D5.7 Report on online land-based system tests and ship-based tests

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1 Executive Summary

The primary objective for the EfficienSea2 work package on Emission Monitoring is to develop new emission monitoring concepts to be used by both shipowners and authorities. The goal is to enable the use of continuous emission monitoring systems to deliver data for the shipowner's own and for port state control purposes, and optionally for public access. The study reports on a sulphur emission reporting design specifying the technical aspects of the data transmission flow, storage, analysis and display based on selected key parameter values. A transferable concept of a ship-to-shore reporting and presentation system for sulphur compliance in shipping was developed for the DFDS vessel Optima Seaways.

The EU sulphur directive and the existing IMO SECA areas in the North Sea and Baltic Sea currently sets a scene regarding fuel in the shipping industry of maximum 0.1% S in SECAs and in EU ports and in 2020 a blanket maximum of 0.5% in EU member states EEZ. Currently, two paths exist for shipping to comply: fuel switch to low sulphur fuels, including LNG and other alternative fuels, or installing exhaust gas cleaning devices, i.e. scrubbers, the latter being the object of the present study.

The present post-delivery laboratory based mechanism for sulphur in fuel is not applicable for SO_x emissions monitoring, and although automated or real-time monitoring systems for detecting sulphur content of fuel are emerging, they have yet to reach technological maturity. The scrubber industry applies continuous emission monitoring systems lending themselves readily for the voluntary compliance monitoring system developed in this study, and despite the differences in existing sensor technologies and software there appear to be no barriers for storage of data in transmissible formats on-board.

The short sea shipping company DFDS, that operates a number of European RO-PAX and RO-RO lines, have agreed to install and test the newly Litehauz system. Actual real-time sulphur emission data from a previous study has been used in land-based test to execute the in-house developed script for the analysis and management of the data. The study is currently in the process of finalising the installations on the DFDS vessel Optima Seaways for the ship-based test. Optima Seaways operates an AlfaLaval's PureSOx scrubber equipped with a CEMS from Dansk Analyse. The work package collaborator, partner 21 DANELEC Marine, has supplied the necessary hardware to record data on the ship and transmit it in a standardised format, and this was recently installed and is ready to be connected. Thus, the ship-board tests are underway, and although slightly delayed the study remains on track.

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2 Introduction

The introduction of sulphur emissions reduction in shipping has led to both global targets from the International Maritime Organization and to the establishment of regional Sulphur Emissions Control Areas (SECAs) e.g. the North Sea and Baltic Sea SECAs both covering EU member states water and governed by the EU Sulphur Directive. Port and Coastal states have an obligation to survey and inspect vessels for their compliance with the international and national law, and while new regulation by default tend to increase the administrative burden and the cost to the industry, it is the ambition of many entrepreneurs in the field of performance monitoring that surveys of compliance can be completely automated, thus reducing or eliminating the hassle of operating highly sophisticated equipment and leaving the record-keeping and reporting to electronic systems.

In the sister activities in work package 5 on “Development of a new common port database concept and structure” it is said that “Good nautical and commercial port information is the foundation for efficient and safe port calls”. The same can be said of the environmental monitoring data which, in the future, will form an increasingly larger part of the data exchange with maritime and port authorities. This work package activity and report focus on improving the exchange of information with authorities, and possibly public stakeholders by enhancing the automatic flow of information sea-to-shore. Standardised templates and reporting forms will ensure an efficient exchange of data by streamlining the information flow and allow the information to be used as a basis for Port State Control purposes. This will reduce the administrative burden of updates to shore. This will also help the shipping industry to remain competitive compared to other modes of transport.

A challenge to the information exchange regarding environmental performance data is the “business model” for a voluntary mechanism, as the benefits potentially reaped may hold different attraction for the range of shipping operating under the sulphur reduction emission schemes.

3 Objectives

The work package 5 focus has been on the delivery of new e-solutions related to two important challenges: Reduction of administrative burdens and monitoring exhaust emissions:

- The aim is to develop, test and, where possible, implement administrative e-maritime solutions for automated transfer of information (reporting) to-and-from ports and for transferring port information from the port to the ship and other maritime stakeholders (work packages 5.1 and 5.2).

