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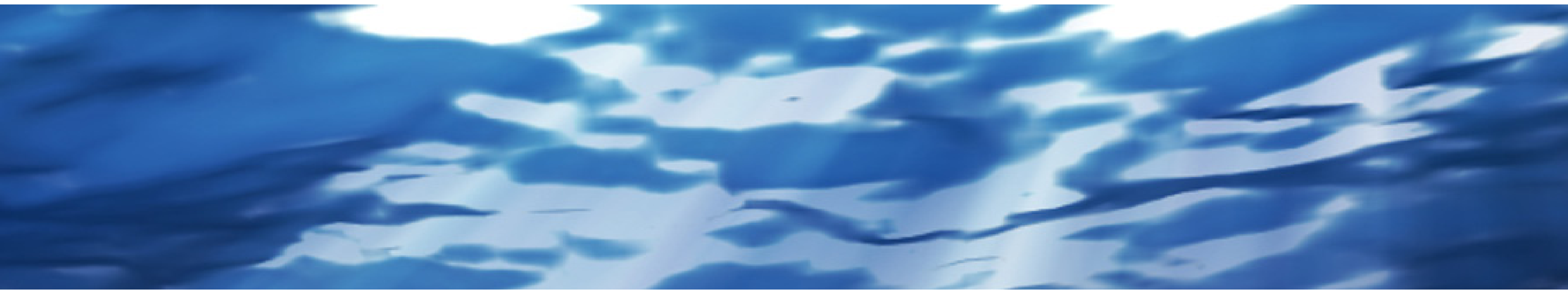
SWEDISH MARITIME COMPETENCE CENTRE



LIGHTHOUSE REPORTS

Transport work and emissions in MRV; methods and potential use of data

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A feasibility study initiated by Lighthouse

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Transport work and emissions in MRV; methods and potential use of data

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Preface

EU has decided on a system for Monitoring, Reporting and Verifying emissions of carbon dioxide from ships in Europe starting in 2018. This means that ship-owners will have to develop systems for the mandatory reporting and also that there will be a potential data source for assessing emissions and fuel consumption for ships. This report is the outcome of a pre-study within the Lighthouse cooperation performed during 2017. It is a collaboration between IVL Swedish Environmental Research Institute and Chalmers with valuable input from Swedish Orient Line and Stena Line. The work has been done as a desktop study, through interviews with stake-holders, and also included a workshop with discussions on MRV.

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Summary

EU has decided on a system for Monitoring, Reporting and Verifying (MRV) emissions of carbon dioxide from ships in Europe starting 1st of January 2018. This means both that ship-owners will have to develop systems for reporting and that there will be a potential data source for assessing emissions and fuel consumption for ships. The MRV system is expected to result in reduced fuel consumption and will open up for future policy measures to reduce the emissions.

This report demonstrates the methods for preparing the data for reporting, looks at uncertainties and drawbacks and discusses the potential use of the data. The MRV will require monitoring of fuel consumption, CO_2-emissions, cargo and other parameters for all voyages to or from EU ports. Yearly average data will be made publicly available on individual ship basis. The fuel consumption can be monitored in four different ways: bunker delivery notes, fuel tank monitoring, fuel flow measurements or direct monitoring of CO_2 emission. The way cargo is calculated varies between ship types. Actual mass of cargo is most common but also unit weight (e.g. for TEU and lane-meter) multiplied by occupancy can be used in some cases. Estimating fuel consumption from bunker delivery notes, or calculating cargo from number of units, are believed to give significant uncertainties in the results for emissions of CO_2 per transport work (g CO_2/tonne-NM).

Drawbacks identified with MRV, in addition to these uncertainties, are that other green-house gases, such as methane, not are included, and that upstream emissions, from fuel production and fuel transportation, also are excluded. Further, the reporting procedures for biogenic CO_2 are still unclear.

However, when large amounts of data are made public in the summer of 2019 there will be an opportunity to improve benchmarking and emission calculations, especially related to transport work, which is important for increasing accuracy of emission inventory studies and cost-benefits studies of shipping. It is also suggested that the uncertainties in the calculation process and data collection should be studied further.

Sammanfattning

EU har beslutat om ett system för övervakning, rapportering och verifiering (MRV) av utsläpp av koldioxid från fartyg i Europa från och med 2018. Detta innebär att redare kommer att behöva utveckla system för rapportering och att det kommer att finnas en potentiell datakälla för att kunna uppskatta utsläpp och bränsleförbrukning för fartyg. MRV beräknas minska bränsleförbrukningen inom sjöfartssektorn och ge möjlighet att införa styrmedel för att minska CO_2-emissionerna i framtiden.

Denna rapport diskuterar metoderna för att beräkna de data som rapporteras, bedömer osäkerheter och nackdelar, och diskuterar den potentiella användningen av data. MRV kommer att kräva rapportering av bränsleförbrukning, CO_2-utsläpp, last och andra parametrar för alla resor till eller från hamnar inom EU. Årliga genomsnittliga uppgifter kommer att offentliggöras på nivån enskilda fartyg. Bränsleförbrukningen kan mätas på fyra olika sätt: bunkerinköp, bränsletankmätning, flödesmätningar eller direkta emissionsmätningar. Hur last beräknas varierar mellan fartygstyper. Faktisk vikt används på flest fartygstyper, men också enhetsvikt (t.ex. TEU och lane-meter) multiplicerat med beläggning används i vissa fall.

I vår studie visar vi att både enhetsvikt-metoden och bunkerinköps-metoden ger osäkerheter i resultaten för utsläpp av CO_2 per transportarbete (g CO_2/ton-NM). Nackdelar som identifieras med MRV i tillägg till dessa osäkerheter är att andra växthusgaser, såsom metan, inte ingår, och att uppströms-utsläpp från produktion och transport av bränsle också är undantagna.

När stora mängder data blir tillgängliga sommaren 2019 ger det emellertid en möjlighet att förbättra benchmarking och utsläppsberäkningar, särskilt med anknytning till transportarbete. Det föreslås också att osäkerheterna i beräkningsprocessen och datainsamlingen bör studeras ytterligare.

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1. Background to the MRV legislation

The European Parliament passed the MRV legislation in April 2015 to monitor, report and verify carbon dioxide emissions from ships. The purpose was to make sure all sectors of the economy, including the international maritime shipping sector, achieved emission reductions. Since no reduction targets were set through the International Maritime Organization (IMO) and no agreement through the United Nations Framework Convention on Climate Change was reached, the MRV legislation was expected to enter into force. At the time of the adoption, international maritime shipping was the only means of transportation not included in the European Union's commitment to reduce greenhouse gas emissions (EU regulation 2015/757).

The EU has set a binding target of reducing domestic greenhouse gas emissions by at least 40% until 2030 compared to 1990 levels. In July 2011, the IMO adopted technical and operational measures, in particular the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP). However, these initiatives will not lead to the necessary absolute reductions of greenhouse gas emissions from international shipping needed to keep efforts in line with the global objective of limiting increases in global temperatures to 2°C. According to data from the IMO, the specific energy consumption and CO_2 emission of the international shipping industry can be decreased with up to 75% by applying existing knowledge on operation or installing best available existing technology.

In order to include international shipping in its efforts to reduce CO_2 emissions, the EU has concluded that efforts beyond what IMO implies are necessary. As a three step process starting with the MRV, the EU suggests greenhouse gas reduction targets for the maritime transport sector, and further measures, including market-based measures, in the medium to long term for reductions of climate gases from ships. According to the EU, the emissions data reported will be public and this will contribute to removing market barriers that prevent the uptake of many cost-effective measures which would reduce greenhouse gas emissions from maritime transport (EU regulation 2015/757).

1.1 General description of the MRV legislation

The EU MRV regulation entered into force on July 1, 2015 and requires ship-owners and operators to annually monitor, report and verify carbon dioxide (CO_2) emissions from ships arriving at, within or departing from ports in the European Union and EEA states; that is EU member states, Iceland and Norway[1]. All internal European

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[1] Territories which are not considered EU territories, and thus non-EU ports, are Greenland and the Faroe Islands, French Polynesia, Mayotte, New Caledonia, Saint-Barthélemy, Saint Pierre and Miquelon, Wallis and Futuna, Aruba, Bonaire, Saba, Sint Eustatius, Curaçao, Sint Maarten, Anguilla, Bermuda, British Antarctic Territory, British Indian Ocean Territory, British Virgin Islands, Cayman Islands, Falkland Islands, Bailiwick of Guernsey, Isle of Man, Jersey, Montserrat, Pitcairn, Henderson, Ducie and Oeno Islands, Saint Helena, Ascension and Tristan da Cunha, South Georgia and the South Sandwich Islands, Turks and Caico Islands, Akrotiri and Dhekelia (DNVGL, 2017).

