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Data Alternatives for Marine Efficiency Monitoring

By
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NHL University of Applied Sciences (MIWB)

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Contents

Data Alternatives for Marine Efficiency Monitoring
Theme: Energy Efficiency and Environmental Matters

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Abstract The implementation of measures to increase the energy efficiency of ships is not so successful as expected. A benchmark is needed to gain insight in the present state of the energy efficiency of ships. That can be used to assess why these measures are less successful as expected and to develop better fitting energy efficiency legislation in the future. Monitoring, Reporting and Verification (MRV) is proposed as benchmark methodology. Ships are required to monitor their fuel consumption and/or carbon emissions on annual basis. MRV is believed to close the knowledge gap of ship specific fuel consumption, the best fitting efficiency technologies for ships, and of split incentives and responsibilities across the total sector. There is a European scheme and a global IMO scheme.

The reasons why shipping lacks to implement energy efficiency seems as well apply for the implementation of MRV. Shipping argues there is a knowledge gap for the implementation of MRV. Secondly, the monitoring results will be published. That information is considered as confidential and too sensitive for third parties. This study tries to find an alternative method which serves both goals: 1. fuel consumption/carbon emissions are still fully monitored and reported because the specific maritime contribution to global warming is important to know; and 2. the direct fuel consumption/emissions are disclosed and the results have been made anonymously to meet the industry. The latter is done by searching for alternative methods, proxies, parameters which deliver information about fuel consumptions emissions, but which do

not directly link to a vessel or present direct information of the fuel consumption. Based on 1. the identification of parameters which are monitored on board presently; 2. making an inventory of methods to calculate fuel consumption and/or CO_2 emissions; and 3. evaluation of which parameters sensitivity and/or anonymizing apply using existing monitored parameters two alternative methods for MRV monitoring seem to meet both objectives.
The method of using on-board monitoring devices is a method which has the potential of qualifying with the objectives of less sensibility and more anonymity. The potential of this method lies in the way that it can determine the efficiency of ships. And efficiency can be shared as function of energy labels which present ranges of efficiencies and thus less sensible data is shared. Emission modelling could also be an alternative. Ship fuel consumption/fuel consumption is monitored via AIS and models. Subsequently, the results are brought to the vessels. The model results are verified by the ships. If the results are in the same order of magnitude, the modelling results will be published and become available to the market. The specific information will be shared confidentially to the relevant authorities.
A list of questions is developed as tool to evaluate the potential of alternative MRV methods. Developers are able to proof with help of the list of questions their method is feasible to use as MRV method. Ship owners might want to develop their own way of monitoring. This list question might close their knowledge gap around MRV.

Keyword: *Monitoring, Reporting and Verification; MRV; Ship Energy Efficiency; MRV methods, Ship Emissions*

Executive Summary

The implementation of measures to increase the energy efficiency of ships is not so successful as expected. A benchmark is needed to gain insight in the present state of the energy efficiency of ships. That can be used to assess why these measures are less successful as expected and to develop better fitting energy efficiency legislation in the future. Monitoring, Reporting and Verification (MRV) is proposed as benchmark methodology. Ships are required to monitor their fuel consumption and/or carbon emissions on annual basis. MRV is believed to close the knowledge gap of ship specific fuel consumption, the best fitting efficiency technologies for ships, and of split incentives and responsibilities across the total sector. The present way of determining ship emissions its accuracy is too small. There is a European scheme and a global IMO scheme.

The reasons why shipping lacks to implement energy efficiency seems as well apply for the implementation of MRV. Shipping argues there is a knowledge gap for the implementation of MRV. Secondly, the monitoring results will be published. That information is considered as confidential and too sensitive for third parties. This study contributes to the discussion of which methodical approaches for MRV could be interesting for the industry to implement. This study raises the premise that values other than direct information about fuel consumption/carbon emissions could be shared too. Such values must present information about the energy performance of a ship without publishing the exact energy performance values. These are proxy values or the results of monitoring methods with different approaches. There is less impediment in relation with anonymity, because the market has merely a direction of the fuel consumption of the vessels. Ships of course still need to share their data with the designated authorities. Though, ship data are treated with care.

The research is arranged in three steps:

1. Identifying parameters which are required for energy consumption and emissions on board presently. A theoretical fuel consumption can be calculated by using the energy related parameters in energy and mass balances following from diesel engine theory. One or more parameters could serve as proxy which presents information about the fuel consumption of a vessel – without presenting the direct fuel consumption.
2. Making an inventory of methods to calculate fuel consumption and/or CO_2 emissions. A second way of tackling the problem is to find another method for determining the fuel consumption/carbon emissions and which meets the objections from the industry.
3. Evaluating to which parameters sensitivity and/or anonymizing apply to develop an alternative methodology for energy efficiency monitoring by using for example proxies for problematic parameters.

Parallel a literature study has been performed to the basic requirements of a successful monitoring, reporting and verification implementation. This list of questions is developed as tool to evaluate the potential of alternative MRV methods. Developers are able to proof with help of the list of questions their method is feasible to use as MRV method. Ship owners might want to develop their own way of monitoring. This list question might close their knowledge gap around MRV.

The potential as alternative method has been assessed by combining the presently monitored parameters and the method inventory. The possible best usable method is found by assessing:

1. if the relevant parameters already are monitored/available on board for the reviewed methods,
2. ranking of methods by scoring for its feasibility (already monitored/available), costs, accuracy, implementation. Methods with a low feasibility are considered less suitable to be used as a method
3. the outcome of each method in relation with research objectives.

A thermo-dynamical analysis of the on-board energy flows is an approach which includes proxies. This analysis makes use of parameters which are already being monitored. The latter is important, because the use of existing infrastructure keeps low the extra workload coming forth from MRV. A proxy in the thermo-dynamical analysis is the energy uptake by other mediums such as cooling water, lubrication and exhaust gasses and other heat losses. Such a method could be useful, but more values are required. The presently monitored parameters are insufficient. Important lacking parameters are mass flows of the various mediums.

Secondly this study looked at different approaches as monitoring method which also not present the direct fuel consumption information. The review and method assessment resulted in two useful methodical approaches: the use of on-board measurement equipment and the use of off-ship modelling (CARB and STEAM 2). The method of using on-board monitoring devices is a method which has the potential of qualifying with the objectives of less sensibility and more anonymity. The potential of this method lies in the way and what is being monitored. Ships can monitor other additional relevant energy processes or proxies like efficiency by using measuring and monitoring equipment. Efficiency does not directly show information about direct fuel consumption. And thus by for example monitoring the mass flows of the relevant medium so that the thermo-dynamical method can be used. An important remark concerning the use of efficiency is that the original measures of EEDI and EEIO were focussing on efficiency. MRV has been proposed to force the industry to have a look at its efficiency. It should be kept in mind that by using efficiency the discussion has arrived at its starting point. One could consider the introduction of energy labels for ships to overcome this issue. An energy label shows in which range of efficiencies a particular ship operates. The vessel itself submits its direct information to the relevant authorities for complying with the regulations. This ensures the knowledge of the fuel consumption at the legislative level and enhances the idea of energy efficient ships in the market. The methods need to be assessed to what is further needed in the application of the methods.

Emission modelling could also be an alternative. This seems to be strange while on of the rationales of the introduction of MRV is that modelling is not specific enough about ship emissions. However, modelling with the aid of AIS – as in STEAM 2 – is very suitable to use as verification method, analogue to air traffic control in the aviation MRV scheme. To overcome the problems by the industry, the approach could be the other way around. Ship fuel consumption/fuel consumption is monitored via AIS and models. Subsequently, the results are brought to the vessels. The model results are verified by the ships. If the results are in the same order of magnitude, the modelling results will be published and available to the market. The specific information will be shared confidentially to the relevant authorities.

An additional outcome of the study is the list of topics and questions which should be asked when considering the development of an MRV scheme and the introduction of a monitoring method. Such a list was not yet available in the maritime context. There is a knowledge gap about the implications of MRV on board and what a proper way of MRV on board could be. These questions could be handful to the industry to the required actions for implementation of MRV. It also helps in the development of MRV methods, because the methods for MRV are not legally prescribed.

The list of questions is a first set up, as are the discussed methods. More work is needed to complete this list. At the same time more work is needed to validate the (still) conceptual proposed methods to make these more mature to be eventually used on board.

1. Introduction

1.1 Maritime environmental impact

Maritime transport is one of the sources for global warming and environmental pollution. The environmental impact of shipping is expressed is various ways: atmospheric emissions as result of the combustion of fossil fuel [1] emissions to water like cargo slops and sewage, ecological impact by the use of ballast water and by fouling [2], noise caused by the propeller [3] and other underwater activities, the spill of oil and other pollutants, and an impact on the spatial use of a sea area [4]. Shipping accounts for approximately 2.8% of global greenhouse gas (GHG, including CO_2, CH_4, and N_2O) emissions in 2012. Shipping is responsible for 15% and 13% of global NO_X and SO_X emissions respectively in 2012 (numbers from [5]). Various measures and methods are proposed to reduce the environmental impact of shipping; like slow steaming [3,6] the use of alternative fuels like hydrogen or LNG [7] or technical and design optimizations [8,9]. Ballast water needs to be cleaned and treated [10].

1.2 Implementation of environmental policies

Poulsen & Johnson [11] argue that effective energy management is incompatible with established business practises through the maritime community and shipping industry in special. An energy efficiency gap is recognized in maritime business [12,13] which is defined as the existence of barriers in the adaptation of efficiency improving measures. Barriers are defined as a "postulated mechanism that inhibits investment in technologies that are both energy-efficient and (apparently) energy efficient" [14], as cited by [12]. Examples of hampering barriers are: lack of reliable information about the reduction potential of efficiency measures, lack or a perceived lack of technical information, costs issues and split financial incentives, organizational structures, inconsistent legislation [11,12,13,15,16].

Measures like Energy Efficiency Design Index (EEDI) and Energy Efficiency Operational Index (EEOI) are introduced to make shipping more efficient. EEDI and EEOI relate the carbon emissions of a ship to its performance. EEDI and EEIO however are merely slowing down the growth of energy consumption and emissions by shipping, and provoke no reduction [11,17,18].

1.3 Emission benchmark

A benchmark has been proposed by the European Commission [19] and IMO [20]. A benchmark was needed to gain insight in the present state of the energy efficiency of ships. That can be used to assess why EEDI/EEIO are less successful as expected and to develop better fitting energy efficiency legislation in the future [21]. A benchmark is also considered as tool to breach the present market failures in increasing energy efficiency.

Monitoring, Reporting and Verification (MRV) is proposed to be implemented on board as benchmark tool by the European Commission (Regulation (EU) 2015/757); IMO has presently agreed upon a global MRV scheme. Regulation 11 of the European measure states very clearly the reasons why MRV has been proposed: "The adoption of measures to reduce greenhouse gas emissions and fuel consumption is hampered by the existence of market barriers such as a lack of reliable information on the fuel efficiency of ships or of technologies available for retrofitting ships, a lack of access to finance for investments in ship efficiency, and split incentives, as ship owners would not benefit from their investments in ship efficiency when fuel bills are paid by operators."

Regulation 13 says about the relevance of the measure to break market barriers and to able to make relevant assessment using the data. The regulation says: "The introduction of a Union MRV system is expected to lead to emission reductions […] as it could contribute to the removal of market barriers […] by providing comparable and reliable information on fuel consumption and energy efficiency to the relevant markets. This reduction of transport costs should facilitate international trade. Furthermore, a robust MRV system is a prerequisite for any market-based measure, efficiency standard or other measure, […]. It also provides reliable data to set precise emission reduction targets and to assess the progress of maritime transport's contribution towards achieving a low carbon economy."

For shipping for example, ill-performing ships will get less attractive for shippers to charter when fuel consumption or atmospheric pollution data has become available. These ships have higher energy costs. These ships might pay higher port fees. Shippers stimulating green image would rather choose to ship their goods with ships with a lower environmental impact.

1.4 On-board monitoring

Ships will be required to monitor their fuel consumption and/or carbon emissions. The annual aggregated number of each individual ship needs to be reported to the legal authorities. The result will be published and verified and assessed if ships comply and what actions need to be taken in the future. Annual reported emission data will be made transparent by making these public accessible as required by the European scheme. This is believed to close the knowledge gap of ship specific fuel consumption, the best fitting efficiency technologies for ships, and of split incentives and responsibilities across the total sector.

The European regulation has been put into force 1 July 2015 and the first reporting period will commence on 1 January 2018. The regulations by IMO will be effective on 1 January 2019, when ships need to monitor their fuel consumption globally.

The next chapter further elaborates the MRV regulations. The subsequent chapter discusses the view of the shipping industry about MRV. The industry views some issues as problematic. This study scientifically evaluates to what extent the arguments of the shipping industry concerning monitoring, reporting and verification could be included in monitoring methods on board.

2. MRV legislation

2.1 EU legislation for MRV

The European measure was initially proposed as result of lacking global actions to enforce shipping to reduce their energy consumption [21]. The measure is whilst part of the Union-wide emission cap/emission reduction scheme: 40% emission reduction of 1990 levels in 2030.

Applicability of MRV is first step in the scheme for the maritime sector [21]. Second step would be the establishment of a (global) energy efficiency standard for ships. Third step is to evaluate emission reductions by the energy efficiency standard and what need to be done more, *e.g.* the introduction of market based measures (MBM's) in the maritime sector.

Ships needs to develop and submit a monitoring plan which elaborates the method of monitoring, and the way of reporting the data, including ship data and all relevant combustion data. The plan must explain how the quality of the measurements and data is guaranteed. The plan and the results will be verified by designated organizations.