- The aim is to develop solutions for monitoring emissions with focus on SO_x and conduct validation trials in the Baltic Sea Region (work package 5.3 as reported here).

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The starting case is SO_x emissions in the Baltic Sea Region and the initial thinking is to use onboard sensor data for compliance monitoring. The project has previously evaluated possible incentive structures that could counteract the economic incentive of non-compliance due to the lower cost of undesirable fuels.

It is assumed that continuous monitoring will encourage shipowners to fully comply with emission regulations compared to a setup with relatively rare occasional inspections. For the righteous shipping line, automated and continuous emission reporting will contribute to fairer competition, by making fuel/emission fraud more difficult.

4 The work covered

This report provides information primarily on the Subtasks 5.3.2 *Definition of sensor and monitoring concepts* and 5.3.4 *Field testing, demonstration and evaluation*. There remains a closing deliverable due at the final phase of the project:

- D5.8 Working prototype of online sensor with cloud-based algorithm (M35), which will report on the final parts of Subtask 5.3.4 and on Subtask 5.3.5 Recommendations.

Information on the Subtasks 5.3.1 *Incentives and enforcement* and 5.3.3 *Mapping of sensor technologies and monitoring networks* can be found in the previous report D5.6 (M10).

LITEHAUZ is lead on WP5.3 with input from:

- Gatehouse (partner 24)
  - assist in service development, service and client side – web-based
- BIMCO (partner 14, WP5 lead)
  - user involvement, ship-owners perspective
- Danish Maritime Authority (DMA) (partner 1)
  - assist with service development, servicer side with Maritime Connectivity Platform usage and client side on web based platform
- DANELEC (partner 21)
  - will liaise from WP2, task 2.4 on integrating sensor data collection

The work undertaken is described in the original application as:

Subtask 5.3.2 Definition of sensor and monitoring concepts

Identification of the current status of existing SO_x measurement technologies is part of the initiating work on defining sensor and monitoring concepts. Evaluation and identification of available monitoring technologies will lead to design of an emission control system, including design of software that can collect, analyse and transmit data to the cloud, where emissions are measured and geocoded in SECA (Sulphur Emission Control Area) zones. When using exhaust gas cleaning systems, sulphur oxide (SO_x) emissions must be logged by the equipment and made available for inspection. It is

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suggested that such an approach is enhanced with an automatic emission report sent from the ship or the equipment supplier on a regular basis. Documenting emissions during all trips and in all sea areas gives the authorities an ability to map the precise geospatial emission.

The standards applicable in sensor technologies and the possible proxies feasible for monitoring will be assessed in light of the 2015 introduction of new sulphur reductions for shipping in European SECAs. Also, the use of scrubbers when operating on HFO or the use of MGO to reduce sulphur emissions can be monitored (automated or manually) and the results stored onboard or in a central data repository.

Subtask 5.3.4 Field testing, demonstration and evaluation

Field tests will be carried out on land-based lab/full-scale facilities as well as on the ships where the monitoring device has been installed. During the tests, the monitoring efficiency, data transfer and analysis will be demonstrated and evaluated. The system will be tested, demonstrated and evaluated on board a vessel.

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5 Field testing, demonstration and evaluation

5.1 Status of the work

The e-solution is developed in a parallel track with the BIMCO, the WP5 lead partner. Over the past 20 months the work has mainly been to develop an implementable solution for the analysis and transfer of large amount of sensitive data in a highly complex existing technical environment. The activities at forefront include to describe the concept behind the e-solutions in details, define sensor technologies and monitoring networks and engaging with the operators in preparation to test the equipment at land/sea. A conceptual design of an emission control system has been developed, including design and production of software that can collect, analyse and transmit data to a cloud solution. During the course of these project activities no “show stoppers” have been identified.

To comply with the sulphur regulation in Sulphur Emission Control Areas (SECAs) ships can either use fuel with a sulphur content of 0.1% or adopt alternative solutions e.g. the installation of a scrubber. The different scrubber techniques are discussed in detail in the previous report D5.6. Generally, type-approved scrubbers (scheme A) require a specific system technical manual, which must meet the requirements and be carried on board. Scheme B scrubbers do not require type approval; instead these systems are continuously monitored and it is the monitoring equipment fitted that must be approved by the administration. Nearly all scrubber systems on the market are scheme B scrubbers and therefore have continuous emission monitoring systems (CEMS) installed, and the data from CEMS are used in the present design for automated reporting of sulphur emissions. At present, there is no automated reliable reporting mechanism feasible for the fuel switch option, when vessels replace fuel with a higher sulphur content with a fuel with a sulphur content of 0.1% upon entering SECA.