Union voyages, all incoming voyages from the last non-EU port to the first EU port of call, and all outgoing voyages from a EU port to the next non-EU port of call, including ballast voyages, should be included in the reporting of data. Stops only for bunkering or for ship-to-ship transfer outside ports are not considered to be stops in Port of Call and are excluded from the MRV scheme. CO_2 emissions in EU ports, including emissions arising from ships at berth or moving within a port, are also covered. The MRV regulation applies to all ships regardless of flag. However, dredging vessels, ice-breaking vessels, pipe laying or offshore installation activity vessels are not included. Vessels also exempted from the regulation are warships, naval auxiliaries, fish-catching or fish-processing ships, wooden ships of a primitive build, ships not propelled by mechanical means or government ships used for non-commercial purposes (EU regulation 2015/757).

In order to minimise the administrative burden for ship-owners and operators, and to optimise the cost-benefit ratio of the MRV system, the EU decided that the MRV should only apply to ships above 5 000 gross tonnage (GT) as they account for about 90% of the emissions in the EU (EU regulation 2015/757).

Shipping companies can select one of four monitoring methods for the reporting on fuel consumption:

- bunker delivery notes
- bunker fuel tank monitoring on-board
- flow meters for applicable combustion processes
- direct emission measurements.

The shipping company needs to establish a monitoring plan for each ship, in which the choice made is documented. The plan should also provide further details on the application of the selected method (see monitoring plan below) (EU regulation 2015/757).

It is allowed to include information regarding a ship's ice class and the navigation through ice in order to ensure that ship operations in cold climates are considered accurately (EU regulation 2015/757).

There are also four delegated regulations amending EU regulation 2015/757: Shipping emissions monitoring methods (2016/2071), Shipping emissions cargo carried (2016/1928), Shipping emissions template (2016/1927) and Shipping emissions verification and accreditation (2016/2072).

Shipping companies are to submit ship-specific monitoring plans to verifiers for approval on August 31st 2017 at the latest. Data collection will start on a per-voyage basis from 1 January 2018. Shipping companies and operators will then need to report to an accredited MRV shipping verifier; data on each ship’s CO_2 emission, fuel consumption and other parameters, such as distance, time spent at sea and cargo carried, so as to determine the ships' average energy efficiency. Starting in 2019, by April 30 of each year, shipping companies or operators need to submit a verified Emissions report for each of the ships concerned to the Commission through THETIS MRV (a dedicated European Union information system currently under development by the European Maritime Safety Agency). Aggregated ship emission and efficiency data will be published by the European Commission by 30 June 2019 and then every consecutive year (DG Clima, 2017).

1.2 Non-compliance and inspection

According to the MRV legislation, EU member states should inspect ships which enter ports under their jurisdiction. According to the regulation, non-compliance with the provisions of the MRV should result in the application of penalties and EU member states should lay down rules on those penalties. According to the regulation, the penalties should be effective, proportionate and dissuasive (EU regulation 2015/757).

1.3 Monitoring plan

All shipping companies should develop a monitoring plan for each ship, though some parts of the monitoring plan can be the same for a company with several vessels, for instance procedures for monitoring fuel. The monitoring plan is a plan consisting of complete and transparent documentation of the monitoring of fuel consumption and CO_2 emissions. A template has been included in the Commission Implementing Regulation (EU) 2016/1927. The monitoring plan had to be sent to an accredited MRV shipping verifier for verification before 31st of August 2017 (EU regulation 2016/1927).

The monitoring plan should include the following information:

A. information about the company and ship, emission sources and types of fuels used on-board and procedures and systems used to update the completeness of emission sources;
B. activity data such as monitoring of fuel consumption, procedures for recording, retrieving, transmitting and storing information, distance travelled, amount of cargo carried and/or number of passengers and time spent at sea, transport work and fuel efficiency;
C. methods to deal with gaps in data on fuel consumption, distance travelled, cargo carried, or time spent at sea;
D. management of regular controls of the adequacy of the monitoring plan or different control activities (EU regulation 2016/1927).

For each voyage, the following should be monitored; fuel consumption (at sea and at berth), time at sea, distance, cargo, transport work and fuel efficiency. The emission sources considered are; main engines, auxiliary engines, boilers, gas turbines, and inert gas generators but not incinerators.

1.4 Verification

Verification by accredited verifiers are meant to ensure that monitoring plans and emission reports are correct and in compliance with the requirements set out in the MRV Regulation. In the legislation it says that “in order to ensure impartiality, verifiers should be independent and competent legal entities and should be accredited by national accreditation bodies established pursuant to EU regulation 765/2008" (EU regulation 2015/757).

The verifier should check

- that all mandatory items are included (described in Annex I in EU regulation 2016/1927)
- that the monitoring plan describes the emission sources
- any measurement equipment installed on-board the ship
- the systems and procedures in place to monitor and report relevant information (in accordance with EU regulation 2015/757).

The verifier should also ensure that adequate monitoring arrangements are provided for, in the event of the ship seeking to benefit from the derogation of 'per voyage' monitoring of fuel and CO_2 emissions (in accordance with Article 9(2) in EU regulation 2015/757). This means that the ship either only operates within the jurisdiction of a particular member state during the reporting period or performs more than 300 voyages during the reporting period.

The verifier should also assess whether the submitted information is part of the ship's existing management systems or covered by harmonized relevant quality, environmental or management standards for monitoring CO_2 emissions and other relevant information and reporting (in accordance with EU Regulation 2015/757 and Commission Implementing EU Regulation 2016/1928 (7)) (EU regulation 2016/2072).

The shipping company owning a ship calling at an EU port, must from June 30 2019 and onwards, carry on-board a document of compliance issued by THETIS MRV, following the approval of an accredited MRV shipping verifier. This document will probably be subject to inspections by Member States' authorities (DG Clima, 2017).

2. Monitoring of fuel consumption

As mentioned there are four different ways to monitor a ship's fuel consumption, as described below;

2.1 Bunker Delivery Note, Method A

When the bunker is delivered at the receiving ship, the bunker delivery note (BDN) should be signed by both parties' representatives. The document is the record of how much bunker is delivered and the information it should contain at the minimum is; date and time, suppliers name, fuel type, temperature, density, viscosity, and quantity in metric tonnes (Bracken 2000). The BDN is the most important document in the bunker purchasing process; it is mandatory and regulated by IMO (Fuel oil availability and quality – Regulation 18). The stated quantity on the BDN combined with periodic stock takes of fuel tanks on-board can give an estimation of the fuel consumption of the ship. Measurements of fuel consumption between two port calls stated "at sea" could be performed as stock takes by manual sounding/ullage at the point of start and the ending point of what is considered as "at sea". Fuel consumption "in port" is the total amount of fuel used from the time the ship arrives and is "finished with engine" at its first berth in the port and up to the time the ship leaves the last berth of the port. Stock takes by sounding/ullage at these two points can state the fuel consumption "in port". To state the volume consumed with the BDN method, there is a need for an accurate ullage/sounding conversion tables, from which one can assess the volume corresponding to the distance measured. When using ullage/sounding tables one have to keep in mind correction values of possible offset in trim. The ullage/sounding table gives the volume-figures to a standard temperature, and the figures must be corrected to match the actual temperature of the fuel, since the volume changes with temperature (Bracken, 2000).

The accuracy of BDN data varies depending on how the fuel quantity stated on the BDN is determined. BDNs have an accuracy level of 1 to 5% (Bunkerspot, 2009), suggested by ship crew members to often report on more fuel being delivered than stated in the BDN. According to Cardiff University (2013), it is common with disputes over the quality and quantity of fuel between bunker providers and ship operators.

2.2 Bunker fuel tank monitoring, Method B

Measuring the fuel tank levels can be done in several ways: electronic, mechanical and manual (Faber et al., 2013).

