in the fuel will eventually transformed to carbon dioxide in the atmosphere. Even with incomplete combustion, resulting in the formation of carbon monoxide (see below), this CO will be oxidized to CO_2 in the atmosphere [15].

CO_2 is a major contributor to the greenhouse effect [35], as it absorbs a part of the radiation emitted by the earth surface. The carbon cycle is quite well understood, and in fact a greenhouse effect is responsible for the earth being livable for mankind.

During the last centuries, anthropogenic discharge of CO_2 has boomed. This may lead to global warming, which could have major effects on the earths' climate and may present future generations with huge problems, such as the melting of the ice caps and rising of the sea level. Using fossil fuels will invariably lead to the formation of CO_2; the only possible way of reducing its emission is burning less fuel and burning it as efficiently as possible.

The presence of carbon dioxide in rain water also has an influence on acidification.

2.4.2.7. METHANE (CH4)

As with NMVOC, small quantities of methane can pass through the combustion chamber of engines without being combusted [28]. The quantity of the emission depends on, amongst others, the methane content of the fuel and the engine type. Methane is one of the three main greenhouse gases, being 23 times as effective in absorbing radiation as CO_2.

2.4.2.8. NITROUS OXIDE (N2O)

Nitrous oxide is produced during the combustion of fossil fuel when nitrogen in the air or fuel is oxidized in the high temperature environment of the engine [14]. Even though the extent of emissions from ships is highly uncertain, they are thought to be small.

N_2O is one of the three major greenhouse gases responsible for climate change. It is a greenhouse gas 298 times more potent than CO_2.

2.4.2.9. PARTICULATE MATTER (PM)

Combustion, especially in diesel engines, may lead to formation of soot [14] [31] [43]. Soot is a generic name for solid particles of size less than 1 µm (The unit for size of particulates is aerodynamic diameter. This is the diameter of a spherical object which behaves in the ambient air in the same way as the particulate, [14]).

Unburnt carbon in the exhaust implies incomplete combustion and hence lower efficiency.

Following particulates are usually distinguished:

- PM10: particulate matter of size less than 10 µm;
- PM2.5: particulate matter of size less than 2.5 µm.

For PM10, the World Health Organisation states there is no safe threshold value under which no harmful effects occur. Even relatively short periods of exposure leads to the aggravation of health problems such as infections of the lungs and asthma. The effects caused by PM10 are estimated to comprise about 70 % of the total of lost healthy years of life caused by environmental factors.

2.4.2.10. HEAVY METALS

If the fuel contains metals, these will finish in the atmosphere in pure or in oxide-form [36]. Metals can be very dangerous and can cause serious health problems. On the other hand, small quantities of some elements are essential for the human body.

Cadmium (Cd), chromium (Cr), mercury (Hg), cupper (Cu), lead (Pb), nickel (Ni) and zinc (Zn) are the most important metals with respect to environmental pollution, but some of them have an important toxicological impact as well [28]. Arsenicum (As) and selenium (Se) are substances that are mainly important because of their toxicological effects.

- Cadmium is a non-essential element for the human body [28]. The most important effects are damage to kidneys and lungs. It is also brought into contact with prostate cancer.
- Chromium is essential for the functioning of the body as it amongst others participates in the carbohydrate and fat metabolism [28]. Certain chromium compounds on the other hand are highly toxic, with effects ranging from irritation of the skin and damage to the mucous membranes to genetic alteration.
- Mercury is a very toxic metal, which is accumulated in oceans and seas [28]. In high concentrations, it can cause high mortality in fish stocks.
- Cupper is in small quantities beneficial to the human body [28]. In larger quantities, it is toxic, with effects ranging from queasiness to damage to the liver on a cellular level.
- Lead is precipitated into the air as small particles with varying dimensions [28]. It is particularly dangerous for young children, but its effects only show after long-term exposure. It has negative effects on the production of blood cells and can cause damage to kidneys and the nervous system.
- Zinc is essential to the growth of plants and animals [28]. It has an important role in the structural development of cells and it stabilizes the structure of proteins and Ribo Nucleic Acid (RNA). Excessive doses of zinc are to be avoided, but the harmful effects are of minor importance compared to other substances. It has relatively unimportant effects on the environment.

2.4.2.11. PERSISTENT ORGANIC POLLUTANTS (POPs)

In addition to their persistence, POPs are lipophilic [33] [77]. Because of this, they tend to accumulate in substances like breast milk and humus. As a consequence, their concentration increases up the food chain. In may 1995, the UNEP classified twelve substances in this category: aldrin, chlordane, DDT, dieldrin, endrin, heptaclor, hexachlorobenzene, mirex, polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans and toxaphene. The list has amongst others been accepted to include carcinogenic polycyclic aromatic hydrocarbons (PAHs) as well.

POPs have varying biologically harmful effects. Disruption of the endocrine system (damaging the reproductive, nervous or immune system), induction of cancer and damage to skin and organs are only a few examples.

2.5. THE BELGIAN FISHING FLEET

2.5.1. EVOLUTION

Figure 6 shows the evolution of the fleet capacity from 1955 until 2005 for each port of register. From the 1950ies till the early 1970ies, the total installed power increased steadily, reaching a maximum of just over 75000 kW in 1971. A major reorganization during the 1970ies decimated the number of ships, resulting in a dramatic decline in both the installed power and the available tonnage. The next decade presented itself as a period of recovery: the total number of ships stayed remarkably stable, whereas both the installed power and the tonnage flourished. The early 1990ies continued this trend, reaching an absolute maximum in installed power of almost 81000 kW and a maximum in tonnage of over 27000 GT. From then on, a rather dramatic decrease occurred. Comparing the record year 1992 with 2005 shows a decrease in number of ships from 205 to 117 (-43 %), while the total installed power and the total tonnage decreased from 80870 kW to 62326 kW (-23 %) and 27089 GT to 22351 GT (-17.5 %). A number of reasons can be found for this decline, which will be discussed later on.

Figure 6 shows the evolution of the number of ships for the past 50 years. The downward trend is obvious: compared to 1958, in 2005 only 26 % of the number of ships remains. Of all ports of register, Oostende suffered the largest decline: in 50 years time, a massive 85 % of the fleet of Oostende was scrapped. The evolution of the total installed power is shown in Figure 7. Here, a somewhat different situation is seen: the power increased during the 1950ies and 1960ies, decreased during the 1970ies, boomed during the 1980ies and steadily decreased from 1992 onwards. For the tonnage, a similar conclusion can be drawn, see Figure 8. It is interesting to note that the average size of the vessels have almost monotonically increased, as has the average power, see Figure 9.

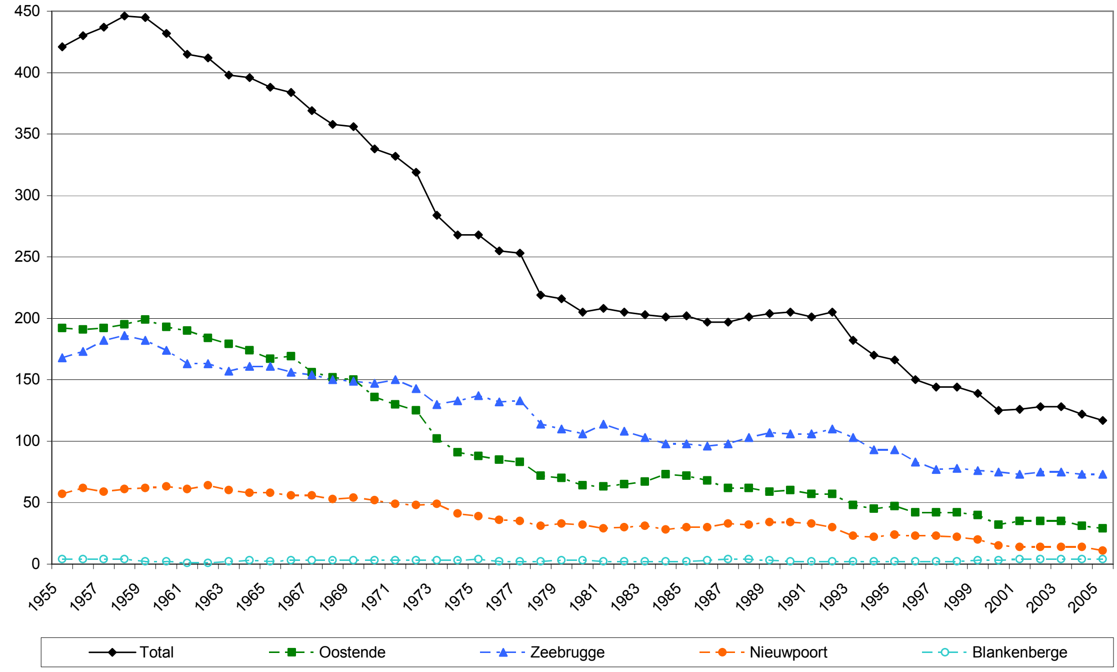


Figure 6: Evolution of the number of Belgian fishing vessels; per port of register; based on [37] [38] [39] [40] [79]

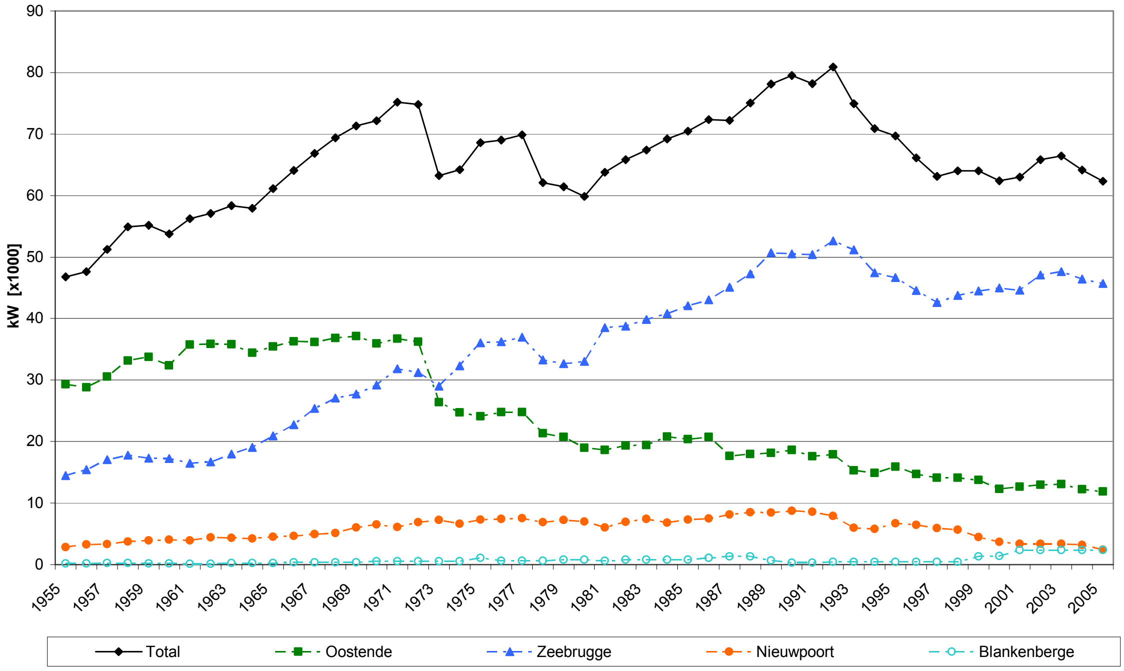


Figure 7: Evolution of the total installed Power (kW); per port of register; based on [37] [38] [39] [40] [79]

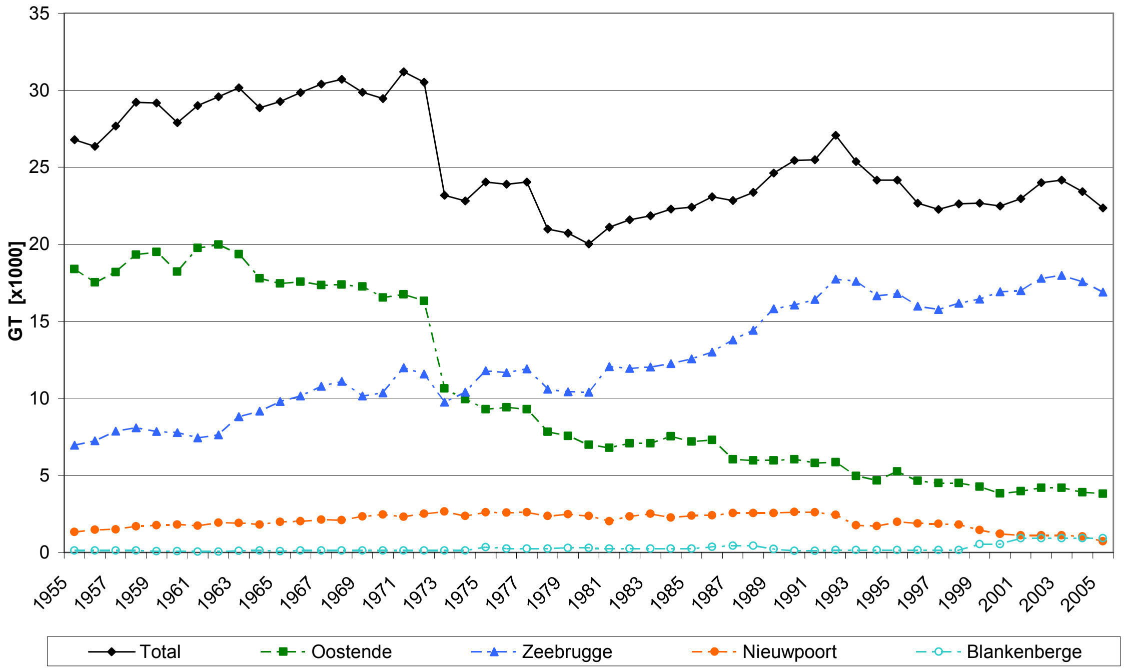


Figure 8: Evolution of the total tonnage (GT), per port of register; based on [37] [38] [39] [40] [79]

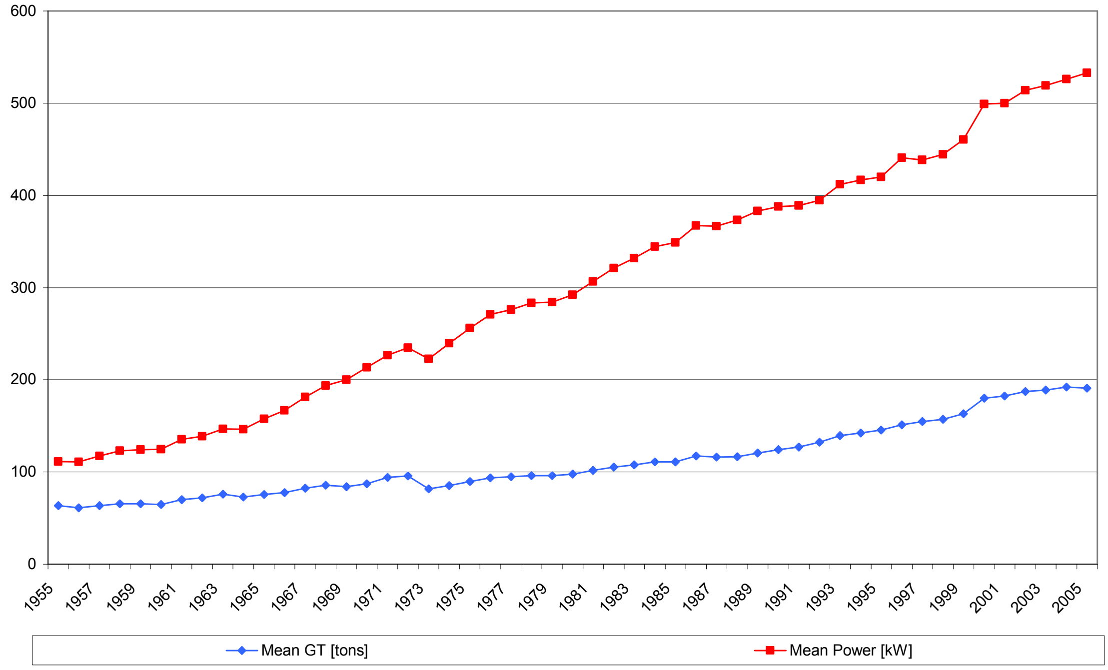


Figure 9: Evolution of the mean tonnage (GT) and the mean power (kW); based on [12]

Table 9: Evolution of the Belgian fishing fleet: number of ships, total installed power (kW) and total tonnage (GT), per port of register; [12]

	Oostende			Zeebrugge			Blankenberge			Nieuwpoort			Total			Average	
year	number	kW	GT	number	kW	GT	number	kW	GT	number	kW	GT	number	kW	GT	kW	GT
1955	192	29289	18384	168	14472	6959	4	194	121	57	2835	1317	421	46790	26781	111	64
1956	191	28805	17518	173	15414	7249	4	194	121	62	3233	1462	430	47646	26350	111	61
1957	192	30573	18202	182	17062	7869	4	268	121	59	3333	1495	437	51237	27687	117	63
1958	195	33169	19326	186	17757	8089	4	268	121	61	3738	1693	446	54931	29229	123	66
1959	199	33742	19489	182	17328	7847	2	186	80	62	3927	1749	445	55183	29165	124	66
1960	193	32350	18225	174	17237	7787	2	168	80	63	4016	1808	432	53771	27900	124	65
1961	190	35733	19758	163	16458	7448	1	130	57	61	3930	1736	415	56251	28999	136	70
1962	184	35866	19974	163	16682	7621	1	130	57	64	4412	1928	412	57091	29580	139	72
1963	179	35835	19363	157	17960	8807	2	231	91	60	4345	1909	398	58372	30170	147	76
1964	174	34430	17782	161	19069	9166	3	261	110	58	4191	1811	396	57950	28869	146	73
1965	167	35457	17450	161	20945	9789	2	220	71	58	4532	1970	388	61154	29280	158	75
1966	169	36315	17572	156	22712	10151	3	384	126	56	4646	2010	384	64057	29859	167	78
1967	156	36188	17363	154	25353	10776	3	384	126	56	4925	2127	369	66851	30392	181	82
1968	152	36816	17375	150	27058	11100	3	384	126	53	5134	2106	358	69392	30707	194	86
1969	150	37157	17269	149	27731	10161	3	384	126	54	6025	2328	356	71297	29884	200	84
1970	136	35920	16529	147	29147	10348	3	548	126	52	6519	2465	338	72134	29468	213	87
1971	130	36717	16761	150	31839	11976	3	548	126	49	6085	2322	332	75189	31185	226	94
1972	125	36222	16324	143	31201	11568	3	548	126	48	6864	2500	319	74835	30518	235	96
1973	102	26420	10644	130	28999	9757	3	548	126	49	7250	2648	284	63216	23175	223	82
1974	91	24735	9942	133	32317	10402	3	548	126	41	6618	2354	268	64218	22824	240	85
1975	88	24137	9302	137	36068	11793	4	1063	337	39	7313	2610	268	68581	24042	256	90
1976	85	24756	9416	132	36242	11666	2	615	240	36	7414	2582	255	69028	23904	271	94
1977	83	24786	9300	133	36960	11906	2	615	240	35	7512	2598	253	69874	24044	276	95
1978	72	21326	7815	114	33258	10584	2	615	240	31	6878	2363	219	62078	21002	283	96
1979	70	20725	7551	110	32657	10414	3	794	288	33	7237	2484	216	61413	20737	284	96
1980	64	19010	6988	106	33046	10398	3	794	288	32	7018	2362	205	59868	20036	292	98
1981	63	18609	6795	114	38550	12060	2	615	240	29	6015	2027	208	63789	21122	307	102

(continued fromTable 9)

	Oostende			Zeebrugge			Blankenberge			Nieuwpoort			Total			Average	
year	number	kW	GT	number	kW	GT	number	kW	GT	number	kW	GT	number	kW	GT	kW	GT
1982	65	19370	7077	108	38743	11948	2	772	240	30	6955	2323	205	65840	21588	321	105
1983	67	19385	7069	103	39845	12046	2	772	240	31	7413	2492	203	67415	21847	332	108
1984	73	20798	7527	98	40789	12241	2	772	240	28	6831	2274	201	69190	22282	344	111
1985	72	20371	7209	98	42057	12576	2	772	240	30	7294	2391	202	70494	22416	349	111
1986	68	20764	7303	96	43018	13010	3	1092	370	30	7465	2413	197	72339	23096	367	117
1987	62	17665	6047	98	45073	13800	4	1316	439	33	8138	2560	197	72192	22846	366	116
1988	62	17966	5978	103	47234	14426	4	1316	439	32	8513	2542	201	75030	23385	373	116
1989	59	18117	5974	107	50679	15820	3	645	228	34	8455	2557	204	78101	24620	383	121
1990	60	18614	6049	106	50493	16066	2	324	98	34	8732	2628	205	79485	25445	388	124
1991	57	17613	5801	106	50376	16405	2	324	98	33	8549	2590	201	78183	25498	389	127
1992	57	17884	5839	110	52647	17745	2	447	153	30	7908	2442	205	80870	27089	394	132
1993	48	15335	4966	103	51177	17599	2	447	153	23	5994	1747	182	74937	25375	412	139
1994	45	14903	4659	93	47426	16650	2	447	153	22	5793	1699	170	70865	24156	417	142
1995	47	15899	5244	93	46673	16802	2	447	153	24	6687	1975	166	69706	24174	420	146
1996	42	14736	4647	83	44521	15991	2	447	153	23	6437	1877	150	66142	22668	441	151
1997	42	14128	4509	77	42644	15764	2	442	153	23	5905	1851	144	63119	22277	438	155
1998	42	14128	4493	78	43768	16188	2	442	153	22	5695	1803	144	64033	22637	445	157
1999	40	13738	4253	76	44464	16430	3	1324	537	20	4486	1449	139	64012	22669	461	163
2000	32	12298	3829	75	44987	16922	3	1399	537	15	3687	1197	125	62371	22485	499	180
2001	35	12645	3967	73	44598	16986	4	2356	922	14	3404	1100	126	63003	22975	500	182
2002	35	12955	4177	75	47097	17793	4	2356	922	14	3404	1100	128	65812	23992	514	187
2003	35	13059	4179	75	47625	17974	4	2356	922	14	3404	1100	128	66444	24175	519	189
2004	31	12214	3899	73	46414	17563	4	2356	922	14	3184	1036	122	64168	23420	526	192
2005	29	11859	3804	73	45698	16910	4	2356	922	11	2413	715	117	62326	22351	533	191

2.5.2. FACTORS INFLUENCING THE SIZE OF THE BELGIAN FISHING FLEET

The marked decrease of the number of ships calls for an explanation. The discussion shall be limited to rather recent developments, concentrating on the decline since the early 1990's.

Perhaps the most important driving force for this decline is an ecological one. The marine ecosystem is a very vulnerable environment and the combination of years of polluting and overfishing has reduced the size of the fishable stocks to a large extend. Basically, the problem is that there are too many ships for too little fish [29].

As a consequence, juridical steps were taken: an overwhelming number of treaties has been adopted, establishing conservation measures for specific species, imposing technical constraints upon the fishing vessels and their equipment, or regulating the behaviour of the vessels. The explicit goal is to reduce the fishing efforts and conservation of the marine environment. The reduction of fleet capacity is stimulated by public aid for final cessation of activities.

Some examples are chosen to illustrate this very complex matter [8].

2.5.2.1. International law, [22]

- Geneva Convention of Fishing and Conservation of Living Resources of the High Seas, 1958
- United Nation Convention on the Law of the Sea, 1982
- United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks, 1995

2.5.2.2. European Union law

- Regulation 2371/2002/EC on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy, [50]
- Regulation 2792/1999/EC laying down the detailed rules and arrangements regarding Community structural assistance in the fisheries sector, [48]

2.5.2.3. Belgian Federal law

- Law of 19 August 1891. Wet betreffende de zeevisserij in de territoriale zee [52] - Law concerning the sea fisheries in the territorial sea
- Law of 12 April 1957. Wet waarbij de Koning wordt gemachtigd maatregelen voor te schrijven ter bescherming van de biologische hulpbronnen van de zee [53] - Law by which the King is empowered to prescribe measures in protection the biological resources of the sea.

[8] Preference is given not to elaborate on this complex issue, as the author has no juridical background.

- Law of 10 October 1978. Wet houdende vaststelling van een Belgische visserijzone [55] - Law concerning the enactment of a Belgian fisheries zone.
- Law of 22 April 1999. Wet betreffende de exclusieve economische zone van België in de Noordzee [56] - Law concerning the exclusive economic zone of Belgium in the North Sea.

2.5.2.4. Flemish Community law

- December 16, 2005. Besluit van de Vlaamse Regering tot de instelling van een visvergunning en houdende tijdelijke maatregelen voor de uitvoering van de communautaire regeling inzake de instandhouding en de duurzame exploitatie van de visbestanden [57] - Decree of the Flemish Government concerning the establishment of a fishing permit and temporary measures for the implementation of the communal regulation concerning the conservation and the sustainable exploitation of the fishing stocks.
- January 26, 2006. Ministerieel besluit houdende tijdelijke aanvullende maatregelen tot het behoud van de visbestanden in zee [58] - Ministerial decision implementing temporary complementary measures for the conservation of the fishing stocks at sea.
- February 9, 2006. Ministerieel besluit tot vaststelling van uitvoeringsbepalingen van het besluit van de Vlaamse Regering van 16 december 2005 tot de instelling van een visvergunning en houdende tijdelijke maatregelen voor de uitvoering van de communautaire regeling inzake de instandhouding en de duurzame exploitatie van de visbestanden met betrekking tot het kustvisserssegment, alsook tot de opheffing van drie ministeriële besluiten [59] - Ministerial decision concerning the enactment of implementing measures of the decree of the Flemish Government of december 16, 2005 concerning the establishment of a fishing permit and temporary measures for the implementation of the communal regulation concerning the conservation and the sustainable exploitation of the fishing stocks with regard to the coastal fisheries segment, as well as the abolition of three ministerial decisions.