The EC regulation prefers to let ships monitor using existing ship systems to keep the extra burden low with as less as possible investments. This is the reason the EC suggests the four methods which (to a certain extent) use existing ship infrastructure: 1. the use of bunker delivery notes; 2. bunker fuel tank monitoring; 3. flow meters; 4. direct measurements of emissions.

For Monitoring the following per ship is covered and needs administrated (table 1):

- Per voyage monitoring of CO_2 emitted which is aggregated in a total amount of annual CO_2 emissions
- Total voyages in, into and out of EU jurisdiction including port emissions
- The method is not prescribed; four methods are suggested (see section 7):
    - The use of bunker delivery notes
    - Bunker fuel tank monitoring
    - Flow meters
    - Direct measurements of emissions
- Distance travelled and time spent at sea and at berth
- Average energy efficiency
- Data on amount of cargo on board and transport work

The Reporting stage covers the following:

- Annual reporting to flag state and to the EC
- According accredited monitoring plan
- Via electronic templates
- Data of each individual ship will be made publicly available including fuel consumption, EEDI and other efficiency parameters and ship data

Verification serves the following purposes:

- Determining and making recommendations for improvement of ship efficiency
- Assessing conformity of the monitoring plan against requirements
- Assessing conformity of the annual emission report with the requirements
- Ensure that emissions and other climate-related data have been determined in accordance with the monitoring plan
- Improvement of monitoring plan

The verification step is mainly a quality-related issue. Here is verified whether the monitoring plan results in proper/correct information of a ship's emissions or not. And if a ship complies with the regulations. The result should however be used to assess the ship impact in global warming and how that can be improved. The verification process should already include the critical analysis about improving a ship's efficiency.
EMSA, the European Maritime Safety Agency is the coordinating body in the verification process (verification actors, submission, verification organizations, Port State Control verifying compliance to the regulations).

2.2 IMO legislation for MRV

The Marine Environmental Protection Committee of IMO (MEPC) agreed on a global MRV scheme for fuel consumption which will enter into force on 1 January 2019 as amendment of MARPOL Annex VI (fig. 1, [20,22]). In this global scheme Ships need to monitor their annual fuel consumption, which will be shared with the ships' Flag State.
The results will be stored in the IMO Ship Fuel Oil Consumption Database. This database will be specially developed for the purpose of storing ship fuel consumption data. The results will be used for (trend) analysis and as benchmark for new regulations, which might be technical or economical. Results from the analyses will be published annually. Annually published will also be a report of which relevant data is missing.
Other that the European measure, the results will not be published. The Marine Environmental Protection Committee decides what is being done with the data from the database. As such this measure has a more legislative purpose than its European counterpart.

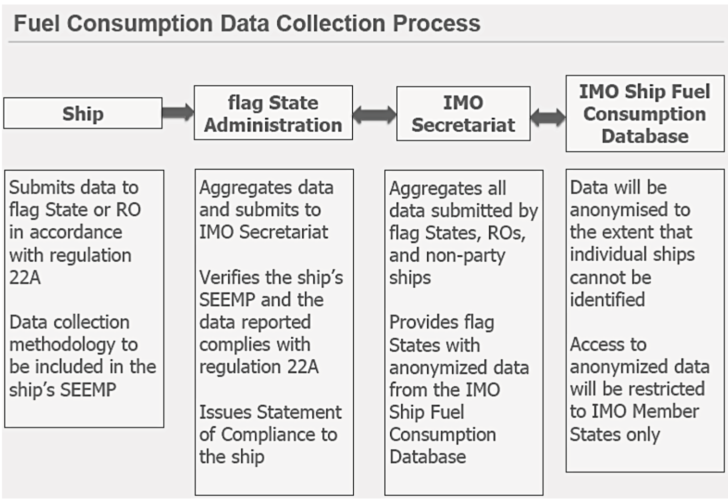

Fig. 1. Schematic overview of IMO MRV scheme.
The scheme is part of MARPOL Annex VI regulations [22].

In the IMO measure Monitoring concerns the following (table 1):

- Annual fuel oil consumption by ships measuring 5000GT and above, by fuel type in metric tonnes
- Method of fuel consumption monitoring; method not prescribed
- Distance travelled
- Hours underway

- Ships do not have to issue a special monitoring plan. Ships need to specify their way of monitoring in the SEEMP. The monitoring approach of a ship will be validated via the SEEMP.

The Reporting stage covers the following:
- Sharing the annual aggregated number electronically to the Flag state
- Time period in which fuel consumption is monitored
- Identity of the ship
- Technical characteristics of the ship
    - Ship type
    - Gross and Net tonnage
    - Deadweight
    - Power output of main engine and auxiliary engines above 130 kW
    - EEDI (if applicable)
    - Ice class

Verification serves the following purposes:
- A Statement of Compliance will be issued after every submission of monitoring results which states the ship has submitted its data and that the monitoring has been performed in accordance with its SEEMP. SEEMP will be verified by Flag states and/or other authorised organizations such as Port State Control
- Results are stored in special database. No entry for third parties. Results will be used by MEPC to verify annual global ship emissions, other trend analyses and as input for future legislation.

Table 1. Overview of the differences and similarities between EU and IMO MRV schemes.

	EU MRV	**IMO Scheme**
Monitoring	Ships 5,000 GT and above	Ships 5,000 GT and above
	Voyages to/from EU port of calls	All voyages
	EU Monitoring Plan	Updated SEEMP
	Starting 01st January 2018	Starting 01st January 2019
First Monitoring period	2018	2019
Exemptions	Warships, naval auxiliaries, fish-catching/processing ships, ships not propelled by mechanical means and government ships used for non-commercial purposes.	TBD
Parameters	Fuel consumption (port/sea)	Fuel Consumption
	Transport work (based on actual cargo carried)	Distance
	Distance	Time
	Time	
Verification	Independent accredited verifiers	Flags/recognized organizations (work in progress)
Reports to	European Commission	Flag State
Certification	Document of Compliance (June 2019)	Statement of Compliance
Publication	Distinctive public database	Anonymous public data

3. Community's scope on the issue

Ship owners or ship managers must publish their data on fuel consumption of their ships. This data must be shared with the relevant authorities. The data will be published for the general public in the European scheme. In the IMO scheme the data will be used within MEPC internally; only general remarks will be made public.
However, for ship owners and operators some difficulties appear:

1. the data that needs to be collected is rather sensitive, for it brings out an economic performance of ships, because the shipping market is highly competitive [17]. The measure may affect level playing fields for ship owners. The answer of shipping is that data needs to be treated as confidential. Monitored data may affect the economic position of ship owners.
   Ship owners and operators do not seem to feel much to share their data to the public, because they could be afraid that authorities will come up with stricter legislation based on the information shipping publishes [17].
   Third, some non-disclosure is required in the negotiations for a new time charter. In time charters the charterers – the party who rents the ship for a certain period – will pay all voyage expenses [23]. Bunker costs are part of the voyage expenses. Ship owners want to put their vessels in the market as interesting as possible. And so are bunker costs part of the negotiations. Ship owners are afraid of losing their position in these negotiations when MRV applies to their ships.
2. The shipping industry demanded anonymity of their data in the future MRV schemes during negotiations for the new MRV legislation, because their data is sensitive and should not fall in the wrong hands (personal communication during MRV discussion groups). The MRV scheme by IMO ensures anonymity in the assessment of the submitted data. Relevant authorities will receive undisclosed data and all data will be stored of each individual ship. All data will be made public in the EU scheme. Some exemptions could be granted however, if important economic interests are at stake.
   The question can be raised to what extent the data can be put into anonymity in order to get proper information about fuel consumption in the demanded extensive level. Otherwise fuel stock analyses would be sufficient enough.
   In our views the industry wants to be sure their data will be well-threat by the relevant authorities. Methods of monitoring and reporting should take anonymity into account.
3. Uncertainty about the way of monitoring: which parameters need to be measured and which data is required, and how? Paradoxically, analogue problems arise around the implementation of MRV as for the introduction of green measures on board ships. Much is uncertain to them, even if the European scheme proposes four ways of performing MRV.
   From a Danish survey about MRV it becomes clear that much about MRV is uncertain for the shipping industry [11]. Particular important baseline information does for example not exist for a proper implementation of MRV. There is the notion of relevant information gaps.
   Personal communication clarified that shipping companies lack the knowledge to choose for particular ways of monitoring, what to do with the data and what to say about the quality of the data. Not to mention the extra costs. How is reliable and credible data gathered from shipping when the data should by reliable and credible?

Agreements like the above result in uncertainty about which stakeholder is responsible for which ship efficiency improvement and who of them will get the incentive to improve energy efficiency on ships.

The MRV measures are ratified and legally valid, so the question is how to solve this issue and does alternative data or methods exist which gives information about the energy efficiency of a ship without sharing sensitive fuel information? Preferably using existing methods and data gathering.

The study by Poulsen and Johnson [11] concludes that current maritime business practices do not permit the search for proper MRV practices and that the required information and data depends on these best practices.

4. Search for alternative method

4.1 Research scope

The scope of this study is to scientifically evaluate whether proxy parameters/alternative methods in a monitoring approach exist or not which could be used to present energy data of a ship which might meet the arguments by the shipping industry concerning monitoring, reporting and verification. The values from proxy parameters or the results from an alternative method could present information about the energy performance of a ship without publishing the exact energy performance values. And so not being commercially sensitive or might present the results anonymously.

4.2 Main research question & objectives

What method should be developed in a data collection scheme on fuel consumption to deal with the issues of sensitivity, anonymizing, and data suitability, so that the difficulties with these issues could be solved and the measure be further developed?

Having the following objectives:

4. to identify parameters which are required for energy consumption and emissions on board presently. A theoretical fuel consumption can be calculated by using the energy related parameters in energy and mass balances following from diesel engine theory. One or more parameters could serve as proxy which presents information about the fuel consumption of a vessel – without presenting the direct fuel consumption.
5. inventory of methods to calculate fuel consumption and/or CO_2 emissions. A second way of tackling the problem is to find another method for determining the fuel consumption/carbon emissions and which meets the objections from the industry.
6. evaluate to which parameters sensitivity and/or anonymizing apply to develop an alternative methodology for energy efficiency monitoring by using for example proxies for problematic parameters.

4.3 Activities

The research is arranged in three activities to meet the objectives of the research.
Activity 1 focuses on the parameters related to energy consumption and emission production on board. An inventory is made about what is already being monitored on board. MRV on board should take as less effort as possible, so the preference is to use existing infrastructure and presently monitored parameters. We visited some ships and consulting some ship operators to establish the inventory.
Second part of the activity is a literature study to the basic requirements of a successful monitoring, reporting and verification implementation. The method of this project is part of an MRV scheme and thus has to comply to the basic requirements of a successful MRV.
Activity 2 is the inventory of various methods which could be used as an alternative method for MRV on board. The inventory is based on literature study.
Activity 3 is the evaluation of the results of both inventories to extract the method which meet the difficulties by the industry most and which could seem the most promising method. This is done by combining the methods with the parameters from activity 1. If no or too less parameters are presently monitored for a certain method, then the method is without doubt unsuitable to use as an alternative method. Second step is to look at the outcomes of the remaining methods if the difficulties are met. The last step is to score the methods to usability for on board.
The results from activity 2 and 3 are presented in chapter 7.

5. Monitoring, Reporting and Verification - Literature review

The properties of MRV need to be understand and what is required within an MRV scheme to meet its goal successfully. The method of this project must to comply with these properties. The method would otherwise not useful within any MRV scheme.
Literature on MRV provides information about the properties of a successful MRV. Specific elements which are emphasized in literature and which might apply to the method of the project is given extra attention.

5.1 Definitions

Ballassen, et al. [24] provide appropriate definitions for monitoring, reporting, and verification:
"'Monitoring' covers the scientific part of the MRV process. It involves getting a number for each variable part of the equation that results in the emissions estimate. This ranges from direct measurement of gas concentration using gas meters to the recording of proxies such as fuel consumption based on the bills of a given entity.
"'Reporting' covers the administrative part of the process. It involves aggregating and recording the numbers, explaining how you came up with them in the requested format, and communicating the results to the relevant authority, such as the regulator or the top management of the company.
"The purpose of 'verification' is to detect errors resulting from either innocent mistakes or fraudulent reporting. It is usually conducted by a party not involved in monitoring and reporting, who checks that these two steps were conducted in compliance with the relevant guidelines."

5.2 Fundamental MRV elements

Schakenbach, Vollaro and Forte [25] present a list of elements what should be included in an MRV scheme – in their case which EPA (Environmental Protection Agency) used in various emission programs. The authors label the element as fundamental for a successful MRV application (under a cap and trade system). Most MRV schemes apply within a cap and trade system of carbon emissions. The EU MRV scheme is a first step to a maritime carbon cab system. According Schakenbach et al. [25] the fundamental MRV elements are:

1. compliance assurance through incentives and automatic penalties
2. strong quality assurance (QA)
3. collaborative approach with a petition process
4. standardized electronic reporting
5. compliance flexibility for low-emitting sources
6. complete emissions data record required
7. centralized administration
8. level playing field
9. publicly available data
10. performance-based approach, and
11. reducing conflicts of interest.

Ballassen et al. [24] highlight the scale of implementation of an MRV scheme to consider uncertainty and reliability of the results in monitoring. Important trade-offs emerge concerning these two issues. When reviewing MRV systems five questions need to be asked based on how to deal or is dealt with the trade-offs in MRV [25]. In their review paper they ask the questions for on existing MRV applications, but the questions are relevant too for future MRV applications.

The questions are as follows:
1. What are the key MRV requirements?
2. What are the costs for entities to meet these requirements?
3. Is a flexible trade-off between requirements and costs allowed?
4. Is requirements stringency adapted to the emissions amount at stake?
5. What is the balance between comparability and information relevance?