5.2 Identification of collaborators and subcontractors

For the task of design and field testing, Litehauz engaged with companies that either participate in the EfficenSea2 project or that Litehauz have previously worked with. Partner 21, DANELEC was identified as hardware supplier for the collection of multiple datasets. A software architecture for the “land-based” data management, i.e. the storage facility, the data access, retrieving and display mechanism has been specified and programmed by a subcontractor BlueBrick for the field tests. For the task at hand the following participants were involved.

- DFDS A/S
    - The largest short sea shipping and logistics company in Northern Europe has kindly agreed to act as a test bench for the activity. DFDS was founded in 1866 and currently operates a network of 25 routes with 50 freight and passenger ships in the North Sea, Baltic Sea and the English Channel under the name DFDS Seaways. DFDS A/S was one

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the first major operators to install scrubbers and now has a number of ships that utilise scrubbers. Ship-based testing is prepared to take place at the DFDS vessel Optima Seaways operating a Ro-Ro route from Karlshamn in Sweden to Kleipeda in Lithuania.

- Dansk Analyse A/S
  - is part of the Norsk Analyse corporate group and provides analytical solutions for the process industry. Norsk Analyse is the largest integrator of analyser systems in Scandinavia with strong focus on Continuous Emission Monitoring Systems (CEMS) for scrubbers. Dansk Analyse's ShipCEMS will be used in the field test.

- DANELEC Marine A/S
  - is a leading manufacturer of VDRs (Voyage Data Recorders) with more than 5,500 installations worldwide and is strongly positioned in ECDIS (Electronic Chart Display and Information Systems). DANELEC Marine's vision is to provide the most efficient product and service solutions to shipowners, resulting in lowest cost of ownership and highest customer satisfaction in the maritime industry. For the ship-based testing DANELEC Marine will provide the hardware necessary to record data on the ship and transmit this in a standardised format.

- BlueBrick
  - a Polish company founded in 2011 that assists companies to build bespoke software and hardware products. They offer comprehensive technological solutions which are carefully tailored to the client needs by teams of talented and creative professionals. BlueBrick has provided their service to develop the software solution that will handle the onshore data handling and processing in this project.

5.3 Definition of sensor and monitoring concepts

5.3.1 Concept of Emission Report System

The general idea is to gather data at the ship and transmit this to a recipient at shore where the data can be processed and made available in a cloud. The concept will initially be implemented on-board Optima Seaways, but steps have been taken to make the solution easily transferrable to other ships and scalable. An analogue signal is delivered by the exhaust gas analyser to the analogue data interpreter. Further, relevant serial lines like GPS coordinates, speed over ground, wind speed, rudder angle are recorded by a serial data interpreter. All data are digitised and transmitted to the Vessel Remote Server (VRS) and the Voyage Data Recorder (VDR). The data collected by the VRS is send through a gateway to a SFTP server from where it is accessible to the ship owners office. A client PC at the ship owner's office will be running an application that will retrieve the data from the SFTP server for processing. Upon finalisation of data processing the

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data is transmitted to a cloud application. In the cloud, the processed data will be made available to relevant authorities, i.e. the Port State Control, in user-friendly charts along with compliance ratios. The overall process can be seen in Figure 1, and serves as a generic overview of the necessary components and cabling required to implement such a system. A more detailed description of the hardware and software involved in the individual steps will be presented in the following sections.