It is noteworthy that restructuring the fleet and reducing its capacity do not necessarily lead to reduction in fishing pressure as advances in technology and design allow new vessels to exert more fishing pressure than older vessels of equivalent tonnage and power. [11]

Market developments have a major influence on the size of the fleet as well. On the one hand, quota's imposed by law have set a limit on the maximum landings of fish, which has of course consequences for the turnover. On the other hand, ever increasing oil prices lead to growing fuel costs (see Figure 10). As fuel costs account for around 25 % of the total operational costs of an average fishing vessel (see Figure 11), rising fuel prices have a major effect on the company results.

Combining the conflicting trends in turnover and costs, the total earnings shrink steadily, causing financial problems for a large number of shipping companies and ship owners. In some cases, it even is cheaper to lay up the vessel for a period of time (for instance the vessels Z.123 and Z.307 were laid up for the entire year 2005). Each year, there are several bankruptcies.

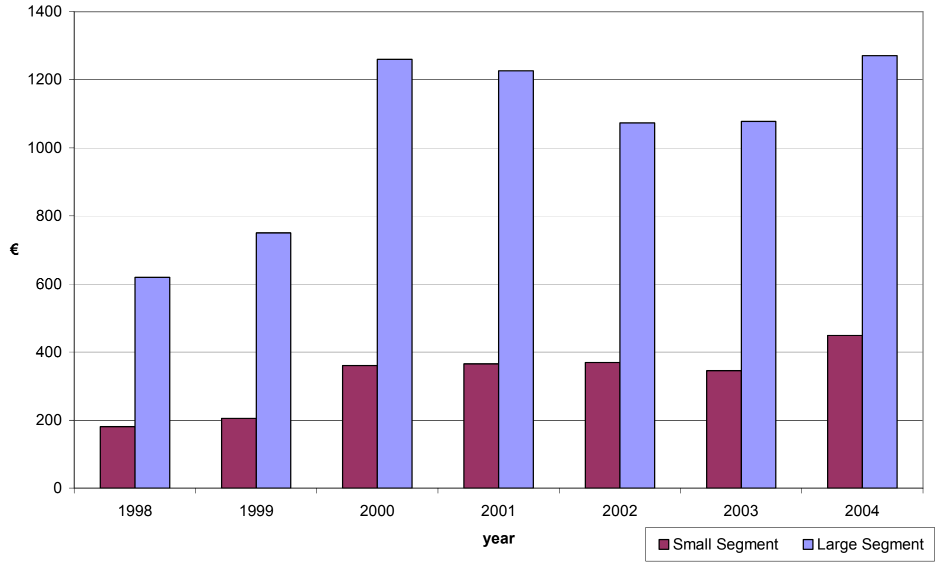
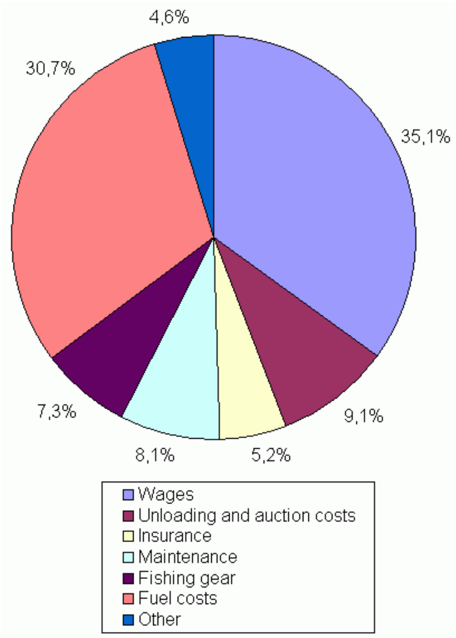


Figure 10: Evolution of the average fuel costs per day at sea; based on [17] [25] [27]



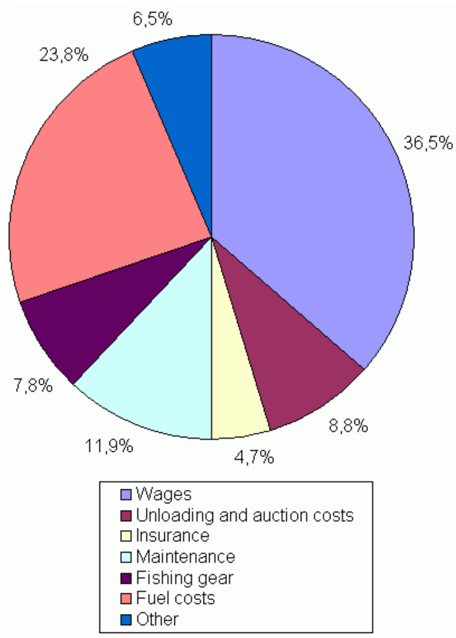


Figure 11: Cost structure of an average Large Segment vessel (left) and an average Small Segment vessel (right); based on [27]

In Figure 12 and Figure 13, average company results for 2003 and 2004 are shown for a large segment and a small segment vessel, respectively. For 2004, the cost structure is shown for both vessel classes in Table 10 and Table 11. Whereas an average vessel gained a small net gain before taxes in 2003, in 2004 the average net company result before taxation was negative! Even with a limited number of ships still profitable, these numbers show that the sector as a whole is in a deep crisis.

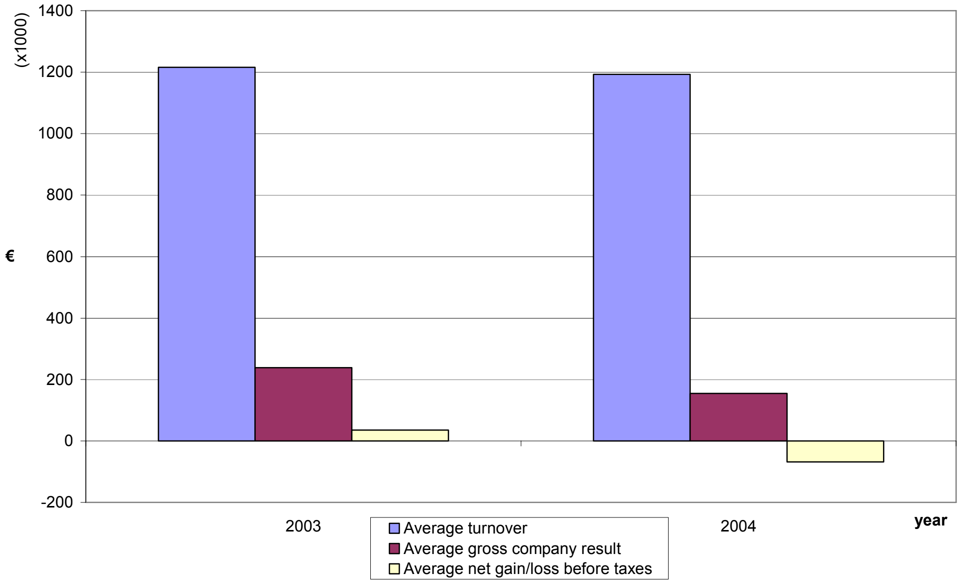


Figure 12: Average company results for a large segment vessel for 2003 & 2004; based on [27]

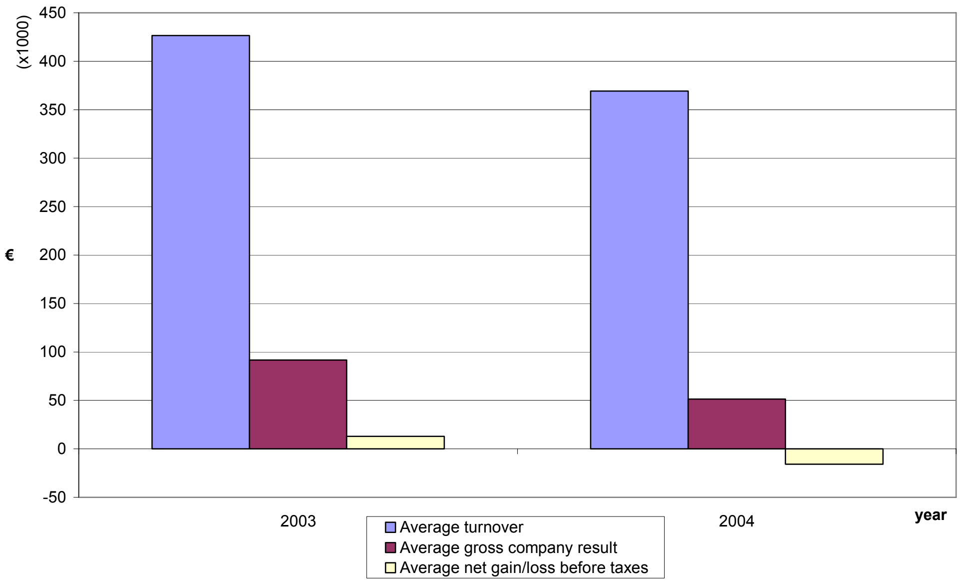


Figure 13: Average company results for a small segment vessel for 2003 & 2004; [27]

Table 10: Detailed cost structure of an average small segment vessel

Net gain/loss before taxes (in EUR); [27]

average days at sea: 168 average power: 208 kW average tonnage: 82 GT			**Per day at sea**	**Per kW**	**% with respect to** **Total costs**	**Turnover**
Turnover	**369,148**		2,191			
Costs						
Wages		116,082	689	558	36.51	31.45
Unloading and auction		27,911	166	134	8.78	7.56
Insurance		14,882	88	72	4.68	4.03
Maintenance		37,852	225	182	11.91	10.25
Fishing gear		24,861	148	120	7.82	6.73
Fuel costs		75,686	449	364	23.81	20.50
Other costs		20,653	123	99	6.50	5.59
Total		**317,927**	1887	1528		86.12
Gross company result	**51,222**		304	181		**13.88**
Debit		55,409	329	196		
Net company result	**-4,187**					
Financial costs		20,625	122	73		
Financial profits	8,957					
Net gain/loss before taxes	**-15,854**					

Table 11: Detailed cost structure of an average large segment vessel

Net gain/loss before taxes (in EUR); [27]

average days at sea: 251 average power: 863 kW average tonnage: 313 GT			**Per day at sea**	**Per kW**	**% with respect to** **Total costs**	**Turnover**
Turnover	**1,192,768**		4760			
Costs						
Wages		364,692	1455	422	35.14	30.58
Unloading and auction		94,227	376	109	9.08	7.90
Insurance		53,800	215	62	5.18	4.51
Maintenance		83,651	334	97	8.06	7.01
Fishing gear		75,350	301	87	7.26	6.32
Fuel costs		318,596	1271	369	30.69	26.71
Other costs		47639	190	55	4.59	3.99
Total		**1,037,956**	4142	1202		87.02
Gross company result	**154,810**		618	132		**12.98**
Debit		210,181	839	179		
Net company result	**-55,370**					
Financial costs		55,961	223	48		
Financial profits	43,463					
Net gain/loss before taxes	**-67,868**					

A final problem of the Belgian fishing sector is it's dependency on a very limited number of species. This is illustrated in Figure 14. The top 5 of the most caught species accounts for 64 % of the total landings. Of these, plaice and sole are by far the most important species as they respresent 25 % and 19 % of the total landings, respectively.

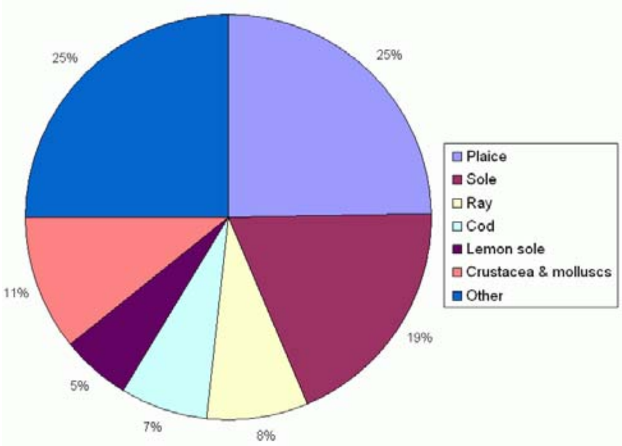


Figure 14: Total landings of the Belgian fishing vessels by species for 2004; based on [26]

This is not a favourable situation, as an accidental fall in numbers of one of these species has direct and important consequences for the landings and the turnover.

2.5.3. CURRENT COMPOSITION OF THE BELGIAN FISHING FLEET (2005)

A complete overview of the Belgian seagoing fishing fleet is given in Appendix A. In Table A.1, a number of characteristics of the vessels is given. The most important data from this table comprises:

- the vessel sign, making it possible to refer to each ship individually;
- the vessel classification, which shall be discussed below;
- the fishing gear, as this is related to the used engine power.

Table A.2 gives detailed information on some key specifications of the main engines installed in the fishing vessels. Without any doubt, the most important characteristic in this study is the maximum output power of the main engine, as this is directly linked to the fuel consumption and the emissions. Other important specifications encompass the engine age, which is related to the fuel consumption and the emissions of NO_x, and the number of revolutions the engine operates at when using full power, as this influences the emission values of NO_x (see Figure 32: Emission factors for NOX used for engines manufactures after 1997, based on IMO MARPOL Annex VI regulations; [60]).

Wherever possible, calculations are performed for each vessel individually (which is possible as the fleet is rather small). However, in some calculation methods (e.g. the fuel consumption estimates using fuel cost data), use is made of characteristic values for a segment of the fleet. Results of certain calculations (e.g. overview of the vessel movement data, see Figure 25 and Figure 26) are also given distinguishing a number of fleet segments, as this can sometimes give an insight in the main trends. Furthermore, these global values may be useful information for future studies.

Following classes are distinguished, after [27]:

- **Small segment vessels (SS)**: Vessels with a maximum main engine power output of 221 kW. During 2005, the fleet contained 56 SS units;
- **Coastal vessels:** Small segment vessels, usually less than 24 consecutive hours at sea. During 2005, there were 23 of these vessels;
- **Eurokotters:** Small segment beam trawlers built after 1981, built specifically for fishing within the 12 nm zones. Notwithstanding present criteria for fishing in these waters, (present criteria for fishing in these waters state that the vessels may have a maximum output power of 221 kW and a maximum L.O.A. of 24 m. [27]) beam trawlers with a power output of maximum 221 kW, measuring over 65 GT are listed in this category as well, regardless of their length. For 2005, 25 vessels belong to this vessel class;
- **Other SS:** Small segment vessels, not belonging to the Eurokotter of coastal vessel classes. The Belgian fleet contained eight of these vessels during 2005;
- **Large Segment vessels:** Vessels with a maximum power output over 221 kW. For 2005, 62 units of this class are counted;
- **Beam trawlers +662 kW:** Beam trawlers with a power output over 662 kW. For 2005, 53 of these vessels are active;
- **Other LS:** A heterogeneous rest fraction, containing nine vessels during 2005.

A graphical decomposition of the fleet by vessel type is shown in Figure 15. Using calculation results obtained from paragraph 2.6.2.3.2, an overview of the fuel use by vessel class is obtained, which is given in Figure 16.

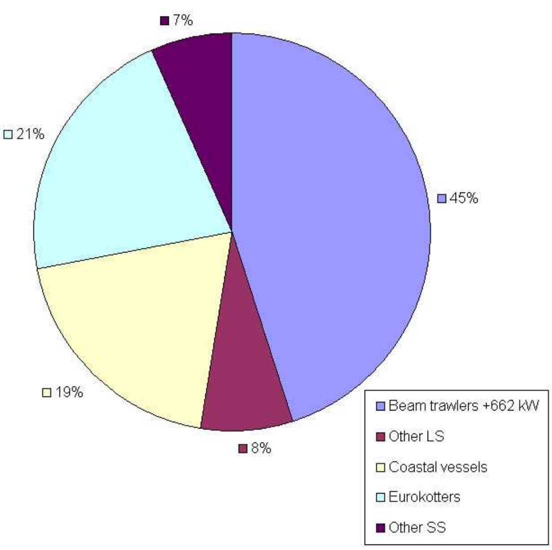


Figure 15: Fleet decomposition by vessel type

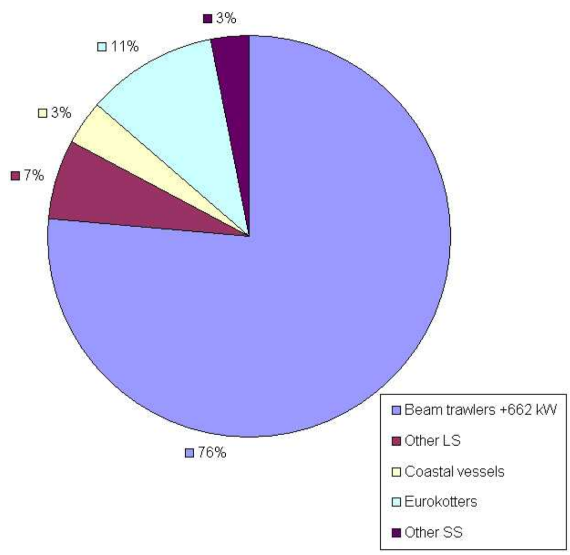


Figure 16: Fleet decomposition by fuel consumption

It is clear from this figures that the large vessel segment accounts for over 80 % of the fuel consumption of the whole fleet. As a consequence, these vessels emit an similar percentage of the emissions.

For 2005, 118 vessels are listed in the official list of the Belgian fishing vessels. However, two of these (Z.123 and Z.307) were laid up for the entire year. Two other vessels tragically sank: the Z.28 sank on 29 April 2005 and the Z.121 sank on 13 December. It is clear that the downwards trend which has been found in Figure 6, continues in 2005. For 2006, no change on this field may be expected. The updated version of the official list of the Belgian Fishing vessels [13], shows that two more vessels have been taken out of service, viz the vessels Z.307 and N.34.

Another interesting feature of the fleet is its age. In Figure 17 an overview of the number of vessels built per year is shown, making a distinction between large and small segment vessels.

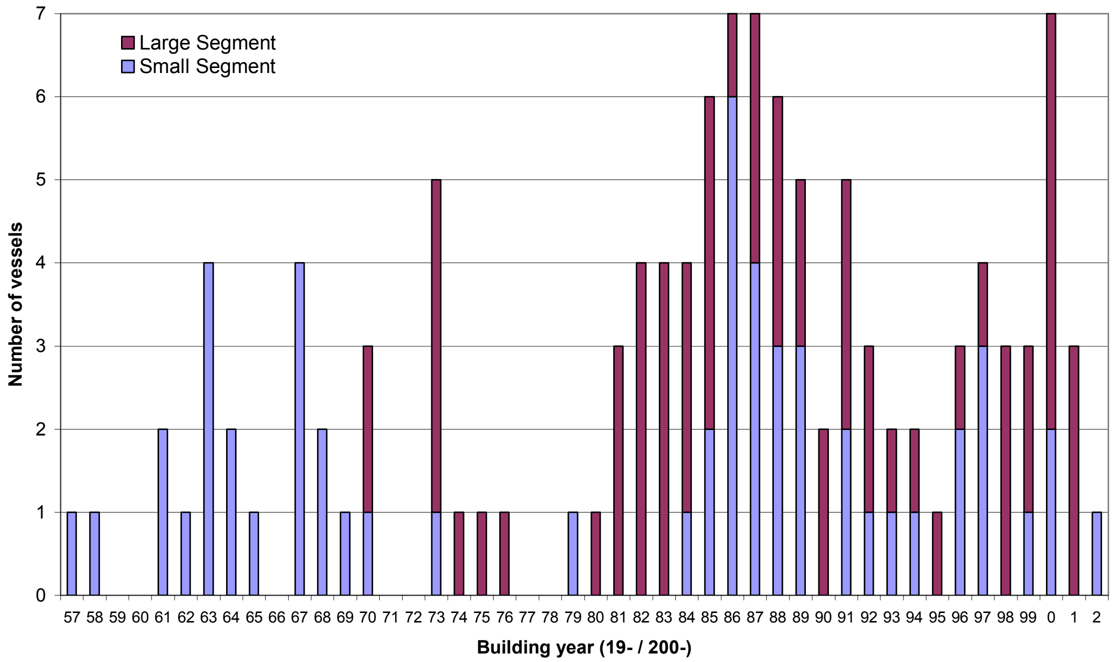


Figure 17: Decomposition of the fleet by vessel age; based on [12]

The trend observed in Figure 6 is confirmed: in periods with a declining number of ships (the 1970ies, early 1990ies), practically no new orders were placed. However, during the 1980ies, a period during which the fleet size stayed remarkably stable, a great deal of new ships were built. It is also observed that an average small segment vessel is significantly older than large segment vessels, respectively averaging 24 and 17 years.

Finally, attention is drawn to the engines. In Table A.2 of Appendix A, an overview of some characteristics of the engines is given. Figure 18 shows that a very significant number of engine manufacturers is active in the Belgian fishing sector. The most important distributor is American Belgian Corporation, accounting for some 32 % of the number of engines, and 43 % of the total installed power. Mitsubishi, Cummins, Caterpillar and MAK are also important players with a market share ranging from 16 % to 9 %. For about one fifth of the vessels another engine type is used.

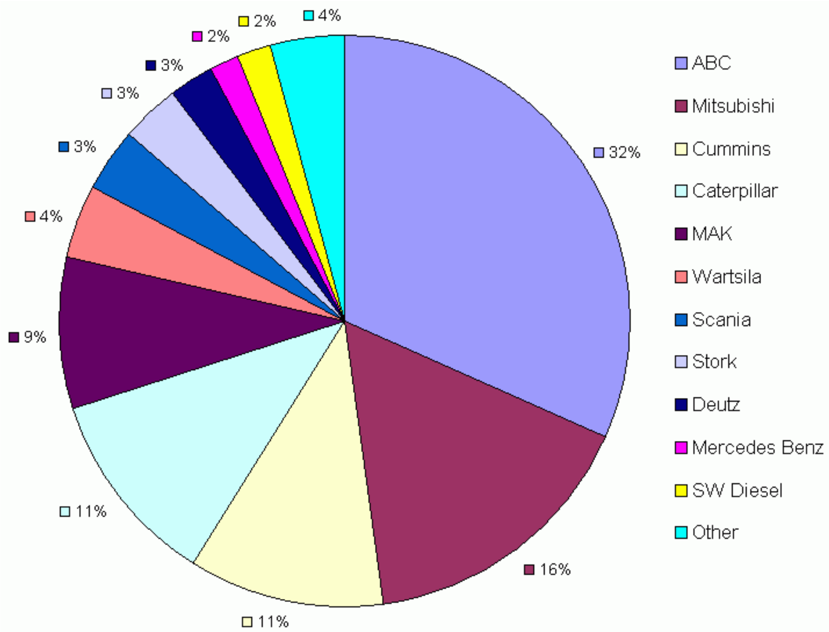


Figure 18: Engine manufacturers - share of the total number of engines installed

In Figure 19, the average maximum output power for the engines is shown per manufacturer. It is seen that there are marked differences: Stork, MAK and Wartsila are specialised in engines with an output power of over 900 kW. Mitsubishi, Cummins, Mercedes Benz and Scania on the other hand are only active for the small vessel segment, their engines having an output power of around 220 kW. ABC is located somewhere in between as they are active in both segments, manufacturing engines with an average maximum output power ranging from 221 kW to 957 kW.

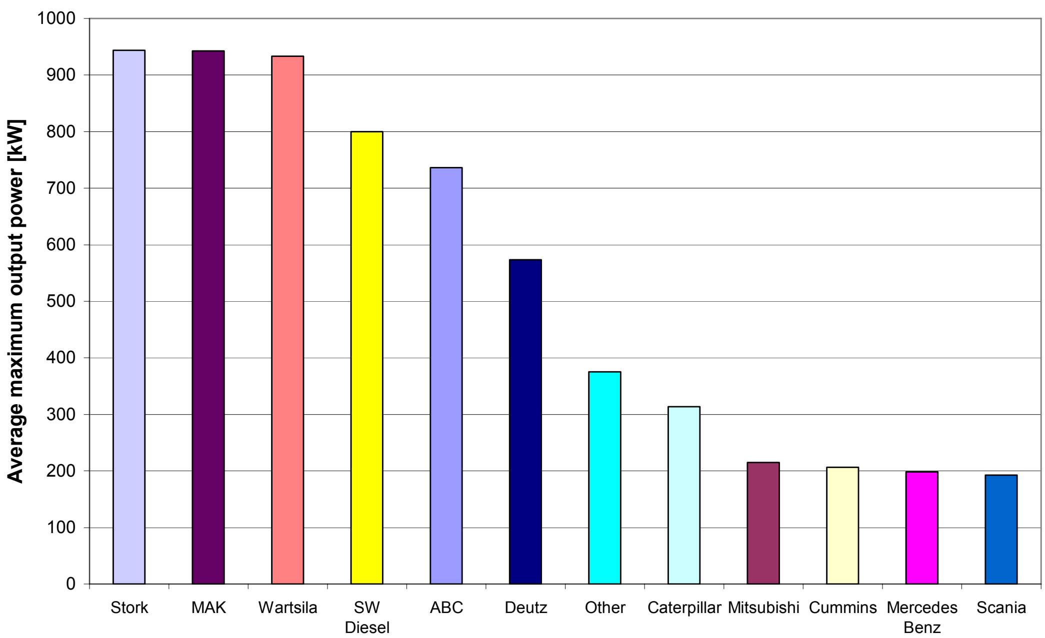


Figure 19: Average maximum output power of the engines, by manufacturer

2.5.4. COMPARISON WITH THE EUROPEAN FISHING FLEET (EU-15)

In this chapter, the Belgian fishing fleet shall be briefly compared to the fishing fleets of other EU-15 states. Even though this is not essential for the rest of this study, it is interesting to get a general idea of the proportional size of the Belgian fleet as this puts this study in a somewhat broader framework.

In Figure 20, the evolution of the fleets of all EU-15 countries is shown. The downwards trend is very clear, which comes as no surprise as the factors influencing the size of the Belgian fleet (see 2.5.2) apply to the other European states as well.