In electronic sounding, a sensor is used which senses the pressure inside the sounding pipe or the tank pressure and sends a signal to the receiver. The signal is translated to the tank's content value. The value is displayed using electrically operated servo gauge or electrical capacitance gauge.

Mechanical sounding is made inside the tank and the level can directly be read through a marker, an indicator or a float level sensor. In the tank, a float can be attached to a pointer through a pulley. As the level varies, pointer readings will change accordingly. A level gauge glass is also attached to the tank to read the quantity of the fluid inside the tank. The gauge may also be a pneumatic/hydraulic operated gauge or differential pressure gauge.

With manual sounding, a sounding tape is used with a heavy weight bob attached to one end of the tape using a strap hook. It is the most commonly used method used for calculation of tank capacity. (Delft, 2013)

The accuracy of tank monitoring is estimated at 2-5% (Saniship). Fuel tank levels are commonly measured on-board ships. In modern ships, tank soundings are normally taken using built-in automatic systems, such as pitot tubes (which measure pressure) or radar tank level indication systems, both of which transmit readings to the engine control room. These devices need to be regularly calibrated to ensure accuracy (CE Delft, 2009). The accuracy of tank monitoring is very sensitive and depends on the means by, and conditions under, which they are carried out.

Many small ships still rely on the traditional (manual) bunkering measurement. Look-up tables and a density measurement are used in conjunction with the 'dip' to calculate the total 'mass' of the bunker fuel delivered. There are many factors that contribute to errors in this calculation, such as the strike plate location, the dip tape, accuracy of tables, tank straps, and human error. Furthermore, large ships may have a large number of fuel tanks, with different quantities and grades of fuel. The accuracy of tank monitoring may be limited by trim, heeling, etc. Manual sounding may be very inaccurate at sea if the ship is moving (IMO/IMarEST, 2012). Another way in which inaccuracy may occur is due to the fact that the tank monitoring devices need to be regularly calibrated to ensure accuracy (calibration dates should be recorded), and this may currently not always be done as there are no regulations for this (CE Delft, 2009).

Discrepancies may exist between the tank volume determined and the actual volume consumed. Differences may exist e.g. due to sludge and water removed from the fuel (fuel treatment on-board). This may lead to a tendency to over-estimate fuel usage (IMO/IMarEST, 2012). In order to derive the emissions on the basis of the fuel consumption monitored, information on the fuel quality is necessary too. This information is available when the tank monitoring approach is applied, since fuel density information is necessary to correctly determine the volume of fuel that is left in the tanks. (Faber et al., 2013)

2.3 Flow meters, Method C

The fuel consumption of a ship can further be determined by means of flow meters. These meters allow for determining the amount of fuel that is flowing through – pipes to engines and boilers. The fuel flow is often measured directly (by volume, velocity or mass) or indirectly (inferential) by pressure. In order to capture all the fuel oil that is used on-board, all outward flows of all storage tanks on-board would need to be monitored.

Different types of flow meters used for fuel consumption monitoring are; electronic flow meters, velocity sensing flow meters, inferential flow meters, optical flow meters, positive displacement flow meters and mass sensing flow meters.

Electronic fuel flow meters are meters that are fitted to the main engine fuel supply and monitor fuel consumption continuously. The values recorded by the flow meters are calculated and form the basis for all other functions in the system (CE Delft, 2009).

Velocity sensing flow meters are measuring the flow rate of the fuel based on the velocity. Examples of these meters are turbine flow meters and ultrasonic meters. Turbine flow meters are common in bigger ships. Turbine flow meters measure rotational speed of a turbine in the pipe, which can be converted to volumetric flow. In many cases, fuel flow to the settling tank or day tank is measured rather than net flow to the engine which requires two flow meters (supply and return flow). Ultrasonic meters measure flow velocity from observations on a sonic wave passed through the flowing fluid that exploit either a Doppler effect or time-of-flight principle.

Inferential flow meters do not sense flow rate through the direct measurement of a flow variable (such as volume, velocity or mass) but estimate flow by inferring its value from other parameters (differential pressure, variable area) They measure differential pressure within a constriction, or by measuring static and stagnation pressures to derive the dynamic pressure (University of Exeter, 2008a).

Optical flow meters use light to determine flow rate. Small particles which accompany natural and industrial gases pass through two laser beams focused a short distance apart in the flow path. By measuring the time interval between pulses, the gas velocity is calculated.

Positive displacement flow meters measure flow-rate based on volumetric displacement of fluid. They remain accurate at small fractions of rated capacity, but have relatively high head-losses; therefore they are generally suited to higher flow-rates. Mechanical parts of the meter are exposed to the fuel. If these are prone to wear or failure, such an event could potentially cause obstructed fuel flow. For this reason, the fuel meter should be installed with a by-pass leg. Examples of positive displacement flow meters include; oval gear flow meters, reciprocating piston flow meters, and nutating discs (wobble meters).

Mass flow meters are meters that measure the mass flow rate, which is the mass of the fluid travelling past a fixed point per unit of time. Examples are the Coriolis meter, linear mass meter, thermal mass meter. The Coriolis meter measures the force resulting from the acceleration caused by mass moving toward (or away from) a center of rotation. Since mass flow is measured, the measurement is not affected by fluid density changes. Coriolis mass flow meters can measure flow extremely accurately, they are therefore often used to measure high value products or the introduction of fluids that affect the production of high value products. (Delft, 2013)

The accuracy of different flow meters are summarised in Table 1 on the next page.

Table 1. Typical accuracy of flow meters.

Type flow meter	**Subcategory**	**Quoted accuracy (%)**
Positive displacement	Oval gear, rotary piston	0.1-0.2%
Inferential flow meter	Variable aperture	3.0%
Velocity sensing	Turbine meter	NA
Mass sensing flow meter	Coriolis meter	0.05%-0.2%

2.4 Direct emission measurements, Method D

Under the previously discussed monitoring approaches, the mass of a ship's fuel consumption is monitored and converted by calculations into emissions. With direct emission monitoring, CO_2 emissions are instead directly measured at the exhaust gas stacks.

The standard Continuous Emissions Monitoring Systems system consists of a sample probe, filter, sample line, gas conditioning system, calibration gas system, and a series of gas analysers which reflect the parameters being monitored. Typical monitored emissions include: sulphur dioxide (SO_2), nitrogen oxides (NO_X), carbon dioxide (CO_2), diluent gases (CO_2 or oxygen O_2), flue gas velocity and opacity (EPA, 1994). Direct monitoring thus permits the combining of CO_2 measurement with the measurement of other air pollutants. (Faber et al., 2013)

There is little information on the accuracy of direct emissions monitoring systems on-board ships. According to the Center for Tankship Excellence (2011), CO_2 stack emissions can be monitored to an accuracy of +/-2%.

2.5 CO_2 emission factors

The emission of CO_2 is calculated from the fuel consumption using emission factors established by the IMO (see Table 2).

Table 2. CO_2 emission factors.

Type of fuel	**Emission factor (kg CO_2/ kg fuel)**
Heavy fuel oil	3.114
Light fuel oil	3.151
Diesel/gas oil	3.206
Liquefied petroleum gas (propane)	3.000
Liquefied petroleum gas (butane)	3.030
Liquefied natural gas	2.750
Methanol	1.375
Ethanol	1.913

For other fuels, the emission factors should be established from a lab analysis. It can be noted that there is no information about emission factors for biofuel. Further, the emission factors do not take into consideration upstream emissions (from fuel production or transportation of fuel). Also, other green-house gases, such as methane and nitrous oxide, are not considered.

3. Transported cargo

How to calculate the transported cargo varies between different ship types. The cargo carried is defined in regulation 2016/1923.