Walsh and Bows [26] accentuate on the use of emission factors to calculate from fuel consumption to emission or back.
Not all elements from Schakenbach et al. [25] are directly relevant in the scope of this. Some elements are more related to policy and influenced by policy. In our case the policy framework is already there. The relevant elements are reviewed in next paragraphs.

5.2.1 Quality assurance
Quality assurance (QA) is a relevant element in MRV [25]. QA is essential for the confidence in a program and the integrity of the work done to reach emission reduction. It ensures the goals of emission reduction are achieved by qualitative high standards. Quality assurance covers for instance the performance standards for monitoring equipment. Audits and competency of testing personnel are a vital part in QA. The monitoring results need to be verified. This needs to be done by qualified personnel, but the quality of the data should also be on the proper level. The results need to have met a proper level of quality.

5.2.2 Collaborative approach
Collaborative approach in the process is therefore important [25]. There is constantly interaction between the legislating, executing, and controlling actors about the implementation and outcomes of an MRV scheme. The authors argue interaction based on collaboration is far more fruitful for the success of a scheme then 'using a "command and control" approach'. Collaboration provides a better compliance rate, resource savings, understanding, and a more productive relationship among the actors.
It is important all actors/stakeholders do what is expected of them in the MRV scheme. Kitada & Ölcer [27] discuss the human part (element) in the implementation of energy efficient measures on board ships as part of corporal sustainable responsibility. Human agency is very important in the way new measures are implemented; something can be embraced or be rejected for various of reasons. Good collaboration will positive influence the success of the implementation etcetera of MRV.

5.2.3 Compliance flexibility for low-emitting sources
Schakenbach et al. [25] highlight what to do with low emitting sources when referring to the item of compliance flexibility for low emitting sources: "One lesson learned from implementing several cap and trade programs is that it is a more efficient use of resources to either exclude sectors that do not contribute significantly to emissions of concern or allow them to use conservative, simpler default factors".
The risk exists that total emission would be overestimated when small sources are included in an inventory. Is every source relevant? Is the quality of the final monitoring results affected with or without low emission sources? They point out that the burden of maintaining the cap and trade MRV program on various agencies would become too high when including low emitters, i.e. not cost effective in terms of time and money relative to the total amount of reported emissions.
The EU and IMO regulations require ships larger than 5000GT to monitor their fuel consumption/carbon emissions. Smaller ships are regarded as less significant for the total emission amount in the union. This leaves open, however, which source on board a ship is to be included, for

example boiler emissions or maybe generator emissions. What emissions are relevant and which are not?

5.2.4 Complete emissions data record required

The monitoring inventory needs to be complete as possible, that is, all emissions of a relevant source have to be monitored [25]. For a ship's main engine this are stages like starting up, manoeuvring, sailing, manoeuvring, and shutting down. However, this should not contradict the flexibility of low-emitting sources.

The total emission figures must be reliable in order to base policy like a cap and trade program on it. Conservative values may be used as substitute if measuring is problematic during particular stages. If for example emission factors are used as substitute for some stages – like manoeuvring – no really reliable emission factors exist [28].

5.2.5 Publicly available data

Confidence in the program is got by making the data publically available [25]. The program becomes transparent and therefore it creates confidence in the program. Secondly, the data is input in all kind of policies, measures, and mechanisms. That is why in the EU measure for MRV the data of each individual ship will be made available. Available data is absolutely required for letting the market do its work to achieve efficiency improvements at the lowest costs. Public data allows others to access the data and to analyse the data [25], like others from the maritime community, researchers, etc. It invites for discussion about the program, program alterations and program improvements.

Ballassen et al. [24] argue that MRV should be followed by incentives to reduce emissions of greenhouse gasses. Incentives can be hard economic, like carbon taxes, but also in softer forms such as image branding. The EU regulation uses hard incentives in a certain way: data is made publicly available and anyone can see which ship underperforms. It is kind of naming and shaming to stimulate ships to improve their environmental performance.

This is a key issue in this study. The EU measure requires to make all data publically available, but the maritime community, especially ship owners and operators have to some extent problems to publish their data. According them the data is too sensitive to publish. This study looks for an alternative which is less problematic to publish, but what delivers information about the efficiency of a vessel.

5.2.6 Scale of implementation and uncertainty

Two important issues about MRV are its scale of implementation, i.e. the extent of what is being monitored, and the level of uncertainty and reliability of the monitoring results. Ballassen et al. [24] mention two trade-offs of these two issues: information relevance versus comparability, and cost versus uncertainty. One can monitor data which is only relevant to a certain ship type, but then the data might not be comparable with other types of ships. Will the data be comparable, the monitored data might lose relevance. The costs of a MRV system might be high when one desires to reduce uncertainties in the monitoring process to a minimum. This also implies that low-cost monitoring systems are affected by higher levels of uncertainty. The trade-offs relate to the issues of compliance flexibility and complete data recordings. Completeness comes at a cost.

When reviewing MRV systems the five questions mentioned earlier need to be asked to assess the trade-offs in MRV [24]:

1. What are the key MRV requirements?
2. What are the costs for entities to meet these requirements?
3. Is a flexible trade-off between requirements and costs allowed?
4. Is requirements stringency adapted to the emissions amount at stake?
5. What is the balance between comparability and information relevance?

These questions focus on the application of MRV, not directly on whether a system is suitable to be used for MRV or not. In fact, the questions focus on the feasibility of an MRV scheme and if the (legal) requirements of it can be met. And additionally, if it's worth to take effort in implementation of a certain MRV application. According to Ballassen et al. [24] the principles and concepts of an MRV scheme are often proposed without significant attention to how such schemes are applied in practise especially in relation with uncertainty. Not many MRV schemes set requirements concerning uncertainty in monitoring and how to deal with them. An example is the notion of what level of uncertainty is acceptable.

5.2.7 Overcoming uncertainties

Uncertainties however are inherent to monitoring. Uncertainty in the monitoring results are caused by lack of accuracy and of precision [24]. The lack of precision can be dealt with by increasing the number of samples. Quality control and verification can be used to deal with the lack of accuracy and precision. Systematic errors can only be reduced by monitoring and reporting the same parameter by different methods.

Additional uncertainties lie in the use of theoretical values in the emission assessment, because theory does not always follow practice. The precautionary principle, i.e. the use of conservative values is an approach to deal with uncertainty. In various MRV schemes the use of the precautionary principle is encouraged [24], yet for just some parameters or variables in the analysis where more parameters are concerned. In many cases to just the most uncertain parameters.

Jenkins, Chadwick and [29] argue that sensitivity analyses are required in the verification process of MRV. Sensitivity analyses are needed to assess uncertainties in the monitoring process and to filter these out. They show if the monitoring method is consistent between observation and expectation or observation and requirement. And whether a chosen method is properly monitor or not.

5.2.8 Emission factors

Walsh & Bows [26] make a key remark about the use of emission factors to calculate the amount of emissions from energy consumption. If emission factors are used there need to be a range of emission factors, relevant emission factors. Uncertainty increases when using generalized emission factors. Relevant emission factors are emission factors which apply for mere specific situations and better cover the processes in those situations. Generalized emission factors may be too generalized for the situation. The emission factors may result from non-transparent assumptions.

Walsh & Bows [26] focus on the use of emission factors in lifecycle analyses for shipping. They argue that the determination of the environmental impact of shipping via LCA lacks representative methods. MRV data from ships could also be supportive in this domain of environmental studies.

For LCA emission factors are very important, because lifecycle assessment is theoretical methodology. The method from this project would probably also be, therefore the remarks from Walsh & Bows [26] should be relevant for the project too.

5.2.9 Perception of MRV

An MRV method needs to be practical. It must not create too much burden on executive personnel and the outcomes should not remain theoretical. Executing personnel need to perceive the necessity and/or effects of MRV in their field. So neither should MRV have an extra burden on either the crew or the communication between ship and shore. This human factor is important in the success of a new environmental-related measure on board [27]. New measures need to be incorporated in the daily routine of the crew's work. According Johnson & Anderson [30] – as cited by [27] – many shipping companies do not possess the ability to address energy efficiency measures on a systematic base within their organisations. That is also implementing and introducing these measures on board of their ships. The least extra burden is created by using existing infrastructure and administration for a new measure. The view by the European Commission is that the burden should be as low as possible which is reflected in the four proposed methods.

5.3 List of questions

We developed a basic list of questions which can be used in a checklist for the development of an alternative way for monitoring on board in an MRV scheme. The questions are based on the remarks in this literature review. The questions put attention on essential matters for the implementation of MRV. The questions could be used in the assessment to the feasibility of a new/alternative monitoring method. The list is not extensive, as is literature on MRV.

Quality

Q1: How is quality assessment in the proposed/possible method addressed?

Cooperation

Q2: How much influence does a monitoring method itself have on the level of cooperation between actors/stakeholders?

Q3: What is needed for the specific method to invite for a collaborative attitude among stakeholders?

Complete data record

Q4: Which operations and processes are to be included in the method and how can the method be as complete as possible?

Q5: How are low emission sources dealt with and which are included?

Available data

Q6: Provides the alternative method enough information to let the market enforce the efficiency improvements of shipping?

Q7: does this mechanism still apply when using proxy data?

Scale of implementation and uncertainty

Q8: What are the results of the trade-off assessment?

Q9: How is uncertainty addressed in the method?

Q10: Where is uncertainty expected in the method?

Sensitivity analyses

Q11: What would be the method to run sensitivity analyses?

Emission factors

Q12: Which emission factors need to be included in the method?

Q13: Do relevant emission factors exist for the method?

Perception of MRV

Q14: How are the operators/crew affected by the alternative method?

Q16: How can operators/crew be involved in the method?

This list can be considered in the assessment in the application process of a new/alternative MRV-scheme on board. The list should be expanded when more MRV literature is reviewed or published.

6. Presently monitored data

An inventory is made about what is already being monitored on board. The aims are to establish the level, quality and availability of machinery data that vessels routinely collect, and to establish the suitability of this data in determining a proxy/alternative method of establishing carbon emissions that would be used for compliance with MRV legislation. MRV on board should take as less effort as possible, so the preference is to use existing infrastructure and presently monitored parameters. Appropriate ships were visited and consulted to establish the inventory with their data. A number of ship owners /operators were approached; however the response was generally poor. In determining the suitability and quality of the collected data an energy flow analysis approach was undertaken.

6.1 Data Collection

Visits were undertaken on several vessels for which the legislation applies; of which most operate in European waters. The ship types were general cargo vessels, ropax ferries and a heavy lift vessel. Full access was provided to all data that is routinely collected; these included the bridge log, engine room log, oil record books and bunkering notes. The owners requested that the data should not be divulged to a third party.

The bridge logs noted all navigational events (courses, weather conditions, etc.) and general events for the vessels. The engine room logs entries varied across the visited vessels. The log book, records the main operational parameters that are considered essential to determine the performance of the machinery in terms of fuel efficiency and operational condition, mainly temperatures for the various engine room items. Some however were very poor, some were more extensive. There was also no evidence provided of any emissions monitoring equipment.

6.1.1 Monitored parameters on board of General Cargo Vessel

This particular vessel provided us with insight in their engine room log book. The vessel is operated by a European ship operator (appendix 1). The log extract covers a period of 31 days in which the vessel spent time at anchor, manoeuvring, loading/discharging and on route from a port in Europe to Africa. Access to other documentation such as the bridge logs, oil record books and bunker notes were unfortunately not made available for publication. The parameters however which were monitored are comparable with the parameters monitored at the ropax ferry. The parameters on board of this general cargo vessel were actively monitored by all kind of sensors, as well as the fuel consumption.

6.1.2 Monitored parameters on board of ROPAX Ferry

Parameters from a ROPAX ferry were collected from a ferry which operates in the North Sea region (table 2). The particular vessel uses automatic monitoring systems for a good overview of the processes in the engine room. Mainly temperatures and pressures of the various machineries are being monitored, but also the power loads/output of the main engine and auxiliary engines and their speeds. Fuel consumption is determined by tank level measurements.

Table 2. Monitored parameters on board of a ropax ferry.

Engine room temperature	
Main Engine & Turbo	
ME Load	
Running hours	
ME speed	
Turbo speed	
ME exhaust gas temperature	Individual cylinders
	Mean of all cylinders
	Turbo exhaust gasses @ entrance
	Turbo exhaust gasses @ exit
ME bearing temperature	Individual cylinder bearings
	Mean of all cylinders
Charging air	Pressure
	Temperature
Fuel Oil	
Heavy fuel oil	Pressure
	Temperature
	Viscosity
HFO day tank	Temperature
	Level
HFO settling tank	Temperature
Diesel oil storage tank	Level
Fuel oil storage tanks	Tank levels
Sludge tank	Level
Lubrication Oil	
Lub oil ME	Pressure
	Temperature
Lub oil turbo ME	Pressure
	Temperature
Lub oil gearbox ME	Pressure
	Temperature
Lub oil storage tanks	Tank levels
Cooling Water & fresh water	
HT cooling water	Pressure @ entrance ME
	Temperature @ entrance ME
	Temperature @ ME exit
LT cooling water	Pressure @ entrance ME
	Temperature @ entrance ME
	Temperature @ entrance charger cooler
Nozzle cooling water	Pressure
	Temperature
Sea Water cooling water	Pressure
	Temperature @ entrance SW coolers
	Temperature @ exit SW coolers
Fresh water storage	Tank levels
Gearbox & Trust	
Gearbox bearings	Temperatures
Trust bearings	Temperatures
Shaft bearings	Temperatures
Stern tube bearings	Temperatures
Shaft clutch	Temperatures
Propeller	
Propeller speed	
CPP pitch	Ordered
	Actual
CPP oil	Pressure
	Temperature
Shaft Generator	
Shaft power	
Shaft generator output	
Electric frequency	
Voltage	
Current	
Shaft generator bearings	Temperatures

6.1.3 Monitored parameters on board of Heavy Lift vessel

This particular vessel has an unconventional energy and propulsion systems. The vessel is equipped with six smaller diesel-generators which supply the 750V DC-bar (table 3). All required energy is taken from the DC-bar: propulsion, auxiliary services, hotel services. Invertors are used to transform from AC to DC and vice versa. Delivered power and currents are important parameters on this vessel. Other important parameters are temperatures and pressures. Fuel consumption is monitored by tank sounding measurements.