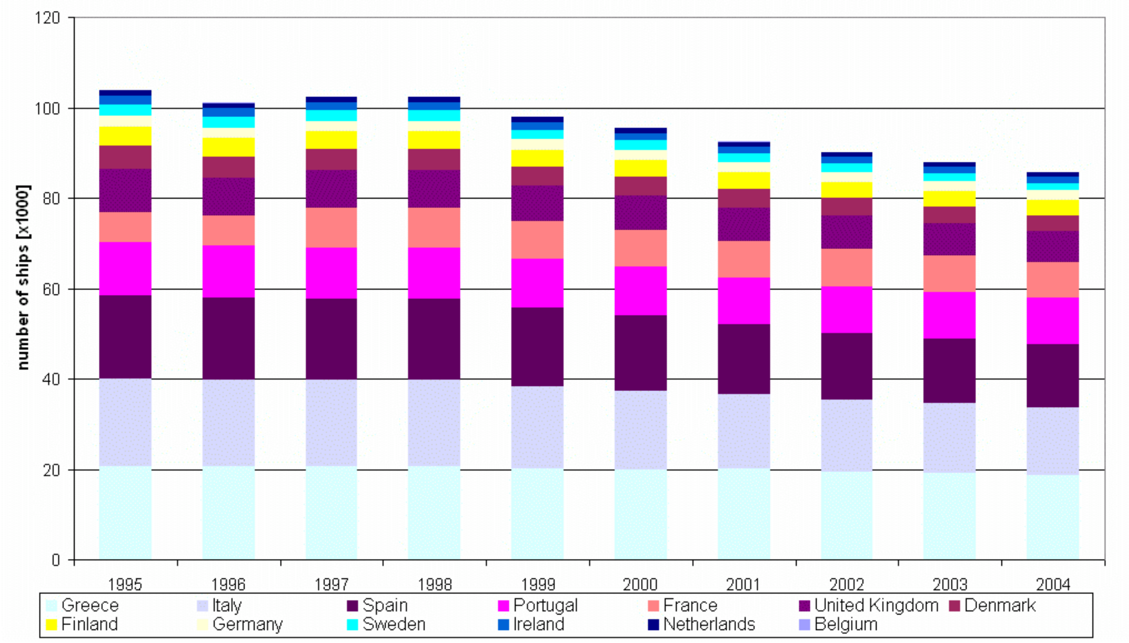


Figure 20: Evolution of the EU-15 fleet: number of ships; [71]

Comparing the base year 1995 with 2004, the total number of EU-vessels has diminished with 18,159 units (17.48 %). There are however noteworthy differences between the member states. The largest proportional decline is found for Sweden, where 910 vessels (36.28 %) were taken out of service in ten years time. Denmark and Ireland also suffered a huge decline, with respectively 34.03 % and 30.14 % of their fleet scrapped. The decline of the Belgian fleet is quite average in European perspective, with a decline of 20.13 % during the period under consideration. An exception is France, having a net growth of the fleet size with 1,285 units (19.48 %). This is due to the fact that from 1997 on, the fishing vessels of French overseas territories are also counted in the statistics. Without this effect, France also would have suffered a decline of some 16 %.

The most recent data on the fleet sizes and their total installed power (for 2004) is shown in figure 21, while the average installed power can be found in figure 22.

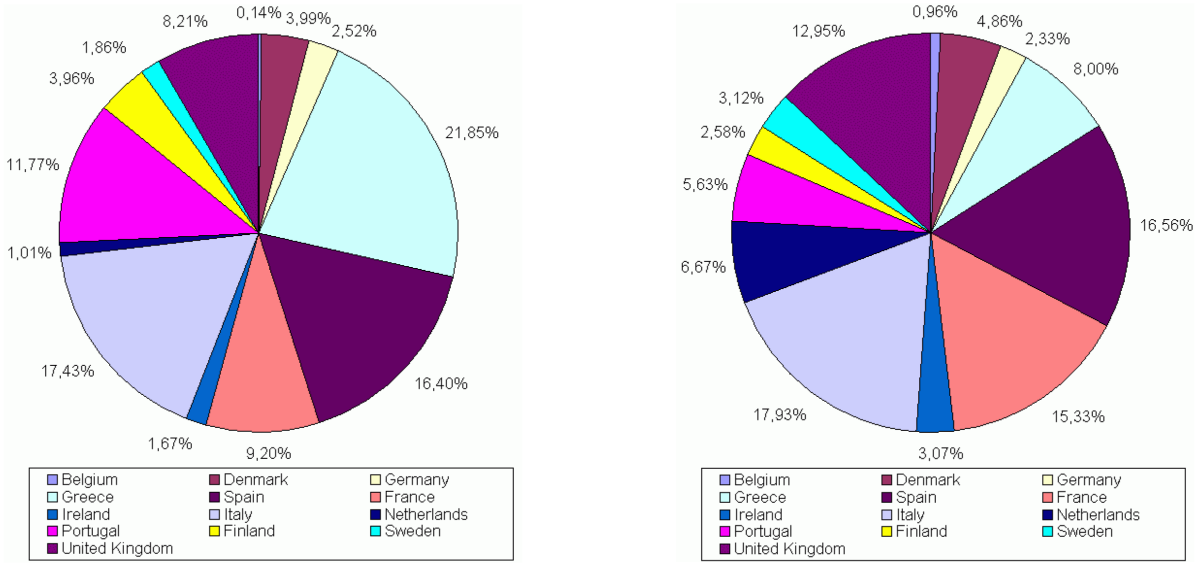


Figure 21: Relative share of the national states of the EU-15 fishing fleet, by number of vessels (left) and by total installed power (right); [71]

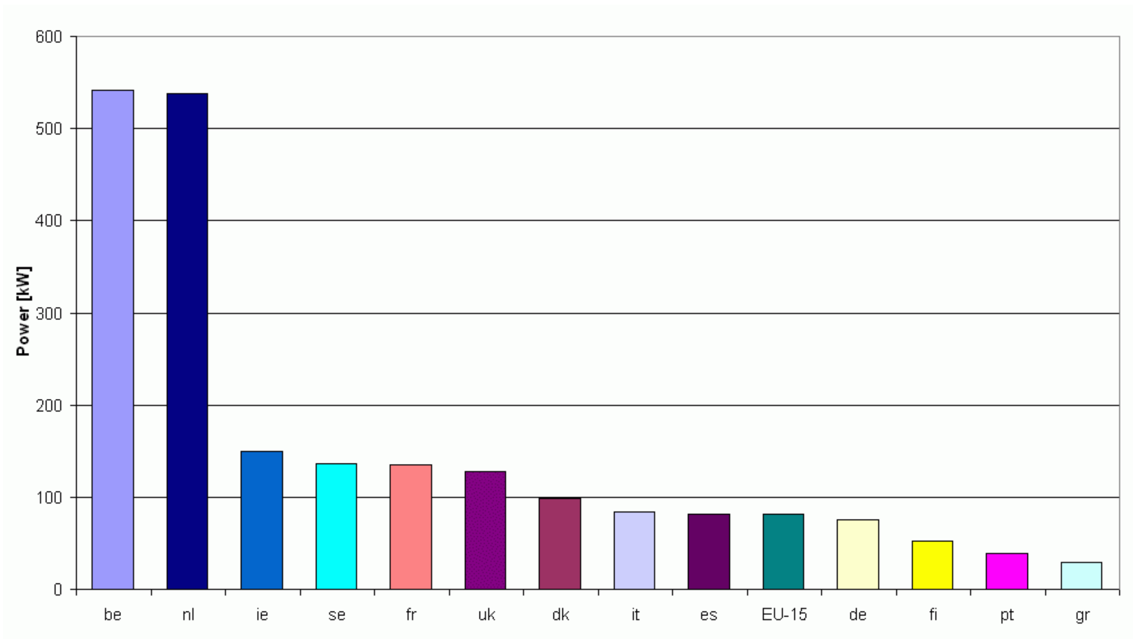


Figure 22: Average installed power on fishing vessels of EU-15 states

A number of interesting conclusions can be drawn from these figures:

Greece, Italy, Spain and Portugal are the most important European fishing nations with respect to the number of vessels: over 67 % of all European vessels are registered in one of these countries. The least important fishing nations, taking the number of vessels as a reference, are Ireland, the Netherlands, Sweden and Belgium. Belgium contributes to the total number of European fishing vessels only with an almost negligible 0.14 %.

When taking the total installed power as a benchmark, which is more directly linked to the air pollution, the situation is somewhat different. Now, the most important fleets are those of Italy, Spain, France and the United Kingdom, together holding almost 63 % of the installed engine power. Ireland, Finland, Germany and Belgium have the smallest fleets, together accounting for just under 9 %.

Looking at the average installed power of the fishing vessels, a completely different image is shown. The Belgian and the Dutch vessels have the largest average installed power per unit (over 500 kW), whereas the fleets of countries such as Finland, Portugal and Greece are composed of mainly of small, low powered fishing vessels. This of course has to do with the fishing methods applied. Belgium and the Netherlands have a specialised fleet that consists mainly of beam trawlers, which are vessels that fish for demersal fish species. In order to trawl their heavy nets over the seafloor, a rather large engine power is required.

The most important conclusion however is that the emissions of the Belgian fishing fleet shall be relatively insignificant with respect to the entire European fleet. Assuming a perfect correlation between total installed power and emissions, it is found that the Belgian fleet contributes to the total emissions of the EU-15 fleet for just about 1 %. Quite evidently, the actual relation between engine power and emissions is not this simple. Other factors such as fuel consumption, fishing method, vessel operational characteristics and engine specifications have a marked effect on this relation. For a general estimate however, these influences can be neglected.

2.6. EMISSION CALCULATION

2.6.1. METHODOLOGIES

In the relevant literature, a number of general methods for calculating ship emissions is proposed [7] [10] [16] [24] [41]. Here, a brief description of these methods shall be given. The exact calculation steps used in this work differ somewhat of these general guidelines because of the specific nature of fishing vessels and their seaborne activities. The detailed calculation procedure will be elaborated upon hereafter, once an overview of the accessible data has been given.

2.6.1.1. Simple Methodology

In the simple methodology, emissions are estimated based on the quantity of fuel sold. An emission factor, depending on the pollutant under investigation, is multiplied with this fuel consumption. This results in following very straightforward formula:

$$Emission = Fuel\ sold\ \ x\ \ Emission\ \ factor$$

A distinction should be made between Residual Bunker Fuel Oil (heavy fuel oil) and Distillate Fuel (gas oil and marine diesel oil). This is particularly important for emissions for SO_2 and heavy metals.

2.6.1.2. Detailed Methodology

2.6.1.2.1. Fuel Consumption Methodology

This calculation procedure is based on annual fuel consumption data for individual vessels or vessel categories. This method requires following steps to be taken:

gathering information on annual fuel consumption by individual ships or vessel categories, making a distinction between residual fuel oil and distillate fuel;

determining for each individual ship or for each vessel category the appropriate emission factors for each pollutant;

multiplying the fuel consumption data with the fuel based emission factors, obtaining an annual emission estimate;

if a spatial distribution is required, data on ship movements and routes should be used.

This methodology is recommended when statistics on fuel consumption for vessel categories or individual ships are available. It is particularly well suited for estimating national emissions. The spatial disaggregation can be expected to be less accurate than when utilising the ship movement methodology.

2.6.1.2.2. Ship Movement Methodology

This methodology is based on ship movement data for individual ships. For most vessel types, a distinction should be made between emissions at sea and emissions while manoeuvring and hotelling in port. For fishing vessels however, port and manoeuvring emissions are insignificant as the time spent entering and leaving the port is negligible. Main and auxiliary engines are shut down while at berth, except maybe for cargo cooling machinery. In any case, the vast majority of the emissions will occur at sea, so concentrating on these is sensible.

In brief, following calculation scheme is proposed:

- compilation of the ship movement data: drawing up an inventory of the place, date and time of departure and arrival. This can be done for a whole year or a representative period thereof, for all ships or a representative section of the fleet;
- determination of the sailing routes and fishing grounds;
- grouping the ships in vessel categories. This is an optional step, but can greatly reduce the calculation time;
- determination of the time at sea for each individual ship or each vessel category, if possible making a distinction between the time spent sailing and the time actually trawling;

- determination of the emission rates (kg/hour) or emission factors (kg/kWh), where possible making a distinction between sailing and trawling. Here, it is possible to differentiate between different fuel types, taking into account relevant engine characteristics (power, speed, age,…);
- combining the sailing and trawling times with the corresponding emission rates or emission factors results in an estimate of the pollutants under investigation;

if required, a geographical distribution can be made.

2.6.1.3. Utilised Methodologies

In this work, the simple methodology will not be applied, as no information about the fuel sales is available. Besides, information concerning the total fuel sold in Belgian ports does not give an accurate view of the fuel consumption by the Belgian fishing vessels: it has been estimated that only about half of the fuel consumed by Belgian fishing vessels is bunkered in Belgium. Furthermore, foreign vessels bunkering in Belgium would also be included in the Belgian fuel sales figures. As the aim of this work is to estimate the emissions by the Belgian fleet, this data would very unpractical to work with.

The fuel consumption methodology can be used for estimating the emissions of the Belgian fishing fleet without significant problems, as far as reliable data on the fuel consumption is available. Several paths were followed to determine the fuel use from individual vessels or vessel classes, which will be discussed in section 2.6.2.3. A drawback using this method is that no distinction can be made between fishing and sailing activity, and that a spatial distribution of the emissions is not readily available. Therefore, this calculation shall be performed as a check on the results of the more thorough ship movement methodology.

The ship movement methodology is the most detailed procedure, as it can take into account the location of the vessel activity and the nature of thereof. The distinction between sailing and trawling is important, as the fuel use, the used engine power and engine speed, and consequently some emission factors (e.g. for NO_x, see Figure 32: Emission factors for NOX used for engines manufactures after 1997, based on IMO Figure 32: Emission factors for NOX used for engines manufactures after 1997, based on IMO MARPOL Annex VI regulations; [60]

MARPOL Annex VI regulations; [60]) and emissions vary with these activities. It is this method that will lay at the basis of the emission estimates: the spatial distribution will be made using the ship movement data and one of the methods for determining the fuel consumption is directly linked to the duration of sailing and trawling activities, taking into account relevant characteristics of both main and auxiliary engines. As mentioned earlier, a detailed overview of the emissions calculation is given in chapter 2.6.3.

2.6.2. DATA COLLECTION, PREPARATORY CALCULATIONS AND ASSUMPTIONS

2.6.2.1. Ship Movement: Determination of Sailing and Trawling Durations

Following an inquiry to the administrative bodies involved (FPS Mobility & Transport), an abundance of data on this matter has been be obtained [3]. This data is summarized in Appendix B, where following information is given for all Belgian fishing vessels:

- Harbour, date and time of departure
- Harbour, date and time of arrival
- The number and average duration of the trawls
- The number of days at sea and the number of days fishing
- The distinction between national and international travels, using a symbolic notation indicating what activity the vessel was performing for how long in Belgian and other waters.

An example of such a detailed vessel movement table is shown in Table 13. For a comprehensive explanation of the symbols used in the last columns, Table 18 is referred to. For a limited number of small segment vessels, this detailed data was not available: only the dates of the days at sea could be obtained, reported in tables such as Table 12.

Table 12: Vessel movement data; N.86 Surcouf

Month	Fishing days	Total
January	10, 11, 13, 14, 17, 25, 27, 28, 29, 30	10
February	2, 3, 4, 5, 6, 7, 8, 9, 16, 17, 18, 24	12
March	15, 18, 20, 21 22, 23, 24, 25, 26, 27, 28, 29, 30, 31	14
April	1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 13, 14, 15, 18, 19, 20, 21, 22, 25, 26, 27, 28, 29	23
May	2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 17, 18, 19, 20, 22, 23, 24, 25, 26, 27, 29, 30, 31	23
June	1, 2, 3, 5, 6, 7, 8, 9, 12, 13, 14, 15, 16, 17, 19, 20, 21, 22, 23, 27, 28, 29, 30	23
July	1, 3, 4, 5, 6, 10, 11, 12, 13, 14, 15, 17, 18, 19, 20, 21, 24, 25, 26, 27, 28, 31	22
August	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 21, 22, 23, 24, 25, 28, 29	24
September	4, 5, 6, 7, 8, 11, 12, 13, 14, 16, 18, 19, 20, 21, 22, 25, 26, 27	18
October	3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 16, 17, 18, 19, 23, 24, 25, 26, 27, 30, 31	21
November	1, 2, 3, 6, 7, 8, 10, 13, 14, 15, 20, 21, 2, 23, 24, 27, 28, 29, 30	19
December	1, 4, 5, 6, 7, 8, 11, 12, 14, 18, 19, 20, 21, 22, 28, 29, 30	17
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Table 13: Vessel movement data; O.33 Marbi

Departure			Arrival			Trawls		Days		Nat		Int	
Harbour	Date	Hour	Harbour	Date	Hour	Nr	Duration	at sea	fishing	Bel	Oth	Bel	Oth
						[-]	[hours]	[days]	[days]				
Oostende	2-01	20:05	Oostende	4-01	18:40	13	3	2	2	1	0		
Oostende	10-01	20:05	Oostende	20-01	17:50	61	3	10	9	OYL*	1		
Oostende	22-01	20:10	Oostende	1-02	16:45	72	2,75	10	10	1/4	3/4		
Oostende	8-02	20:05	Oostende	15-02	20:00	49	3	7	7	1/3	2/3		
Oostende	17-02	20:05	Oostende	26-02	11:35	62	2,75	9	9	OYL*	1		
Oostende	27-02	14:55	Swansea	9-03	15:40	65	3	11	10			OYL	1
Swansea	10-03	20:05	Oostende	20-03	19:20	64	3	10	9			OYL	1
Oostende	24-03	20:05	Oostende	3-04	16:40	71	3	10	10	OYL*	1		
Oostende	7-04	16:35	Oostende	17-04	18:40	68	3	11	10	OYL*	1		
Oostende	20-04	20:00	Oostende	3-05	14:50	77	3	14	11	OYL*	1		
Oostende	1-06	20:10	Thyboron	13-06	18:15	79	3	12	11			OZL	1
Thyboron	14-06	20:15	Thyboron	22-06	17:10	60	3	8	8			0	1
Thyboron	23-06	20:05	Thyboron	29-06	18:30	44	3	6	6			0	1
Thyboron	30-06	20:05	Oostende	7-07	13:00	43	3	7	6			OZL	1
Oostende	20-07	20:05	Thyboron	27-07	18:00	43	3	7	6			OZL	1
Thyboron	28-07	20:05	Thyboron	3-08	17:55	46	2,75	6	6			0	1
Thyboron	4-08	20:05	Thyboron	10-08	17:30	46	2,75	6	6			0	1
Thyboron	12-08	9:00	Thyboron	17-08	18:00	42	2,75	6	6			0	1
Thyboron	18-08	20:05	Thyboron	24-08	18:00	46	2,75	6	6			0	1
Thyboron	25-08	20:05	Thyboron	31-08	17:50	46	2,75	6	6			0	1
Thyboron	1-09	20:10	Thyboron	7-09	15:15	44	2,75	6	6			0	1
Thyboron	9-09	12:00	Oostende	18-09	14:50	61	3	10	9			OZL	1
Oostende	24-09	20:05	Swansea	4-10	8:25	60	3	10	9			OYL	1
Swansea	4-10	19:30	Milford	9-10	0:00	28	3	4	4			OYL	1
Milford	10-10	11:30	Oostende	20-10	18:30	68	2,75	11	10			OYL	1
Oostende	23-10	20:05	Oostende	2-11	19:05	75	2,75	10	10	OYL*	1		
Oostende	5-11	20:15	Milford	12-11	16:00	43	3	7	6			OYL	1
Milford	13-11	16:00	Milford	17-11	6:50	25	3	4	4			0	1
Milford	17-11	20:00	Oostende	27-11	12:30	65	3	10	10			OYL	1
Oostende	29-11	20:05	Oostende	8-12	9:15	61	3	9	8	1/2	1/2		

This data is crafted into a more useful format. For each vessel, following quantities were calculated using elementary mathematics:

- the total time the vessel spent at sea, [hours];
- the total time the vessel spent trawling and sailing, [hours];
- the share of trawling and sailing activities, [%];
- the total number of days at sea, [-];
- the time per day at sea for both offshore activities, [hours].

The results of these computations are summarized inTable 14 for large segment vessels. For small segment vessels, a distinction is made between those vessels for which complete or fragmentary detailed information is available (Table 15) and those for which this is not the case (Table 16). This information will prove very valuable for calculating the fuel consumption (see 2.6.2.3) and for a direct calculation of the emissions using the emission rates methodology.

Table 14: Summary of the computations regarding vessel movement characteristics, Large Segment vessels

SHIP sign	TOTAL TIME at sea [hours]	sailing [hours]	trawling [hours]	PERCENTAGE sailing [%]	trawling [%]	days at sea	hours sailed per d.a.s.	hours trawled per d.a.s.
O.14	5,719	981	4,738	17.1	82.9	253	3.9	18.7
O.15	6,052	2,412	3,640	39.9	60.1	261	9.2	13.9
O.33	5,667	922	4,744	16.3	83.7	245	3.8	19.4
O.51	5,992	1,892	4,100	31.6	68.4	266	7.1	15.4
O.89	5,743	954	4,789	16.6	83.4	256	3.7	18.7
O.124	5,749	1,564	4,185	27.2	72.8	255	6.1	16.4
O.154	5,494	1,058	4,435	19.3	80.7	244	4.3	18.2
O.231	6,022	1,397	4,625	23.2	76.8	262	5.3	17.7
O.316	5,859	1,954	3,906	33.3	66.7	256	7.6	15.3
O.333	6,070	1,418	4,652	23.4	76.6	262	5.4	17.8
O.554	3,650	966	2,684	26.5	73.5	175	5.5	15.3
Z.16	6,038	1,401	4,637	23.2	76.8	255	5.5	18.2
Z.18	5,962	846	5,116	14.2	85.8	260	3.3	19.7
Z.19	5,936	940	4,996	15.8	84.2	258	3.6	19.4
Z.35	5,476	1,852	3,625	33.8	66.2	251	7.4	14.4
Z.36	5,577	1,834	3,744	32.9	67.1	241	7.6	15.5
Z.39	5,828	1,302	4,527	22.3	77.7	251	5.2	18.0
Z.45	5,992	1,522	4,470	25.4	74.6	256	5.9	17.5
Z.46	6,010	1,753	4,258	29.2	70.8	255	6.9	16.7
Z.47	5,960	1,721	4,240	28.9	71.1	254	6.8	16.7
Z.48	5,543	1,042	4,501	18.8	81.2	236	4.4	19.1
Z.53	5,789	1,802	3,986	31.1	68.9	251	7.2	15.9
Z.54	3,027	993	2,034	32.8	67.2	128	7.8	15.9
Z.59	5,109	1,685	3,425	33.0	67.0	226	7.5	15.2
Z.60	5,924	1,539	4,385	26.0	74.0	262	5.9	16.7
Z.67	5,891	1,444	4,447	24.5	75.5	252	5.7	17.6
Z.69	5,421	1,844	3,577	34.0	66.0	228	8.1	15.7
Z.76	5,972	1,703	4,269	28.5	71.5	255	6.7	16.7
Z.78	5,754	1,572	4,182	27.3	72.7	247	6.4	16.9
Z.84	6,008	1,454	4,554	24.2	75.8	255	5.7	17.9
Z.90	6,007	1,407	4,600	23.4	76.6	255	5.5	18.0
Z.91	5,998	1,565	4,433	26.1	73.9	255	6.1	17.4
Z.92	5,958	1,765	4,193	29.6	70.4	253	7.0	16.6
Z.96	5,510	1,458	4,053	265	73.5	227	6.4	17.9
Z.98	6,050	1,855	4,195	30.7	69.3	255	7.3	16.5
Z.99	5,977	1,627	4,350	27.2	72.8	252	6.5	17.3
Z.105	6,121	1,473	4,648	24.1	75.9	271	5.4	17.2
Z.121	5,950	1,813	4,137	30.5	69.5	260	7.0	15.9
Z.126	5,659	2,204	3,455	39.0	61.0	241	9.1	14.3
Z.137	4,233	1,397	2,836	33.0	67.0	181	7.7	15.7
Z.162	6,009	1,303	5,706	21.7	78.3	255	5.1	18.5
Z.183	5,563	1,215	4,348	21.8	78.2	252	4.8	17.3
Z.185	6,009	1,298	4,711	21.6	78.4	251	5.2	18.8
Z.186	6,068	1,620	4,448	26.7	73.3	257	6.3	17.3
Z.196	6,148	1,713	4,433	27.9	72.1	255	6.7	17.4
Z.198	1,491	479	1,012	32.1	67.9	72	6.6	14.1
Z.200	2,916	871	2,045	29.9	70.1	124	7.0	16.5
Z.243	6,121	1,595	4,526	26.1	73.9	255	6.3	17.7

(Continued from Table 14)

SHIP sign	TOTAL TIME at sea [hours]	sailing [hours]	trawling [hours]	PERCENTAGE sailing [%]	trawling [%]	days at sea	hours sailed per d.a.s.	hours trawled per d.a.s.
Z.284	3,530	837	2,693	23.7	76.3	165	5.1	16.3
Z.296	3,569	1,208	2,361	33.8	66.2	155	7.8	15.2
Z.483	6,099	1,008	5,090	16.5	83.5	256	3.9	19.9
Z.510	6,062	1,594	4,468	26.3	73.7	254	6.3	17.6
Z.526	5,932	1,301	4,631	21.9	78.1	247	5.3	18.7
Z.548	5,473	1,543	3,930	28.2	71.8	235	6.6	16.7
Z.571	4,767	1,406	3,361	29.5	70.5	221	6.4	15.2
Z.576	5,973	2,036	3,938	34.1	65.9	258	7.9	15.3
Z.583	4,710	703	4,006	14.9	85.1	216	3.3	18.5
Z.596	3,182	869	2,313	27.3	72.7	139	6.2	16.6
B.462	6,174	1,361	4,813	22.0	78.0	257	5.3	18.7
B.518	5,948	1,868	4,080	31.4	68.6	255	7.3	16.0

It should be noted that for vessel O.554 only the total time at sea could be calculated. Sailing and trawling times for this ship are based on the average percentages for sailing and trawling for the other large segment vessels.

For some small segment vessels, detailed information was available for only a part of the year. This is the case for the vessels printed in italics in Table 15. For these ships, calculations are executed using the detailed base data, the results of which are extrapolated to the fragmentary data. Extrapolations are based on the percentages of sailing and trawling for vessels Z.55, Z.63, Z.582 and N.28, as the fragmentary information for these ships encompasses data on the total time at sea. Conversely, for vessels Z.519, N.58, N.79 and N.350, extrapolations are based on the hours sailed and trawled per day at sea, as fragmentary data for these ships includes the number of days at sea.