- For **Oil tankers** as the mass of cargo on-board. Should be in line with EEOI definition in MEPC1./Circ684 where it says “metric tonnes of the cargo carried”.
- For **Chemical tankers** as the mass of cargo on-board. Should be in line with EEOI definition in MEPC1./Circ684 where it says “metric tonnes of the cargo carried”.
- For **LNG carriers** as the volume of cargo on discharge. Should reflect industry practices.
- For **Gas carriers** as the mass of cargo on-board. Should be in line with EEOI definition in MEPC1./Circ684 where it says “metric tonnes of the cargo carried”.
- For **Bulk carriers** as the mass of cargo on-board. Should be in line with EEOI definition in MEPC1./Circ684 where it says “metric tonnes of the cargo carried”.
- For **General cargo ships** as deadweight carried for laden voyages and as zero for ballast voyages. Mass can be used on a voluntary basis as an additional parameter.
- For **Refrigerated cargo ships** as the mass of cargo on-board. Should be in line with EEOI definition in MEPC1./Circ684 where it says “metric tonnes of the cargo carried”.
- For **Vehicle carriers** as the mass of the cargo on-board, determined as the actual mass or as the number of cargo units or occupied lane meters multiplied by default values for their weight. Deadweight carried for laden voyages and as zero for ballast voyages can be used on a voluntary basis as an additional parameter.
- For **Combination carriers** as the mass of cargo on-board. Should be in line with EEOI definition in MEPC1./Circ684 where it says “metric tonnes of the cargo carried”.
- For **RoPax ships** as the number of passengers and the mass of cargo on-board determined as the actual mass or the number of cargo units (trucks, cars, etc.) or occupied lane meters multiplied by default values for their weight.
- For **Container/ro-ro cargo ships**, as the volume of the cargo on-board, determined as the sum of the number of cargo units (cars, trailers, trucks and other standard units) multiplied by a default area and by the height of the deck (the distance between the floor and the structural beam), of the number of occupied lane-metres multiplied by the height of the deck (for other ro-ro cargo) and of the number of TEUs multiplied by 38,3 m^3.

- For **Passenger ships** 2016/1923 refers to the definition in 2009/16/EU as number of passengers.
- For **RoRo ships** 2016/1923 refers to the definition in 2009/16/EU as the actual mass or as number of cargo units (trucks, cars, etc.) or lane-metres multiplied by default values for their weight.
- For **Container ships** 2016/1923 refers to the definition in 2009/16/EU as the total weight in metric tonnes of the cargo or, failing that, the amount of 20-foot equivalent units (TEU) multiplied by default values for their weight. Where cargo carried by a container ship is defined in accordance with applicable IMO Guidelines or instruments pursuant to the Convention for the Safety of Life at Sea (SOLAS Convention), that definition shall be deemed to comply with this Regulation.
- For **Other ship types** as mass of cargo on-board or as deadweight carried for laden voyages and zero for ballast voyages.

Deadweight carried (in metric tonnes) is the volume displacement multiplied with the water density, with the mass of fuel and lightweight subtracted. The default values for cargo units and lane meters have to be representative for the trade in which the vessel is intended to trade and have to be accepted by the verifier. The values should be based on, e.g. past performance.

4. Reported data

For each ship, annual data for the voyages included in the reporting obligations are reported. This comprises:

- Amount of fuel consumed in total, and emissions factor for each type of fuel used.
- Aggregated emissions from all reportable voyages (domestic / outbound / inbound / total).
- Emissions within ports at berth
- Total distance travelled
- Total time spent at sea
- Total transport work
- Fuel consumption per distance = total annual fuel consumption/total distance travelled
- Fuel consumption per transport work= total annual fuel consumption/total transport work
- CO_2 emissions per distance = total annual CO_2 emissions/total distance travelled
- CO_2 emissions per transport work= total annual CO_2 emissions/total transport work

The regulations state that the data should be reported to EMSA in the THETIS system and should be publicly available (non-anonymised) on individual ship basis (EU 2017/1927).

It can also be mentioned that the IMO is developing a system for measuring CO_2 emissions from shipping worldwide. The IMO system will however not cover the carried cargo; neither will data for individual ships be public.

5. Calculation examples

In order to illustrate the calculations of efficiency in the MRV system, data were collected for existing ships. Two examples are used to illustrate the methods used in the MRV system. A special focus is placed on the issue of how to allocate the emissions between passengers and freight for RoPax vessels.

The calculation sheet can be found in Appendix 2. It contains all the steps necessary for obtaining the data required in MRV for one trip.

5.1 MRV monitoring requirements

As mentioned above, parameters to be calculated for each trip, according to the MRV regulation are:

- Fuel consumption per distance
- Fuel consumption per transport work
- CO_2 emission per distance
- CO_2 emission per transport work

The calculation of the indicators listed above is carried out by applying the following steps:

1. Data for the total annual consumption of each occurring fuel type is collected.

2. The total CO_2 emission related to the total fuel consumption is calculated. The CO_2 calculation is a straight forward multiplication of the total annual consumption of each fuel type by the CO_2 emission factor (Table 2) for respective fuel type. Specific CO_2 factor should be used if available.

3. For RoPax vessels, data calculated in steps 1 and 2 is allocated between passengers and cargo according to either the weight or the area method as described in annex B of the European Standard EN 16258:2012.

4. The total annual production of transport work is calculated first and for each voyage, by multiplying the amount of transported cargo and passengers by the travelled distance, and then by forming the sum of all voyages during the year. The definition of cargo and which unit of measure to use is stipulated in the regulation text, see chapter 2. For RoPax vessels transport work is calculated separately as passenger (*) nautical miles and freight as tonne (*) nautical miles. The weight of passengers and vehicles/cargo units could either be actual weight or a calculated value based on average weights per passenger and vehicles/cargo units.

5.2 Example 1 – RoRo vessel

This calculation example is based on the operational data for a 12 month period of operation of a RoRo vessel in short sea traffic. A total of 207 voyages were included in the dataset. The parameters in Table 3 were logged for each voyage.

Table 3. Logged vessel operational data set (minimum) for each voyage.

Departure time from berth
Arrival time to berth
Fuel type 1 bunker level when departing 1st port
Fuel type 1 bunker level when arriving at final port
Fuel type n bunker level when departing 1st port
Fuel type n bunker level when arriving at final port
Cargo carried on-board
Distance total (berth – berth)
Fuel type X – consumption during stay at 1st port

The example vessel used HFO for main engines and MGO for auxiliary engines. The fuel consumption was calculated as the difference in bunker readings made in each port. The time spent at sea was calculated likewise.

The results, presented in Table 4, were obtained from the calculations, the numbers to the left corresponds to the section and headline in the MRV reporting template, see Appendix 2.

Table 4. MRV reporting format, selected sections, fuel consumption and CO_2 emitted.

D-1.0 FUEL CONSUMPTION AND CO2 EMITTED		
D-1.1 a) HFO Fuel Type - HFO		YES
D-1.1 a) MDO/MGO Fuel Type - MDO/MGO		YES
D-1.1 b) HFO Emission factor	[tonnes CO2 / tonne fuel]	3.114
D-1.1 b) MDO/MGO Emission factor	[tonnes CO2 / tonne fuel]	3.206
D-1.1 c) HFO Total fuel consumption	[tonnes/year]	9 424
D-1.1 c) MDO/MGO Total fuel consumption	[tonnes/year]	189
D-1.2 Total aggregated CO2 emitted	[tonnes/year]	29 950
D-1.3 Total aggregated CO2 emissions from all voyages which departed from EU-ports	[tonnes/year]	0
D-1.4 Total aggregated CO2 emissions from all voyages TO EU-ports	[tonnes/year]	0
D-1.5 Total aggregated CO2 emissions from all voyages BETWEEN from EU-ports	[tonnes/year]	29 950
D-1.6 CO2 emissions emitted while at berth in EU-ports	[tonnes/year]	372
D-2.1 Total distance travelled	[nm]	109 900
D-2.3 Total TIME spent at sea	[h]	6 639

D-2.5 b) Total transport work e.g. for ro-ro ships, container ships, oil tankers, chemical tankers, gas carriers, bulk carriers, refrigerated cargo carriers, vehicle carriers, combination carriers	[tonne*nm]	555 900 000
D-3.1 a Fuel consumption per distance	[kg/nm]	87
D-3.1 b Fuel consumption per transport work e.g. for ro-ro ships, container ships, oil tankers, chemical tankers, gas carriers, bulk carriers, refrigerated cargo carriers, vehicle carriers, combination carriers	[grams/(tonne*nm)]	17
D-3.1 d CO2 emissions per transport work e.g. for ro-ro ships, container ships, oil tankers, chemical tankers, gas carriers, bulk carriers, refrigerated cargo carriers, vehicle carriers, combination carriers	[gramsCO2/(tonne*nm)]	54

The Total transport work (D-2.5 b) is the sum of the transport work for each voyage, calculated as the gross weight of all cargo multiplied as the distance for each voyage. There was no navigation in ice conditions, why no such data was reported.