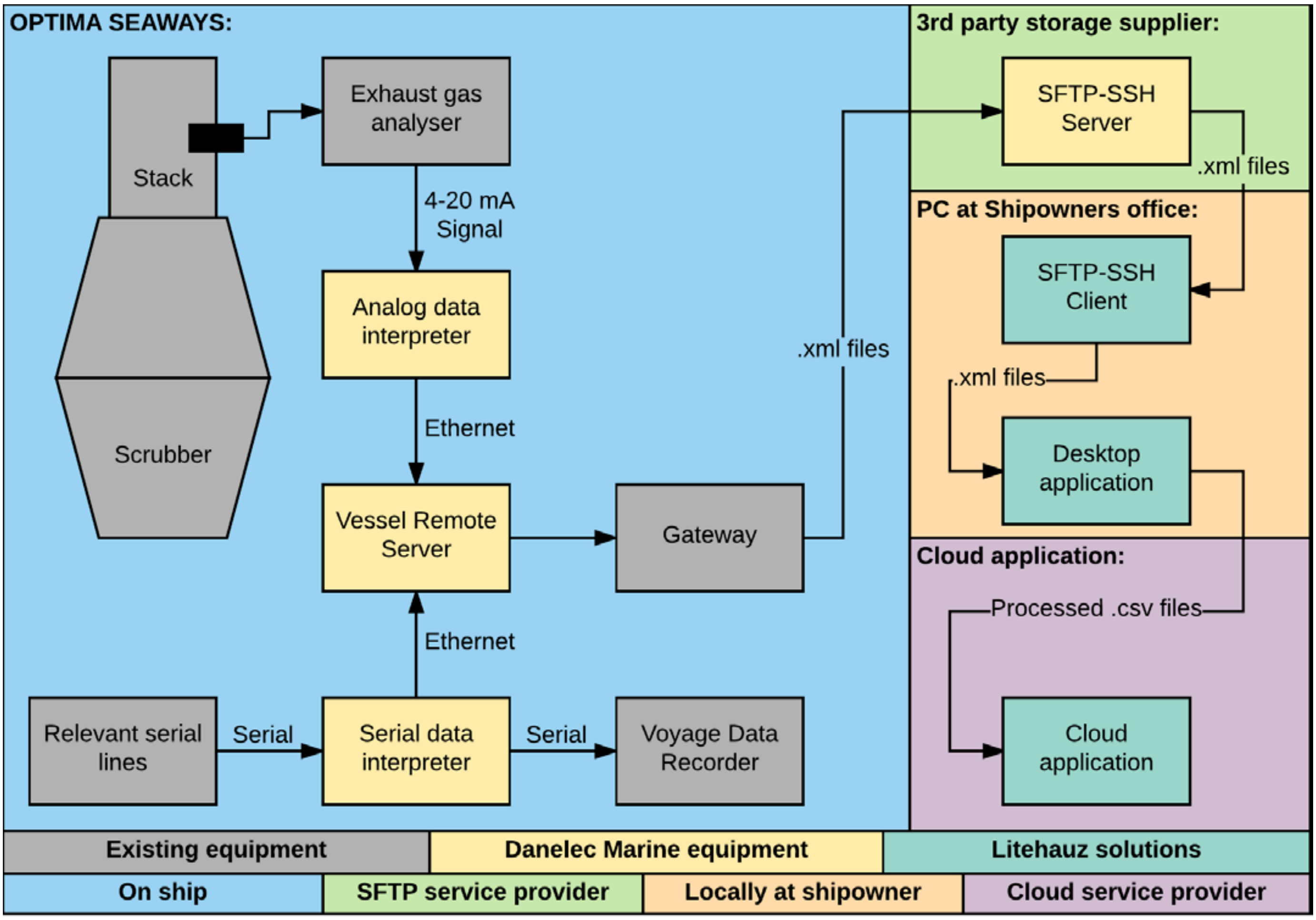

Figure 1: Monitoring concept for Optima Seaways

5.3.2 Hardware

In the following subsections the hardware installed on Optima Seaways during the project will be presented along with hardware already in place prior the project.

ShipCEMS

Identification of the current status of existing SO_x measurement technologies has been a part of the initiating work on defining sensor and monitoring concepts. The existing SO_x sensor technologies were fully described in report D5.6. From the range of companies that offer these sensor technologies in package deals or as turn-key application for continuous emission monitoring, the ShipCEMS sensor is used for field testing as this was already a part Optima Seaways scrubber installation. ShipCEMS continuous emission monitoring system is a Dansk Analyse A/S product, which is type-approved for

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continuous emission. The CEMS is designed to monitor and report concentrations of SO_2 and CO_2 in the exhaust gas of the stack by applying extractive measuring technology and non-dispersive infrared spectroscopy (NDIR) technology.