For vessels Z.8 and Z.13, information could be gathered regarding the total time at sea, but no data on the sailing and trawling times has been obtained. Calculations for these ships are based on the average percentages of sailing and trawling, calculated for the vessels for which this data is available.

As mentioned earlier, for some small segment vessels only the dates of the days at sea could be obtained. For these vessels, the average hours sailing and trawling per day at sea, calculated for the vessels for which detailed information is available, were used for extrapolation purposes. The results of these calculations are given in Table 16 . For the vessels Z.55, Z.63, Z.582, Z.519, N.28, N.58, N.79 and N.350, which are included in both Table 15 and Table 16 the final results are to be found in Table 16.

A summary of the vessel movement characteristics for large vessel and small vessel segments is given in Table 17.

Table 15: Summary of the computations regarding vessel movement characteristics, Small Segment vessels with (partly) detailed base data

SHIP sign	TOTAL TIME at sea [hours]	TOTAL TIME sailing [hours]	TOTAL TIME trawling [hours]	PERCENTAGE sailing [%]	PERCENTAGE trawling [%]	days at sea	hours sailed per d.a.s.	hours trawled per d.a.s.
O.187	3,856	1,036	2,820	26.9	73.1	199	5.2	14.2
O.229	3,469	805	2,664	23.2	76.8	188	4.3	14.2
Z.28	1,072	309	763	28.8	71.	57	5.4	13.4
Z.41	3,464	1,369	2,095	39.5	60.5	158	8.7	13.3
Z.55	1,749	382	1,367	21.8	78.2	83	4.6	16.5
Z.56	4,279	1,335	2,944	31.2	68.8	190	7.0	15.5
Z.63	2,097	409	1,688	19.5	80.5	94	4.0	18.0
Z.70	3,494	986	2,508	28.2	71.8	163	6.0	15.4
Z.75	4,721	1,723	2,998	39.5	63.5	214	8.0	14.0
Z.80	4,288	1,386	2,903	32.3	67.7	201	6.9	14.4
Z.85	5,400	1,670	3,730	30.9	69.1	247	6.8	15.1
Z.87	4,263	1,345	2,919	31.5	68.5	196	6.9	14.9
Z.122	4,144	1,554	2,590	37.5	62.5	188	8.3	13.8
Z.201	4,038	1,975	2,063	48.9	51.1	187	10.6	11.0
Z.279	4,231	1,371	2,860	32.4	67.6	190	7.2	15.1
Z.402	4,514	2,102	2,412	46.6	53.4	206	10.2	11.7
Z.431	4,542	959	3,582	21.1	78.9	202	4.7	17.7
Z.470	2,637	452	2,185	17.1	82.9	12	3.7	17.9
Z.474	4,490	1,491	2,999	33.2	66.8	206	7.2	14.6
Z.519	1,084	244	840	22.5	77.5	48	5.1	17.5
Z.525	4,548	1,517	3,031	33.4	66.6	218	7.0	13.9
Z.568	3,874	1,588	2,286	41.0	59.0	200	7.9	11.4
Z.575	4,480	1,472	3,008	32.8	67.2	206	7.1	14.6
Z.582	1,565	398	1,167	25.4	74.6	78	5.1	15.0
Z.738	5,272	1,848	3,424	35.1	64.9	231	8.0	14.8
N.28	1,590	598	992	37.6	62.4	148	4.0	6.7
N.57	4,872	2,073	2,799	42.5	57.5	233	8.9	12.0
N.58	2,147	535	1,612	24.9	75.1	111	4.8	14.5
N.79	2,447	705	1,743	28.8	71.2	124	5.7	14.1
N.88	1,914	584	1,330	305	69.5	92	6.3	14.5
N.350	3,396	1,043	2,352	30.7	69.3	168	6.2	14.0
N.501	4,891	577	4,314	11.8	88.2	223	2.6	19.3
B.65	5,663	1,841	3,822	32.5	67.5	257	7.2	14.9
B.601	3,933	1,354	2,579	34.4	65.6	186	7.3	13.9

Table 16: Summary of the computations regarding vessel movement characteristics, Small segment vessels with less detailed base data

SHIP sign	TOTAL TIME at sea [hours]	TOTAL TIME sailing [hours]	TOTAL TIME trawling [hours]	PERCENTAGE sailing [%]	PERCENTAGE trawling [%]	days at sea	hours sailed per d.a.s.	hours trawled per d.a.s.
O.2	3,233	1,055	2,178	32.6	67.4	151	7.0	14.4
O.20	2,612	852	1,760	32.6	67.4	122	7.0	14.4
O.29	2,398	782	1,616	32.6	67.4	112	7.0	14.4
O.62	4,411	1,439	2,972	32.6	67.4	206	7.0	14.4
O.82	3,448	1,125	2,323	32.6	67.4	161	7.0	14.4
O.100	3,426	1,118	2,308	32.6	67.4	160	7.0	14.4
O.101	3,319	1,083	2,236	32.6	67.4	155	7.0	14.4
O.116	557	182	375	32.6	67.4	26	7.0	14.4
O.148	4,196	1,369	2,827	32.6	67.4	196	7.0	14.4
O.152	3,619	1,181	2,438	32.6	67.4	169	7.0	14.4
O.190	2,312	754	1,558	32.6	67.4	108	7.0	14.4
O.191	3,105	1,013	2,092	32.6	67.4	145	7.0	14.4
O.225	2,013	657	1,356	32.6	67.4	94	7.0	14.4
O.369	1,563	510	1,053	32.6	67.4	73	7.0	14.4
O.536	3,533	1,153	2,380	32.6	67.4	165	7.0	14.4
O.700	4,025	1,313	2,712	32.6	67.4	188	7.0	14.4
Z.8	1,796	586	1,210	32.6	67.4	128	4.6	14.4
Z.13	3,656	1,193	2,463	32.6	67.4	188	6.3	14.4
Z.55	3,332	728	2,605	21.8	78.2	195	3.7	13.4
Z.63	4,213	822	3,391	19.5	80.5	225	3.7	15.1
Z.519	1,309	294	1,015	22.5	77.5	58	5.1	17.5
Z.582	3,498	889	2,609	25.4	74.6	198	4.5	13.2
N.28	2,709	1,018	1,690	37.6	62.4	148	6.9	11.4
N.34	2,270	740	1,529	32.6	67.4	106	7.0	14.4
N.58	2,920	727	2,193	24.9	75.1	151	4.8	14.5
N.79	4,460	1,284	3,176	28.8	71.2	226	5.7	14.1
N.86	4,839	1,579	3,260	32.6	67.4	226	7.0	14.4
N.93	3,661	1,194	2,467	32.6	32.6	171	7.0	14.4
N.95	2,162	706	1,457	32.6	32.6	101	7.0	14.4
N.350	3,618	1,112	2,506	30.7	69.3	179	6.2	14.0

Table 17: Summary of the vessel movement characteristics

	Unit	Large Segment	Small Segment
Time at sea	[hours]	328,422	202,206
Days at sea	[days]	14,185	9,667
Time sailing	[hours]	86,125	64,999
Time trawling	[hours]	242,297	137,208
Percentage sailing	[%]	26.2	32.1
Percentage trawling	[%]	73.8	67.9
Time sailing per d.a.s.	[hours/day]	6.1	6.7
Time trawling per d.a.s.	[hours/day]	17.1	14.2

A similar calculation can be performed, taking into account the location of the vessel activity and the nature of the voyage. International and national voyages are distinguished easily, employing following definitions:

- **National voyage:** an uninterrupted journey originating and terminating in a Belgian port, regardless of the location of the fishing activities;
- **International voyage:** a journey with departure or arrival in a Belgian port, originating or terminating in another country, regardless of the location of the fishing activities. Voyages between non-Belgian ports are considered international as well.

This distinction is of an artificial nature, but in some legal regulations these categories are utilised.

In determining a spatial emissions distribution, knowledge about the location of the fishing and sailing activities is essential. Under Regulation 2244/2003/EC, all fishing vessels are to be equipped with a Vessel Monitoring System, in order to facilitate surveillance with respect to quota's, access rights to certain fishing grounds and so on. In principle, this data is perfectly fit to make an accurate assessment of the spatial disaggregation of the emissions. However, this data is not systematically recorded, or at least it is not publicly accessible.

It is practically impossible to give an exact image of all vessel movements, yet a general distinction between emissions in Belgian waters and outside of these can be reasonably accurately performed. First, the Belgian maritime areas will be defined. Subsequently, the methodology of assigning vessel movements to these waters, based on the information available, will be elaborated upon.

The Belgian maritime zones comprise the territorial sea (TS) and the Exclusive Economic Zone (EEZ). The former consists of an area extending 12 nm into the North Sea, measured from the base line. The latter comprises that part of the North Sea the contour of which consists of lines connecting following points in the order of numeration [56]:

1. 51°16'09" N – 02°23'25" O
2. 51°33'28" N – 02°14'18" O
3. 51°36'47" N – 02°15'12" O
4. 51°48'18" N – 02°28'54" O
5. 51°52'34.012" N – 02°32'21,599" O
6. 51°33'06" N – 03°04'53" O

A map of the Belgian maritime areas is shown in Figure 23.

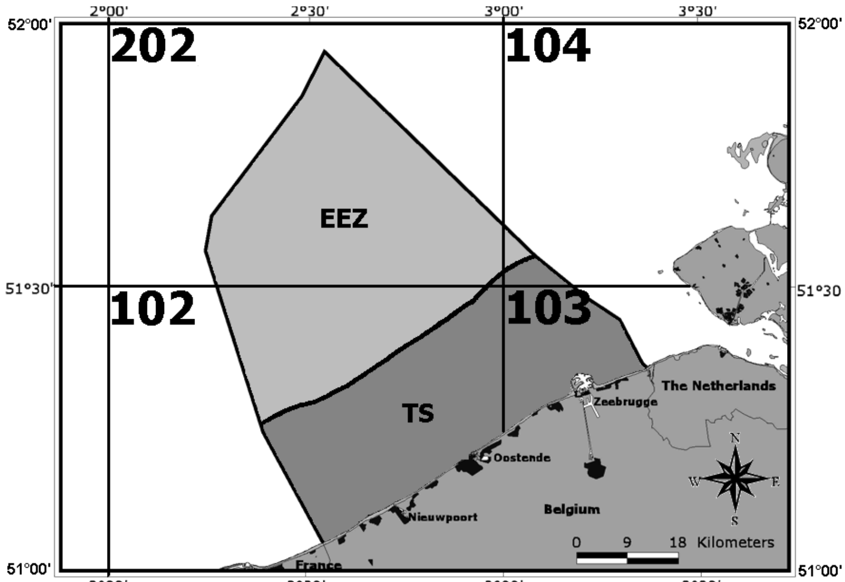

Figure 23: Map of the Belgian maritime areas; adapted from [72]

The waters of the North Sea, the Irish Sea and the English Channel are divided in fishing sectors, for the purpose of assigning quota's to the fishing grounds. These sectors are shown in Figure 24. In the administrative bodies acting on this matter, record is kept on which fishing sectors are trawled during each voyage. This information has been systematically implemented in the detailed vessel movement tables (e.g. Table 13), summarized in Appendix B. For a series of ships, mainly belonging to the small segment however, no such data is available.

For the purpose of this study, it is assumed that fishing sector 102 is situated completely in Belgian waters, and sector 103 and 202 for 50 %. As is easily appreciated from Figure 23, this is not fully correct, but based on the information available this is the best possible estimate.

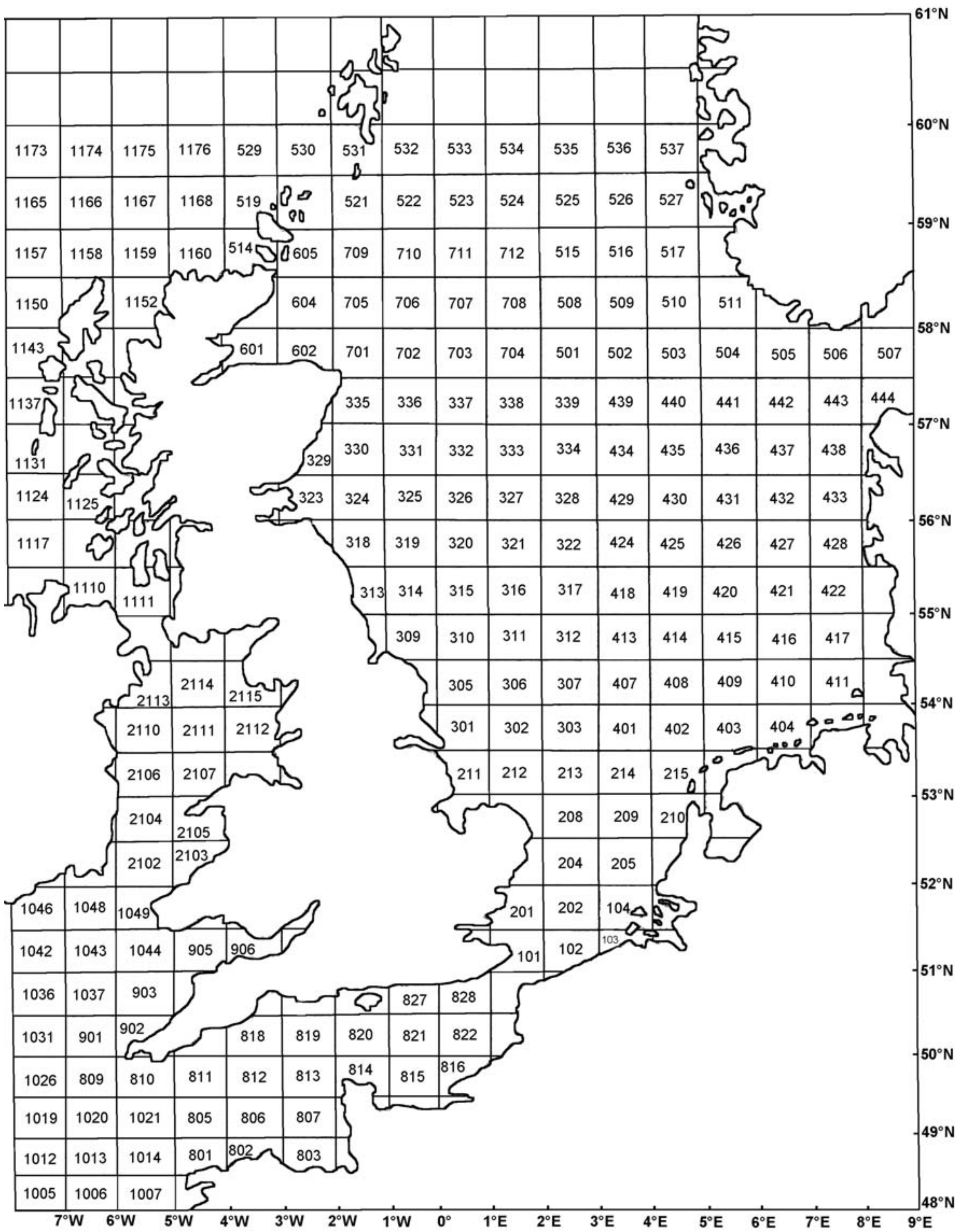

Figure 24: Fishing sectors in the North Sea, the Channel and the Irish Sea; adapted from [3]

The basic idea is to allocate sailing and trawling times for each voyage to the maritime areas under investigation (Belgian and non-Belgian waters). These can be easily computed using elementary mathematics, based on the symbolism in the relevant columns of the vessel movement tables. This symbolism is explained in the table below.

Table 18: Explanation of the symbolism used in the vessel movement tables

Symbol	Explanation
A/B	The vessel fished in B sectors, of which A are (partly) in Belgian waters. Sector 102 is assumed to be 100 % Belgian maritime area, sectors 103 and 202 50 %. Total sailing and trawling times for the applicable voyage are divided according to this fraction.
0	The vessel was engaged in national or international travel, depending on in which column the symbol is placed. No sailing or fishing activity has been conducted in the waters corresponding with the relevant column.
1	The vessel was engaged in national or international travel, depending on in which column the symbol is placed. All fishing activity has been conducted in the waters corresponding to the relevant column; however, it is possible that the ship sailed for some time in waters not corresponding to the column this symbol is placed in.
OXS	A three character symbol is used to indicate how long a vessel sailed in Belgian waters. • The first character represents the Belgian harbour of departure or arrival: O for Oostende, Z for Zeebrugge and N for Nieuwpoort. • The second character shows in what direction the vessel sailed, when sailing from a Belgian harbour, or from which direction it came, when sailing to a Belgian port: X is used for fishing zones 800, 900, 1000, 2000 and 2100 Y is used for sectors 200, 300, 500, 600, 700 and 1100 Z is used for sectors 100 and 400 The fishing sectors with their corresponding numbers are shown in Figure 19. • The third character indicates to which fleet segment the vessel belongs: S for small segment, L for large segment. The first two letters can be used to determine the distance sailed in Belgian waters; the last letter gives an indication of the vessel speed. Combining these, the time spent sailing in Belgian waters can be estimated. Further details can be found in Table 19.
OXS*	When engaged in a national journey, an asterisk (*) is used to remind to the fact that the vessel spends the time, indicated by the first three characters (as explained above), two times in Belgian waters: once when departing and another time at its arrival.
x (SS) **o (LS)**	The vessel merely sails through Belgian waters, without any fishing activity, nor berthing in a Belgian port. “x” is used for small segment vessels, “o” for large segment vessels.

For vessels engaged in a voyage where no trawls are executed in Belgian waters, but departing and/or arriving in a Belgian harbour, an estimate is made of the time the vessel sailed in Belgian waters. The same is done for international voyages during which the vessel passes through Belgian waters, not performing any fishing activities in these areas, nor berthing in a Belgian port.

For this purpose, an estimation of the distance navigated through Belgian waters is made, along with an assessment of the vessel sailing speed. The distances depend on the harbour and the sailing direction, which is identified using information on the fishing sectors in which is trawled during the voyage. For the ship speed, a distinction is to be made between large segment and small segment vessels. Following an inquiry to some fishermen for the latter an average of 8 kn was found, whereas for the former, 11.5 kn was adopted.

An estimation of the distances sailed and the time spent in Belgian waters, using the symbolism introduced in Table 18, is to be found in Table 19.

Table 19: Sailing times in Belgian waters corresponding to the symbols used in the vessel movement tables

Symbol	Distance [nm]	Speed [kn]	Time [hours]	Symbol	Distance [nm]	Speed [kn]	Time [hours]
OXS	19	8	2 ½	OXL	19	11,5	1 ¾
OYS	45	8	5 ¾	OYL	45	11,5	4
OZS	19	8	2 ½	OZL	19	11,5	1 ¾
ZXS	30	8	3 ¾	ZXL	30	11,5	2 ½
ZYS	45	8	5 ¾	ZYL	45	11,5	4
ZZS	8	8	1	ZZL	8	11,5	¾
NXS	8	8	1	NXL	8	11,5	¾
NYS	45	8	5 ¾	NYL	45	11,5	4
NZS	30	8	3 ¾	NZL	30	11,5	2 ½
x	36	8	4 ½	o	36	11.5	3 ¼

The data concerning the total vessel sailing and trawling times (Table 15 and Table 16), combined with the information on the fishing sectors and sailing times through Belgian waters, leads to a reasonably accurate estimate of the geographical distribution of the vessel activity. The calculations on this matter are summarized in Table 20.

Table 20: Sailing and trawling times for the Belgian fishing vessels, subdivided in national and international voyage and Belgian and other waters (hours)
(S = Sailing, T = Trawling)

SHIP sign	NATIONAL VOYAGE				INTERNATIONAL VOYAGE				UNKNOWN	
	Belgian waters		Other		Belgian waters		Other			
	S	T	S	T	S	T	S	T	S	T
O.2									1,055	2,178
O.14	24	0	66	600	20	0	871	4,138		
O.15	152	113	663	1,242	51	48	1,485	2,236		
O.20									852	1,760
O.29									782	1,616
O.33	84	229	270	1,546	35	0	469	2,712		
O.51	73	80	169	567	40	0	1,542	3,454		
O.62									1,439	2,972
O.82									1,125	2,323
O.89	8	0	77	242	16	0	559	4,547		
O.100									1,118	2,308
O.101									1,083	2,236
O.116									182	375
O.124	35	0	161	619	57	34	911	3,532		
O.148									1,369	2,827
O.152									1,181	2,438
O.154	272	0	677	4,063	8	0	101	372		
O.187	259	60	355	1464	94	344	329	952		
O.190									754	1,558
O.191									1,013	2,092
O.225									657	1,356
O.229	124	32	96	550	185	685	404	1,331		
O.231	0	0	0	0	38	0	1,359	4,625		
O.316	68	0	499	1,033	36	22	1,351	2,851		
O.333	53	85	135	905	57	0	1,179	3,663		
O.369									510	1,053
O.536									1,153	2,380
O.554	216	0	583	2,299	11	0	132	409		
O.700									1,313	2,712
Z.8									586	1,210
Z.13									1,193	2,463
Z.16	102	176	671	2,378	14	0	562	2,082		
Z.18	48	0	171	1,020	31	0	597	4,096		
Z.19	53	17	187	1,133	21	0	680	3,846		
Z.28	0	0	0	0	81	117	227	646		
Z.35	56	0	258	663	92	77	1,345	2,885		
Z.36	4	0	0	0	29	0	1,804	3,744		
Z.39	16	0	35	325	30	0	1,221	4,202		
Z.41	0	0	0	0	0	0	1,369	2,095		
Z.45	143	312	486	1,465	54	56	839	2,511		
Z.46	70	50	275	838	78	69	1,268	3,063		
Z.47	32	0	251	783	102	98	1,337	3,360		
Z.48	109	185	489	2,297	62	84	387	1,936		
Z.53	112	0	767	2,020	48	47	654	1,414		
Z.54	0	0	0	0	6	0	987	2,034		
Z.55	98	0	234	1,315	13	0	67	190	427	1,156
Z.56	27	60	70	211	312	605	926	2,068		

(Continued from Table 20)

SHIP sign	NATIONAL VOYAGE				INTERNATIONAL VOYAGE				UNKNOWN	
	Belgian waters		Other		Belgian waters		Other			
	S	T	S	T	S	T	S	T	S	T
Z.59	100	145	460	967	18	0	1,107	2,313		
Z.60	70	173	98	345	264	676	1,108	3,192		
Z.63	93	60	101	574	35	0	184	1,055	551	1,561
Z.67	72	157	331	1,394	63	81	98	2,814		
Z.69	63	0	594	1,344	24	0	1,319	2,598		
Z.70	352	0	17	765	197	65	421	1,679		
Z.75	332	151	609	1,649	109	97	671	1,101		
Z.76	65	32	444	969	27	0	1,167	3,269		
Z.78	87	109	484	1,683	27	0	974	2,390		
Z.80	123	127	172	518	195	314	904	1,959		
Z.84	43	0	328	1,377	26	0	1,058	3,177		
Z.85	185	0	526	2,065	77	33	769	1,632		
Z.87	220	349	277	570	247	370	731	1,879		
Z.90	2	0	0	0	52	0	1,355	4,600		
Z.91	0	0	0	0	61	94	1,019	4,338		
Z.92	72	34	458	964	45	0	1,191	3,195		
Z.96	130	239	622	1,831	49	12	923	2,465		
Z.98	169	111	895	2,222	32	0	759	1,863		
Z.99	8	0	0	0	19	0	1,608	4,350		
Z.105	23	0	119	374	44	0	1,225	4,120		
Z.121	48	0	323	628	100	140	1,657	3,790		
Z.122	306	231	916	2,017	63	10	270	332		
Z.123										
Z.126	201	42	1,347	2,496	24	0	633	918		
Z.137	139	158	684	1,791	28	0	648	886		
Z.162	21	0	201	1,108	30	0	1,052	3,599		
Z.183	200	0	971	4,216	8	0	36	132		
Z.185	100	238	382	1,896	97	192	1,015	3,488		
Z.186	70	41	417	1,416	80	98	1,054	2,893		
Z.196	196	134	1,168	3,434	16	0	332	865		
Z.198	0	0	0	0	2	0	477	1,012		
Z.200	24	0	180	600	37	52	834	1,993		
Z.201	382	310	873	1,026	102	93	844	858		
Z.243	17	0	5	96	45	21	1,528	4,409		
Z.279	219	0	784	2,305	28	0	337	555		
Z.284	8	0	17	93	30	0	782	2,601		
Z.296	70	52	303	654	38	0	1,283	2,751		
Z.307										
Z.402	253	0	721	974	117	0	1,003	1,439		
Z.431	113	28	14	755	188	417	530	2,287		
Z.470	82	0	143	1,237	51	106	214	1,076		
Z.474	402	313	618	1,754	46	56	425	876		
Z.483	109	34	328	2,549	64	188	496	2,284		
Z.510	69	124	220	686	62	94	1,331	3,761		
Z.519	45	59	33	285	33	49	132	447	54	170
Z.525	434	126	785	2,145	26	19	271	741		
Z.526	72	0	415	1,983	31	0	783	2,648		
Z.548	56	0	374	1,188	42	0	4,071	2,743		

(Continued from Table 20)

SHIP sign	NATIONAL VOYAGE Belgian waters		NATIONAL VOYAGE Other		INTERNATIONAL VOYAGE Belgian waters		INTERNATIONAL VOYAGE Other		UNKNOWN	
	S	T	S	T	S	T	S	T	S	T
Z.568	345	283	545	1,055	60	5	638	943		
Z.571	72	0	199	652	15	0	1,120	2,709		
Z.575	300	41	542	1,722	17	0	612	1,245		
Z.576	88	0	546	1,558	64	58	1,339	2,322		
Z.582	46	0	29	96	150	34	189	1,079	568	1,365
Z.583	216	0	487	4,006	0	0	0	0		
Z.596	19	0	53	230	47	45	750	2,038		
Z.738	425	180	822	2,279	64	30	538	935		
N.28	0	0	0	0	0	0	598	992	397	722
N.34									740	1,529
N.57	382	178	829	1,397	89	128	773	1,095		
N.58	154	374	48	199	142		195	1,039	216	580
N.79	8	13	0	0	210	58	492	1,673	640	1,451
N.86									1,579	3,260
N.88	86	0	326	1,008	23	0	149	323		
N.93									1,194	2,467
N.95									706	1,457
N.350	0	0	0	0	5	0	1,086	2,352	69	154
N.501	220	0	287	3,741	35	0	37	573		
B.65	156	0	917	2,463	30	0	738	1,359		
B.462	26	46	113	581	73	86	1,149	4,099		
B.518	59	60	522	1,460	53	0	1,235	2,560		
B.601	332	471	609	1,471	76	34	359	581		

A graphical representation of these calculations is shown in Figure 25 for large segment vessels and in Figure 26 for small segment vessels. It is clear that small vessels are more active in Belgian waters than large vessels, and that they are more engaged in national journeys. As mentioned, a rather large part of small vessel activity location is unknown.