5.3 Example 2 – RoPax vessel

Calculation of data for a RoPax vessel to report in the MRV system contains an allocation step. The total annual fuel- and emission data have to be divided between passengers and freight categories. This allocation can be made in several different ways, each yielding large differences in result. In Bäckström (1999) the author demonstrates a difference in result, due to different allocation methods, in the order of a factor 10. The investigation concluded that no scientifically correct method could be established why the conclusion was to suggest to the RoPax industry to select a method and make an agreement on its use together with all concerned parties. Such a process was conducted within the standardisation process leading up to the Annex B, "Allocation methods for ferries (maritime transport)", found in the EN 16258 standard. The standard, however, allows the user to select between two methods why there is need to describe (in the monitoring plan) why the selected method is the best suited. The methods suggested are the MASS method and the AREA method. While the mass method is straight forward, the area method involves an allocation of the area used for vehicle and cargo. The standard states that this secondary allocation can be based on weight of the vehicles. Thus, a total of three combinations of allocation methods can be selected when calculating the data to report to the MRV- system. In order to illustrate how the different methods influence the results, a calculation example based on real annual operational data for a RoPax vessel in European traffic was put together.

Note on allocation: The allocation method selected must be specified in the monitoring plan together with any assumptions made during the calculations. The weight allocation method is the most straight-forward when using measured values. However, passenger and cargo statistics usually do not contain exact data per unit or passenger. Conversion factors must be used in order to assess the total weight. If no trade lane specific values are available, other applicable sets of conversion factors could be used. Table 5, extracted from the EN 16258-standard, illustrates an example of such a compilation. Again, more specific data for the ferry line operating the RoPax vessel should be used if available.

Table 5. Example of cargo units conversion factors for RoPax load calculations.

Default values	**Mass**	**Length**	**Width**
	(kg)	(m)	(m)
Passenger and luggage	80		
Passenger car	1 200	6	3.1
Bus	12 000	12	3.1
Caravan S	800	3	3.1
Caravan M	1 600	6	3.1
Caravan L	2 000	10	3.1
Mobile home	2 800	8	3.1
Motorcycle	160	1.5	3.1
Unaccompanied trailer	6 400	14	3.1
Accompanied/articulated trailer	12 800	17	3.1
Road train Continent	14 800	19	3.1
Road Train Scandinavia	16 000	24.5	3.1
Source: Standard EN 16258:2012, Table B.1 — Default values for mass and lengths			

The area method categorises the available areas on-board the vessel as passenger areas or vehicle areas. All areas not directly designated for, or related to the needs of, passengers or vehicles are omitted, e.g. engine rooms, tanks, bridge etc. Areas identified as passenger related (cabins, restaurants, lobby, shops etc.) are allocated to passengers only. Vehicle related areas have to be split between passengers and cargo. According to the standard EN 16258:2012, this allocation can be done in two ways, either by

i) the weight of passenger and cargo related vehicles or
ii) the area occupied by respective vehicle category

There is no further guidance as to which method to use when, therefore we suggest that results should be calculated by applying both methods and then assessed which method can be considered most justified.

The calculation results to be reported according the MRV regulation are presented in table 6 on next page. All data are based on observed operational data for one calendar year.

Table 6. Calculation results for three different RoPax allocation methods.

		Weight	Area+Area	Area+weight
D-1.1 a) MDO/MGO Fuel Type - MDO/MGO		YES	YES	YES
D-1.1 b) MDO/MGO Emission factor	[tonnes CO2 / tonne fuel]	3.206	3.206	3.206
D-1.1 c) MDO/MGO Total fuel consumption	[tonnes / year]	14 910	14 910	14 910
D-1.2 Total aggregated CO2 emitted	[tonnes / year]	47 810	47 810	47 810
D-1.5 Total aggregated CO2 emissions from all voyages BETWEEN from EU-ports	[tonnes / year]	47 810	47 810	47 810
D-1.6 CO2 emissions emitted while at berth in EU-ports	[tonnes / year]	5 976	5 976	5 976
D-2.1 Total distance travelled	[nm]	87 600	87 600	87 600
D-2.3 Total TIME spent at sea	[h]	4 775	4 775	4 775
D-2.5 e) Total transport work Ro-Pax	[pass*nm]	53 030 000	53 030 000	53 030 000
D-2.5 e) Total transport work Ro-Pax	[tonne*nm]	214 900 000	214 900 000	214 900 000
D-3.1 a Fuel consumption per distance	[kg/nm]	169	169	169
D-3.1 b Fuel consumption per transport work Ro-Pax	[grams / (pass*nm)]	34	194	159
D-3.1 b Fuel consumption per transport work Ro-Pax	[grams / (tonne*nm)]	61	22	30
D-3.1 d CO2 emissions per transport work Ro-Pax	[grams CO2 /(pass*nm)]	110	620	509
D-3.1 d CO2 emissions per transport work Ro-Pax	[grams CO2 /(tonne*nm)]	196	69	97
D-3.4 Additional information to facilitate the understanding of the reported average operational energy efficiency indicators of the ship (voluntary)		Allocation: EN 16258 WEIGHT, operational data	Allocation: EN 16258 AREA, (vehicle deck by occupied area) operational data	Allocation: EN 16258 AREA, (vehicle deck by loaded mass) operational data

The “Area+Area”- variant allocation was carried out according to EN 16258 using alternative B.3 "AREA method" as base for allocation. Passenger deck area entirely allocated to passengers. Vehicle deck area allocated between passenger and freight in proportion to total annual area occupation of vehicle deck.

The “Area+Weight”-variant allocation was carried out according to EN 16258 using alternative B.3 "AREA method" as base for allocation. Passenger deck area entirely allocated to passengers. Vehicle deck area allocated between passenger and freight in proportion to total annual area occupation of vehicle deck.

6. Discussion

The MRV system will produce large amounts of data that can be used in different ways. First of all it should give information of fuel efficiency and CO_2 emissions as averages for different ship types that can be used to asses emissions from the fleet and in analysis of the climate burden for freight and passenger transportation. The data can also be used to compare the performance of individual ships and ship-owners. This opens up for use by transport buyers opting for a transport with low CO_2 emissions. The MRV system will lead to a much-improved situation in these respects, compared with the situation today. For ship-owners, the system gives an opportunity to improve the quality of fuel consumption data and for benchmarking towards other ships. Further, using the MRV system in creating policy instruments on CO_2 emissions from shipping will contribute valuable data and should come with great benefits.

When it comes to the quality of data, it is important to realise the limitations and how different choices, e.g. for fuel monitoring, influence these limitations. In Appendix 3 we present an analysis of the uncertainties that can be expected in the data on CO_2 efficiency using estimations on uncertainties in the used and monitored parameters. As can be seen, the 95% confidence interval found in this analysis is from around 3% to 15% of the mean. The uncertainties are expected to be especially large when fuel tank monitoring or bunker delivery notes are used. Further, it can be seen that, using the uncertainties in the ingoing parameters as described, the use of unit weights can be expected to lead to large uncertainties. This means that caution should be taken when comparing individual ships and it should be made sure that the differences between ships are significant. However, when using average data for a large number of ships, the uncertainty will be much lower.

A special case is RoPax ships where, as described above, the chosen method of allocation of the emissions will have large consequences on the resulting fuel efficiency and CO_2 efficiency data. As predicted, the results presented indicate a large impact from choice of allocation method on the calculation result. Since the choice is to burden either passengers or cargo, the method most benign to the market situation is likely to be chosen. Again, whichever method chosen, a justification must be supplied in the MRV-plan. We suggest that a calculation is made for each of the three methods and that these results are presented as information in the MRV plan.

Calculations based on default values for passenger and vehicle/cargo unit weights and dimensions are sensitive to variations and uncertainties in such values. the resulting sensitivity is greatest for the most abundant units why we suggest that more situation/trade lane specific values are used for categories contributing to more than 20% of the total allocation base. In our example, this would demand real data for passenger cars, articulated trucks and unaccompanied semi-trailers.