Table 3. Monitored parameters on board of a heavy lift vessel.

Auxiliary engines 1-6	Load
	Running hours
	Lubrication oil pressure
	Fuel pressure
	Cooling water temperature @ entrance
	Cooling water temperature @ exit
	Cooling water pressure
	Battery voltage
	Air boost pressure
	Lubrication oil added to sump
Thrusters PS/SB	Speed
	Running hours
	Power
	Current
	Lubrication oil pressure
	Lubrication oil temperature
	Cooling water E-motor temperature @ entrance
	Cooling water E-motor temperature @ exit
	Cooling water lub. oil cooler temperature @ entrance
	Cooling water lub. oil cooler temperature @ exit
	Cooling water pressure
	Filter pressure difference
	Tank level expansion tank
Bow thrusters FW/AFT	Running hours
	Cooling water pressure
	Tank level expansion tank
Steering gear PS/SB	Planetary gear temperatures
Rotating converters	Power
	Current
Box coolers bow thrusters	Cooling water temperature @ entrance
	Cooling water temperature @ exit
Box coolers thrusters	Cooling water temperature @ entrance
	Cooling water temperature @ exit
Box coolers switchboards	Cooling water temperature @ entrance
	Cooling water temperature @ exit
	Cooling water pressure
Batteries	Voltage
Gasoil separators	Gasoil pressure
Working air	Air pressure vessel
	Air pressure reducer
Fresh water	Heater temperature @ entrance
	Heater temperature @ exit
Potable water	Pressure reducer

6.1.4 Monitored parameters on board of a General cargo vessel

Parameters from this vessel were collected from a general cargo vessel which operates globally (table 4). On board this vessel are mainly temperatures and pressures being monitored, as well as the power loads/output of the main engine and auxiliary engines and their speeds. Fuel consumption is again determined by tank level measurements.

Table 4. Monitored parameters on board of a general cargo vessel.

Main Engine	Load
	Speed
	Governor index
	Fuel timing/rack index
	Turbo speed
	Charge air temperature
	Charge air pressure
	Cylinder liner temperatures
	Cylinder exhaust gas temperatures
	Cylinder exhaust average temperature
	Exhaust gas temperature @ entrance turbo
	Exhaust gas temperature @ exit turbo
	Main bearings temperatures
	Big end bearing temperatures
Electrical power production	Shaft generator load
	Auxiliary generators load
Engine room	Engine room temperature
Gearbox/shaft/propeller	Propeller pitch
	Thrust bearing temperature FWD/AFT
	Upper radial plain bearing temperature FWD/AFT
	Lower radial plain bearing temperature FWD/AFT
	Shaft bearing aft temperature
	Contr. pitch propeller oil temperature (CPP)
	Contr. pitch propeller oil pressure (CPP)
Cooling water	HT cooling water pressure @ entrance ME
	HT cooling water temperature @ entrance ME
	HT cooling water temperature @ exit ME
	LT cooling water temperature @ entrance ME
	LT cooling water pressure @ entrance ME
	LT cooling water temperature @ exit LO cooler
	LT cooling water temperature @ entrance gearbox
	LT cooling water temperature @ exit gearbox
	LT cooling water temperature @ entrance CPP
	LT cooling water temperature @ exit CPP
	Sea cooling water temperature @ entrance LT cooler
	Sea cooling water temperature @ exit LT cooler
	Sea cooling water pressure
	Sea cooling water cooler pressure difference
	LT cooling water temperature @ auxiliary engines
Fuel oil	HFO temperature @ entrance ME
	HFO pressure @ entrance ME
	HFO viscosity
	HFO temperature
	HFO feeder & booster pump pressure
	HFO day tank temperatures
	HFO settling tank temperature
	HFO storage tank temperatures
	HFO temperature @ entrance HFO separators
	HFO pressure @ entrance HFO separators
Lubrication oil	Lubrication oil temperature @ entrance LO cooler
	Lubrication oil temperature @ exit turbo
	Lubrication oil pressure @ entrance turbo
	Lubrication oil pressure @ auxiliary engines
	Lub. oil temperature @ entrance LO separators
	Lub. oil pressure @ entrance LO separators
	Lubrication oil temperature @ exit gearbox cooler
	Lubrication oil temperature @ entrance gearbox cooler
	Lubrication oil pressure @ exit gearbox cooler
	Lubrication oil pressure @ entrance gearbox cooler
Heat production	Thermal oil temperature @ oil fired boiler
	Thermal oil temperature @ economiser
	Thermal oil flow
	Thermal oil circulation pump pressure @ suction
	Thermal oil circulation pump pressure @ discharge
	Thermal oil temperature @ exit dump cooler
	Thermal oil temperature @ entrance dump cooler
	Thermal oil pressure difference @ economiser
	Thermal oil temperature difference @ economiser

6.2 Energy analysis

What is being monitored on board of a vessel depends – quite logically – on the type of vessel. And besides of that the range differs of what is being monitored and in which detail. One vessel only recorded the monitoring results once every day while the other vessel was monitoring continuously. However, each ship has one or more engines, a fuel system, cooling water systems, a lubrication oil system and has propeller propulsion. The information might be used in energy flow path modelling for fuel consumption calculation.

6.2.1Energy flow path modelling

The energy flow approach in determining carbon emissions relies on completing an energy balance for the machinery being analysed. The energy flow approach by default would allow for the energy input in the fuel to be established, by coupling the fuel energy flow and the its calorific value, the fuel consumption and the energy uptake by the various systems (fig. 2). Transfer of energy in and out of a system is complex and takes many forms e.g. energy transfer into cooling water, lubricating oil, energy out in the exhaust gasses and energy loss from surfaces (wild heat) etc.
Energy flow path modelling is part of power efficiency analysis:

$$Efficiency\ \eta = \frac{Energy\ output}{Energy\ input} \tag{1}$$

The effective power to the propeller shaft is the energy output. The energy input is delivered by the fuel. The difference between input and output is the uptake by the systems and losses. And is the energy input:

$$Energy\ input = Energy\ uptake + Energy\ output \tag{2}$$

Energy input could therefore be reversely determined when the output and energy uptake are known. This method of establishing fuel consumption by reverse energy balance approach is an established technique in industry. Such an approach may act as method to find a parameter which may act as proxy for the direct fuel consumption of the vessel, and which might be shared instead of the direct fuel consumption. However, it does rely on a substantial degree of calibrated instrumentation and whether the right parameters are monitored or not.

The energy uptake could also be interesting to know from an efficiency perspective. Because

$$Efficiency\ \eta = \frac{Energy\ output}{Energy\ uptake + Energy\ output} \tag{3}$$

The energy uptake is thus of importance for the efficiency of a system relative to the energy output. This is logical, because the higher the uptake of energy and the losses the lower the efficiency. This means that the uptake and losses from energy in the ships engine could act as a proxy for the energy input – the fuel consumption – and also for the efficiency of the engine. The usability of efficiency is further elaborated in the discussion section.

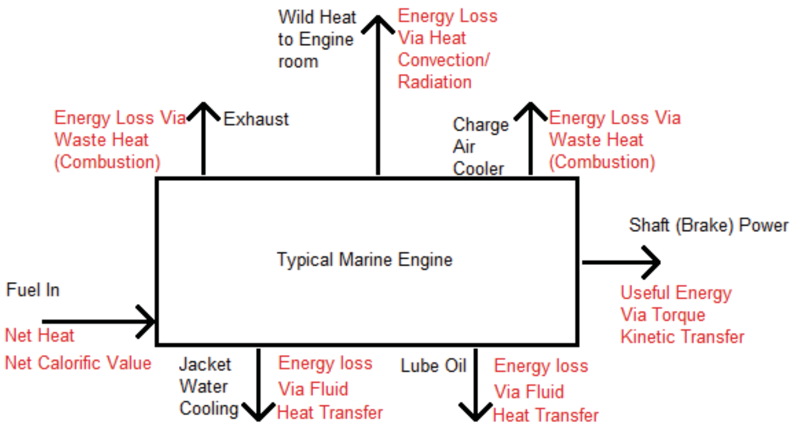

Fig. 2. Generic Diesel Engine Energy Plant

6.2.2 On-board energy flow path modelling

To relate this technique to a ship, generic energy flow diagrams were developed for the main engine (fig. 2) and auxiliary energy plant (fig. 3). The purpose of these diagrams is to establish the extent of energy uptake flows. Of most of the systems temperatures and pressures are monitored which could be used to calculate these energy flows.

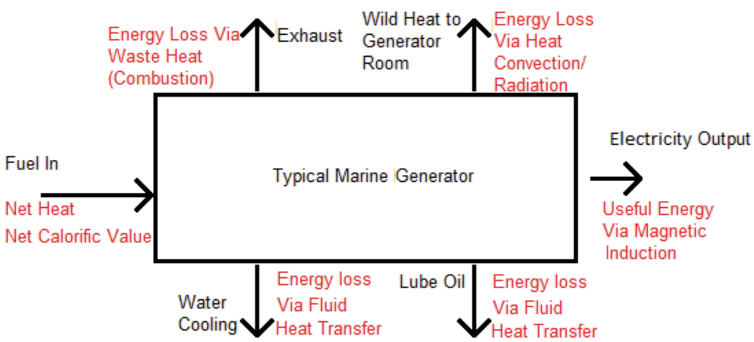

Fig 3. Generic Marine Generator Energy Plant

Although determining the energy transfer into a fluid system is relatively simple, it does rely on having the fluids differential temperatures and mass flow rate

$$\Delta\, Heat\ medium\ \dot{Q}\ = Mass\ flow\ \dot{m} \times Specific\ heat\ c \times\ temperature\ difference\ \Delta T \qquad (4)$$

Wild heat on the other hand is difficult to establish and is generally given by the equipment manufacturer as a percentage of the fuel energy flow. Radiation depends on the temperature of the radiator following Stefan-Boltzmann law. There is also loss of heat by confection and engine room ventilation.

Many temperatures concerning the energy flows of the main engines are monitored. The uptake of heat could theoretically be determined on board. Problem however is that the required flows are not

being monitored; at least not by a flow measuring device. Some crucial temperatures – for example at the inlet – are not being measured on some of the vessels.
Theoretical flow could be determined by pump and pressure theories which calculate mass flow by the delivered manometric pressure and pump characteristics for fluids and with aid of the ideal gas law for gasses (i.e. exhaust gasses)

$$pV = nRT \tag{5}$$

This exercise however is rather theoretical and one can argue if such exercises are suitable in day to day maritime work.
Given the need for fluid mass flow in determining the energy transfer it is clear that the data that is routinely collected in the operation of a ship will not be suitable for the energy flow method. It was also established that the quality of data collected was inconsistent and sometimes incomplete, this would only further undermine the technique.

6.3 Direct suitability of the data and parameters

The method of determining CO_2 by reverse energy flow balancing is a relatively simple technique, however it is totally dependent on high quality data, and the omission of one parameter renders the technique useless. Since the quality of the of data from the sources varied substantially, coupled by the lack of fluid mass flow data it is evident that the lack of data does not allow for a direct proxy method of determining fuel consumption and CO_2 emissions and are not suitable to allow for the determination as a proxy method. The available data that would be available is therefore reliant on establishing fuel consumption via modelling and other techniques. Possible methods are elaborated in the next part of this report.

7. Existing methods for fuel consumption and emission determination

Possible methods on establishing fuel consumption are elaborated in this chapter. The theoretical approach does not satisfy. The use of other approaches may. A review is made of various energy consumption and emission calculations methods. These methods have been analysed and assessed for their usability as method to meet the objections by the shipping industry. This chapter lists the methods including a short summary of each of them. Tables 5a and 5b present an overview of the requirements of each method: the use of which parameters, investments, expected accuracy.
The second part of the chapter focusses on the outcomes of the methods and if the methods are useful in the research's perspective. The outcomes of each method are assessed whether the method is suitable for meeting the objectives of anonymity and sensitivity.

7.1.1 Bunker Fuel Delivery Note (BDN)

BDN contains information that may be used for the monitoring of fuel consumption in a certain time period and therefore to estimate CO_2 emissions [31]. 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% and they can provide an insight into the absolute amount of fuel consumed in a specific period of time when combined with a stock-take at the beginning and at the end of the time period under consideration. This monitoring approach can therefore be used for time-based policy measures and direct incentive for emissions reductions.

7.1.2 Bunker fuel tank monitoring on board

This method is based on fuel tank readings for all fuel tanks on-board [21]. The tank readings shall occur daily when the ship is at sea and each time the ship is bunkering or de-bunkering.
The cumulative variations of the fuel tank level between two readings constitute the fuel consumed over the period. Fuel tank readings shall be carried out by appropriate methods such as automated systems, sounding and dip tapes. The method for tank sounding and uncertainty associated shall be specified in the monitoring plan.

7.1.3 Flow meters for applicable combustion processes

This method is based on measured fuel flows on-board [21]. The data from all flow meters linked to relevant CO_2 emission sources shall be combined to determine all fuel consumption for a specific period. The period means the time between two port calls or time within a port. For the fuel used during a period, the fuel type and the sulphur content need to be monitored. The calibration methods applied and the uncertainty associated with flow meters used shall be specified in the monitoring plan.