These results give a preliminary idea about the spatial distribution of the emissions. Emissions in the Belgian maritime zone will sum to around 5 % of the total emissions, of which about two thirds are made during national journeys (about 3.5 % of the total). The vast majority of the pollutants is emitted in other waters: around 95% of the grand total. The exact figures will be discussed in further detail in 2.6.

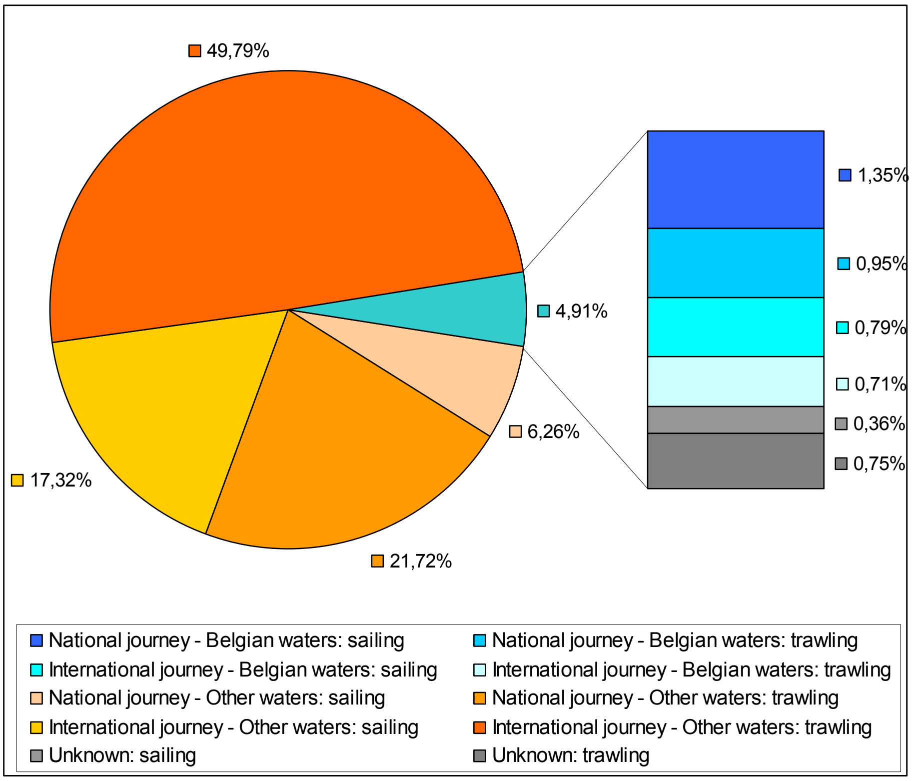

Figure 25: Decomposition of the vessel activity - Large Segment Vessels National vs International journeys, Belgian vs other maritime zones

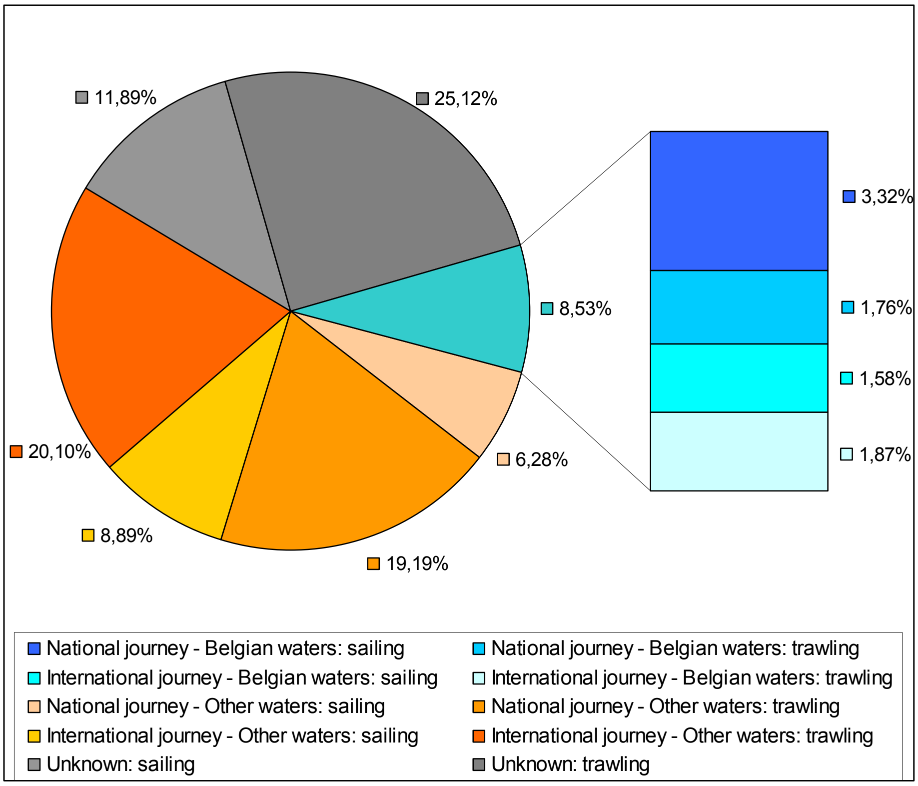

Figure 26: Decomposition of the vessel activity - Small Segment Vessels National vs International journeys, Belgian vs other maritime zones

2.6.2.2. Operational Characteristics: Survey amongst Fishermen

For the vessel movement methodology and the fuel consumption methodology based on vessel movement data and engine specifications, a number of operational characteristics is needed. As no publications on this matter could be found, a survey amongst fishermen has been performed.

Each fisherman or shipping company has been written to, with the kind request to fill in a form with a number of questions concerning characteristics of the vessel and the engine. In addition, some data on operational performance of the vessel could be gathered. An example of such a form is to be found in Appendix C. Over 110 forms were sent, 12 of which were returned. The information thus obtained may seem to be not very representative, but the used expert advise is the best possible option under the given circumstances.

In order to check the results of the survey, these were presented to Mr. Jan Geleyns, nautical teacher at the Maritime Institute of Oostende. With his help, valuable data could be forged for use in this study.

An important note concerns the privacy of the fishermen. As it was clear from the start of this study, fishermen aren't quite keen on giving away data about their vessel for varying reasons. In particular, data on fuel consumption and other operational characteristics is not easily obtained. Therefore, it has been promised to them that the information they provided would be impossible to trace back to them individually.

The fishermen also asked that no data on fuel consumption of individual vessels would be published. As this is of fundamental importance for this study, this data is given anyway. Obliging to the request of the fishermen however, this document is to be regarded as classified. This means – as has been stated on the first page – that no data from this study may be used without the prior written consent of the author or one of the supervising professors.

The results of this survey will be given where appropriate in the following sections.

2.6.2.3. Fuel Consumption and Fuel Characteristics

As has been mentioned earlier, a number of different methods have been used to estimate the fuel use by the Belgian fishing vessels. These are summarized as follows:

- based on fuel costs;
- based on estimates made by a number of fishermen;
- based on engine characteristics and ship movement data.

Before discussing these methods, some general characteristics of the fuel used by the fishing vessels will be given. Following the discussion of the methods, a comparison of the results thus obtained shall be made.

2.6.2.3.1. Fuel Characteristics

In this section, a short overview is given of some key technical characteristics of the fuel types which are used by the Belgian fishing vessels. This is of particular importance with respect to the emissions of SO_x, as this is directly linked to the sulphur content of the fuel. Another important property for the purposes of this study is the fuel density.

About half of all bunkering operations is performed in Belgium. On the Belgian market, Bunkers Dobbelaere-Dagreda nv is the sole supplier for fishing vessels, which is in turn supplied by Total nv. Following an inquiry to a Total-representative (see contacts), it is concluded that the fleet uses two types of fuel [66]:

- MGO: Marine Gas Oil, which is clear and not blended with heavy fuel;
- MDO/DMA: Marine Diesel Oil, which is a blend of gas oil and heavy oil.

It is assumed that the other half of the fuel bunkers, which is delivered in foreign harbours, are of the same type and have the same specifications.

The International Organisation for Standardisation (ISO) has issued a standard for these fuels, which contains maximum or minimum values for certain characteristics. The market follows these standards, which are found in ISO 8217:2005 [64].

In Table 21, a number of key features of MDO/DMA is given.

Table 21: Some characteristics of MDO/DMA, ISO 8217:2005 standard; [63]

Parameter	Unit	Value
Density at 15 °C	[kg/m^3]	845 – 890
Viscosity at 40 °C	[mm^2/s]	1.5 – 6.0
Micro Carbon Residue (MCR)	[% by mass]	0.30
Sulphur	[% by mass]	1.5
Ash	[% by mass]	0.01
Flash point	[°C]	60
Pour point, summer	[°C]	0
Pour point, winter	[°C]	-6
Calculated Cetane Index	[-]	40

Remarks: - Flash point: the temperature at which vapour given off will ignite when an external flame is applied under specified test conditions [21];

- Viscosity: a liquid's resistance to shear or flow; a measure of the adhesive, cohesive or frictional properties of the fuel [21];

- Pour point: the lowest temperature at which a marine fuel can be handled without excessive amount of wax crystals being formed, so preventing flow [21];

- CCI: An approximation of the Cetane Number, which is a measure of the ignition quality of diesel fuel. The higher the number, the easier the fuel ignites when injected into an engine [21];

- MCR: a fuel's tendency to form carbon deposits under high temperature conditions [21].

The specifications of Marine Gas Oil (MGO) typically align with these of MDO/DMA, except for the density, which is normally under 860 kg/m^3.

In practice, both MGO and MDO/DMA have a sulphur content of maximum 0.2 % by mass [51]. This percentage has been used in the calculations for this study. For the density of the fuel, a mean value of 860 kg/m^3 is applied.

2.6.2.3.2. Fuel Costs Methodology

This fairly simple method uses information on the fuel costs per day at sea, the fuel price and the total number of days at sea. For this purpose, 7 vessel classes have been distinguished, which have been introduced in chapter 2.5.3. In Table 22, data about the average number of days at sea, the fuel costs and the fuel use per day at sea is summarized. These calculations are based on an average fuel price of € 0.31/litre.

Table 22: Fuel use per d.a.s. based on fuel costs, with an average fuel price of € 0.31, for 2004; calculations based on [27]

Vessel class	Average number of d.a.s.	Total fuel costs	Fuel cost per d.a.s.	Fuel use per d.a.s.
	[-]	[€]	[€/day]	[litres/day]
SMALL SEGMENT	168	75,686	451	1,453
Coastal vessel	149	34,485	231	747
Eurokotter	178	98,838	555	1,791
Other Small Segment	184	89,552	487	1,570
LARGE SEGMENT	251	318,596	1,269	4,095
Beam Trawler +662 kW	253	334,209	1,321	4,261
Other Large Segment	224	170,271	760	2,452

This information, combined with the total number of days at sea obtained from the vessel movement data, easily leads to an estimate of the total fuel use of each vessel class, evidently taking into account the number of ships belonging to each vessel class. It should be noted that the estimates are made twice: once based on information for the detailed vessel classification (5 classes), and another time based only on the distinction between small and large vessels.

Table 23: Fuel use for the different vessel classes; Fuel costs methodology

Vessel class	Number of vessels	Average number of d.a.s.	Fuel use per d.a.s.	Total fuel use
	[-]	[-]	[litres/day]	[tonnes]
SMALL SEGMENT	56	173	1,453	12,106
Coastal vessel	23	150	747	2,216
Eurokotter	26	182	1,791	7,289
Other Small Segment	7	178	1,570	1,682
LARGE SEGMENT	62	232	4,095	50,656
Beam Trawler +662 kW	54	235	4,261	46,502
Other Large Segment	8	220	2,452	3,711
			TOTAL (a)	**62762**
			TOTAL (b)	**61401**
			TOTAL (c)	**62081**

Remarks: - Total (a): based on the distinction between small and large vessel segments
- Total (b): based on the detailed (5 classes) vessel classification
- Total (c): average of totals (a) and (b)

For further calculations, the average total fuel consumption (c) is utilised.

2.6.2.3.3. Fishermen's Estimates Methodology

Following an inquiry at the administrative body acting on this matter, a wealth of information on the fuel use of a sample of the fishing vessels has been obtained. Until 2003, fishermen were requested by the FOD Mobility and Transportation to keep record of the fuel consumption for each voyage. An estimate of the fuel use for 2005 can easily be calculate using the number of days at sea for 2003 and 2005 as a conversion factor.

This leads to following simple formula, with self-explaining notations:

$$Fuel\ consumption_{2005} = Fuel\ consumption_{2003} \cdot \frac{d.a.s._{2005}}{d.a.s._{2003}}$$

Table 24: Fuel use, Fishermen's estimates methodology

SHIP	TOTAL DAYS AT SEA		FUEL USE		SHIP	TOTAL DAYS AT SEA		FUEL USE	
	2003 [-]	2005 [-]	2003 [litres]	2005 [litres]		2003 [-]	2005 [-]	2003 [litres]	2005 [litres]
O.15	263	261	1,153,000	1,144,000	**Z.122**	227	188	370,000	306,000
O.187	114	199	236,000	412,000	**Z.137**	210	181	1,080,000	931,000
O.229	109	188	229,000	395,000	**Z.185**	227	251	1,163,000	1,286,000
O.333	261	262	1,139,000	1,143,000	**Z.196**	260	255	810,500	795,000
Z.16	260	255	954,000	936,000	**Z.198**	239	72	1,062,100	320,000
Z.18	240	260	1,260,500	1,366,000	**Z.200**	260	124	1,317,000	628,000
Z.19	260	258	987,000	979,000	**Z.201**	193	187	339,600	329,000
Z.36	247	241	1,538,000	1,501,000	**Z.243**	260	255	1,406,000	1,379,000
Z.41	248	158	255,000	162,000	**Z.284**	167	165	806,100	796,000
Z.45	259	256	1,485,000	1,468,000	**Z.296**	260	155	1,475,000	879,000
Z.46	257	255	1,346,000	1,336,000	**Z.402**	229	206	485,600	437,000
Z.47	249	254	1,438,000	1,467,000	**Z.431**	167	202	357,200	432,000
Z.48	221	236	1,101,000	1,176,000	**Z.470**	217	122	254,800	143,000
Z.54	256	128	1,504,000	752,000	**Z.483**	260	256	1,434,000	1,412,000
Z.56	190	190	404,900	405,000	**Z.510**	261	254	1,454,000	1,415,000
Z.76	260	255	1,233,000	1,209,000	**Z.519**	57	58	126,000	128,000
Z.78	248	247	1,297,000	1,292,000	**Z.525**	128	218	193,700	330,000
Z.80	162	201	306,100	380,000	**Z.526**	260	247	1,476,000	1,402,000
Z.84	260	255	1,155,000	1,133,000	**Z.568**	238	200	360,000	303,000
Z.85	245	247	400,400	404,000	**Z.576**	260	258	1,421,000	1,410,000
Z.87	181	196	256,200	277,000	**Z.583**	149	216	402,000	583,000
Z.90	259	255	1,440,000	1,418,000	**Z.738**	206	231	387,500	435,000
Z.91	259	255	1,320,000	1,300,000	**N.28**	89	148	125,700	209,000
Z.92	113	253	650,000	1,455,000	**N.350**	152	179	192,500	227,000
Z.98	261	255	1,206,000	1,178,000	**B.65**	263	257	436,400	426,000
Z.99	259	252	1,888,000	1,837,000	**B.462**	271	257	1,548,000	1,468,000
Z.105	260	271	1,385,000	1,444,000	**B.518**	260	255	1,505,000	1,476,000
Z.121	260	260	1,342,000	1,342,000	**B.601**	166	186	218,800	245,000

The data and calculations for the vessels for which this information is available are summarized in Table 24.

For the vessels this data could not be obtained for, a reasonable estimate of the fuel consumption can be made using linear least squares regression analysis (In brief, this technique calculates a "best fitting" curve between the dependent variable and the independent variable(s), minimizing the sum of the squares of the distances of the data points to the curve to be estimated. The simplest curve is a straight line; however, it is perfectly possible to estimate a polynomial curve of higher order, or even other basic mathematical functions (exponential, logarithmic). The dependent variable is of course the fuel consumption for 2005 for as calculated in Table 16 for the 58 vessels. As independent variable, the used kWh for the corresponding vessel for the year 2005 is chosen. Why this a meaningful choice will be explained in paragraph 2.6.2.3.4. The calculation of the kWh for each vessel will be elaborated upon there as well. The results of these calculations are given in Figure 27.

Using this methodology, a grand total of 71070 tonnes is found for the whole fleet.

The regression curve in Figure 27 follows this simple mathematical function:

$$Fuel\ Use = 0.2469 \cdot kWh_{M.E.+A.E.,total}$$

The fuel use is expressed here in litres, and the expression in the right hand side of the equation is the total yearly used kWh by main and auxiliary engines for the specified vessel.

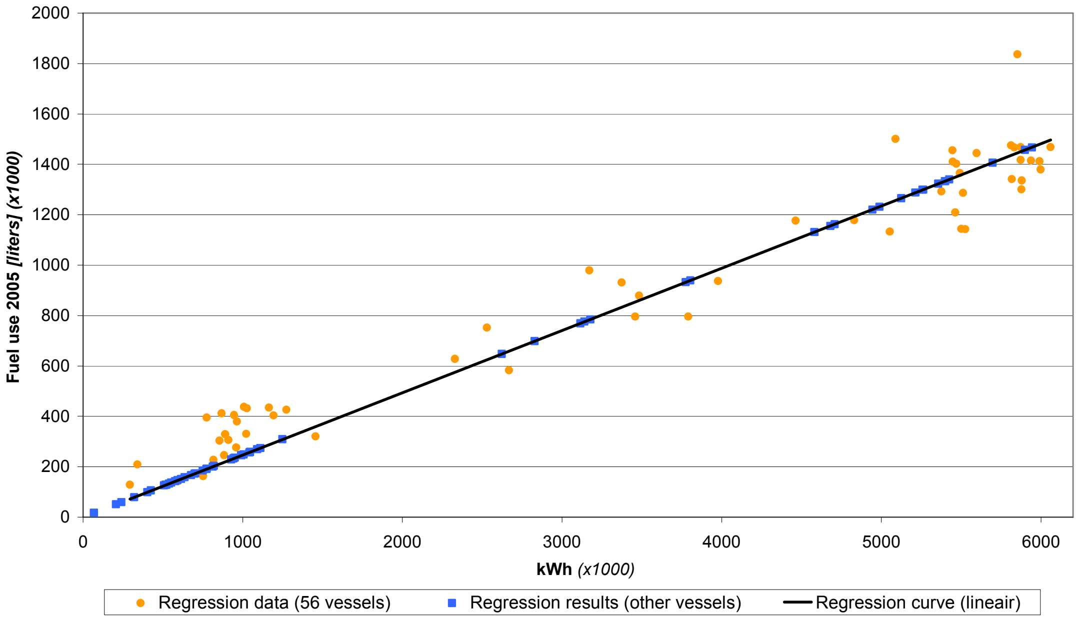

Figure 27: Fuel use 2005 vs used kWh - linear regression analysis data and results

As this quantity is quite complicated to calculate, using a great deal of data, another regression analysis is performed. Following expression for the yearly fuel consumption of a fishing vessel has been obtained:

$$Fuel\ Consumption = 5.11 \cdot 10^{-3} \cdot d.a.s. \cdot P_{\max,M.E.}$$

Here, the fuel consumption is given in tonnes. $P_{max,M.E.}$ is the maximum output power of the main engine and d.a.s. represents the total number of days at sea of the vessel. The advantage of this formula is the fact that the data is readily available.

This expression is proposed to be used for estimating the fuel consumption of Belgian fishing vessels for future studies (see 2.6.4).

2.6.2.3.4. Engine Characteristics - Vessel Movement Data Methodology

In the third and final method for calculating the fuel consumption of the Belgian fishing vessels, data concerning engine specifications and vessel movement characteristics for each individual ship is used, whereas the previous methods are based on averages for a vessel class or extrapolations based on a limited data set. In addition, results obtained during the calculation process can be utilised directly to estimate the spatially distributed emissions, using emission factors in g/kWh.

The outline of this calculation method is shown in Figure 28. Starting from vessel movement data, divided both in location (Belgian waters and outside of these) and in vessel activity (sailing or trawling), engine specifications and vessel operation characteristics are used to calculate the used kWh for the year 2005. This in turn lays at the basis of the determination of the fuel use for the vessel under consideration, using engine specifications data. The obtained kWh can also be used for a direct calculation of the spatially distributed emissions, using emission factors in g/kWh.

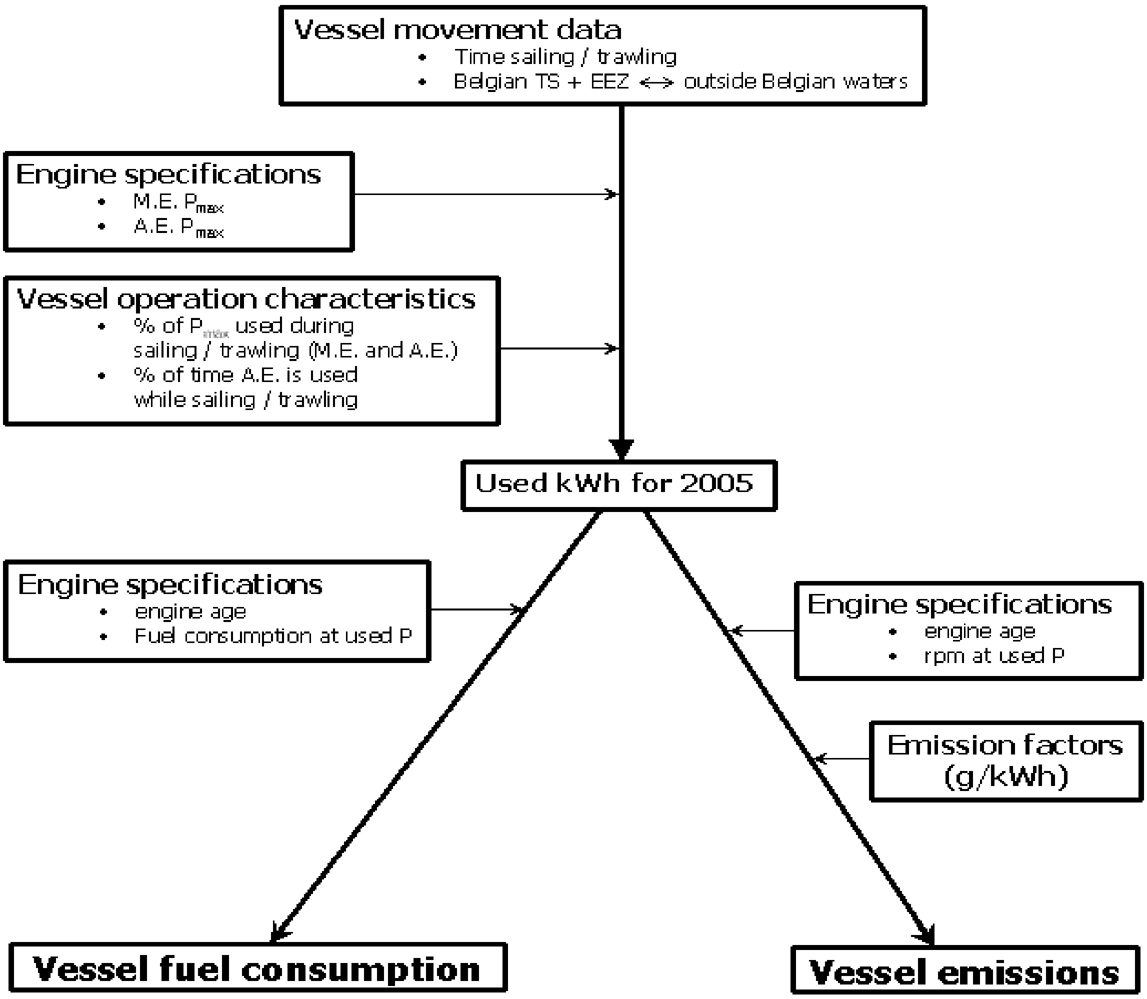

Figure 28: Overview of the detailed calculation procedure for vessel fuel consumption and vessel emissions

The main engine maximum power is found in Table A.2 of Appendix A [3] [18]. For the auxiliary engines, no information is readily available. However, based on a survey amongst the Belgian fishermen, a quite crude estimate can be made for the maximum power of the auxiliary engines. The survey data is shown in Figure 29, along with a somewhat arbitrary classification of the auxiliary engine power into four classes, which is summarized in Table 17. The fishermen were sent a letter or an email, with the request to answer a number of questions. As most fishermen showed concern as for the use of the data they granted (especially with respect to the fuel use), it was agreed that the information could be used in this work, as long as the information could not be traced back to them individually.

Even though this classification is not highly accurate, more detailed information simply is not available. Moreover, the fuel consumption of the auxiliary engine comprises only a quite small fraction of the total fuel consumption, so any error on this point has relatively insignificant repercussions; calculations based on the results obtained in this chapter show that for an average large segment vessel, the fuel use of the auxiliary engine adds to the total fuel consumption by some 18 %. For small segment vessels, this is about 12 %.