One deficit in the system is that it does not take into account other green-house gases. This will be especially important for LNG, where a significant slip of methane have been reported. Further, no upstream emissions are considered. This will be significant when new energy carriers are used, e.g. alcohols produced from natural gas. It is also unclear how bio-fuels will be treated. In EU 2015/757 it is stated that appropriate factors determined by a laboratory should be used for biofuels and alternative fuels. One can expect that the result will be that fossil CO_2 is counted but not biogenic CO_2. However, this is not clear at the moment and neither is how the production of biofuels will be accounted for.

Table 7 shows an example of how other GHGs and upstream emission can add to the GHG emissions using data from Brynolf et al. (2014). The exact data will depend on the place of production; raw material used etc. but Table 7 gives a good indication using typical data. As can be seen, considering other GHGs has little effect for CO_{2eq} for traditional fuel oil (1%) but is significant for LNG (32%). Including WtT data gives increases in the CO_{2eq} emissions of 11% for HFO, 17% for LNG and 30% for methanol.

Table 7. GHG emissions using different fuels from Brynolf et al. (2014). TtP = tank to propeller; WtT = well to tank.

Fuel	TtP CO_2 (fossil) (g/MJ)	TtP CO_{2eq}^{+} (g/MJ)	WtT CO_2 (fossil) (g/MJ)	WtT CO_{2eq}^{+} (g/MJ)
HFO	77	78	6.7	8.6
LNG	54	72	8.3	9.2
Methanol (from natural gas)	69	69*	20	20.4
LBG	0	20	27	32
Bio-methanol	0	0*	17	18

*emission factors of CH_4 and N_2O not available for methanol

$^{+}$using factors of 298 for N_2O and 25 for CH_4

8. Outlook

When the data become available from EMSA in the summer of 2019, there are some obvious applications of the average data. For example, Clean Shipping Index (a system for scoring ships' environmental performance) uses reference curves for different ship-types that are obtained from EEDI-reference curves and estimate relationships between typical cargo carried and size of the ship. With MRV data, these reference curves can be much improved. Further, for calculating emissions from transport chains, where data on the exact ship are used and/or the ship's cargo volume, much improved assumptions can be made with the MRV data. This will make calculations of "carbon footprint" for different commodities much more certain.

The data for individual ships and ship-owners can be used in procurement but also for benchmarking the performance of the ships and the crew. Further, ships with abnormally high fuel consumption can be identified.

Given the uncertainties in the data, and the difficulty in assessing the uncertainty itself, it would be valuable with a deeper analysis of the data. This could mean a study where the parameter values used in the calculations are carefully considered and measured; an improved uncertainty analysis can then be made. Further measures to improve the data quality should be suggested.

The regulation also states that "In the event that an international agreement on a global monitoring, reporting and verification system for greenhouse gas emissions (...) is reached, the Commission shall review this Regulation and shall, if appropriate, propose amendments to this Regulation in order to ensure alignment with that international agreement". The IMO has adopted a data collection system and therefore the EC has initiated a public consultation[2] on the possibility of an alignment between MRV and the IMO system. A decision about the future of MRV is expected during 2018. The main differences between MRV and the IMO system is that the latter does not take actual cargo into account, rather the capacity of the ship, and that the data is not expected to be publicly available on individual ship basis.

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[2] https://ec.europa.eu/clima/consultations/articles/0032_en

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Appendix 1 Workshop

A workshop with 18 people was organized on June 16 2017 at IVL. The agenda was as follows:

- Presentation 9:00-9:15
- Introduction to MRV 9:15-9:45
- How to measure fuel consumption? 9:45-10:15
- Examples of calculation of emissions per transport work 10:15-10:45
- Group discussions on the following questions: 10:45-11:40
    - How to look at upstream emissions and other green-house gases
    - Fuel measurement methods
    - Definition of goods
    - How to treat missing/bad data
    - Use of MRV data in research and as benchmarking
    - Is there a need for support on MRV in the maritime sector
- Common round up 11:40-12:00
- Finish 12:00

The groups discussed the following questions:

- How to look at upstream emissions and other green-house gases?
- Fuel measurement methods
- Definition of goods
- How to treat missing/bad data
- Use of MRV data in research and as benchmarking
- Is there a need for support on MRV in the maritime sector?

Appendix 2 Template

A			Data identifying the ship and the company			[unit]	VESSEL SPECIFIC DATA
A	1	1			Vessel name		
A	1	2			IMO nr.		
A	1	3			port of registry/home port		
A	1	4			Vessel category		
A	1	5			ice class (if included in MP)		
A	1	6	a		EEDI	[g/CO2/tonne*nm]	
A	1	6	b		EIV	[g/CO2/tonne*nm]	
A	1	7			Name of ship owner		
A	1	8	1		adress of ship owner - address line		
A	1	8	2		adress of ship owner - city, state/province/region, postal code/ZIP, Country		
A	1	9			name of the company (ship operator, if not the owner)		
A	1	10	1		adress of the company - address line		
A	1	10	2		adress of ship owner - city, state/province/region, postal code/ZIP, Country		
A	1	11	a		Contact person name (title, first name surname, job title)		
A	1	11	b		Contact person adress		
A	1	11	c		contact person telephone		
A	1	11	d		contact person e-mail		
B			**Verification**				
B	1	1			Name of verifier		
B	1	2	1		adress of the verifyer - address line		
B	1	2	2		adress of ship verifyer - city, state/province/region, postal code/ZIP, Country		
B	1	3			Accreditation number		
B	1	4			Verifier's statement		
C			**Information on the monitoring method used and the related level of uncertainty**				
C	1	1	**A**		Emission source - All sources		
C	1	1	**B**		Emission source - Main engines		
C	1	1	**C**		Emission source - Auxiliary engines		
C	1	1	**D**		Emission source - Gas Turbines		
C	1	1	**E**		Emission source - Boilers		
C	1	1	**F**		Emission source - Inert gas generators		
C	1	2	**A**		Monitoring method(s) used (A-D)		
C	1	2	**B**		Monitoring method(s) used (A-D)		
C	1	2	**C**		Monitoring method(s) used (A-D)		
C	1	2	**D**		Monitoring method(s) used (A-D)		
C	1	2	**E**		Monitoring method(s) used (A-D)		
C	1	2	**F**		Monitoring method(s) used (A-D)		
C	1	3	**A**		Related level of uncertainty, expressed as % (per monitoring method used)		
C	1	3	**B**		Related level of uncertainty, expressed as % (per monitoring method used)		
C	1	3	**C**		Related level of uncertainty, expressed as % (per monitoring method used)		
C	1	3	**D**		Related level of uncertainty, expressed as % (per monitoring method used)		
C	1	3	**E**		Related level of uncertainty, expressed as % (per monitoring method used)		
C	1	3	**F**		Related level of uncertainty, expressed as % (per monitoring method used)		
D			**Results from annual monitoring of the parameters in accordance with Article 10**				
D	1	0		FUEL CONSUMPTION AND CO2 EMITTED			
D	1	1	**a)**	HFO	Fuel Type - HFO		
D	1	1	**a)**	LFO	Fuel Type - LFO		
D	1	1	**a)**	MDO/MGO	Fuel Type - MDO/MGO		
D	1	1	**a)**	LPG Propane	Fuel Type - LPG Propane		
D	1	1	**a)**	LPG Butane	Fuel Type - LPG Butane		
D	1	1	**a)**	LNG	Fuel Type - LNG		
D	1	1	**a)**	Methanol	Fuel Type - Methanol		
D	1	1	**a)**	Ethanol	Fuel Type - Ethanol		
D	1	1	**a)**	Other fuel	Fuel Type - Other fuel		
D	1	1	**b)**	HFO	Emission factor	[tonnes CO2 / tonne fuel]	
D	1	1	**b)**	LFO	Emission factor	[tonnes CO2 / tonne fuel]	
D	1	1	**b)**	MDO/MGO	Emission factor	[tonnes CO2 / tonne fuel]	
D	1	1	**b)**	LPG Propane	Emission factor	[tonnes CO2 / tonne fuel]	
D	1	1	**b)**	LPG Butane	Emission factor	[tonnes CO2 / tonne fuel]	
D	1	1	**b)**	LNG	Emission factor	[tonnes CO2 / tonne fuel]	
D	1	1	**b)**	Methanol	Emission factor	[tonnes CO2 / tonne fuel]	
D	1	1	**b)**	Ethanol	Emission factor	[tonnes CO2 / tonne fuel]	
D	1	1	**b)**	Other fuel	Emission factor	[tonnes CO2 / tonne fuel]	
D	1	1	**c)**	HFO	Total fuel consumption	[tonnes/year]	
D	1	1	**c)**	LFO	Total fuel consumption	[tonnes/year]	
D	1	1	**c)**	MDO/MGO	Total fuel consumption	[tonnes/year]	
D	1	1	**c)**	LPG Propane	Total fuel consumption	[tonnes/year]	
D	1	1	**c)**	LPG Butane	Total fuel consumption	[tonnes/year]	
D	1	1	**c)**	LNG	Total fuel consumption	[tonnes/year]	
D	1	1	**c)**	Methanol	Total fuel consumption	[tonnes/year]	
D	1	1	**c)**	Ethanol	Total fuel consumption	[tonnes/year]	
D	1	1	**c)**	Other fuel	Total fuel consumption	[tonnes/year]	
D	1	2			Total aggregated CO2 emitted	[tonnes/year]	
D	1	3			Total aggregated CO2 emissions from all voyages which departed from	[tonnes/year]	
D	1	4			Total aggregated CO2 emissions from all voyages TO EU-ports	[tonnes/year]	
D	1	5			Total aggregated CO2 emissions from all voyages BETWEEN from EU	[tonnes/year]	
D	1	6			CO2 emissions emitted while at berth in EU-ports	[tonnes/year]	
D	1	7	EMISSION		Total CO2 emission assigned to passenger transport (RoPax only)	[tonnes/year]	
D	1	7	FUEL		Total fuel consumption assigned to passenger transport (RoPax only)	[tonnes/year]	
D	1	8	EMISSION		Total CO2 emission assigned to freight transport (RoPax only)	[tonnes/year]	
D	1	8	FUEL		Total fuel consumption assigned to freight transport (RoPax only)	[tonnes/year]	
D	1	9	EMISSION		Total CO2 emission on LADEN voyages (voluntary)	[tonnes/year]	
D	1	9	FUEL		Total fuel consumption on LADEN voyages (voluntary)	[tonnes/year]	
D	1	10	FUEL		Total fuel consumption for CARGO HEATING (for chemical tankers, vo	[tonnes/year]	
D	1	11	FUEL		Total fuel consumption for dynamic positioning (for oil tankers and 'oth	[tonnes/year]	
D	2	0		DISTANCE TRAVELLED TIME SPENT AT SEA AND TRANSPORT WORK			
D	2	1		Total distance travelled		[nm]	
D	2	1		Total distance travelled when navigating through ICE (voluntary)		[nm]	
D	2	3		Total TIME spent at sea		[h]	
D	2	4		Total time spent at sea when navigating through ice (voluntary)			
D	2	5	**a)**	Total transport work	passenger ships	[pass*nm]	
D	2	5	**b)**	Total transport work	e.g. for ro-ro ships, container ships, oil tankers, chemiclal tankers, gas	[tonne*nm]	
D	2	5	**c)**	Total transport work	LNG carrieris, container/ro-ro cargo ships	[m3*nm]	
D	2	5	**d)**	Total transport work	general cargo ships	[DWT*nm]	
D	2	5	**e)**	Total transport work	Ro-Pax	[pass*nm]	
D	2	5	**e)**	Total transport work	Ro-Pax	[tonne*nm]	
D	2	5	**f)**	Total transport work	other ships	[tonne*nm OR DWT*nm]	
D	2	6	**a**	Second parameter for total transport work (voluntary)	for general cargo ships	[tonne*nm]	
				Second parameter for	for vehicle carriers		