7.1.4 Direct CO_2 emissions measurements

With direct emissions monitoring, emissions are directly measured at exhaust gas stacks [21]. The method determines the emissions of a ship over a specific period of time. Direct emissions monitoring is thus an approach that can be used for time-based policy measures.

7.1.5 Use of The California Air Resources Board (CARB) Method

This method is obtained from the 2007 Ocean-Going Ship [32]. The survey targeted the owners or operators of tankers, cruise lines, car carriers, container ships etc. (both domestic and foreign-flagged) that visited California ports in 2006. The purpose of the survey was to gather information to help update the state-wide emissions inventory for ocean-going vessels, support the development of a proposed regulation to reduce emissions from the operation of their main engines and to better understand dockside power needs while loading/unloading in California ports.

7.1.6 On-board monitoring devices

This method is based on the monitoring devices that vessels have on board: Global Positioning System (GPS) and engines fuel consumption meters [19], but other kinds of sensors and monitoring equipment also.

7.1.7 Use of questionnaires method

This method uses questionnaire to obtain emission from ships in port [33]. The questionnaire contains questions about general ships characteristics such as ships name, type, volume, year of construction, IMO number (to access more detailed ship data later). Furthermore, the questionnaire asked for fuel consumption at different stages of shipping: cruising at open sea, manoeuvring towards harbour and while at berth together with duration of stay at berth. Simultaneously, fuel quality and the type of engine and/or machinery in which the fuel is used was requested. The method aims to cover the full spectrum of ship types as well as ships volumes and succeeded rather well at this by covering a wide range of ships volumes for most current ship types.

7.1.8 Use of tugs

Tugs could be used as a proxy for manoeuvring ships [34]. The main duties of the harbour tug is to assist ships on and off their moorings, and assisting their manoeuvring in and out of port. A harbour tug exhibits widely varying operation in typical everyday scenarios, and they are operated often by their masters independently of control orders from shore. These factors often lead to potential ambiguity and fluctuations in data which vary from one voyage, or job, to the next. This makes the analysis of such data-stream challenging when determining ship activity type. It is for these reasons that a harbour tug has become popular as the basis ship type for analysis, the argument being that if analysis can successfully be conducted in a tug boat, it can certainly be done for ship types with less variance in their data-streams for a specific activity.

7.1.9 Use of Portable Emissions Measurement System (PEMS)

A portable emissions measurement system (PEMS) is essentially a lightweight ‘laboratory’ that is used to test and/or assess mobile source emissions (i.e. ships, cars, trucks, buses, construction equipment, generators, trains, cranes, etc.) for the purposes of compliance, regulation, or decision-making. With PEMS it’s possible to measure CO_2, NO_X, SO_X and PM [35,36].

7.1.10 Ship Traffic Emissions Assessment Model (STEAM 2)

This method is presented for the evaluation of exhaust emissions of marine traffic, based on the messages provided by the Automatic Identification System (AIS) [37]. AIS enables the positioning of ship emissions with high spatial resolution. The model also takes into account the detailed technical data of each individual vessel. There was a former model called STEAM, which took into account NO_X, SO_X and CO_2 emissions. STEAM 2 also allows the mass-based emissions of particulate matter (PM) and carbon monoxide (CO). In addition, the model allows for the influence of accurate travel routes and ship speed, engine load, fuel sulphur content, multi-engine set up, abatement methods and waves.

This method can also evaluate the total PM emissions and those of organic carbon, elemental carbon, ash and hydrated sulphate. The creators of the method have also evaluated the performance of the extended model against available experimental data on engine power, fuel consumptions and the composition-resolved emissions of PM.

7.1.11 Methods used by TNO

Methodologies for estimating shipping emissions as defined by the Netherland Organization for Applied Scientific Research (TNO) [38]. The focus in the methods are also on emission factors and activity data that are currently in use to estimate emissions from berthed ships and from inland and sea shipping.

7.1.12 Energy Efficency Design Index (EEDI)

To be inclusive, EEDI and EEIO are also reviewed. The Energy Efficiency Design Index (EEDI) is mandatory for new ships since January 2013 [39]. The EEDI for new ships is the most important technical measure and it aims at promoting the use of more energy efficient (less polluting) equipment and engines. The EEDI requires a minimum energy efficiency level per capacity mile (e.g. tonne-mile) for different ship type and size segments.

There is a reference level for ship type which is to be tightened incrementally every five years. Therefore EEDI was expected to stimulate continued innovation and technical development of all the components influencing the fuel efficiency of a ship from its design phase.

The EEDI leaves the choice of technologies to use in a specific ship design to the industry. As long as the required energy efficiency level is attained, ship designers and builders are free to use the most cost-efficient solutions for the ship to comply with the regulations. The EEDI provides a specific figure for an individual ship design, expressed in grams of carbon dioxide (CO_2) per ship's capacity-mile (the smaller the EEDI the more energy efficient ship design).

CO_2 emission taking into account the combustion in the main engines, auxiliary engines and boilers divided by the work to carry out the goods transport (this transport being expressed as the product between the vessel's deadweight and the ship design speed measured at maximum design load condition and at 75% of the rated installed shaft power).

7.1.13 Energy Efficiency Operational Indicator (EEOI)

EEOI is one element of the IMO regulatory framework that is intended to act as an "energy efficiency performance indicator" during the operational phase of the ship and be used to monitor overall ship energy efficiency performance [40]. The purpose of EEOI is to establish a consistent approach for measuring a ship's energy efficiency for each voyage or over a certain period of time. The EEOI was expected to assist ship-owners and ship operators in the evaluation of the operational performance of their fleet. However, like EEDI – EEOI isn't implement very well.

7.1.14 ENTEC UK Limited

This method investigates the costs, emissions reductions and cost effectiveness of specific SO_2 abatement measures on ships [41]. The following three measures are investigated:

1. Sea water scrubbing
2. Fuel switching from 2.7% Sulphur residual oil (RO) down to 1.5% Sulphur RO
3. Fuel switching from 2.7% Sulphur residual oil (RO) down to 0.5% Sulphur RO

These methods imply the use of different variables, the need of different types of technology, different levels of accuracy and, obviously, a wide range of different costs involved. Hence, the table below has the aim to compare all the methods and to enable the choice of one of them depending on their suitability.

Table 5a. Overview of reviewed methods considering required parameters, accuracy and costs for methods which need equipment on board.

	Parameters needed	Equipment needed?	Accuracy	Costs
Bunker fuel tank monitoring	Readings of fuel tanks on-board Period of time considered Fuel type Fuel sulphur content	Yes. Larger ships have it on board	Sensitive to inaccuracies as it relies only on fuel tank readings Discrepancies between the tank volume calculated and the actual volume consumed due to on-board fuel treatment processes	1,000-3,000 USD per tank Maintenance of devices Data reporting costs/burden modest if automatically monitored Costs may have to be incurred to prove the device works properly*[31]
Flow meters	Capture de fuel that is used on board Measure de fuel flow directly or indirectly Monitor all entries of fuel consumers	Yes. Modern fuel systems already have it	Highest potential accuracy	15,000-60,000 USD Maintenance of device Data reporting costs/burden modest if automatically monitored Costs may have to be incurred to prove the device works properly*[31]
CEM	CEM system on every stack System continuously working System working properly Monitored data correctly documented Documented data correctly been reported	Yes, but not widely used in the sector yet	+/- 2%	120,000-130,000 USD Automatic monitoring and recording means modest costs Costs may have to be incurred to prove the device works properly*[31]
On-board monitoring devices	Capture all fuel used on board Measure fuel flow directly (by volume, velocity or mass) or indirectly (by pressure) Monitoring all entrances of fuel consumers	All kind of meters	High potential accuracy depending on the choice of flow metering system, improper operating environment, installation and maintenance, calibration requirements and operator competence	Depending on type of sensors
PEMS	System on every stack System continuously working Monitored data correctly documented Documented data correctly been reported Experienced operators Frequent calibration	Portable emissions measurement device	PEMS are typically limited in size, weight and power consumption, it is often difficult for PEMS to offer the same accuracy and variety of species measured as is possible with top of the line laboratory instrumentation	-
ENTEC	Test duration 150 min Data logged at 15 sec intervals Average SO_2 value before scrubbing Average SO_2 value after scrubbing Best average continuous rate of SO_2 removal Best maximum continuous rate of SO_2 removal Worst average continuous rate of SO_2 removal NO_X average removal rate	Scrubber	The method has a good accuracy but its objective is to reduce emissions of SO_2 and NO_X by using seawater scrubbing (SWS) and not to measure them	-

Table 5b. Overview of reviewed methods considering required parameters, accuracy and costs for methods which do NOT need equipment on board.

	Parameters needed	Accuracy	Costs
BDN	BDN notes Oil record book	1 to 5% Varies depending on how the fuel quantity is determined	No equipment costs No running costs Data reporting costs/high burden due to use of paper records*[31]
CARB	**Ship** Name, Date Built, Type, Ship Electrical Power, GT, NT, DWT, average daily fuel consumption at normal cruise speed at sea **Main engine (ME):** number, type, Date Built, Fuel Used, Average cruise power at sea, Average cruise speed at sea, Engine modifications completed to either improve fuel efficiency or reduce emissions **Auxiliary engines (AE):** Make, Model, Date Built, Rated Power at MCR, Type, Fuel Type used within 24 nm of CA baseline, Average total ship power generated from engines (at sea, manoeuvring and hoteling) Potential vessel modifications for using marine distillate fuels	Only ocean-going vessels. Only explains the parameters, but not the method to calculate emissions	Working time for employees comparing data from CARB method with the vessel's ones
Use of questionnaires	Ship type GT or length	Correlation coefficients are rather low due to number of ships per ship type is small and the variability in the outcome was rather large. Nevertheless, ships GT showed overall the best correlation with fuel rate. It showed much better correlation than the amount of auxiliary power available on a ship	Working time for employees comparing data from Use of Questionnaires method with the vessel's ones
Use of tugs	Engine's horse power Operating mode	Very low as the method compares the data from the vessel being analysed to data from tugs which are considered the worst case	Working time for employees comparing data from Use of tugs method with the vessel's ones
STEAM 2	Data from AIS (location, instantaneous speed) Data from HIS Fairplay and others Ship technical data (ship type, ship speed, engine load, fuel sulphur content, multi-engine set up, abatement method, waves)	Geographical resolution of emission grids is limited by the accuracy of GPS, few tens of meters. The update frequency of AIS signals varies according to the data source (from five to six minutes for small areas). The best available update rate is once in every two seconds. STEAM2 updates the ship positions every second, as it interpolates the location information between two subsequent AIS position reports.	Not commercialized
TNO	Fuel consumption, Fuel type Emission factors Statistics of freight transport	The complexity and diversity of the data obtained from these parameters make the accuracy unreliable	Working time invested by employees in using the method
EEDI	CO_2 emission from combustion of fuel Ship's capacity (DWT) Ship design speed measured at maximum design load condition and at 75% of the rated installed shaft power	It is a robust mechanism that may be used to increase the energy efficiency of ships, stepwise, to keep pace with technical developments for many decades to come	Time used for gathering the information needed to calculate EEDI
EEOI	Fuel type, Trip number Mass of consumed fuel per trip Fuel mass to CO_2 mass conversion factor for fuel Cargo carried (tonnes) of work done (number of TEU or passengers) or gross tonnes for passenger ships Distance in nautical miles corresponding to the cargo carried or work done		Working time

7.2 Best useable alternative methods

Which of the reviewed methods would be suitable to use on board as an alternative? The possible best usable method is found by assessing (table 5a end 5b):

4. if the relevant parameters already are monitored/available on board for the reviewed methods,
5. ranking of methods,
6. the outcome of each method in relation with research objectives.

7.2.1 Ranking of methods

The methods of the review are ranked for their feasibility (table 6a and 6b). Preliminary can be concluded that use of the bunker delivery note would be the best method to perform MRV, based on parameters needed, equipment needed, accuracy (as well as on-board monitoring devices and use of Flow meters), and costs. However, how do the methods score when their readiness for implementation is concerned? Therefore, all methods are scored for data availability (already monitored/available), costs, expected accuracy, readiness for implementation. Methods with a low feasibility are considered less suitable to be used as a method:

0 lowest score (data not available, DNA)
5 highest score

If data is not available, the method obtains a 0 regardless its accuracy, implementation or cost.
If data is available, the method obtains points as below:

0-2 data availability on board
0-1 readiness for implementation
0-1 expected accuracy
0-1 costs

The methods are divided into Ship Based Methods (SBM, table 6a) and Theoretical Based Methods (TBM, table 6b). SMB's have their emphasis on the collection of data on board of each individual ship. In TBM's emission results are (partly) obtained via modelling. There is no data recorded on board.
Preferably, only SBMs will be considered appropriate according to the aim of the project. The MRV regulations have their focus on individual ships. In the European scheme the monitoring results are published of each individual ship. TBM's however could be taken into account to verify that on-board data complies with theoretical values obtained from these TBMs, analogue to the verification process in aviation.

7.2.2 Ranking results

As a result, four ship based methods have been prioritized in the score as feasible ship based method. These four methods are Bunker Fuel Delivery Note (BDN), Bunker Fuel Tank Monitoring, Flow Meters and On-board Monitoring Devices. These methods are all provided by the European MRV scheme. BDN, fuel tank monitoring and flow meters have very low acceptance by the shipping industry as these share direct fuel consumptions. These methods are thus less feasible as method to be used in the context of the study. For on-board monitoring devices this depends, because it relies on what is monitored and what the outcome of the combined parameters is (see table 3 and discussion).
CARB and STEAM2 score the highest of the TBM's. Most of the required data is available for the methods. CARB scores 1 on costs and STEAM2 on accuracy. It depends on the output of the methods if the methods could be useful.