Figure 2:Gas conditioner from Dansk Analyse A/S

Figure 3:Gas analyser from Dansk Analyse A/S

The gas conditioner (Figure 2) and gas analyser (Figure 3) are connected to the stack where sample gas is extracted. The moisture-saturated sample gas from the stack is heated in the conditioner to dry the wet gas and avoid interference with the results of the measurement of CO2 concentrations. The analyser cabinet contains a NDIR gas analyser where the conditioned sample gas is continuously analysed.

Working principle of NDIR gas analysers

Inside the sample chamber the sample gas is analysed where it is led through and exposed to infrared light. The infrared light is a specific type called NDIR (Non-Dispersive InfraRed), which allows the analysing device to emit a beam of infrared light, which does not disperse or scatters between the light source and the detector. Like many other gasses CO_2, SO_2 absorb infrared light at a specific wavelength. The amount of NDIR-light reaching the infrared sensor at the end of the sample chamber is proportional to the concentrations CO_2 and SO_2 in the sample gas. To specifically measure the concentrations of e.g. SO_2 a filter that only allows light with the wavelength SO_2 absorbs is placed in front of the infrared light sensor.

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To be able to determine the concentrations of SO_2 and CO_2 in the exhaust gas, a reference gas is needed; typically, nitrogen is used. This reference gas is subjected to the same infrared light as the sample gas, at the same time. The amount of light absorbed by the nitrogen is measured on a reference infrared light detector. The absorbance measured in the sample and reference gas is compared and from this the concentration of SO_2 and CO_2 can be calculated. In Figure 4 the working principle of this has been presented.

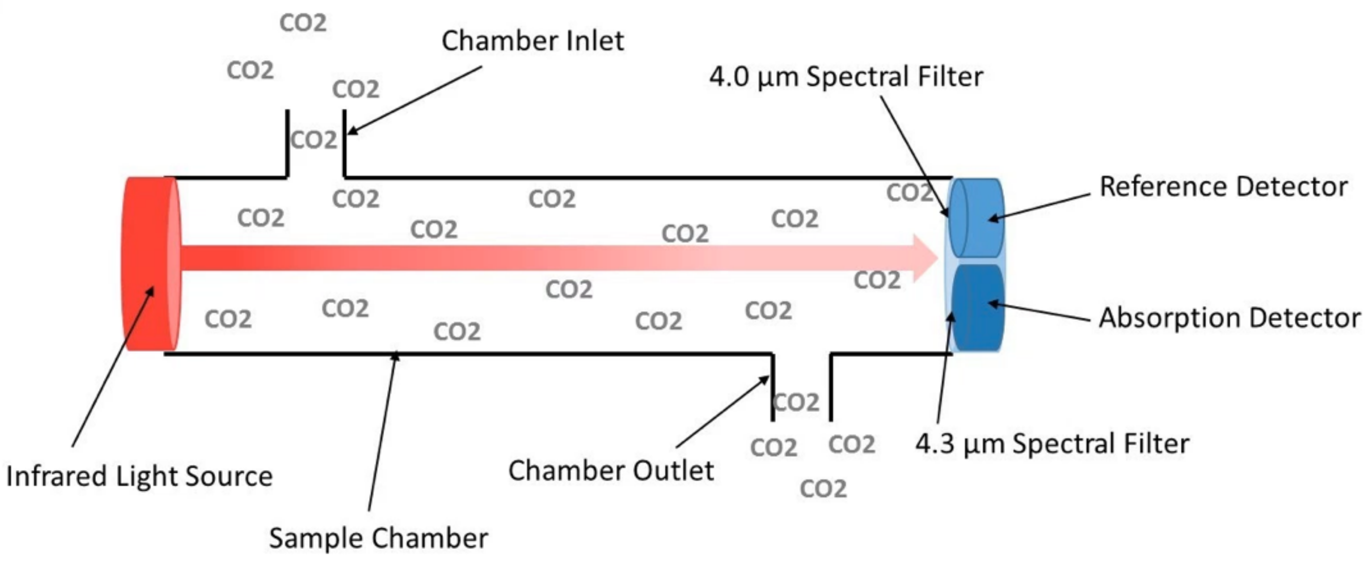

Figure 4: Principle of extractive NDIR spectrometer[1]