D	2	5	**f)**	Total transport work	other ships	[tonne*nm OR DWT*nm]
D	2	6	**a**	Second parameter for total transport work (voluntary)	for general cargo ships	[tonne*nm]
D	2	6	**b**	Second parameter for total transport work (voluntary)	for vehicle carriers	[DWT*nm]
D	2	7		Average density of the cargoes transported in the reporting period (for chemical tankers, bulk carriers and combination carriers, voluntary)		[tonnes/m3]
D	3	0		ENERGY EFFICIENCY		
D	3	1	**a**	Fuel consumption per distance		[kg/nm]
D	3	1	**b**	Fuel consumption per transport work	passenger ships	[grams/(pass*nm)]
D	3	1	**b**	Fuel consumption per transport work	e.g. for ro-ro ships, container ships, oil tankers, chemiclal tankers, ga	[grams/(tonne*nm)]
D	3	1	**b**	Fuel consumption per transport work	LNG carrieris, container/ro-ro cargo ships	[grams/(m3*nm)]
D	3	1	**b**	Fuel consumption per transport work	general cargo ships	[grams/(DWT*nm)]
D	3	1	**b**	Fuel consumption per transport work	Ro-Pax	[grams/(pass*nm)]
D	3	1	**b**	Fuel consumption per transport work	Ro-Pax	[grams/(tonne*nm)]
D	3	1	**b**	Fuel consumption per transport work	other ships	[grams/(tonne*nm) OR grams/(DWT*nm)]
D	3	1	**c**	CO2 emissions per distance		[(kg CO2/nm)]
D	3	1	**d**	CO2 emissions per transport work	passenger ships	[grams CO2/(pass*nm)]
D	3	1	**d**	CO2 emissions per transport work	e.g. for ro-ro ships, container ships, oil tankers, chemiclal tankers, ga	[gramsCO2/(tonne*nm)]
D	3	1	**d**	CO2 emissions per transport work	LNG carrieris, container/ro-ro cargo ships	[grams CO2/(m3*nm)]
D	3	1	**d**	CO2 emissions per transport work	general cargo ships	[grams CO2/(DWT*nm)]
D	3	1	**d**	CO2 emissions per transport work	Ro-Pax	[grams CO2/(pass*nm)]
D	3	1	**d**	CO2 emissions per transport work	Ro-Pax	[grams CO2/(tonne*nm)]
D	3	1	**d**	CO2 emissions per transport work	other ships	[grams CO2/(tonne*nm) OR grams CO2/(DWT*nm)]
D	3	2	**a**	Second parameter for average energy efficiency per transport work (voluntary)	general cargo ships	[grams/(tonne*nm)]
D	3	2	**a**	Second parameter for average energy efficiency per transport work (voluntary)	general cargo ships	[grams CO2/(tonne*nm)]
D	3	2	**b**	Second parameter for average energy efficiency per transport work (voluntary)	vehicle carriers	[grams/(DWT*nm)]
D	3	2	**b**	Second parameter for average energy efficiency per transport work (voluntary)	vehicle carriers	[grams CO2/(DWT*nm)]
D	3	3	**a**	Differentiated average energy efficiency of LADEN voyages (voluntary)	fuel consumption	[kg/nm]
D	3	3	**b**	Differentiated average energy efficiency of LADEN voyages (voluntary)	fuel consumption	[grams/(DWT*nm)] or [grams/(pass*nm)] or [grams/(tonne*nm)] or
D	3	3	**c**	Differentiated average energy efficiency of LADEN voyages (voluntary)	CO2 emitted	[kg CO2/nm]
D	3	3	**d**	Differentiated average energy efficiency of LADEN voyages (voluntary)	CO2 emitted	[(kg CO2/nm)] or [grams CO2/(pass*nm)] or [gramsCO2/(tonne*nm)] or [grams CO2/(m3*nm)]
D	3	4		Additional information to facilitate the understanding of the reported average operational energy efficiency indicators of the ship (voluntary)		

Appendix 3 Uncertainty Analysis

In order to illustrate the uncertainties that can be expected in the energy efficiency parameters reported in THETIS following the MRV regulations, a series of simulations were made. It should be noted that the uncertainties in most of the ingoing parameters are not well known and have been simulated by the project team. However, we believe that this exercise gives an indication of the uncertainties that is valuable to have noted when using the data for different purposes.

The analysis is done for an imaginary ship using made up values for cargo, distances etc. However, the values used should be realistic. In this example we use a container ship with five voyages in the year that fulfill the criteria for being included in the reporting. The focus is on the resulting efficiency for CO_2, i.e. the emitted mass of CO_2 divided by the transport work for the year:

$$EEOI = \sum_i \frac{FC_i EF_i}{l_i d_i}$$

where EEOI is the CO_2 efficiency (g CO_2/tonne-nm), FC_i the fuel consumed for voyage i, EF_i the CO_2 emission factor for the fuel used in voyage i (g CO_2/g fuel), l_i the cargo carried in voyage i (tonne) and d_i the distance of voyage i (nm).