Table 6a. Assessment of the methods for their potential to be used as alternative method. The assessment included the analysis of required and available parameters and the score for their direct feasibility for Ships Based Methods

Methods	Parameters needed	Presently available parameters	Scores	
BDN	BDN notes	BDN are available on all vessels, however there is an absolute reluctance to divulge this information to a third party. Establishing specify fuel usage for a particular time period/voyage would be time consuming and require reference to the oil record book.	**SMB**	**4**
	Oil record book	Maintaining the oil record book (ORB) is a mandatory requirement for most vessels, the data for establishing fuel usage is available. The ORB viewed for this lacked completeness and clarity. Extracting the data to establish specify fuel usage for a particular time period/voyage would be time consuming and cumbersome.		
Bunker fuel tank monitoring	Readings of fuel tanks on-board	Generally, this data is collected on a daily basis, the data was not available on the vessel visited, other ships did sound their tanks, but were not happy to share the data.	**SBM**	**3**
	Period of time considered	Data not made available.		
	Fuel type	HFO, MDO, sludge etc.		
	Fuel sulphur content	Available from bunker delivery note and fuel sample testing. Information not made available.		
Flow meters	Capture de fuel that is used on-board	This data is recorded in the engine room log book and made available in WP1. The data is provided on a daily basis covering a period of a completed voyage and includes usage of HFO & MDO.	**SBM**	**4**
	Measure de fuel flow directly or indirectly	Fuel flow is measured directly, however fuel consumption by individual users is derived from direct values, this is a characteristic of most fuel systems that need to deal with oil recirculation.		
	Monitor all entries of fuel consumers	Consumption for main and auxiliary engines was made available. Boiler and incinerator consumptions are not measured but could possibly be derived.		
CEM	CEM system on every stack	No use of CEM	**SMB**	**0**
	System continuously working	No data available		
	System working properly	No data available		
	Monitored data correctly documented	No data available		
	Documented data correctly been reported	No data available		
On-board monitoring devices	Capture all fuel used on board	This data is recorded in the engine room log book and made available. The data is provided on a daily basis covering a period of a completed voyage and includes usage of HFO & MDO.	**SBM**	**4**
	Fuel flow directly or indirectly measured	Fuel flow is measured directly, however fuel consumption by individual users is derived from direct values, this is a characteristic of most fuel systems that need to deal with oil recirculation. WP1 identified that the log book entry of fuel consumption is derived from metered values.		
	Monitoring of all the consumers	Consumption for main and auxiliary engines was made available. Boiler and incinerator consumptions are not measured but could possibly be derived.		
	Position of vessel	This information is recorded in the bridge log		

	Speed of vessel	This information is recorded in the bridge log		
Use of question-naires	Ship type	Data available	**SBM**	**3**
	GT	Data available		
	Length	Data available		
Use of tugs	Engine's horse power	Information is unlikely to be available.	Obscure method	
	Operating mode	Information is unlikely to be available.		
PEMS	Use system on every stack	No use of PEMS	**SBM**	**0**
	System continuously working	No data available		
	Monitored data correctly documented	No data available		
	Documented data correctly been reported	No data available		
	Experienced operators	No data available		
	Frequent calibration	No data available		
EEOI	Fuel type	Data available	**SBM**	**0**
	Trip number	Data available		
	Mass of consumed fuel per trip	This data is recorded in the engine room log book and made available. The data is provided on a daily basis covering a period of a completed voyage and includes usage of HFO & MDO.		
	Fuel mass to CO_2 mass conversion factor for fuel	IMO defined factor. Available via BDN		
	Cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships	Not directly available		
ENTEC	Test duration 150 min		**SBM**	**0**
	Data logged at 15 sec intervals			
	Average SO_2 value before scrubbing			
	Average SO_2 value after scrubbing			
	Best average continuous rate of SO_2 removal			
	Best maximum continuous rate of SO_2 removal			
	Worst average continuous rate of SO_2 removal			
	NO_x average removal rate			

Table 6b. Assessment of the methods for their potential to be used as alternative method. The assessment included the analysis of required and available parameters and the score for their direct feasibility for Theoretical Based Methods

Methods	Parameters needed	Presently available parameters	Scores	
CARB	Ship data	Available	**TBM**	**3**
	ME data	Data showed that ME performance can be verified since fuel consumption, rpm and power are recorded. Manufacturer's engine data was made available.		
	AE data	Data showed that AE performance can be verified since fuel consumption and power (data is suspect) are recorded. Manufacturer's engine data was made available.		
	Potential vessels modification for using marine distillate fuels	N/A		
STEAM 2	Data from AIS (location, instantaneous speed)	Information not considered, but available at each ship	**TBM**	**3**
	Data from HIS Fairplay and others	Information not considered		
	Ship technical data (ship type, ship speed, engine load, fuel sulphur content, multi-engine set up, abatement method, waves)	General ship data the vessels availalble The bridge log containing vessel speed and position was requested,b ut not made available. The engine room log was made available. The data is provided on a daily basis covering a period of a completed voyage and includes usage of HFO, MDO and LO for main and auxiliary engines.		
TNO method	Fuel consumption	This data is recorded in the engine room log book and made available. The data is provided on a daily basis covering a period of a completed voyage and includes usage of HFO & MDO.	**TBM**	**0**
	Fuel type	HFO and MDO.		
	Emission factors	Not available		
	Statistics	Not avaialbe		
EEDI	CO_2 emission from combustion of fuel	The vessels for which data was collected were pre-introduction of EEDI, as such EEDI supporting data is not available for both vessels.	**TBM**	**0**
	Ship's capacity (DWT)			
	Ship design speed measured at maximum design load condition and at 75% of the rated installed shaft power			

7.2.3 Relation with research objectives

The output of each method is assessed whether a method would be suitable or not for meeting the objectives of anonymity and sensitivity (table 7). Most methods do not satisfy as method in this context. It is not possible to share data anonymously or share less sensitive data. The four proposed methods score high, but their output is problematic.

The methods which could be useful are on-board monitoring devices, CARB and the approach of STEAM2. Both methods have these same rationale, namely to calculate fuel consumption/emission data off the ship. CARB consults the vessels and calculates the results externally. STEAM 2 models the emissions by tracking the vessels and using external data. Table 3 discusses why these methods could be useful.

Table 7. Assessment of the methods for their potential to be used as alternative method. This table shows whether the outcomes fit with anonymity and sensibility for SBM and TBM.

	Method outcome in relation with project objectives
BDN	BDN data provided direct information about the fuel consumption of a vessel. The data has a very high confidentially for ship owners, and cannot be made anonym, the willingness to share is very low. This method is useful for to meet the EU goals, but far less useful to meet the objections by the shipping industry.
Bunker fuel tank monitoring	As with BDN establishing specific fuel usage would be difficult with regards to the confidentiality of the data and of anonymity in publication of the data.
Flow meters	The method is able to show the fuel consumption on a direct basis. This is however the considered confident data directly undisclosed too.
CEM	Continuous emission measurements present direct information about the emissions from a ship. The method is less sensitive than fuel consumption, because there is less information available about the fuel consumption. The method determines the resulting emissions. Yet, this can be back calculated via emission factors. Data from emission monitoring can be part of a national (or nautical) emission inventory. In inventories, data can be presented anonym; which will be the case in the IMO MRV scheme. Not many ships have CEM equipment installed, so this method is less feasible for in the near future.
CARB	The CARB method uses questionnaires for collecting the data. The data is first-hand, but is not directly submitted by the vessels themselves. Emissions are calculated by the fuel consumption numbers from the vessels. The output of CARB can be problematic for the shipping industry, because all their data is known by the questioners. It is up to them what is being published, but that depends on the objectives of the questionnaire. If this is part of an inventory than anonymity is less problematic. This method is suitable to use in the verification process.
On-board monitoring devices	The output depends on what is being monitored. Ships can monitor their fuel consumption with monitoring devices. Though, the approach can be basic by just monitoring the required parameters. But ships can monitor more to be able to assess all kinds of processes on board related to its energy use by installing all kinds of sensors and monitoring equipment. And so, possibly monitoring parameters which are less sensible to share.
Use of question-naires	More or less the same method as CARB, but using a different emission calculation model and emission factors.
PEMS	The use of Portable Emission Monitoring Systems is very useful for emission factor calculations. The disadvantage of the method for ship emissions determination is that the measurements are mere periodical. Results need to be extrapolated when used as method for aggregated emissions, which reduces accuracy. For individual ships this method is useful to determine combustion efficiency and the ship’s specific emission factor.
STEAM 2	This is a guessing method, because almost all data does not originate from the vessels themselves. The method is developed to be able to calculate ship emissions without the very specific information of each ship. This modelling method uses recorded AIS data as input to calculate the emissions from ships. Technical data is retrieved from external parties. The method takes into account emission abatement technologies and natural conditions. This method is the most detailed method of all modelling methods in this method assessment. As such, the method could meet the anonymity objection, by making a first calculation based on external data which in turn will be verified by the ships (within a certain accuracy range). The model data will be published as monitoring results This approach also assures careful use of ship sensitive data.
TNO	A modelling method based emission factors and questionnaires. The emission factors are based on GT to circumvent the often-lacking information about installed power. This method is suitable to use in emission inventories but less for emission determination of individual ships.

8. Discussion

8.1 Use of on-board monitoring equipment

The method of using on-board monitoring equipment ranks high in the scoring and is feasible when the output is considered. The potential of this method lies in the way what is being monitored. Firstly, one can monitor the fuel consumption and carbon content of the exhaust gasses; the basic approach to comply to the regulations. But secondly, ships can monitor other additional (relevant energy) processes or proxies by implementing more measuring and monitoring equipment. More on-board processes can be followed.

Here is also a direct link with the theoretical approach in the parameter study. Presently too few relevant parameters are collected on board to perform a proper energy flow path analysis. Ship operators may install equipment to monitor the missing parameters to be able to calculate the energy uptake by the various mediums. The latter can act as proxy for energy consumption and in the energy efficiency analysis.

8.2 The use of efficiency

Energy efficiency, even so, has characteristics to share energy related information and how an entity performs without sharing information about direct fuel consumption. Energy efficiency describes the overall performance of energy consuming entity. And so, no direct confidential data would be shared. Thus, energy efficiency information is less sensible to share. Efficiency appears several times in this study as a concept to overcome the problem of sensitivity in the MRV schemes. Efficiency is less relevant concerning anonymity, because ships still have to publish the efficiency of each individual ship. For statistics, the efficiency of a group is sufficient, but quite general. When it concerns actions from the market, the market needs to know the efficiency of specific ships to take now if it's suitable for hire or not.

It's the lack of information about energy efficiency on board ships and the lack of energy related actions, however, which triggered the development of MRV legislation. EEDI and EEOI deal with energy efficiency. EEDI is a measure for efficiency itself [39] based on CO_2 output per work done:

$$EEDI = \frac{Shaft\ Power \times Specific\ Fuel\ Consumption \times Carbon\ Emission\ Factor}{Deadweight \times Ship\ Speed} \quad (6)$$

So, using efficiency in MRV is more or less complying to EEDI/EEIO regulations. It may be the best way for the industry to put more effort into EEDI and EEIO from this point of view. Although the analyses are different – energy efficiency is energy output divided by energy input, EEDI is the resulting emission efficiency of the performed work by a ship – both describe how the energetic performance of a ship.

A way to consider energy efficiency and sharing efficiency data in an MRV scheme is to introduce energy efficiency labels presently in use in Europe. In Energy Labelling Framework Directive (2010/30/EU) every energy consuming entity needs to have a label which states how much that entity performs in relation to its energy use [42]. Label A products are more efficient than label C products for example. Each label covers a range of efficiencies. The direct efficiency is not directly known, but works for the market. Such a system could work for shipping: the market knows in which range of efficiencies a vessel operates. The vessel itself submits its direct information to the relevant authorities to comply with the regulations.

8.3 Theoretical Based Methods

The assessment shows that two TBM's could be feasible as alternative method: the use of questionnaires (CARB) and the use of AIS data (STEAM 2). Questionnaires are used to extract activity data from ships. In the second method activity data is subtracted from AIS data. The emission/fuel consumption results of both approaches are obtained by model calculations.

Emission modelling is the present way of working in extracting ship emissions. There is a ship information knowledge gap which was one of the motives to develop MRV to gain more exact insight in ship emissions. Using these approaches would seem to be a step backward instead of forward.

The modelling approach could be useful when MRV in aviation is considered, in particular when verification is concerned.

8.4 MRV in aviation

European aviation is too obliged to monitor their annual fuel consumption as part of the European Emission Trading Scheme [43,44]. Aviation is quite comparable with shipping. Aviation is like shipping international oriented as are its operations in navigation, technologies, and load and stability. Shipping might thus learn from, or at least have a look at, the MRV experiences in aviation.

From 2012 onwards, all flights departing and arriving in European airspaces monitor their fuel consumption. Only intra-European flights fall under the directive. To reduce administrative burden, flight operators emitting less than 1000 metric tonnes CO_2 annually are exempted for the regulations. Simpler requirements apply when operators emit more than 1000 metric tonnes but less than 25,000 metric tonnes of CO_2 and operate less than 243 flights per consecutive four months. Monitoring in aviation concerns the following (also according their monitoring plans):

- For each type of fuel for which emissions are calculated:
    - fuel consumption, generally measured on board of a plane
    - emission factor
- Tonne-kilometre data
    - tonne-kilometres = distance × payload where

Verification serves the same goal as in the maritime schemes [44]. Important part in the verification process is the air traffic control (ATC) check. ATC controls all flight movements and receives all kind of data from planes during the flight. ATC monitors and stores all this data and so all historic flight data of each individual airplane can be scrutinized. This offers the possibility to examine the monitoring results by the operators with the ATC data and to check if these are correct.