Analog output

As it was identified that Optima Seaways utilised ShipCEMS by Dansk Analyse A/S to monitor emissions it was necessary to establish how it would be possible to interface with this. Dansk Analyse A/S was approached on the behalf of DFDS A/S to acquire information on this issue. Electrical diagrams of the system, allowing for planning of an interface were subsequently provided by Dansk Analyse A/S. As these diagrams are proprietary to Dansk Analyse A/S, only simplified representations of these have been made available in this report, see Figure 5. The full diagram further provides numbering of the actual physical terminals where analogue signals are available.

From the diagram, it was concluded that the interface consisted of two analogue 4-20mA outputs that are individually tasked with providing a signal describing the CO_2 and SO_2 concentration in the exhaust gas. As seen from Figure 5 the span in which the sensors are able to measure is respectively 0-10mol% and 0-100ppm. Considering the CO_2 analogue output and a case of where the exhaust gasses in the stack contain 10mol% CO_2, a current of 20mA should be produced, while a concentration of 0mol% CO_2 would produce 4mA at the resistor marked by R in the below figure.

[1] http://www.edaphic.com.au/knowledge-base/articles/gas-articles/ndir-explained/

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As the analogue signals, are already logged locally and used in adjusting the scrubbers' performance and for proof of compliance in the event of a PSC inspection, a secondary current loop was installed. This would make the signal available to the analogue data interpreter provided by DANELEC Marine A/S, without interfering with transmission to the original recipient of the signal.

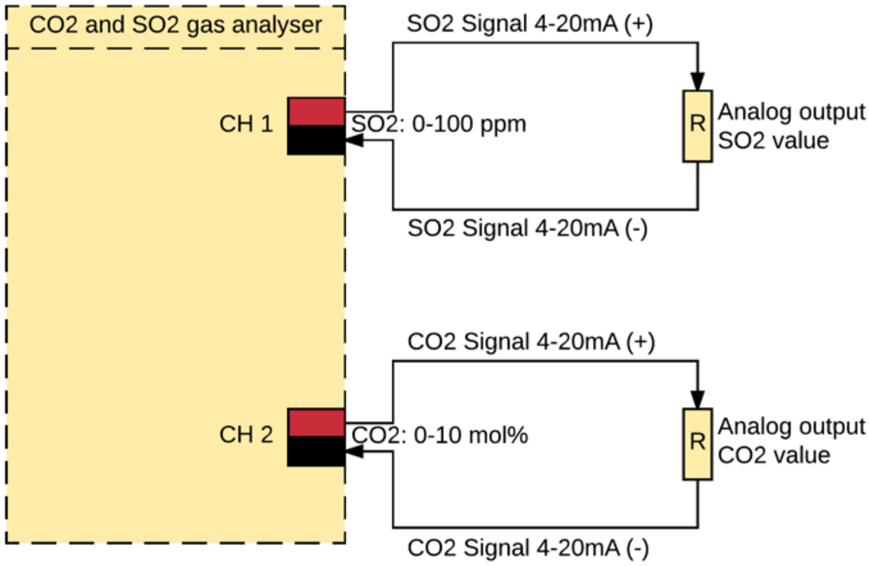

Figure 5: Electric diagram of the present analogue interface on the ShipCEMS equipment

DANELEC Marine A/S

As described previously DANELEC Marine A/S has served as the provider of all the hardware installed on Optima Seaways, that weren't already in place prior to the project. The equipment provided were two Remote Data Interfaces (RDI), one for analogue signal input and one for serial input. A RDI is able to convert a given input to a digital output that the VRS is able to interpret. Dependant on the capabilities of the RDI, it is denoted by –S or –A, referring to whether it is able to read analogue (-A) or serial (-S) inputs. The RDI-A is tasked with digitisation of the analogue signal received from the CEMS, i.e. signals describing the CO_2 and SO_2 concentrations in exhaust gas. The RDI-S is an interface between the serial lines providing information on AIS, GPS, Doppler log, anemometer, echo sounder, gyro compass, and auto pilot etc. and the VRS. As these serial lines are originally intended to be logged by the VDR, for forensic work post an emergency (collision, fire or similar), the RDI-S is installed along with a junction box that allows for serial signals to be transmitted uninterrupted to the VDR.