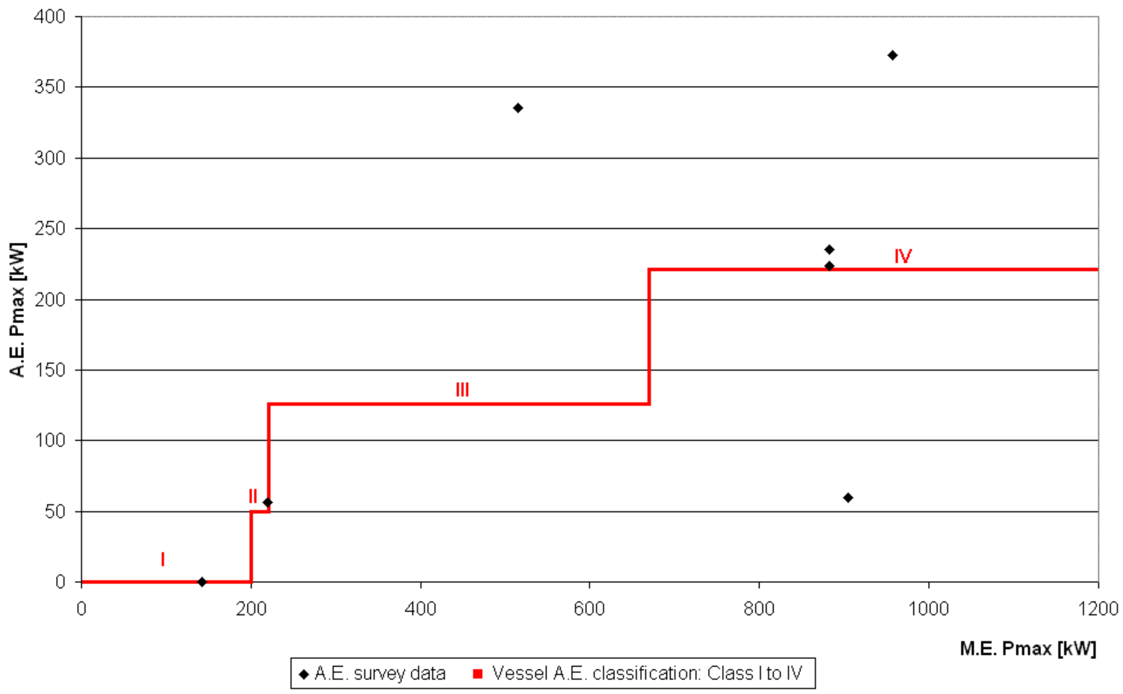

Figure 29: Auxiliary engine P_{max}: survey results and classification

Table 25: A.E. classification based on survey results

A.E. Class	M.E. P_{max} range [kW]	A.E. P_{max} [kW]	A.E. rpm @ P_{max} [rpm]
I	0 - 200	0	-
II	200 - 221	50	2,000
III	221 - 670	125	1,900
IV	over 670	221	1,800

Through the survey to some fishermen (see 2.6.2.2), other valuable information could be obtained as well. For the power use of the main engine during sailing and trawling, a distinction is made between 3 vessel types, according to the fishing method: the beam trawlers, otter trawlers and fishing vessels with entangling nets. This is summarized in Table 26. It should be noted here that some vessels are equipped with two sets of fishing gear (beam and otter trawling equipment). For these vessels, it is assumed that each fishing method has been used for half of the time. The fishing gear of the fishing vessels is to be found in Table A.1 of Appendix A.

Concerning the percentage of the time the auxiliary engine is used while fishing and trawling, for both these categories a value of 95 % is assumed based on survey results, which is plausible considering the fact that auxiliary engines are mainly used for electric power generation. In line with this, for the power use of the auxiliary engine, a distinction should be made between sailing and trawling. For the former, a value of 40 % is obtained from the survey; for the latter, a value of 85 % is utilised.

Table 26: Percentage of power use of M.E. with respect to P_{max}

VESSEL TYPE BY FISHING GEAR	PERCENTAGE OF POWER USE Sailing	Trawling
Beam trawler	90	85
Otter trawler	90	80
Fishing vessel with entangling nets	85	85

As is clear from Figure 28, all information is now available to calculate the used kWh for 2005 for each vessel individually. The results are to be found in Table 20, with a division between kWh from main and auxiliary engines and kWh from sailing and trawling activities.

To calculate the fuel consumption for each vessel, information on the fuel use for each engine is required. The fuel use of a diesel engine is dependent of the number of revolutions the engine operates at. This in turn is linked to the power use through the so-called propeller law [21] [30]:

$$P = C \cdot n^3$$

In this formula, P represents the power output of the engine (in kW) at engine revolution speed n (in rpm). C is a constant, which can be easily calculated when (at least) one operating point is known.

The fuel use per kWh is also dependent on the engine type. In principle, this data could be determined for each engine, for all manufacturers. However, detailed information could only be obtained for a very limited number of manufacturers. [62] [65] [67] [73] [81]. As is observed from Figure 30 however, with respect to the fuel consumption the engines can be divided in three classes. The first class comprises high power, medium speed engines, such as ABC 6DZC, 8DZC and MAK M20, with a maximum power output of more than 670 kW. The second class comprises medium power, medium speed engine (e.g. ABC 6DX, 8DX and 6DXC) with a maximum power output between 221 kW and 670 kW. The third engine class includes high speed, low power engines (e.g. Cummins KTA 19-M3), with a maximum power output of equal to or less than 221 kW.

As can be appreciated from Figure 18, these engine types are quite representative for the whole fleet. Summing all vessels equipped with one of the engines from Figure 30, it is found that these add to the total fleet by about 50 %. Moreover, ABC, Cummins, Baudouin and MAK are reasonably representative manufacturers of the range of the average maximum power outputs, as has been found in Figure 19.

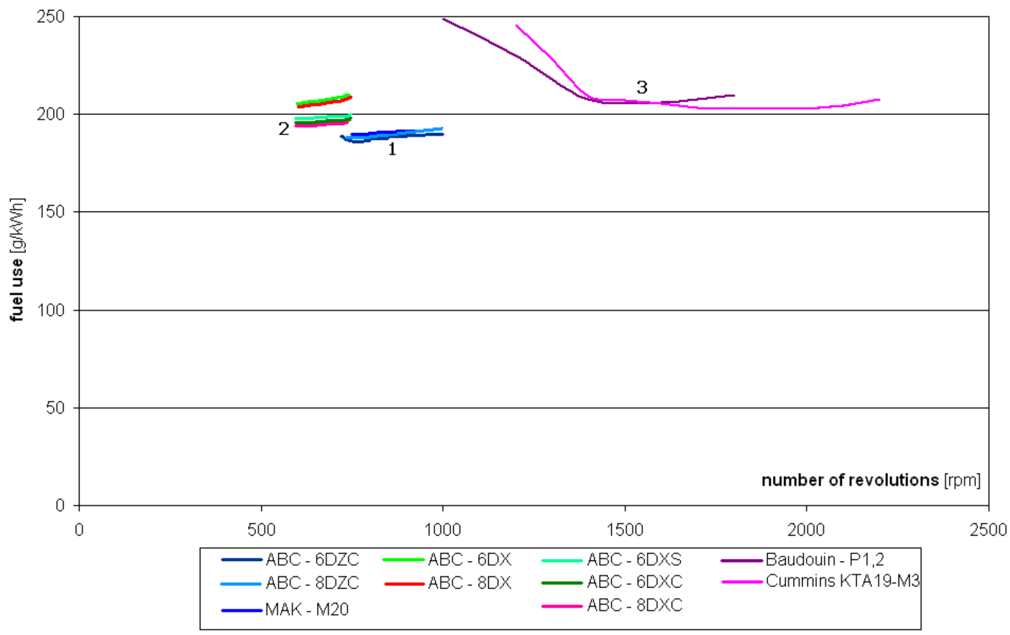

Figure 30: Fuel use (g/kWh) vs number of revolutions for a number of marine diesel engines; based on [1] [2] [4] [8] and [20]

Even though the classification is somewhat arbitrary, the results are quite obvious: the higher the maximum power output, the lower the fuel use per kWh. Furthermore, in each class the fuel use per kWh is very alike for different engine types. Marine diesel engines are usually designed for maximum power output. Depending on the actual specifications desired by the client, taking into account technical data such as ship resistance, propeller design and fishing method, the engine is optimised to these specifications. This practice is referred to as "derating of marine diesel engines". Because of this, practically all marine diesel engines will differ to a certain extend, yet general conclusions can be drawn, as is proven in Figure 30. For instance, the engine types ABC-6DX and ABC-8DX are power optimised marine diesels, whereas ABC-6DXS, ABC-6DXC and ABC-8DXC are derated versions of these designs [21].

The fuel use figures that have been actually used for calculation purposes are summarized in Table19.

Table 27: Fuel use (g/kWh) for various power use percentages; three engine classes - engines built before 1997 (brackets) & thereafter

ENGINE CLASS	POWER USE				
	40 %	**80 %**	**85 %**	**90 %**	**100 %**
1 Medium speed, high power	-	189 (202)	188 (201)	189 (202)	190 (203)
2 Medium speed, medium power	-	198 (212)	196 (210)	197 (211)	198 (212)
3 High speed, low power	260 (278)	218 (233)	209 (224)	204 (218)	210 (225)

Another important factor influencing the fuel consumption of a diesel engine is its age: older engines burn more fuel to obtain the same output power. In more recent years, manufacturers have done considerable efforts to reduce the fuel use. To take this effect into account, fuel consumption values for vessels older that 1997, are augmented with 7 %, a method copied from [7]. These values are typed between brackets in The year of manufacturing of the main engines is given in Table A.2 of Appendix A.

A final note concerns the auxiliary engines. For all auxiliary engines, the data obtained for the third engine class is utilised in the calculations. Since for the age of the auxiliary engines no data is available, it is assumed that these are built in the same year of the main engine of the vessel.

All data now is available to calculate the fuel consumption for each vessel, making use of the calculation scheme of Figure 28. In Table 28,calculation results for each vessel are summarised. Apart from the annual fuel consumption, the kWh for the main and the auxiliary engine is given, distinguishing sailing and trawling. This may be used to calculate the spatially distributed emissions for each vessel.

Table 28: Summary of the fuel consumption calculations - Engine characteristics & vessel movement data methodology

SHIP	kWh USED IN 2005 M.E. Sailing [kWh]	M.E. Trawling [kWh]	A.E. Sailing [kWh]	A.E. Trawling [kWh]	TOTAL FUEL USE [litres]	FUEL USE PER D.A.S. [litres/day]
O.2	202,244	394,327	20,045	87,937	187,584	1,242
O.14	584,182	2,666,073	46,574	478,242	892,495	3,528
O.15	1,917,015	2,731,814	202,581	649,541	1,267,050	4,855
O.20	165,629	323,136	16,188	71,060	153,346	1,257
O.29	155,540	303,566	14,858	65,246	143,526	1,281
O.33	732,082	3,556,764	77,451	846,647	1,279,060	5,221
O.51	1,253,095	2,565,116	158,869	731,720	1,163,386	4,374
O.62	286,217	558,290	27,341	119,995	246,736	1,198
O.82	223,763	436,376	21,375	93,791	192,869	1,198
O.89	729,619	3,459,872	80,096	854,588	1,175,938	4,594
O.100	177,091	345,277	0	0	137,940	862
O.101	179,345	339,425	0	0	126,997	819
O.116	23,260	45,263	0	0	18,094	696
O.124	1,243,189	3,140,789	131,374	746,782	1,209,126	4,742
O.148	272,294	515,433	26,011	114,140	245,340	1,252
O.152	187,070	364,725	0	0	145,711	862
O.154	493,356	1,837,968	50,267	447,683	675,886	2,770
O.187	206,060	529,643	19,684	113,837	216,240	1,087
O.190	149,971	292,670	14,326	62,904	129,326	1,197
O.191	201,486	392,982	19,247	84,465	173,683	1,198
O.225	108,799	212,078	0	0	79,190	842
O.229	157,990	493,593	15,300	107,549	192,674	1,025
O.231	1,178,090	3,575,241	117,320	825,366	1,309,044	4,996
O.316	968,369	1,721,655	92,756	394,237	812,905	3,175
O.333	1,116,675	3,459,925	119,084	830,184	1,269,033	4,844
O.369	165,597	341,909	24,225	106,287	152,362	2,087
O.536	172,258	335,818	0	0	134,166	813
O.554	241,701	691,155	44,725	271,770	299,129	1,709
O.700	207,979	405,715	0	0	151,455	806
Z.8	116,028	226,270	11,134	48,854	100,078	782
Z.13	234,067	456,301	22,667	99,423	202,130	1,075
Z.16	834,716	2,608,959	66,548	467,997	1,007,467	3,951
Z.18	671,555	3,835,465	71,047	912,989	1,258,664	4,841
Z.19	435,690	2,186,999	44,650	504,284	751,770	2,914
Z.28	61,361	143,330	5,862	30,806	60,043	1,053
Z.35	1,594,697	2,861,633	155,489	646,819	1,210,033	4,821
Z.36	1,457,082	2,809,684	153,977	668,056	1,170,556	4,857
Z.39	878,513	2,885,644	109,300	807,788	1,153,798	4,597
Z.41	272,294	370,396	26,011	84,586	204,747	1,296
Z.45	1,310,899	3,636,122	127,818	797,705	1,346,790	5,261
Z.46	1,509,428	3,463,263	147,175	759,783	1,349,328	5,291
Z.47	1,481,867	3,448,621	144,488	756,571	1,338,219	5,269
Z.48	703,350	2,869,388	87,507	803,237	1,027,389	4,353
Z.53	1,073,781	2,243,063	85,607	402,362	901,817	3,593
Z.54	710,313	1,374,307	83,371	362,938	583,511	4,559
Z.55	178,702	457,142	17,071	98,255	186,871	958

(continued from Table 28)

SHIP	kWh USED IN 2005 M.E. Sailing [kWh]	M.E. Trawling [kWh]	A.E. Sailing [kWh]	A.E. Trawling [kWh]	TOTAL FUEL USE [litres]	FUEL USE PER D.A.S. [litres/day]
Z.56	265,482	536,810	25,360	118,874	233,867	1,231
Z.59	1,450,860	2,785,660	141,464	611,128	1,145,742	5,070
Z.60	1,223,043	3,291,162	129,245	782,536	1,246,485	4,758
Z.63	216,648	579,591	20,884	125,710	234,565	1,043
Z.67	1,147,547	3,337,321	121,267	793,511	1,326,897	5,265
Z.69	1,465,228	2,684,530	154,838	638,298	1,137,240	4,988
Z.70	196,115	457,271	18,734	101,261	191,034	1,172
Z.75	337,955	555,529	32,728	121,044	260,543	1,217
Z.76	1,353,573	3,203,910	143,039	761,790	1,255,434	4,923
Z.78	1,280,598	3,216,811	132,038	746,265	1,321,058	5,348
Z.80	275,576	545,235	26,325	117,188	239,891	1,193
Z.84	1,040,337	3,077,028	122,107	812,606	1,162,723	4,560
Z.85	332,163	680,072	31,730	150,599	295,144	1,195
Z.87	267,421	548,240	25,546	117,834	238,578	1,217
Z.90	1,206,569	3,726,027	118,139	820,860	1,346,203	5,279
Z.91	1,347,935	3,605,617	131,429	791,013	1,347,749	5,285
Z.92	1,402,646	3,146,681	148,225	748,183	1,251,887	4,948
Z.96	1,255,345	3,296,506	122,401	723,199	1,324,731	5,836
Z.98	1,251,956	2,674,472	155,762	748,674	1,114,752	4,372
Z.99	1,400,904	3,538,508	136,593	776,290	1,436,563	5,701
Z.105	1,166,814	3,476,517	123,724	829,426	1,375,244	5,075
Z.121	1,561,537	3,365,243	152,256	738,279	1,335,337	5,136
Z.122	307,692	470,085	29,526	104,571	225,445	1,199
Z.126	874,867	1,295,013	104,702	348,714	626,518	2,600
Z.137	942,975	1,807,631	117,320	506,016	778,949	4,304
Z.162	1,122,059	3,828,299	109,405	839,866	1,352,103	5,302
Z.183	603,736	2,039,964	57,724	438,851	744,640	2,955
Z.185	1,030,154	3,531,649	108,985	840,669	1,265,101	5,040
Z.186	1,395,306	3,617,819	136,048	793,690	1,458,660	5,676
Z.196	850,770	2,079,729	81,344	447,405	878,783	3,446
Z.198	412,132	823,211	40,184	180,599	334,345	4,644
Z.200	587,588	1,303,688	73,105	364,946	537,414	4,334
Z.201	392,877	376,091	37,530	83,284	220,207	1,178
Z.243	1,373,774	3,681,268	133,948	807,609	1,471,681	5,771
Z.279	272,692	537,251	26,049	115,473	236,692	1,246
Z.284	801,785	2,437,838	70,249	480,586	867,331	5,257
Z.296	1,040,020	1,920,555	101,406	421,338	800,064	5,162
Z.402	418,088	453,094	39,938	97,385	250,862	1,218
Z.431	190,795	672,926	18,226	144,633	255,394	1,264
Z.470	89,853	410,499	8,583	88,229	148,567	1,218
Z.474	295,218	560,720	28,329	121,064	250,099	1,214
Z.483	866,591	4,132,010	84,673	908,393	1,371,991	5,359
Z.510	1,372,912	3,634,088	133,864	797,259	1,362,048	5,362
Z.519	62,326	184,892	5,954	39,739	72,870	1,256
Z.525	301,731	569,373	28,823	122,377	254,313	1,167
Z.526	1,039,360	3,495,479	109,216	826,437	1,255,608	5,083
Z.548	1,328,555	3,196,859	129,539	701,338	1,229,007	5,230

(Continued from table 28)

SHIP	kWh USED IN 2005 M.E. Sailing [kWh]	M.E. Trawling [kWh]	A.E. Sailing [kWh]	A.E. Trawling [kWh]	TOTAL FUEL USE [litres]	FUEL USE PER D.A.S. [litres/day]
Z.548	1,328,555	3,196,859	129,539	701,338	1,229,007	5,230
Z.568	315,853	416,795	30,172	92,297	211,473	1,057
Z.571	1,210,557	2,653,594	118,034	599,796	1,127,377	5,101
Z.575	292,681	565,053	27,959	121,448	250,542	1,216
Z.576	1,617,612	2,955,291	170,941	702,676	1,253,128	4,857
Z.582	463,586	219,268	44,284	47,128	192,574	973
Z.583	349,375	1,879,733	33,404	404,381	675,699	3,128
Z.596	748,039	1,881,510	72,937	412,772	764,714	5,502
Z.738	367,567	624,190	35,112	138,224	287,972	1,247
N.28	125,616	215,186	0	0	84,047	568
N.34	73,303	134,562	0	0	56,415	532
N.57	412,270	525,745	39,382	113,000	271,238	1,164
N.58	161,936	411,161	15,469	88,372	168,404	1,115
N.79	281,841	603,733	26,923	129,762	259,281	1,147
N.86	204,595	387,310	0	0	144,901	641
N.88	114,483	246,449	11,087	53,699	113,328	1,232
N.93	236,507	461,287	22,695	99,596	204,015	1,140
N.95	282,451	583,304	33,512	147,064	248,973	2,465
N.350	222,785	471,678	21,282	101,379	203,274	1,136
N.501	114,666	810,385	10,954	174,178	276,206	1,239
B.65	366,075	717,963	34,970	154,313	316,758	1,233
B.462	1,171,799	3,915,135	114,255	858,916	1,388,970	5,405
B.518	1,609,124	3,318,673	156,896	728,062	1,334,515	5,233
B.601	269,311	484,371	25,726	104,107	219,786	1,182

The estimated fuel consumption using this rather lengthy calculation procedure sums to a total of 66359 tonnes.

2.6.2.3.5. Comparison of the Results of the Methodologies

With the results of the three methodologies which have been used to estimate the fuel consumption of the Belgian fishing fleet available, it is interesting to compare the results. This comparison is performed in Figure 31. As independent variable, the total kWh for 2005 is chosen. As is clear from the third methodology, the fuel consumption is directly linked to this quantity in a more or less linear relation: The relation between the kWh and the fuel consumption is strictly speaking not linear, as the fuel consumption of the engine in g/kWh depends on the power use of the engine. When simply adding all kWh data for the vessel, the distinction between fuel consumption during sailing and trawling is lost. Similarly, the distinction between power provided by M.E. and A.E. cannot be made anymore.. The total fuel consumption as calculated from the different methodologies is summarised in Table 29, as is the general average of these estimates.

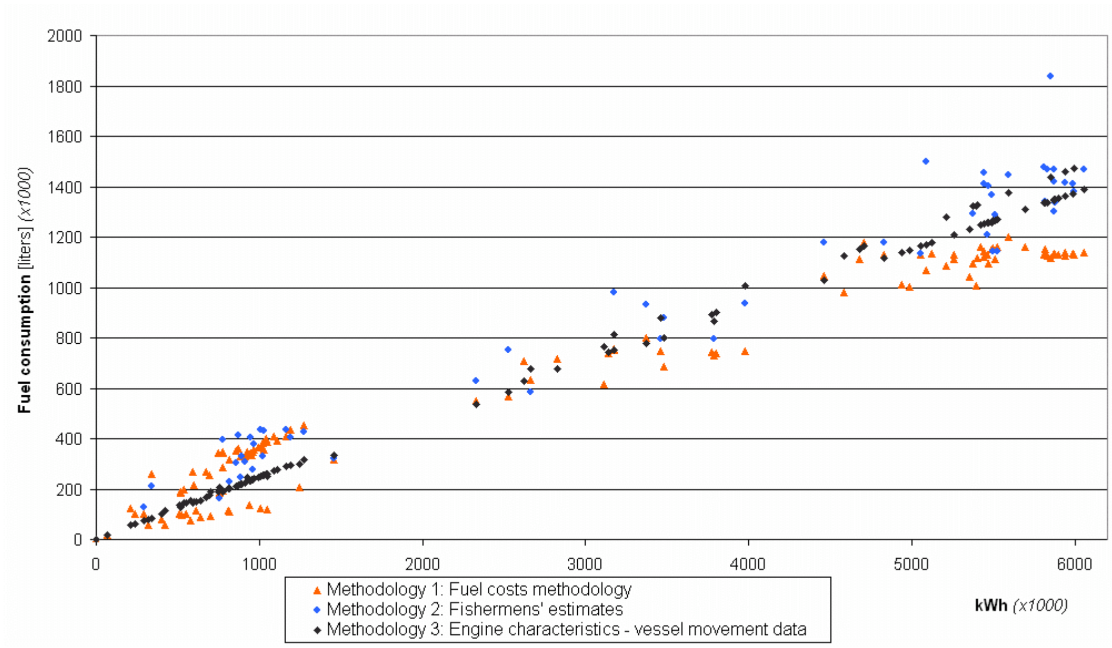

Figure 31: Comparison of the fuel consumption results for the three calculation procedures

Table 29: Summary of the total fuel consumption estimates from the three proposed methodologies

Methodology		Estimated total fuel consumption [tonnes]
1	Fuel costs	62,081
2	Fishermen's estimates	71,070
3	Engine characteristics - vessel movement	66,359
Average		66,503

In Table 22, the results for the vessel movement – engine characteristics methodology are summarized into data for each vessel class, as discussed in section 2.5.3. These values are compared to the equivalent data obtained using the fuel costs methodology.

Table 30: Comparison of the fuel use per day at sea for the various vessel classes, Fuel cost vs. vessel movement – engine characteristics methodologies

Vessel class	**Fuel use per day at sea** [litres/day]	
	Fuel cost methodology	**Vessel movement – engine characteristics methodology**
SMALL SEGMENT	1453	1236
Coastal vessel	747	866
Eurokotter	1791	1534
Other Small Segment	1570	1345
LARGE SEGMENT	4095	4764
Beam Trawler +662 kW	4261	5033
Other Large Segment	2452	2947

Remarks: - The fuel use per d.a.s. has not been calculated for the fishermen's estimates methodology, as the data consists largely of extrapolations using linear least squares statistics. For an estimate of the total fuel consumption, this approach is correct, but it is too generalizing to give adequate results for vessel classes.

Following conclusions can be drawn from Figure 31, Table 29 and Table 30:

- The average fuel consumption is almost identical to the estimate obtained from the third methodology: the discrepancy is only a meagre 144 tonnes (0.22 %). The results of the first and second methodology differ somewhat from this average: the estimate resulting from the first methodology is 9.3 % lower. For the second methodology, the estimate is 6.9 % higher.
- Observing the estimates for each individual vessel, practically all results obtained from the second methodology are higher than the estimates obtained from the third methodology.
- Comparing the second and the third methodology, it is understood that the estimates for large segment vessels are lower for the second methodology, whereas for the small segment vessels, the eurokotter vessel class' estimates are higher and the coastal vessels' results lower than the values obtained from the third methodology.
- All this leads to the general conclusion that the third methodology gives the best estimate for the total fuel consumption of the Belgian fishing vessels for 2005, summing to a value of 66,359 tonnes or 77,161,905 litres.

2.6.2.3.6. Fuel Use during Sailing and Trawling

An interesting point, which has caused quite some doubt, is the question whether a fishing vessel uses more fuel during trawling or during sailing activities. One naturally assumes that for trawling activities of beam trawlers, the fuel consumption is higher. This seems logical, as dragging the nets over the sea floor brings about a high resistance.

However, expert advise and survey results contradict this intuitive assumption. For certain vessels, fuel consumption during trawling is indeed higher, yet for others, it is somewhat lower. This calls for an explanation.

It is a fact that dragging heavy nets over the sea floor inflicts a high ship resistance. On the other hand, trawling activities are performed at very slow speeds, around 2 to 3 kn. Fishing vessels sail at speeds around 8 kn (small segment - SS) and 11.5 kn (large segment - LS).

The ship resistance roughly varies with speed to a power of three at low speeds (mainly caused by the friction between the ship and the water) and a power of four at higher speeds (predominantly due to wave making) [30]. An example illustrates this: assume a ship sailing at 3 kn has a resistance of 1 kN. The same ship sailing at 11 kn will have a resistance of around 70 kN.

This implies that the total resistance during trawling activities is almost completely caused by the dragging of the nets as the ship resistance caused by it's motion through the water can be neglected. At higher speeds, during sailing activities, the ship's wave making resistance is the predominant factor.

Combining these facts, it is understood that the total resistance during sailing and trawling activities will be close to one another.

Another point concerns the engine efficiency. Each engine has a working point at which it runs most efficiently, generally at around 85 % of it's maximum power [21]. Here, fuel is consumed most economically with respect to the power output of the engine. It is clear that regardless of the vessel activity, the most important matter is the economic efficiency. This explains why the fuel consumption is quite alike for sailing and trawling.

The fuel consumption calculation based on vessel movement and engine characteristics, confirms this conclusion. In Table 23, a comparison is made of the fuel consumption during sailing and trawling. Distinction is made between the fuel consumption of the main engine and the total fuel consumption (main and auxiliary engines). The values are averages for large and small segment vessels, so for individual vessels the numbers may differ somewhat.