The monitoring results will be non-disclosed as function of each individual airplane or operator. An aggregated number of all aviation emissions will be part of a Member State's emission inventory and published as such [43].

Aviation is dominated by just a few aircraft manufacturers which assemble standard aircraft types. There is also a limited number of aircraft engine manufactures and thus engine types. This simplifies the monitoring stage. There is only a limited of systems available. The limited available engines ensure less uncertain emission factors.

Shipping, other than aviation, has a wide variation of ship types, hull shapes, engines, operations. The energy consumption of an average ship is far more difficult to predict than for airplanes. In most monitoring cases for ships emission factors have to be used too. Emission factors can only be general numbers, because each ship is different. The emission uncertainty is therefore far higher on ships.

8.5 Modelling approach as monitoring tool

Both TBM approaches are excellent methods to verify the monitoring by ships. CARB verifies fuel consumption on board by means of questionnaires. STEAM 2 verifies ship emissions by modelling the ship's work based on AIS, technical data and real-time weather and sea conditions. The methods – especially STEAM 2 – could be used in the verification process analogue to the ATC verification in aviation.

The approaches could be used the other way around to use these for monitoring itself. The methods are useful in the context of this study. Both approaches collect data about fuel consumption and emissions beyond the responsibility of ship operators. And so is relevant data collected without sharing direct consumption data. In this approach, relevant data is collected via modelling. The model results are verified by the ships – ships still need to do monitoring. If the results are in the same order of magnitude, the modelling results will be published and available to the market. The specific information will be shared confidentially to the relevant authorities. The ship data is treated with care and there is less impediment in relation with anonymity, because the market has merely a direction of the fuel consumption of the vessels. This work could be done by a dedicated organization which monitors the ships via AIS and modelling. Subsequently, the results are brought to the vessels during for example Port State or any other audit.

8.6 Paradox

The main topic of the research is the search for a method for MRV on board ships which shares less sensitive data about the fuel consumption of vessels. That information is considered as confidential and too sensitive for third parties. Legislation demands non-disclosure of the data from shipping.

This study tries to find an alternative method which serves both goals: 1. fuel consumption/carbon emissions are still fully monitored and reported, and 2. the direct fuel consumption/emissions are disclosed and the results have been made anonymously. The latter is done by searching for methods, proxies, parameters which deliver information about fuel consumptions emissions, but which do not directly link to a vessel or present direct information of the fuel consumption.

This seems paradoxical, because even with a proxy value one would be able to find out the real values of a ship – when the method for the calculation or determination is known. And thus, would the alternative method unsuccessful in meeting the arguments by the shipping industry. And would such a method not exist. Shipping has simply to comply.

This study tries to look for possibilities for serving both goals, notwithstanding this paradox. This is done by looking at what already is being monitored on board and could be shared less problematic and by looking at proxies or alternative methods for monitoring. A different monitoring approach might shift focus and so take away some of the constraints of the maritime industry, yet ships comply with the regulations.

To address this paradoxical problem, this study assessed each method to firstly if the method would be feasible from shipping perspective, and secondly from the perspective of the regulations. Fully compliance with both goals seemed to be difficult. However, to certain extents meeting the goals is possible in some of the monitoring methods.

8.7 Implications

The implication of using efficiency or the modelling approach is that no suitable infrastructure exists. These suggested approaches are quite conceptual and need further development. An energy label scheme needs to be developed or an organization for modelling needs to be established. This has its costs in time, money and work. This raises also the question who will be responsible: are ship operators for their own energy labels or relevant authorities; who will perform the modelling and will deliver the model's input? Preferably ships should be saved from all this to reduce the workload. In

Europe, EMSA is an important actor in the validation process [19]. EMSA could also be made responsible in the development of an agent for the modelling or the distribution of the energy labels. EMSA has already access to relevant data, which could make this process less expensive. The designated agent should act independent from EMSA, because EMSA will also have access to the submitted data from the ships themselves. Port State Control or classification societies would be capable, because both validate already safety and performance of ships.

8.8 List of questions

Parallel to the search for a suitable alternative method the list of questions was developed. The MRV methods in the maritime schemes are not legally prescribed. Each party is allowed to develop a new method to perform MRV on board. However, each method will be verified before the specific method may be used. Developers are able to proof with help of the list of questions their method is feasible to use as MRV method. The topics of the questions are relevant in order to develop an MRV scheme with satisfactory results.

The topics of the questions are based on fundamental elements needed in MRV. The potential of a new MRV method depends on how it scores in relation with these elements. The list of questions is a first set up and should be further developed, because not all MRV literature which could be relevant is included in the analysis.

Due to a lack of resources the methods were unfortunately not assessed by the questions into depth. Using the question would however pull the suggested methods further out their present basic conceptual stage. This is unfortunate, because the validity of the methods could not be tested in the present study. Though, this study already provided the input for filling this gap.

8.9 Future work

The main objective of this research was the proposal of a new MRV method through a data collection scheme on fuel consumption to deal with issues of sensitivity, anonymizing and data suitability. There are two approaches which can be used as method of MRV on board which are suitable to incorporate the sensitivity of the data and the problem of anonymity of the shared data. The methods, however, need further development. They need for example to be assessed with the list of questions – the list of questions needs also to be extended. Additional, the methods need to be assessed to what is further needed in the application of the methods. The methods could conflict with legislation. The methods could also conflict with interests of stakeholders, e.g. the owners of the model or the AIS data. Research is needed to validate the methods and to verify what is required to get the methods out of the conceptual stage. Case studies on board or between ship and shore could deliver practical results. For instance, research can implement each of these MRV methods analysed in previous sections simultaneously on several vessels to determine the accuracy of each method. This will allow to compare and contrast each MRV method and be able to provide insights as to how much error could be expected from each MRV method.

Because the resulting methods are conceptual, our suggestion is to first have a look at the validity of the methods before consulting the maritime industry and relevant actors. There is a large risk the approaches will be disapproved beforehand

Further developed measures are likely to be easier accepted as possible solution rather than conceptual suggestions with possible potential. First the base needs to be studied before the industry should have its say whether they would use such methods or not.

Further research could elaborate more the relation with the aviation MRV scheme: what can shipping learn more from its little airborne sister? There is to our knowledge no literature dealing with this topic. Questions could be: what will the practical implementations be? How will for example MBM's work out for shipping?

Another different approach is to make other parties responsible for the data. The idea is that no direct information of a ship will be published. Other stakeholders than shipping for example have already a large role in the emission modelling method. Most of the data comes from other parties. This approach is a step further. For example, a bunker supplier could submit its annual delivered amount of fuel instead. Further research would focus on whether the rationale of maritime MRV still stands or not following this idea. Secondly, a stakeholder analysis is required to find out which data from which stakeholder suits and which doesn't suit.

9. Conclusions

This research is one of the first attempts to scientifically evaluate to what extent the arguments of the shipping industry concerning monitoring, reporting and verification could be included in monitoring methods on board. MRV has been introduced to benchmark the present carbon emission and fuel consumption by shipping. The purpose is to evaluate the effect of present and future energy efficiency measures. As such, the measure is valuable, because the results will stimulate sustainable ship operations. It is therefore important that the shipping industry adopts MRV.

The arguments by the industry, however, should also be taken into account. The industry fears it is obliged to share and publish company sensitive information. The industry also wonders what will happen with their data. It prefers to see their data anonymized. Lastly there is a perceived lack of knowledge about how to implement MRV on board their ships in relation with costs, responsibilities, monitoring methods and the way shipping firms operate. These arguments should be taken into account in order to involve the industry for this important environmental measure.

This study contributes to the discussion of which methodical approaches for MRV could be interesting for the industry to implement. The study raises the premise that values other than direct information about fuel consumption/carbon emissions could be shared too. Such values must present information about the energy performance of a ship without publishing the exact energy performance values. These are proxy values or the results of monitoring methods with different approaches. There is less impediment in relation with anonymity, because the market has merely a direction of the fuel consumption of the vessels. Ships of course still need to share their data with the designated authorities. Though, ship data are treated with care.

A thermo-dynamical analysis of the on-board energy flows is an approach which includes proxies. This analysis makes use of parameters which are already being monitored. The latter is important, because the use of existing infrastructure keeps low the extra workload coming forth from MRV. A proxy in the thermo-dynamical analysis is the energy uptake by other mediums such as cooling water, lubrication and exhaust gasses and other heat losses. Such a method could be useful, but more values are required. The presently monitored parameters are insufficient. Important lacking parameters are mass flows of the various mediums.

Secondly this study looked at different approaches as monitoring method which also not present the direct fuel consumption information. The review and method assessment resulted in two useful methodical approaches: the use of on-board measurement equipment and the use of off-ship modelling (CARB and STEAM 2). The method of using on-board monitoring devices is a method which has the potential of qualifying with the objectives of less sensibility and more anonymity. The potential of this method lies in the way and what is being monitored. Ships can monitor other additional relevant energy processes or proxies like efficiency by using measuring and monitoring equipment. Efficiency does not directly show information about direct fuel consumption. And thus by for example monitoring the mass flows of the relevant medium so that the thermo-dynamical method can be used. An important remark concerning the use of efficiency is that the original measures of EEDI and EEIO were focussing on efficiency. MRV has been proposed to force the industry to have a look at its efficiency. It should be kept in mind that by using efficiency the discussion has arrived at its starting point. One could consider the introduction of energy labels for ships to overcome this issue. An energy label shows in which range of efficiencies a particular ship operates. The vessel itself submits its direct information to the relevant authorities for complying with the regulations. This ensures the knowledge of the fuel consumption at the legislative level and enhances the idea of energy efficient ships in the market. The methods need to be assessed to what is further needed in the application of the methods.

Emission modelling could also be an alternative. This seems to be strange while on of the rationales of the introduction of MRV is that modelling is not specific enough about ship emissions. However, modelling with the aid of AIS – as in STEAM 2 – is very suitable to use as verification method, analogue to air traffic control in the aviation MRV scheme. To overcome the problems by the industry, the approach could be the other way around. Ship fuel consumption/fuel consumption is monitored via AIS and models. Subsequently, the results are brought to the vessels. The model results are verified by the ships. If the results are in the same order of magnitude, the modelling results will be published and available to the market. The specific information will be shared confidentially to the relevant authorities.

An additional outcome of the study is the list of topics and questions which should be asked when considering the development of an MRV scheme and the introduction of a monitoring method. Such a list was not yet available in the maritime context. There is a knowledge gap about the implications of MRV on board and what a proper way of MRV on board could be. These questions could be handful to the industry to the required actions for implementation of MRV. It also helps in the development of MRV methods, because the methods for MRV are not legally prescribed.

The list of questions is a first set up, as are the discussed methods. More work is needed to complete this list. At the same time more work is needed to validate the (still) conceptual proposed methods to make these more mature to be eventually used on board.

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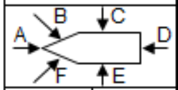
appendix

Appendix

Appendix 1 - Engine Room Log Book Extract

DATE	VESSEL'S POSITION	TIME SHIFT +/-HRS	WIND  FORCE BFT	WIND DIRECTION	DURATIONS: MAIN ENGINE IN OPERATION: SEA HRS	MIN	MANOEUVRE HRS	MIN	FOR CARGO OPERATION HRS	MIN	TOTAL HRS	MIN	VESSEL: Anchorage DRIFTING HRS	MIN	IN PORT HRS	MIN
1	La Pallice												24			
2	La Pallice												24			
3	La Pallice												2			
4	La Pall-Antw				13						13					
5	La Pall-Antw				24						24					
6	La Pall-Antw						19				19					
7	Antwerp															
8	Antwerp															
9	Antwerp-Boma				8		9				17					
10	Antwerp-Boma				24						24					
11	Antwerp-Boma				24						24					
12	Antwerp-Boma				24						24					
13	Antwerp-Boma				24						24					
14	Antwerp-Boma				24						24					
15	Antwerp-Boma				24						24					
16	Antwerp-Boma				24						24					
17	Antwerp-Boma				24						24					
18	Antwerp-Boma				24						24					
19	Antwerp-Boma				24						24					
20	Antwerp-Boma				24						24					
21	Antwerp-Boma				24						24					
22	Antwerp-Boma				24						24					
23	Antwerp-Boma				24						24					
24	Antwerp-Boma				24						24					
25	Antwerp-Boma				17	30	6	30			24					
26	Boma															
27	Boma															
28	Boma															
29	Matadi						3				3					
30	Matadi															
31																
				TOTALS	422	30	37	30			459		50			

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	MAIN ENGINE TEMPERATURES								
DATE	SCAV AIR °C	HIGHEST EXHAUST GAS °C	EXHAUST BEFORE T/C °C	PISTON COOLANT OUTLET °C	CYL COOLANT OUTLET °C	LO INLET MAIN ENGINE °C	LO INLET RED. GEAR °C	INJECTOR COOLANT INLET °C	FUEL INLET °C
1				N/A	78	46	n/a	n/a	128
2				N/A	78	46	n/a	n/a	130
3				N/A	78	46	n/a	n/a	130
4	42	359	365	N/A	78	46	n/a	n/a	132
5	37	320	320	N/A	78	46	n/a	n/a	47
6				N/A	78	46	n/a	n/a	44
7				N/A	78	46	n/a	n/a	44
8				N/A	78	46	n/a	n/a	44
9	36	320	320	N/A	78	46	n/a	n/a	44
10	38	338	330	N/A	78	46	n/a	n/a	130
11	38	336	330	N/A	78	46	n/a	n/a	134
12	38	334	340	N/A	78	46	n/a	n/a	130
13	38	336	340	N/A	78	46	n/a	n/a	130
14	37	336	340	N/A	78	46	n/a	n/a	132
15	37	334	345	N/A	78	46	n/a	n/a	132
16	38	336	345	N/A	78	46	n/a	n/a	132
17	39	344	350	N/A	78	46	n/a	n/a	133
18	39	348	350	N/A	78	46	n/a	n/a	133
19	40	349	350	N/A	78	46	n/a	n/a	133
20	40	350	355	N/A	78	46	n/a	n/a	132
21	40	348	350	N/A	78	46	n/a	n/a	132
22	40	349	350	N/A	78	46	n/a	n/a	132
23	40	347	350	N/A	78	46	n/a	n/a	132
24	40	342	347	N/A	78	46	n/a	n/a	134
25				N/A	78	46	n/a	n/a	134
26				N/A	78	46	n/a	n/a	134
27				N/A	78	46	n/a	n/a	134
28				N/A	78	46	n/a	n/a	134
29				N/A	78	46	n/a	n/a	134
30				N/A	78	46	n/a	n/a	134
31				N/A			n/a	n/a	