Some of the ingoing parameters can be measured in different ways and we have here done an analysis of these. This applies to the fuel consumption which is assumed to be measured in one of three ways: bunker delivery notes, fuel tank monitoring or with mass flow meters. The distance can be monitored either as real distance travelled (voyage distance from the logbook) or as the most direct route between port of departure and port of arrival with use of conservative correction factor. Finally, the cargo carried can be determined either as the actual mass or the amount of 20-foot equivalent units (TEU) multiplied by default values for their weight. Thus, we end up with in total twelve combinations of methods for fuel consumption, cargo mass and distance.

The five voyages are (arbitrarily) chosen as follows (expectation values for distance and cargo mass): 200 nm, 80 000 tonne; 1000 nm, 71500 tonne; 100 nm, 100000 tonne, 300 nm, 42 000 tonne; 1200 nm, 85 000 tonne.

In Table A1 the ingoing parameters and their uncertainties can be found.

Table A1. Data for uncertainties for different ingoing parameters.

Para-meter	**Unit**	**Uncertainty distribution**	**Moment**	**Value of moment**	**Method**	**Source**
FC	tonne	Normal	Standard deviation	5% of expectation value	Bunker delivery note	Assumption 1-5%
FC	tonne	Normal	Standard deviation	3% of expectation value	Fuel tank monitoring	Assumption 2-5%
FC	tonne	Normal	Standard deviation	0.5% of expectation value	Flow meter	Assumption 0,05-3% (see discussion of flow meters above)
EF	gCO_2/ gfuel	Normal	Standard deviation	2% of expectation value		Analysis of fuel analyses
l	tonne	Normal	Standard deviation	5% of expectation value	Actual mass	Assumption
l	tonne	Triangular	Min, Max	0 and 21.6 tonne/TEU	No of TEU * default weight	After data from port
d	nm	Normal	Standard deviation	3% of expectation value	Real distance travelled	Assumption
d	nm	Normal	Standard deviation	8% of expectation value	Direct route + correction factor	Correction factor is set to 15% (ccwg). Assumption

The resulting CO_2 efficiency is simulated for the twelve cases, using Monte Carlo simulation in order to assess the resulting uncertainties. The assumptions in Table A2 are used as expectation values.

Table A2. Values for different ingoing parameters.

Parameter	Unit	Expectation Value
SFC	g/kWh	200
Speed, s	knots	18
Engine power, P	MW	50
EF	gCO_2/gfuel	3.206
FC	tonne	=SFC*P*d/s
TEU unit weight	tonne	10

The resulting CO_2 efficiency and uncertainties can be found in Table A23 and an example of the distribution in Fig. A21.

In the case average data is used for a number of ships the uncertainty will be much lower. For example if 50 ships of the same type as the one used for the data here send in data in the system the uncertainty in the first line in Table A3 will drop from 5.6 gCO_2/tonne-nm to 0.8.

Table A3. Resulting CO_2 efficiency and uncertainty.

Fuel method	Distance method	Cargo method	EEOI (g CO_2/tonne-nm)	95% confidence (2σ)
Bunker delivery note	Real distance travelled	Actual mass	23.6	3.1
Fuel tank monitoring	Real distance travelled	Actual mass	23.6	2.9
Flow meter	Real distance travelled	Actual mass	23.6	2.8
Bunker delivery note	Direct route + correction factor	Actual mass	23.6	3.2
Fuel tank monitoring	Direct route + correction factor	Actual mass	23.6	2.9
Flow meter	Direct route + correction factor	Actual mass	23.6	2.8
Bunker delivery note	Real distance travelled	No of TEU * default weight	24.1	15.2
Fuel tank monitoring	Real distance travelled	No of TEU * default weight	24.1	15.1
Flow meter	Real distance travelled	No of TEU * default weight	24.1	14.9
Bunker delivery note	Direct route + correction factor	No of TEU * default weight	24.1	15.4
Fuel tank monitoring	Direct route + correction factor	No of TEU * default weight	24.1	15.0
Flow meter	Direct route + correction factor	No of TEU * default weight	24.1	15.1

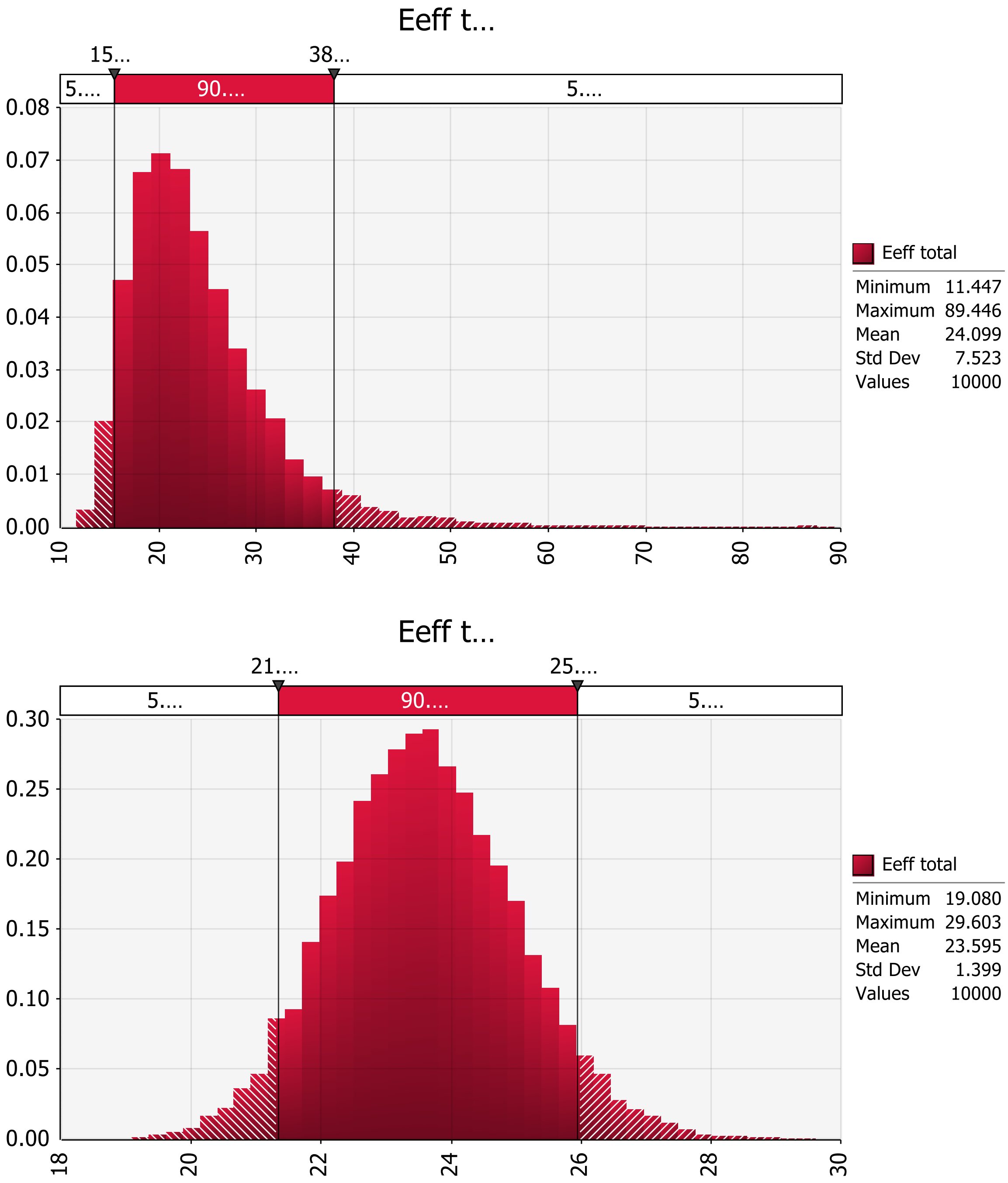

Figure A21. Example of resulting uncertainty distribution for CO_2 efficiency.