It is seen that for large segment vessels, the total fuel consumption is somewhat higher during trawling than during sailing, whereas the fuel consumption is higher during sailing when only main engine is taken into account. Similar conclusions can be drawn for small segment vessels.

Table 31: Average fuel consumption for LS and SS vessels during sailing and trawling, [tonnes/hr]

	Sailing		Trawling	
	M.E. only	**M.E. and A.E.**	**M.E. only**	**M.E. and A.E.**
Large Segment	166.1	189.6	155.9	196.0
Small Segment	45.3	50.1	43.5	51.6

This is in close accordance with the results of the survey. Some fishermen stated that more fuel is consumed during sailing than during trawling. Others reported the opposite is true. In many cases however, it was not fully clear whether the total fuel use or the portion of the main engine was considered.

As a general conclusion however, it can be stated that although there is a certain difference between the fuel consumption for the two activities, this discrepancy is rather small. In this work, the distinction is made (complicating calculations to a large extent). In future studies, this subdivision should not necessarily be made.

2.6.2.4. Emission Factors

In the relevant literature, emission factors (kg/tonne fuel and g/kWh) and emission rates (kg/hour at sea) are readily available. Two sets of emission factors were obtained from different sources; these are given in Table 24 and Table 25(Emission Inventory Guidebook) and Table 26 (SMED).

Table 32: Emission factors, Emission Inventory Guidebook; [16]

Substance	**Emission factor** [kg/tonne fuel]	**Substance**	**Emission factor** [g/tonne fuel]
CO_2	3170	**As**	0.05
SO_2	20 · %S	**Cd**	0.1
CO	7.4	**Cr**	0.04
NMVOC	2.4	**Pb**	0.1
CH_4	0.05	**Zn**	0.5
N_2O	0.08	**PM_{10}**	1200

Remarks: %S = sulphur content of fuel (% by weight)

Table 33: Emission rates (kg/hour), Emission Inventory Guidebook; [16]

Substance	**Emission rate**
NO_x	$4.25 \cdot 10^{-3} \cdot P^{1.15} \cdot N$
CO	$15.32 \cdot 10^{-3} \cdot P^{0.68} \cdot N$
SO_2	$2.31 \cdot 10^{-3} \cdot P^{0.69} \cdot N$

Remarks: - These emission rates apply to medium and high speed diesel engines, and may be used for both main and auxiliary engines.
- P is the effectively used engine power (kW).
- N is the number of engines.

Table 34: Emission factors for Medium Speed Diesel engines (MSD) and High Speed Diesel engines (HSD), Swedish Methodology for Environmental Data (SMED); [7]

Substance	MSD [g/kWh]	HSD [g/kWh]	MSD [g/tonne]	HSD [g/tonne]	uncertainty [%]
Main Pollutants					
NO_x	13.2	12.0	63,221	58,326	5 – 10
CO	1.1		5,339	5,336	10 – 20
NMVOC	0.2		970	976	10 – 20
SO_x	0.8		4,000		20 – 50
NH_3	0.003		22	15	20 – 50
Greenhouse Gases					
CO_2	652		3,179,000		5 – 10
CH_4	0.004		19.5		20 – 50
N_2O	0.031		151		20 – 50
Particulate Matter					
PM_{10}	0.2		976		> 50
$PM_{2.5}$	0.2		976		> 50
Priority Metals					
Cd	$1.03 \cdot 10^{-6}$		0.005		> 50
Hg	$1 \cdot 10^{-8}$		$5 \cdot 10^{-5}$		> 50
Pb	$3 \cdot 10^{-5}$		0.15		> 50
Other Metals					
As	$6 \cdot 10^{-6}$		0.03		> 50
Cr	$1 \cdot 10^{-5}$		0.05		> 50
Cu	$3.49 \cdot 10^{-4}$		1.7		> 50
Ni	$2 \cdot 10^{-4}$		1		20 – 50
Se	$1.03 \cdot 10^{-8}$		$5 \cdot 10^{-5}$		> 50
Zn	$2 \cdot 10^{-4}$		1		20 – 50
POP's					
PCB	$1 \cdot 10^{-7}$		$4.9 \cdot 10^{-4}$		> 50
Diox/Fur	$1 \cdot 10^{-9}$		$4.9 \cdot 10^{-6}$		> 50
Ben(a)pyr	$1 \cdot 10^{-6}$		$4.9 \cdot 10^{-3}$		20 – 50
Ben(b)flu	$2 \cdot 10^{-6}$		$9.8 \cdot 10^{-3}$		20 – 50
Ben(k)flu	$1 \cdot 10^{-6}$		$4.9 \cdot 10^{-3}$		20 – 50
Indenopyr	$2 \cdot 10^{-6}$		$9.8 \cdot 10^{-3}$		20 – 50
PAH-4	$6 \cdot 10^{-6}$		0.029		20 – 50
HCB	$8 \cdot 10^{-9}$		$3.9 \cdot 10^{-5}$		> 50

Remarks: - The emission factors for SO_x are based on a sulphur content of 0.2 % by weight for distillate fuels such as marine gas oil, see 2.6.2.3.1.

- The speed of a diesel engine is referred to as the engine speed at the crankshaft in terms of number of revolutions per minute (rpm). Here, medium speed ranges from 300 rpm – 1000 rpm and high speed covers the 1000 rpm – 3000 rpm interval.

- These emission factors may be applied to both main and auxiliary engines.

2.6.3. EMISSIONS FOR THE BELGIAN FISHING FLEET

The general outline of the methodologies for emissions calculations have already been discussed in chapter 2.6.1. Here, a brief recapitulation is given, giving further details where necessary. Obviously, the calculation of the emissions shall be performed and discussed. First, the more detailed vessel movement methodology shall be elaborated upon. Thereafter, the fuel consumption methodology shall be discussed as a check of the results obtained. Finally, both results are compared and for pollutants for which data is available and a comparison shall be made with estimates which are available in the literature.

2.6.3.1. Emissions as Estimated from the Vessel Movement Methodology

The general outline of this calculation procedure is given in paragraph 2.6.1.2.2. The vessel movement data has been discussed thoroughly in paragraph 2.6.2.1, where the spatial distribution of the vessel activities has been obtained. In the calculation procedure for the fuel consumption, based on vessel movement data and engine specifications, the calculation scheme for the used kWh for both M.E. and A.E. has been introduced (Figure 28). In this figure, an overview of the steps to be taken to obtain the emissions using the emission factors (g/kWh) is given.

The calculation scheme is shown in further detail in Figure 33. For each vessel and for both main and auxiliary engines, a distinction is made between the duration of sailing and trawling activities in both the Belgian waters and outside of these, starting from the total time the vessel was at sea during 2005. The duration of each activity is multiplied with the maximum power output P_{max} and the percentage of the available power that is actually used, as given in Table 18 (For the A.E.'s, a value of 40% has been proposed for sailing, and 85% for trawling). For auxiliary engines, the percentage of the time the engine is actually used (estimated at 95 %) is also multiplied with. This results in the used kWh for each activity, in each spatial sector, for main and auxiliary engines.

The applied emission factors are summarized in Table 26. For NO_x however, the emission factor depends on the age of the engine. In IMO Marpol Annex VI - 13 [60], engine manufacturers are urged to limit the emission of NO_x to a legally prescribed value. This maximum value is expressed in g/kWh, and depends on the revolution rate of the engine. The limits are as follows:

- $n \leq 130$ rpm: 17 g/kWh;
- 130 rpm< n < 2000 rpm: $45 \cdot n^{0.2}$ g/kWh;
- $n \geq 2000$ rpm: 9.8 g/kWh

This is also shown in Figure 32: Emission factors for NOX used for engines manufactures after 1997, based on IMO MARPOL Annex VI regulations ; [60] Figure

32: Emission factors for NOX used for engines manufactures after 1997, based on IMO MARPOL Annex VI regulations; [60]

The IMO Marpol emission factors are used in this calculation procedure for engines manufactured before 1997, whereas for older engines, the emission factors from Table 26 are applied. In fact, most engine manufactures obtain actual NO_x emissions that are somewhat lower than the maximum value imposed by IMO regulations. However, the overestimation may be considered minimal.

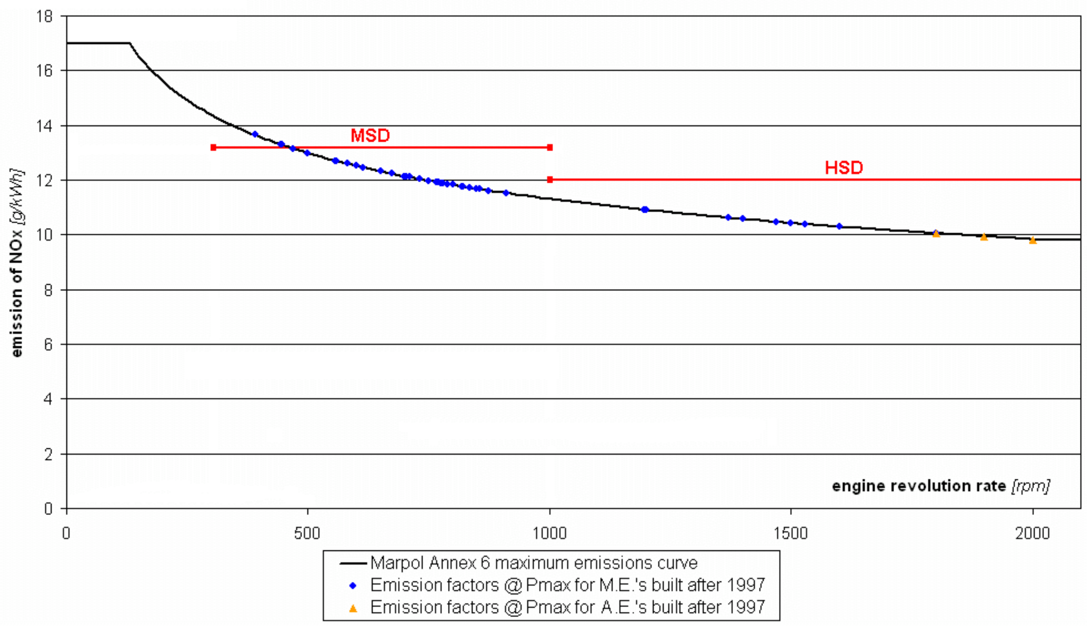

Figure 32: Emission factors for NO_X used for engines manufactures after 1997, based on IMO MARPOL Annex VI regulations; [60]

As the emission factors for engines manufactured after 1997 depend on the engine revolution rate, they are linked to the used engine power as well. The relation between engine output power and engine speed which may be used for diesel engines, has already been mentioned in paragraph 2.6.2.3.4. This relation is known as the propeller law:

$$P = C \cdot n^3$$

Using this relation, the engine speed for the actually used engine power for sailing and trawling activities is easily obtained, keeping in mind the data from Table 26.

The emissions now can be easily obtained multiplying the calculated kWh and the relevant emission factor. It is important to note that the calculation procedure shown in Figure 33 is executed for both national and international voyages, and for both main and auxiliary engines. The results for main and auxiliary engines are summed, thus obtaining the total emissions for national and international travels, distinguishing emissions in Belgian and other waters. This calculation scheme is executed for each individual vessel. The results are then summed for all vessels, obtaining the grand total for the whole fleet.

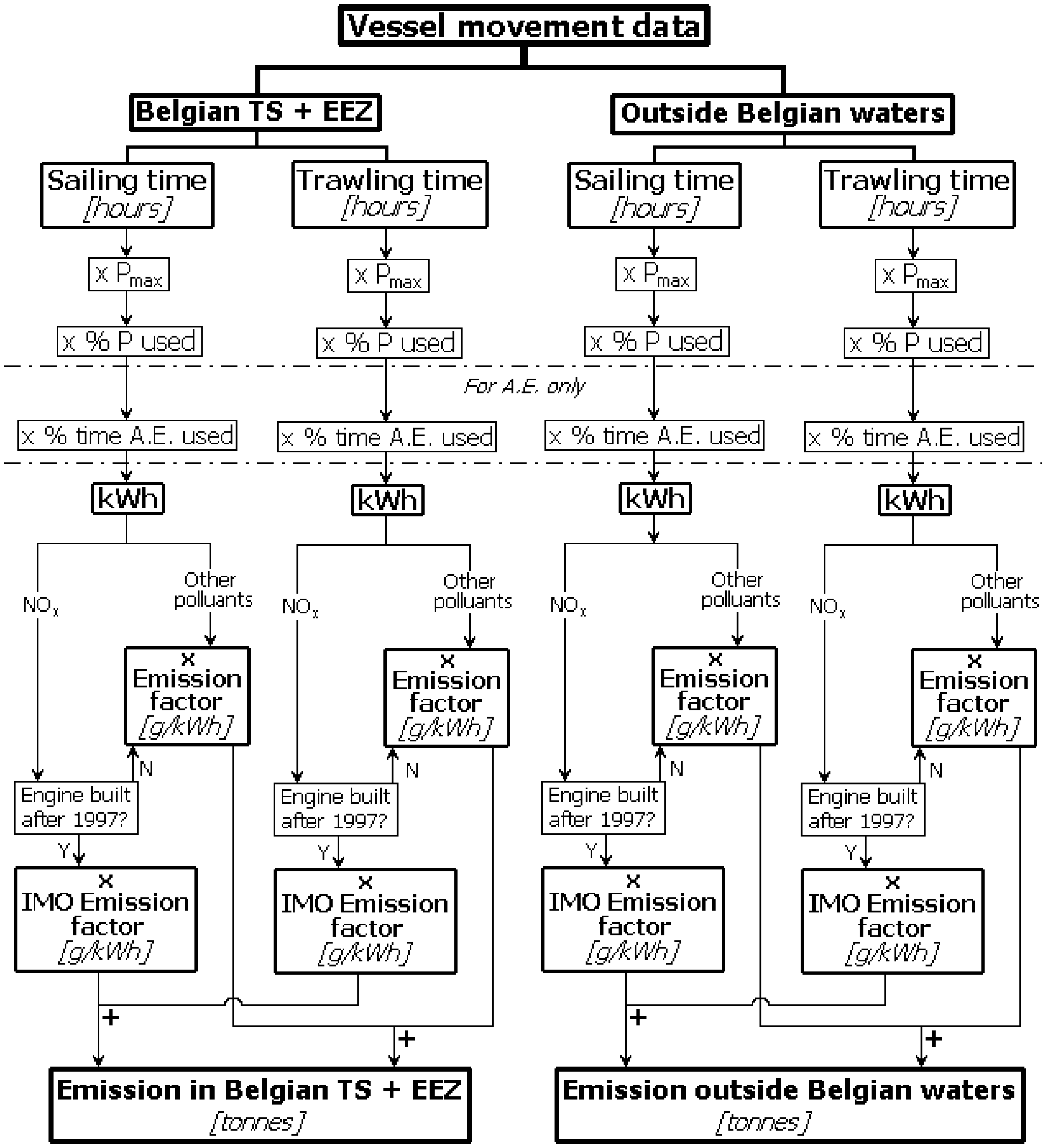

Figure 33: Detailed calculation scheme for vessel emissions using the vessel movement methodology

The calculation results are summarized in Table 35, where the total emission for each pollutant is given as calculated according to this methodology. In Figure 34, the spatial distribution of NO_x-emissions is given, and for the other pollutants this is done in Figure 35.

Table 35: Summary of the total emissions of the Belgian fishing vessels; Vessel movement methodology, SMED g/kWh emission factors

POLLUTANT	Unit	Estimated total emission
Main Pollutants		
NO_x	[tonnes]	3,938
CO	[tonnes]	362
NMVOC	[tonnes]	66
SO_x	[tonnes]	261
NH_3	[kg]	976
Particulate Matter		
PM_{10}	[tonnes]	65
$PM_{2.5}$	[tonnes]	65
Greenhouse Gases		
CO_2	[tonnes]	212,316
CH_4	[kg]	1,303
N_2O	[tonnes]	10
Priority Metals		
Cd	[g]	335
Hg	[g]	3.3
Pb	[kg]	9.8
Other Metals		
As	[kg]	2.0
Cr	[kg]	3.3
Cu	[kg]	114
Ni	[kg]	65
Se	[g]	3.4
Zn	[kg]	65
Persistent Organic Pollutants		
PCB	[g]	33
Diox/Fur	[g]	0.33
Ben(a)pyr	[g]	326
Ben(b)flu	[g]	651
Ben(k)flu	[g]	326
Indenopyr	[g]	651
PAH-4	[kg]	2.0
HCB	[g]	2.6

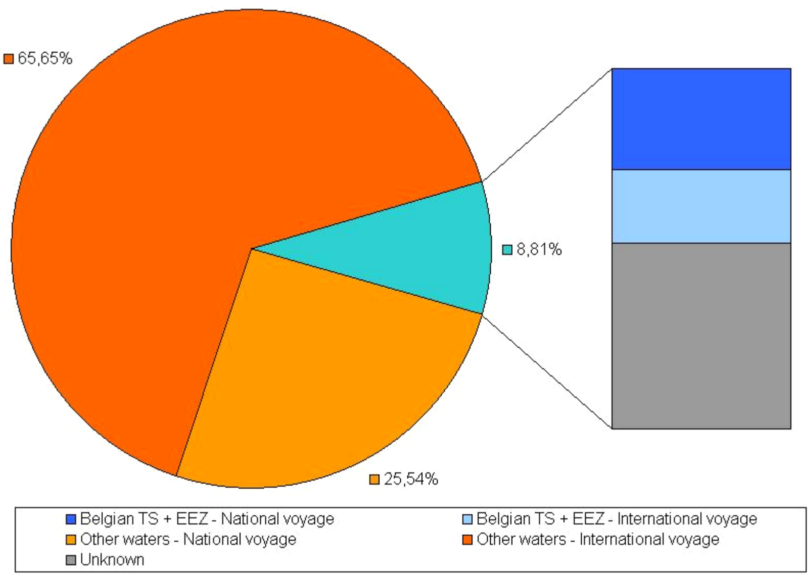

Figure 34: Spatial distribution of NO_x emissions for the Belgian fishing fleet

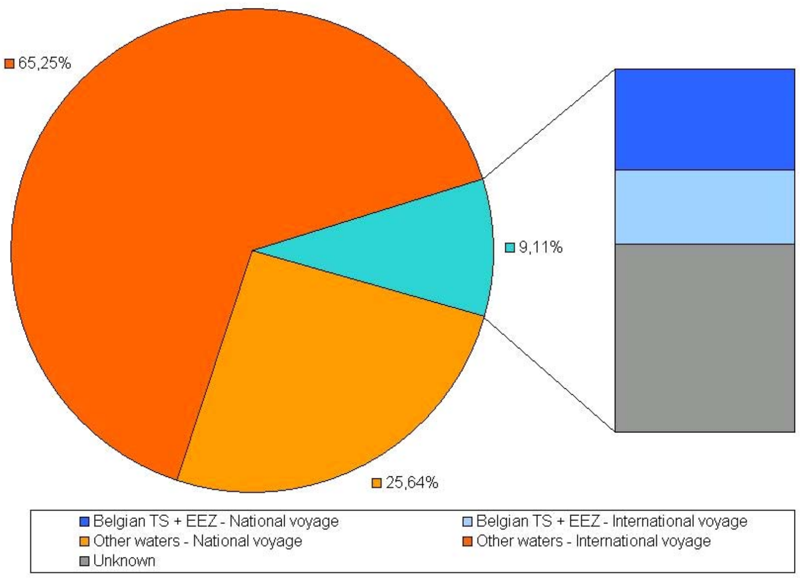

Figure 35: Spatial distribution of emissions of other pollutants for the Belgian fishing fleet

The small difference between the spatial distribution of NO_x on the one hand and the other pollutants on the other hand, is easily explained. Small vessels are more active in Belgian waters than large ships (as noticed in paragraph 2.6.2.1, comparing Figure 25 and Figure 26), and small vessels usually have engines operating at higher speeds, which agree with lower NO_x emission factors, as can be seen in Figure 32: Emission factors for NOX used for engines manufactures after 1997, based on IMO MARPOL Annex VI regulations; [60] Figure 32: Emission factors for NOX used for engines manufactures after 1997, based on IMO MARPOL Annex VI regulations; [60]

Other emission factors are not to this extend dependent on the engine speed. This implies that NO_x-emissions will be proportionally slightly smaller in Belgian waters in comparison with emissions of other pollutants in these areas.

In order to eliminate the proportion of the emissions the location and voyage type is unknown of, following calculation scheme is utilised:

For the small and the large vessel segment, the emissions are calculated, distinguishing Belgian and other waters, national and international voyages, and unknown location and voyage type. The distinction between large and small vessels is made because it is clear from Figure 25 and Figure 26 that there is a marked difference in the decomposition of the vessel activities;

The emissions for each vessel segment are proportionally increased according to the applicable fraction of the location and voyage type category, as formulated in the equation below;

$$Emission_{category\ X,final} = \frac{Emission_{category\ X}}{100 - \%_{unknown}} \cdot 100$$

In this formula, the left hand side represents the amount of emissions of a certain category X (depending on location and voyage type) with the unknown fraction eliminated. $Emission_{category\ X}$ is the amount of emissions in the specified category and $\%_{unknown}$ is the amount of unknown emissions for the vessel segment.

The thus obtained values are added for each category, and the percentages for each category are calculated.

The results of these calculations for NO_x and for other pollutants are shown in Table 28.

Table 36: Final spatial distribution of the total emissions for NOx and other pollutants; vessel movement methodology

Pollutant	National voyages		International voyages	
	Belgian TS + EEZ	Other waters	Belgian TS + EEZ	Other waters
NO_x	2.83 %	27.31 %	2.02 %	67.84 %
Other	2.90 %	27.48 %	2.08 %	67.53 %

For a very limited number of pollutants, emissions can be calculated using emission rates rather than emission factors. This is the case for NO_x, CO and SO_2, as shown inTable 33. The calculation method is fairly simple:

For each vessel, the duration of sailing and trawling activities is calculated, distinguishing national and international voyages, Belgian and other waters and unknown conditions. This has already been done in Table 20. The emission rates are calculated according to the formulas given in Table 33. A distinction is to be made for emission rates of sailing and trawling activities and for main and auxiliary engines, as the formulas depend on the effectively used power. This matter has been discussed extensively in paragraph 2.6.2.3.4.

The emissions now can be easily computed for each activity, location and voyage type using following formula:

$$Emission = emission\,rate \cdot time_{activity,location,voyage\ type}$$

Summing the thus obtained emissions for sailing and trawling for main and auxiliary engines, the total values for each vessel are obtained. Quite obviously, summing the individual vessel emissions, the grand total for the whole fleet is found.

The thus obtained results include an estimate of the total emissions along with a spatial distribution thereof. The results of this calculation scheme are presented in Table 37. It should be noted that concerning the spatial distribution, the "unknown" category has been eliminated according to the methodology discussed on the previous page (distinguishing large and small segment vessels).

Table 37: Summary of the total emission estimates and spatial distribution for NO_x, CO and SO_2; vessel movement methodology - emission rates

Pollutant	National voyages		International voyages		Estimated total emission
	Belgian TS + EEZ	Other waters	Belgian TS + EEZ	Other waters	
	[%]	[%]	[%]	[%]	[tonnes]
NO_x	2,73	1,98	26,37	68,92	3625
CO	3,21	2,26	29,01	65,52	722
SO_2	2,89	2,14	27,47	67,50	761

Using this methodology, no regard is given to the engine age in calculating the emissions for NO_x.

2.6.3.2. Emissions Estimates based on the Fuel Consumption Methodology

As has been discussed in paragraph 2.6.1.3, this very simple methodology is used only as a check of the more detailed vessel movement methodology. The basic equation governing this methodology is:

$$Emission = Emission\ factor \cdot Fuel\ Consumption$$

A number of calculation procedures have been proposed to obtain a reliable estimate of the fuel consumption of individual vessels, vessel categories and the entire fleet as has been discussed in detail in paragraph 2.6.2.3. Two sets of emission factors are available for this methodology; these have been summarized in Table 24 and Table 26.

From Table 26, it is clear that for a number of pollutants there is a marked difference between emission factors for medium and high speed diesel engines. These are taken into account by calculating these emissions for each vessel separately and summing the results to get the estimate for the whole fleet. For the other pollutants, calculations are performed using the fuel consumption totals as shown in Table 29.

The results of the emission estimates based on the fuel consumption methodology are summarized in Table 38.

Table 38: Emission estimates based on the fuel consumption methodology

		SMED Emission Factors			EIG Emission Factors		
POLLUTANT	**Unit**	**I**	**II**	**III**	**I**	**II**	**III**
Main Pollutants							
NO_x	[tonnes]	3,796	4,377	4,087	-	-	-
CO	[tonnes]	330	380	355	-	-	-
NMVOC	[tonnes]	60	69	65	147	171	160
SO_x / SO_2 (*)	[tonnes]	247	284	266	247	284	266
NH_3	[kg]	1212	1,398	1,305	-	-	-
Particulate Matter							
PM_{10}	[tonnes]	60	70	65	74	85	80
$PM_{2.5}$	[tonnes]	60	70	65	-	-	-
GHG's							
CO_2	[tonnes]	195,952	225,921	210,956	195,397	225,291	210,359
CH_4	[kg]	1,202	1,386	1,294	3,082	3,554	3,318
N_2O	[tonnes]	9.3	10.8	10.0	4.9	5.7	5.3
Priority Metals							
Cd	[g]	308	355	332	616	711	663
Hg	[g]	3.1	3.6	3.3	-	-	-
Pb	[kg]	9.2	10.6	9.9	6.1	7.1	6.7
Other Metals							
As	[kg]	1.8	2.1	1.9	3.1	3.6	3.3
Cr	[kg]	3.1	3.5	3.2	2.5	2.9	2.7
Cu	[kg]	104	118	110	-	-	-
Ni	[kg]	61	69	65	-	-	-
Se	[g]	3.1	3.5	3.2	-	-	-
Zn	[kg]	61	69	65	31	36	33
POP's							
PCB	[g]	30	35	33	-	-	-
Diox/Fur	[g]	0.31	0.35	0.33	-	-	-
Ben(a)pyr	[g]	302	348	326	-	-	-
Ben(b)flu	[g]	604	696	650	-	-	-
Ben(k)flu	[g]	302	348	326	-	-	-
Indenopyr	[g]	604	696	650	-	-	-

PAH-4	[kg]	1.8	2.1	1.9	-	-	-
HCB	[g]	2.4	2.8	2.5	-	-	-

Remarks: - The SMED and EIG Emission factors are found in Table 26 and Table 24 respectively
- For the calculation of NOx emissions, no distinction is made here between older and newer engine types;
- (*): The values obtained using SMED Emission factors are for SO_x, these for the EIG Emission factors are for SO_2;
- I: Fuel cost fuel consumption methodology;
- II: Fishermen's estimates fuel consumption methodology
- III: Engine characteristics - vessel movement data fuel consumption methodology

2.6.3.3. Comparison of the Results and Estimated Accuracy

In order to get insight in the accuracy of the estimates, it is interesting to compare the results of the calculations. To this means, the estimates of all substances placed next to one another in a series of figures, which are to be found in Appendix D. Furthermore, for a number of pollutants the estimates are compared to results that have been published in the literature [34].