	FUEL CONSUMPTIONS												
	MAIN ENGINE				AUX. ENGINES						BOILERS, IGG		
DATE	HFO AT SEA MT	HFO MANOEUV. MT	HFO CARGO OP. MT	MDO(MGO) MT	HFO AT SEA MT	HFO MANOUEV. MT	HFO PORT MT	MDO(MGO) MT	GENERATOR LOAD kW	HFO AT SEA MT	HFO PORT MT	MANOEUV. ANCHOR DRIFTING MT	MDO(MGO) MT
1							2.5		450		2.0		
2							2.6		450		2.0		
3		0.5					0.4	2.3	450			0.2	1.7
4	10.6	0.3			1.6			1.4	450				1.0
5	3.4			13.7	0.5			1.6	450				
6				15.0				2.8	450				0.4
7								2.6	450				1.5
8								3.1	450				1.5
9				14.5				3.2	450				0.8
10	3.1			22.9	0.4			1.6	450				
11	21.5				2.9				450				
12	21.6				3.0				450				
13	21.5				2.9				440				
14	21.0				3.1				450				
15	21.1				3.1				450				
16	21.1				3.1				450				
17	21.0				3.1				450				
18	21.1				3.1				450				
19	21.6				3.1				450				
20	22.3				3.1				450				
21	22.1				3.1				450				
22	22.3				3.1				450				
23	22.1				3.1				450				
24	21.0				3.1				450				
25	14.8				3.1				450			0.2	
26					3.6				450		1.6		
27					4.2				450		1.6		
28					3.8				450		1.6		
29	2.3				4.2				450		1.5		
30					4.2				450		1.6		
31									450				
TOTALS	335.5	0.8		66.1	68.5		5.5	18.6			11.9	0.4	6.9

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DATE	LUBOIL CONSUMPTION MAIN ENGINE SUMP LTR	 CYL. OIL LTR	 RED GEAR SUMP LTR	 AUX. ENGINES NO.1 LTR	 NO.2 LTR	 NO.3 LTR	RUNNING HOURS MAIN ENGINE HRS	 AUX. ENGINES NO.1 HRS	 NO.2 HRS	 NO.3 HRS	SHAFT GEN. HRS	FRESH WATER GEN PROD MT
1								24			n/a	
2								24	1		n/a	
3		10			60			24	2	2	n/a	
4		158					13	15	4	12	n/a	
5		260					24	6	2	24	n/a	13
6		245					19	18		24	n/a	
7								12		24	n/a	
8								24		24	n/a	
9		188					17	3	13	24	n/a	
10		279					24	1		24	n/a	
11		275					24	4		24	n/a	17
12		280					24	3	1	22	n/a	17
13		280			100		24	1		23	n/a	17
14		275					24			24	n/a	17
15		275					24	19	19	5	n/a	17
16		275					24	24	24	1	n/a	17
17		275					24	3	4	21	n/a	18
18		275					24	4	3	21	n/a	18
19		275			600		24	7	5	19	n/a	3
20		275					24	1		24	n/a	
21		275					24		1	24	n/a	
22		275					24			24	n/a	2
23		275					24		3	24	n/a	16
24		255					24	1	4	24	n/a	
25		258					24	12		24	n/a	
26								24	20	4	n/a	
27								24	24		n/a	
28								24	24		n/a	
29		40					3	24	24		n/a	
30								24	24		n/a	
31											n/a	
TOTALS		5278			760		459	350.0	202.0	466.0		172.0

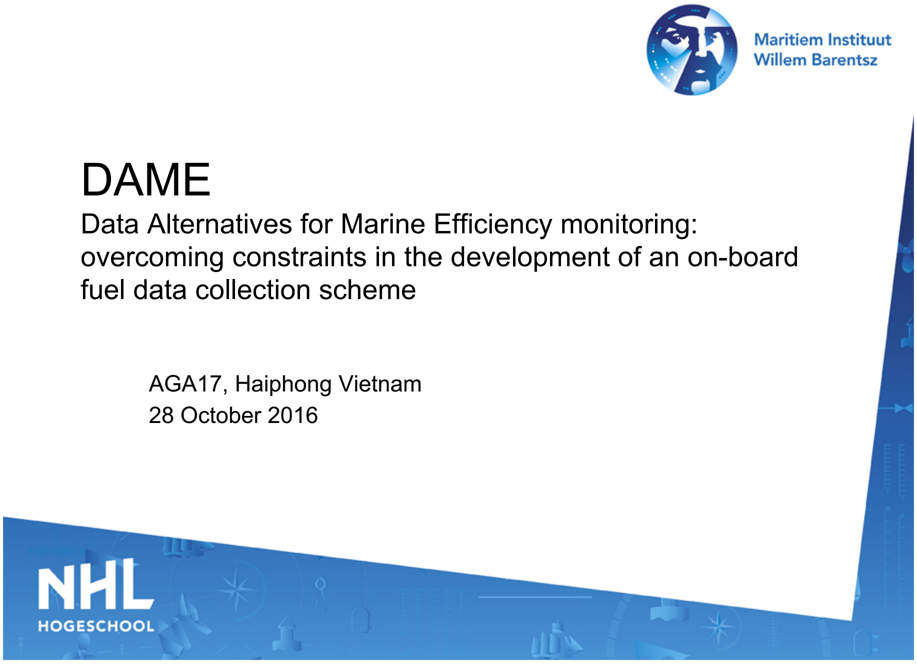
	TOTAL RUNNING HOURS MAIN ENGINE	 RED GEAR	RUNNING HOURS SINCE LAST OVERHAUL A/E NO. 1	 A/E NO.2	 A/E NO. 3	 SHAFT GEN
1ST OF MONTH	22399		17345	15473	26791	N/A
THIS MONTH	459		350	202	466	
END OF MONTH	22858		17695	15675	27257	
TOTAL RUN HRS OF AUX. ENGINES						
LAST LO SAMPLE AT:	12.09.16		12.09.16	12.09.16	12.09.16	
GIVEN ASHORE ON:	17.09.16		17.09.16	17.09.16	17.09.16	

SPEED AT SEA		KNOTS
NOMINAL SLIP AT SEA		%
MAIN ENGINE FUEL CONSUMPTION AT SEA	19.07	MT/D
MAIN ENGINE FUEL CONSUMPTION AT SEA	#DIV/0!	KG/NM
AUX ENGINE FUEL CONSUMPTION	2.47	MT/D
BOILER FUEL CONSUMPTION	0.64	MT/D
MAIN ENGINE LUB OIL CONSUMPTION		LTR/H
MAIN ENGINE CYL. OIL CONSUMPTION	11.49	LTR/H
REDUCTION GEAR LUB OIL CONSUMPTION		LTR/H
AUX. ENGINE NO.1 LUB OIL CONSUMPTION		LTR/H
AUX. ENGINE NO.2 LUB OIL CONSUMPTION	3.76	LTR/H
AUX. ENGINE NO.3 LUB OIL CONSUMPTION		LTR/H
NBR. OF AUX ENGINES RUNNING	1.41	GEN'S/DAY

	FUEL		SLUDGE			LUBRICATING OIL			
SUPPLIERS AND TYPE	HFO MT	MDO (GASOIL) MT	DISPOSED ASHORE M3	INCINERAT ON BOARD M3	REMAIN ON BOARD M3	ME SUMP OIL LTR	ME CYL OIL LTR	AE SUMP OIL LTR	GEAR BOX OIL LTR
R.O.B	387.9	120.3				12300	9911	3380	
RECEIVED	748.2	145.7					14000		
RECEIVED	25.7	7.6							
RECEIVED									
TOTAL AMOUNT	1161.8	273.6				12300	23911	3380	
CONSUMED	422.6	91.6					5278	760	
R.O.B.	739.2	182.0				12300	18633	2620	

			REFRIG.	CHEMICALS					
SUPPLIERS AND TYPE	HYDR. OIL LTR	REFRIG. OIL LTR	GAS KG	BOILER W. TREATM. LTR	COOLING W TREATM. LTR	ELECTRIC CLEANER LTR	CARBON REMOVER LTR	STAIN REMOVER LTR	EMULSIFIER LTR
R.O.B		136		150	25	35	50		
RECEIVED									
RECEIVED									
TOTAL AMOUNT		136		150	25	35	50		
CONSUMED				27					
R.O.B.		136		123	25	35	50		

Appendix 2 - Interim report PPT presentation held AGA17 in Vietnam



Topic of research

Motivation:

Introduction of Monitoring, Reporting, Verification schemes

• EU measurement already in force (2015)

• IMO still debate at MEPC about MRV (2018)

Topic of research

- Fuel consumption and CO_2 emissions are measured to know the amount of energy is being used on board a ship and the ship's contribution to global warming.
- EU provides 4 methods:
  - bunker delivery note
  - tank soundings
  - flow meters
  - direct emission measurements

Topic of research

Preamble 11 of the EU MRV measure

“The adoption of measures to reduce greenhouse gas emissions and fuel consumption is **hampered** by the existence of **market barriers** such as:

- a lack of reliable information on the fuel efficiency of ships
- a lack of reliable information on available technologies
- a lack of access to finance for investments in ship efficiency

Topic of research

The main purpose of this research project is to verify the energy efficiency of a ship and whether existing efficiency measures are sufficient or not.

Is more action needed to comply to international carbon agreements?

Topic of research

Having the following objectives:

1. to identify parameters which are required for energy consumption and emissions on board
2. to evaluate to which parameters sensitivity and/or anonymizing apply
3. to develop an alternative method for energy efficiency monitoring by using for example proxies for problematic parameters.

Project and research design

WP1. Energy parameter inventory

WP2. Evaluation and inventory of alternative methods to calculate fuel consumption and emissions

WP3. Evaluation of parameter inventory in relation with methods inventory from WP2. Finding best fitting method

WP4. Communication and meetings

Topic of research

Having the following objectives:

1. to identify parameters which are required for energy consumption and emissions on board
2. to evaluate to which parameters sensitivity and/or anonymizing apply
3. to develop an alternative method for energy efficiency monitoring by using for example proxies for problematic parameters.

WP1. Energy parameter inventory results

Inventory from cargo ship.

Energy parameter inventory

- Students from LJMU did research to which parameters are measured on board. From one cases, they found that only minor quantifications were measured.

WP1. Energy parameter inventory results

- Another vessel that is being measured is measuring a lot.
- Then we have to extreme cases.
- More ships are needed for inventory: presently going on.

WP2. Evaluation and inventory of alternative methods to calculate fuel consumption and emissions

Just commenced on work package 2. what methods exist which can determine energy consumption and/or carbon emissions?

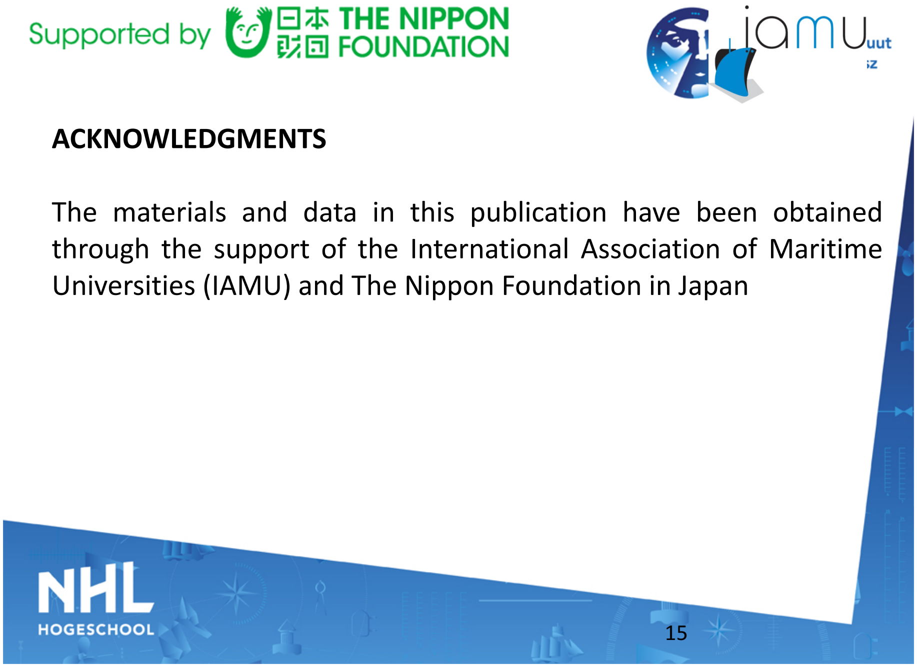
Inventory of alternative energy efficiency methods

Meanwhile literature study on MRV and what a successful MRV implies

At the end of WP1 and WP2, will start WP3. Evaluation of parameter inventory in relation with methods inventory in order to find best fitting method

WP4. Communication and meetings

- 7th March 2016 Amsterdam
- 11th July 2016 Skype
- 14th October 2016 Liverpool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15

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