First, some general conclusions are drawn. Subsequently, each pollutant is briefly attended to, resulting in a final estimate of the emissions. Finally, an overall assessment of the accuracy for the estimates is given.

2.6.3.3.1. General Remarks

As is clear from a quick glance at Figures C.1 to C.27, the estimates obtained from the various methodologies discussed in this work are generally in fairly close range of one another.

The most obvious difference in the estimates is caused by the inaccuracy of the emission factors, a factor which is solely influenced by the reliability of the data available from literature studies concerning this matter [7] [9] [16]. In most cases, emissions calculated using EIG emission factors are higher than those obtained from SMED emission factors. For a number of substances however, the opposite is true.

The author has a preference for the estimates based on SMED emission factors, for following reasons:

The publication is of a more recent date, implying that the data set covers both older and more recent engines types;

In the SMED methodology, a distinction is made between high speed and medium speed diesel engines. In the EIG publication, this distinction is not made as high speed and medium speed engines are treated as one category. This approach doesn't fully appreciate the specific differences between the engine types (f.i. concerning fuel consumption, speed dependence of NO_x emissions,…);

In the EIG publication, some default values are given for fishing vessels in case no detailed information were available for the purpose of emission estimates. When comparing this default (average) data with the detailed data which has been obtained for this study, large discrepancies are found. F.i., the EIG publication gives estimates for the main engine power for fishing vessels with a GT ranging from 500 to 5000; smaller vessels are not attended. Belgian small segment fishing vessels have an average GT of 77; for large segment vessels this is still only 292 GT. For the fuel consumption, an average of 5.5 tonnes/day is proposed, whereas for Belgian large segment vessels a more reliable value of 3.9 tonnes/day and for small segment vessels 0.9 tonnes/day is found in this study.

All this leads to the conclusion that the EIG publication is based on emissions data for fishing vessels that are significantly larger than the Belgian vessels.

From all figures, it is clear that the various estimates based on different fuel consumption methodologies are within close range. This has indeed been concluded when these fuel consumption methodologies were discussed in 2.6.2.3.5.

A final remark is to be made concerning the comparison of the results obtained in this study with results available from VMM [34]. For a number of pollutants, the estimates of both studies are within reasonable range. However, for other substances differ quite considerably, leading to the conclusion that one of the estimates (or both, for that matter) is fundamentally wrong.

2.6.3.4. Comparison of the Estimates for Each Pollutant

In order to obtain a final estimate for the substances, a somewhat more detailed comparison of the results is made for each pollutant. In Table 31, some statistics are given concerning the estimates for the various methodologies:

- The maximum value of the estimates and the methodology for which this is obtained (MAX);
- Idem for the minimum value (MIN);
- The median value (the "middle" number of the set of estimates) (MED);
- The average value (AVG);

Reference is made to the figures (to be found in Appendix D) in which a graphical comparison is presented for the various pollutants.

Table 39: Statistical overview of the estimates for the various methodologies

POLLUTANT	UNIT	FIG	MAX		MIN		MED	AVG
			Value	Method	Value	Method		
Main Pollutants								
NOx	[tonnes]	D.1	4,377	SMED II	3,146	VMM	3782	3699
CO	[tonnes]	D.2	2,622	VMM	330	SMED I	542	1015
NMVOC	[tonnes]	D.3	524	VMM	60	SMED I	113	203
SOX	[tonnes]	D.4	284	SMED II	247	SMED I	263	263
SO2	[tonnes]		761	VM (ER)	241	VMM	266	423
NH3	[kg]	D.5	1,398	SMED II	976	VM	1141	1141
Particulate Matter								
PM10	[tonnes]	D.6	802	VMM	60	SMED I	72	253
PM2.5	[tonnes]	D.7	70	SMED II	60	SMED I	65	65
Greenhouse Gases								
CO2	[tonnes]	D.8	225,921	SMED II	192,200	VMM	210,646	206,452
CH4	[kg]	D.9	14,000	VMM	1,202	SMED I	2,310	4,979
N20	[tonnes]	D.10	10.8	SMED II	2	VMM	8	7
Priority Metals								
Cd	[g]	D.11	711	EIG II	308	SMED I	335	443
Hg	[g]	D.12	3.6	SMED II	3.1	SMED I	3.3	3.3
Pb	[kg]	D.13	10.6	SMED II	4	VMM	8	7
Other Metals								
As	[kg]	D.14	3.6	EIG II	1.8	SMED I	2	2.4
Cr	[kg]	D.15	3.6	SMED II	2.5	EIG I	3.3	3.1
Cu	[kg]	D.16	120	SMED II	104	SMED I	113	113
Ni	[kg]	D.17	71	SMED II	61	SMED I	66	66
Se	[g]	D.18	3.6	SMED II	3.1	SMED I	3.4	3.4
Zn	[kg]	D.19	70	SMED II	31	EIG I	65	55
Persistent Organic Pollutants								
PCB	[g]	D.20	35	SMED II	30.2	SMED I	33	33
Diox/Fur	[g]	D.21	0.35	SMED II	0.31	SMED I	0.33	0.33
Ben(a)pyr	[g]	D.22	349	SMED II	302	SMED I	326	326
Ben(b)flu	[g]	D.23	696	SMED II	604	SMED I	651	651
Ben(k)flu	[g]	D.24	349	SMED II	302	SMED I	326	326
Indenopyr	[g]	D.25	696	SMED II	604	SMED I	651	651
PAH-4	[kg]	D.26	2.06	SMED II	1.79	SMED I	1.96	1.96
HCB	[g]	D.27	2.8	SMED II	2.4	SMED I	2.6	2.6

Remarks: - The abbreviated nomenclature for the methodologies is explained in Appendix D;
- For the calculation of the median value, for the EIG and SMED methodologies, only the average value of the three fuel consumption methodologies is used.

For **NO_x**, the estimates from the calculations in this work and those obtained from VMM [34] are relatively close to one another: for the latter, 3146 tonnes is found, whereas own calculations range from 3625 to 4,377 tonnes. The most reliable estimate seems to be that obtained from the vessel movement methodology, in casu 3938 tonnes, as this is the only methodology for which the engine age is taken into account. It is 4.1 % higher than the median value, and 25.2 higher than the VMM-estimate.

For **CO**, the most reliable estimate is that obtained by the vessel movement methodology: 362 tonnes. It is in good agreement with the other own calculations, except for the calculation based on vessel movement characteristics using EIG emission rates data, which is just about 100 % higher. The reason for this is suspected to be that the EIG emission rates are based on a set of larger fishing vessels than for SMED factors. The results from VMM [34] are 7.2 times higher than the proposed value. Given the fact that all own calculations are within close range (except for the vessel movement methodology based on emission rates), it is suspected that the VMM-values are systematically too high.

The estimates for **NMVOC** differ quite considerably: the maximum value from own calculations is 171 tonnes, the minimum 60 tonnes. VMM-calculations [34] are again of another order of magnitude, summing to 524 tonnes. As explained, preference is given to SMED-factors. The best estimate seems to be based on the fuel consumption methodology with engine characteristics, resulting in 65 tonnes.

For **SO_x**, all values are very close to one another. Both the vessel movement methodology and the fuel consumption method result in about 260 tonnes. This value is chosen as a final result. Comparing these values to the results for SO_2 (which is not fully justifiable) leads to the conclusion that all other methods, including the VMM-values [34] are more or less accurate. The only exception is the vessel movement method based on emission rates, which comes as no surprise as these rates are based on data for larger vessels.

The estimates for **NH_3** are quite consistent. The value obtained from the vessel movement methodology is about 23 % lower that the value obtained from the fuel consumption methodology. As a final value, 1275 kg is adopted.

For **PM_{10}**, all own calculations are consistent. A final value of 65 tonnes is chosen, as calculated from the vessel movement methodology. The VMM-values [34] are more than 10 times as high, putting question marks to both own and VMM-results.It should be noted that in the relevant literature, emission factors for PM range spectacularly as well. It is obvious that this leads to significant discrepancies between emission studies. For **$PM_{2.5}$** the conclusions are similar, and a value of 65 tonnes is also chosen.

The values for **CO_2** are in good agreement of one another. The maximum value differs some 10 % of the minimum value. As a final value, 211 kilotonnes is adopted, as obtained from the fuel consumption methodology. The results from the VMM-publication [34] are in good agreement as well, differing about 9.5 % of the proposed value.

The results for **CH_4** are less consistent. The EIG-values are about double those from SMED-data. VMM-values are of a complete order of magnitude, being more than 10 times as high as the estimates obtained from SMED emission factors. As a final value, the author proposes 1303 kg, the value obtained from the vessel moment methodology.

For **N_2O**, the values differ quite considerably: SMED-based calculations sum to about 10 tonnes, whereas EIG-estimates and VMM-values are about 5 tonnes and 2 tonnes, respectively. As a final value, the estimate obtained from the fuel consumption methodology, based on engine specifications is proposed, namely 10 tonnes.

For cadmium (**Cd**), SMED and EIG values differ about 200 %. For reasons explained above (see 2.6.3.3.1), SMED values are regarded as more dependable. The value obtained from the vessel movement methodology is chosen: 335 g.

The estimates for mercury (**Hg**) are consistent, which is quite normal given the fact that only SMED emission factors are used. As a final value, 3.3 g is proposed, as obtained from the fuel consumption methodology with engine specifications.

The estimates for lead (**Pb**) differ significantly from one another. SMED-calculations lead to an estimated value of about 10 kg, whereas EIG emission factors lead to about 6 kg. The results obtained from the VMM-publication are 4 kg. As a final value, 9.8 kg is proposed, as obtained from the vessel movement methodology.

For arsenicum (**As**), chromium (**Cr**) and zinc (**Zn**) results based on SMED and EIG emission factors differ rather considerably. The SMED factors are regarded as more dependable. As final values, 2 kg is proposed for As, 3.3 kg for Cr and 65 kg for Zn, all based on the vessel movement methodology.

The estimates for the other metals; copper (**Cu**), nickel (**Ni**) and selenium (**Se**); are calculated only based on SMED-factors. The proposed values are based on fuel consumption estimates obtained using engine specifications: 110 kg for Cu, 65 kg for Ni and 3.2 g for Se.

Estimates for persistent organic compounds are based exclusively on SMED emission factors. As a consequence, the several values are within close range. For the final values of these substances, the fuel consumption methodology using engine characteristics is used. The final values are:

- PCB: 33 g
- Diox/Fur: 0.33 g
- Ben(a)pyr: 326 g
- Ben(b)flu: 650 g
- Ben(k)flu: 326 g
- Indenopyr: 650 g

- PAH-4: 1.9 kg
- HCB: 2.5 g

2.6.3.4.1. Accuracy

It is clear that the accuracy of the calculations depends to a large extent on the accuracy of the emission factors. As this information is gathered in the literature, the author has no impact on this factor. Other factors of influence comprise the accuracy of the fuel consumption data and the accuracy of the vessel movement data. These shall be discussed here.

2.6.3.4.2. FUEL CONSUMPTION DATA

From paragraph 2.6.2.3.5, it is concluded that the mean value of the fuel consumption is in very good agreement with the calculation results based on the vessel movement – engine characteristics methodology. The other estimation methods differ 9.3 % and 6.9 % of this value. Therefore, the default error on fuel consumption is taken as 10 %, which is to be regarded as a safe estimate.

2.6.3.4.3. VESSEL MOVEMENT DATA

The vessel movement data, which is summarized in Appendix B, may be regarded as relatively accurate. The time of departure and arrival is considered to be free of errors.

The duration of sailing and trawling is somewhat more erroneous, as the number of trawls and the average duration of these is estimated by the fishermen. Given the fact that they have a professional experience, the error may be considered rather small.

The distinction between national and international sailing is very straightforward; no errors can occur on this matter. The distinction between emissions in Belgian and other waters is made on a rather pragmatic base, as explained in paragraph 2.6.2.1. The problem is that the fishing sectors and the Belgian maritime zones don't coincide. As a consequence, the trawling activities attributed to Belgian waters are somewhat inaccurate. The sailing activities in Belgian waters are based on estimated distances sailed in these waters and generic speeds the vessels sail at.

The spatial distribution is somewhat inaccurate, though the results may be regarded as a firm guideline. In terms of percentages of emissions in the various zones (see Table 28), it may be stated that the error is about 0.5 %.

2.6.3.4.4. TOTAL ACCURACY

Combined with the uncertainty factors from Table 26 for SMED emission factors, the total uncertainty for the emission totals for the various substances is found. This is summarized in Table 32.

Table 40: Total accuracy of the emission estimates

Substance	uncertainty [%]	Substance	uncertainty [%]
NO_x	15 – 20	Cr	> 60
CO	20 – 30	Cu	> 60
NMVOC	20 – 30	Ni	30 – 60
SO_x	30 – 60	Se	> 60
NH_3	30 – 60	Zn	25 – 55
CO_2	15 – 20	PCB	> 60
CH_4	30 – 60	Diox/Fur	> 60
N_2O	30 – 60	Ben(a)pyr	30 – 60
PM_{10}	> 60	Ben(b)flu	30 – 60
$PM_{2.5}$	> 60	Ben(k)flu	30 – 60
Cd	> 60	Indenopyr	30 – 60
Hg	> 60	PAH-4	30 – 60
Pb	> 60	HCB	> 60
As	> 60		

For the spatial distribution, each segment (national vs international and Belgian vs other waters) is estimated to be correct within 0.5 %.

2.6.3.5. Final Values

In this short section, an overview of the final estimated values for the various pollutants is shown. Apart from the total emissions, the spatial disaggregated values are also given. This is done in Table 33.

Table 41: Total emission estimates and spatial distribution, final results

Substance	Unit	Total value	Belgian TS + EEZ National voyages	Belgian TS + EEZ International voyages	Other waters National voyages	Other waters International voyages
Main Pollutants						
NO_x	[tonnes]	3938	111	80	1075	2672
CO	[tonnes]	362	10	8	99	244
NMVOC	[tonnes]	65	1.9	1.4	18	43
SO_x	[tonnes]	260	8	5	71	176
SO_2	[tonnes]	260	8	5	71	176
NH_3	[kg]	1275	37	27	350	861
Particulate Matter						
PM_{10}	[tonnes]	65	1.9	1.4	17.9	43.9
$PM_{2.5}$	[tonnes]	65	1.9	1.4	17.9	43.9
Greenhouse Gases						
CO_2	[ktonnes]	211	6.1	4.4	58.0	142.5
CH_4	[kg]	1303	38	27	358	880
N_2O	[tonnes]	10	0.3	0.2	2.7	6.8
Priority Metals						
Cd	[g]	335	9.7	7.0	92.1	226.2
Hg	[g]	3.3	0.1	0.1	0.9	2.2
Pb	[kg]	9.8	0.3	0.2	2.7	6.6
Other Metals						
As	[kg]	2	0.06	0.04	0.55	1.35
Cr	[kg]	3.3	0.1	0.07	0.91	2.23
Cu	[kg]	110	3.2	2.3	30.2	74.3
Ni	[kg]	65	1.9	1.4	17.9	43.9
Se	[g]	3	0.1	0.1	0.9	2.2
Zn	[kg]	65	1.9	1.4	17.9	43.9
Persistent Organic Pollutants						
PCB	[g]	33	1.0	0.7	9.1	22.3
Diox/Fur	[g]	0.33	0.01	0.01	0.09	0.22
Ben(a)pyr	[g]	326	9.5	6.8	89.6	220.1
Ben(b)flu	[g]	650	19	14	179	439
Ben(k)flu	[g]	326	9.5	6.8	89.6	220.1
Indenopyr	[g]	650	19	14	179	439
PAH-4	[kg]	1.9	0.06	0.04	0.52	1.28
HCB	[g]	2.5	0.07	0.05	0.69	1.69

2.6.3.6. Comparison to Other Sources

In this section, the emissions for the Belgian fishing fleet will be compared to emissions from other shipping activities in the Belgian maritime zones (including harbour emissions). Comparisons shall only be made for CO_2, NO_x and SO_2, which have been estimated in [19] for the Belgian part of the North Sea. In table 42, the emission of SO_x is used for fishing vessels, whereas the values for SO_2 are used for other vessels. This is not fully correct, though due to the fact that sulphur-based emissions by the fishing vessels are insignificant, this has only minor implications to get a general idea of the relative importance. The values given in Table 42 are total estimated emissions of the vessel classes, both at sea and during harbour operations (except for fishing, for which harbour emissions have not been estimated).

Table 42: Total emissions from ships in the Belgian part of the North Sea per aerial gas and per vessel class [tonnes/year]; **[19] (ENTEC calculations)**

Ship type	CO_2	SO_2	NO_x
Oil Tanker	98.431	1.671	1.693
Chemical Tanker + Refined	109.888	1.870	2.270
Gas Tanker	77.436	1.172	0.709
RoRo Cargo	500.615	8.511	10.752
Passenger Ship	5.767	0.097	0.103
Ropax	226.936	3.307	3.961
Container	431.410	7.321	10.823
Reefer	65.560	1.111	1.577
General Cargo	136.206	2.304	2.981
Dry Bulk Carrier	72.441	1.231	1.838
Other Dry Cargo	5.742	0.098	0.083
Towing / Pushing	44.260	0.710	0.673
Dredger	44.251	0.752	0.755
LNG	19.434	0	0
Fishing Vessel	10.500	0.013	0.191
TOTAL	**1,848.877**	**30.168**	**38.409**

The relative importance of the emissions of the Belgian fishing vessels in Belgian waters is very limited: for CO_2, the fishing fleets adds to the total emission by 0.57 %. For SO_2, this is 0.04 % and for NO_x this is 0.50 %. For SO_2, the fishing vessels are completely insignificant, as the fuel (marine gas oil) contains far less sulphur than other marine bunker fuels. For NO_x, the importance is somewhat less in comparison with CO_2, which can be explained by the fact that the engines of the fishing vessels operate at higher revolution speeds, which correspond to lower emissions of NO_x.

Concluding, it can be stated that the Belgian fishing fleet is a minor polluter.

2.6.4. Recommendations for Future Estimates of the Belgian Fishing Fleet's Emissions

Based on experiences gained by performing this study, some useful recommendations are given in this section for possible future estimates of the emissions of the Belgian fishing fleet.

Given the fact that the emissions of the Belgian fishing fleet are rather insignificant compared to other sources (in casu other shipping activities), the accuracy of the method is of less importance; the time used for calculating these emissions is equally or even more important.

In Table 43, an overview of the information required to perform an emission estimate of the Belgian fishing fleet is given for each methodology used in this study. In addition, reference is made to where this information can be found. Following abbreviations are utilised:

VM: Vessel movement methodology;

FC I: Fuel consumption methodology based on fuel costs;

FC II: Fuel consumption methodology based on fishermen's estimates;

FC III: Fuel consumption methodology based on vessel movement data and engine characteristics.

Table 43: Required information for the emission estimation methodologies

Method	Required data	Source
VM	**Vessel movement data (individual vessel)**	
	Time of arrival and departure	[3]
	Habour of arrival and departure	[3]
	Number and duration of trawls	[3]
	Location of trawling activities	[3]
	Engine characteristics (M.E.& A.E.) (individual vessel)	
	Maximum power (P_{max})	[12]
	Number of revolutions at P_{max}	[18]
	Engine age	[12]
	Operational characteristics (per vessel class)	
	% of P_{max} used during sailing and trawling	Table 26
	% of time A.E. is used during sailing and trawling	2.6.2.3.4
	Emission factors in g/kWh or kg/hour	[7], [16]
FC I	Number of vessels in each vessel class	[3], [27]
	Average number of days at sea per vessel class	[3], [27], Table 17, Table 23
	Fuel consumption per d.a.s.	[27], Table 30
	Emission factors in g/tonne	[7], [16]

(Continued from table 35)

FC II	Days at sea per individual vessel Main engine maximum power Emission factors in g/tonne	[3] [12] [7], [16]
FC III	**Same data as Vessel Movement methodology (supra)** **In addition** Engine age for each individual vessel Specific fuel consumption for engine classes, distinguishing sailing and trawling for the various vessel types (by equipment) **Emission factors in g/tonne**	 [12] Table 26 Table 27 [7], [16]

In Table 44, the advantages and disadvantages of each methodology are summarized.

Table 44: Summary of the advantages and disadvantages of the various methodologies applied in this study

Method	Advantages	Disadvantages
VM	• Possibility to obtain a spatial distribution • High accuracy • Takes into account the specific equipment of each vessel • Takes into account the evolution of fleet composition	• A lot of data needed • Data not quickly accessible • Complicated calculation scheme • Time-consuming calculations
FC I	• Few data needed • Data is quickly accessible • Simple methodology • Straightforward calculation • Calculation time is very limited • Fairly accurate	• Doesn't take into account the detailed evolution of the composition of the fleet (new engines, other equipment,…) • No spatial distribution can be obtained
FC II	• Data is quite easily obtained • Simple methodology • Very straightforward calculation • Calculation time is fairly short • Fairly accurate • Takes into account the evolution of the fleet composition	• Moderate amount of data required • No spatial distribution can be obtained
FC III	• Same comments as vessel movement methodology • This method is in fact even more time consuming calculations due to a unnecessary detour around the fuel consumption	

From this discussion, it is clear that the fuel consumption methodology based on fuel costs is the most appropriate method for future estimates of the emissions of the Belgian fishing fleet. It combines accuracy and speed of calculation. Moreover, the data needed to perform the estimates is readily available from official bodies.

The fuel consumption methodology based on fishermen's estimates is an option too, provided information about the number of days at sea for each vessel is available. It is somewhat more time-consuming, with no significant benefits in accuracy.

The two methods above have the disadvantage of not being capable of giving an answer to the question where the pollutants are emitted into the atmosphere. The much more demanding vessel movement methodology, both in terms of information required and computing time, provides an answer to this problem. It is however recommended to use a methodology based on fuel consumption, assigning emissions to the appropriate zones in according to the results of Table 28. These values are valid for 2005, but it may be expected that the fishing activities in years to come will be quite similar to this reference year.

The final method, the fuel consumption method based on vessel movement data and engine specifications, is strongly advised against. It is too complicated, uses too much data and takes too much computing time.

In addition to this, a few general remarks are made:

For some substances, especially SO_x, it is recommended to obtain accurate data on the quality of the fuel. The sulphur content in marine fuels can show quite significant differences for various suppliers or fuel grades. Under directive 2005/33/EC [51], from 2008 on a sulphur limit of 0.1 % by mass shall be applied to a number of marine gas oils;

It is advised to use the most recent emission factors available, hereby of course critically investigating to which extend these factors may be applied to the Belgian fishing fleet. The average size of the vessels and the main engines are important characteristics in this context;

Finally, a very simple methodology is proposed, which can be used for an extremely quick estimate of the evolution of the emissions of the fleet. Based on emission estimates calculated in this work (given in Table 33), the estimates for another year are made using the total installed power of the fleet as a conversion factor. This leads to following equation:

$$Polluant_{future} = Polluant_{2005} \cdot \frac{kW_{total\ fleet,future}}{kW_{total\ fleet,2005}}$$

Though scientifically ill-founded, the results shall be reasonably accurate. The methodology however doesn't take into account the actual composition of the fleet (average tonnage, equipment), nor evolutions in engine specifications (engine speed, fuel consumption). Improvements in fuel quality are also ignored.

2.7. General Conclusion

In 2.32.2, an overview of the international emission reporting requirements for Belgium has been outlined, explaining why this study is performed.

2.4.3 has presented a definition of air pollution and a short description of the substances which are estimated in this study.

In 2.5, the Belgian fishing fleet has been discussed. It's evolution is examined and several reasons are cited as to why the number of vessels has diminished during the last decennia. Ecological, legal and economic reasons were given. The current composition of the Belgian is examined, giving attention to the vessel types, the age of the vessels and the manufacturers of the engines. Finally, the Belgian fleet has been compared to the European fishing fleet, showing that Belgian vessels represent a small fraction in number of vessels, but with relatively high average engine power.

In 2.6, the emission calculations are performed. A discussion of some general methodologies for emission estimation is given, after which a detailed discussion of the methodologies used in this work is presented. The vessel movement methodology resulted in a reasonably accurate estimate, with the advantage of presenting a spatial distribution of the emissions, distinguishing national and international voyages. The fuel consumption methodology is executed for three estimated fuel uses, viz based on fuel costs, fishermen's estimates and vessel movement data, combined with engine specifications. All methods are reasonably accurate, the fuel costs methodology being preferable for future use as it has the shortest calculation time. The final results of the estimates along with their spatial distribution is given in Table 33. The emissions of the Belgian fishing fleet in Belgian waters have been compared to other shipping activities, showing that its relative importance is very limited.

2.8. CONTACTS

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2.10. APPENDICES

This fishery report also holds a number of additional appendices. These are not presented in this annex, except for their title, for specific reasons. The fact is that to become the current results, the author (Floris Goerlandt) interviewed a number of fishermen and he also had access to information that is considered 'confidential' to certain people and the fishermen in specific. For this reason the appendices, which contain this sensitive information are not incorporated. You can always contact the author in case you would be interested in this information.

Appendix A: Official list of the Belgian fishing vessels

Appendix B: Vessel movement data for all Belgian fishing vessels, 2005

Appendix C: Survey Form Belgian Fishing Fleet

Appendix D: Comparison of the Emission Estimates

(available upon request)