The VRS receives the real-time data from the RDI-S and the RDI-A, where the data is compiled into reports that are transmitted to an onshore reception facility at set intervals. These reports are in an Extensible Markup Language (XML) format, which can be interpreted by the software application described in the following sections.

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The interconnectivity between the different hardware is visible in Figure 1, it should also be noted that this is achieved through Ethernet cabling. This also applies to the outbound connection through a gateway provided by the ship.

5.3.3 Installation

The installation of DANELEC Marines' hardware on-board the vessel Optima Seaways is divided in three phases, the pre-installation, the installation/s and the commissioning phase. Optima Seaways is equipped with an AlfaLaval's PureSOx scrubber system which was installed in 2015. The scrubbers operate under a Type B approval that enforces continuous monitoring of the performance regarding sulphur emissions and on the washwater properties. As Optima Seaways was built in 1999, the fitting of a scrubber unit was a retrofit project meaning additional structure had to added. In Figure 6 the location of the scrubber unit is marked by a red circle.

Figure 6: The structure inside the red circle houses the scrubber on the vessel Optima Seaways

Pre-installation

Throughout this initial phase relevant material, e.g. installation, performance manuals, were reviewed. As shown in Figure 7 and Figure 8 the three DANELEC components RDI-A, RDI-S and VRD had to be installed and RDI-A cable connection had to be fitted. An inspection of the DFDS vessel Optima Seaways was arranged and carried out with the scope to study the ships design and develop a plan for the installation of the hardware. As shown in Figure 7 the scrubber area is located at the aft part of the ship and the installed equipment has to be connected with cables to the hardware installed on the bridge which is located in the fore part of the ship. This of course poses a number of challenges, e.g. that it is not advised to run single stretches of Ethernet more than 100m and that cable penetrations through transvers watertight bulk need to of a standard

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satisfying the ships' class. Further, as the VDR system aboard Optima Seaways is of Kelvin Hughes make, an external service technician would have to run a performance test of the equipment post installation to verify that the new installation had not impaired its functionality.

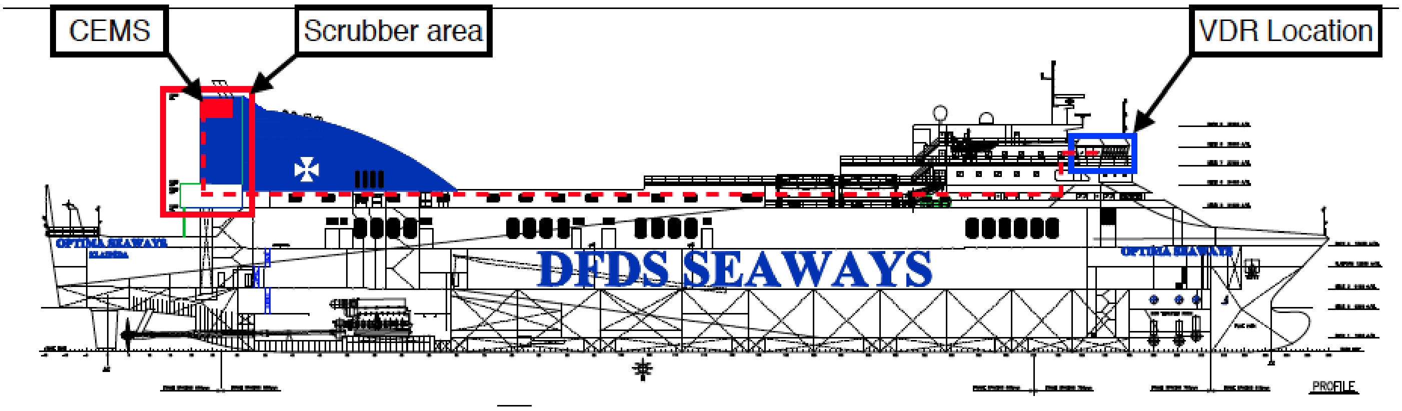

Figure 7: Schematic of cable connection between the CEMS and the VDR on-board of Optima Seaways

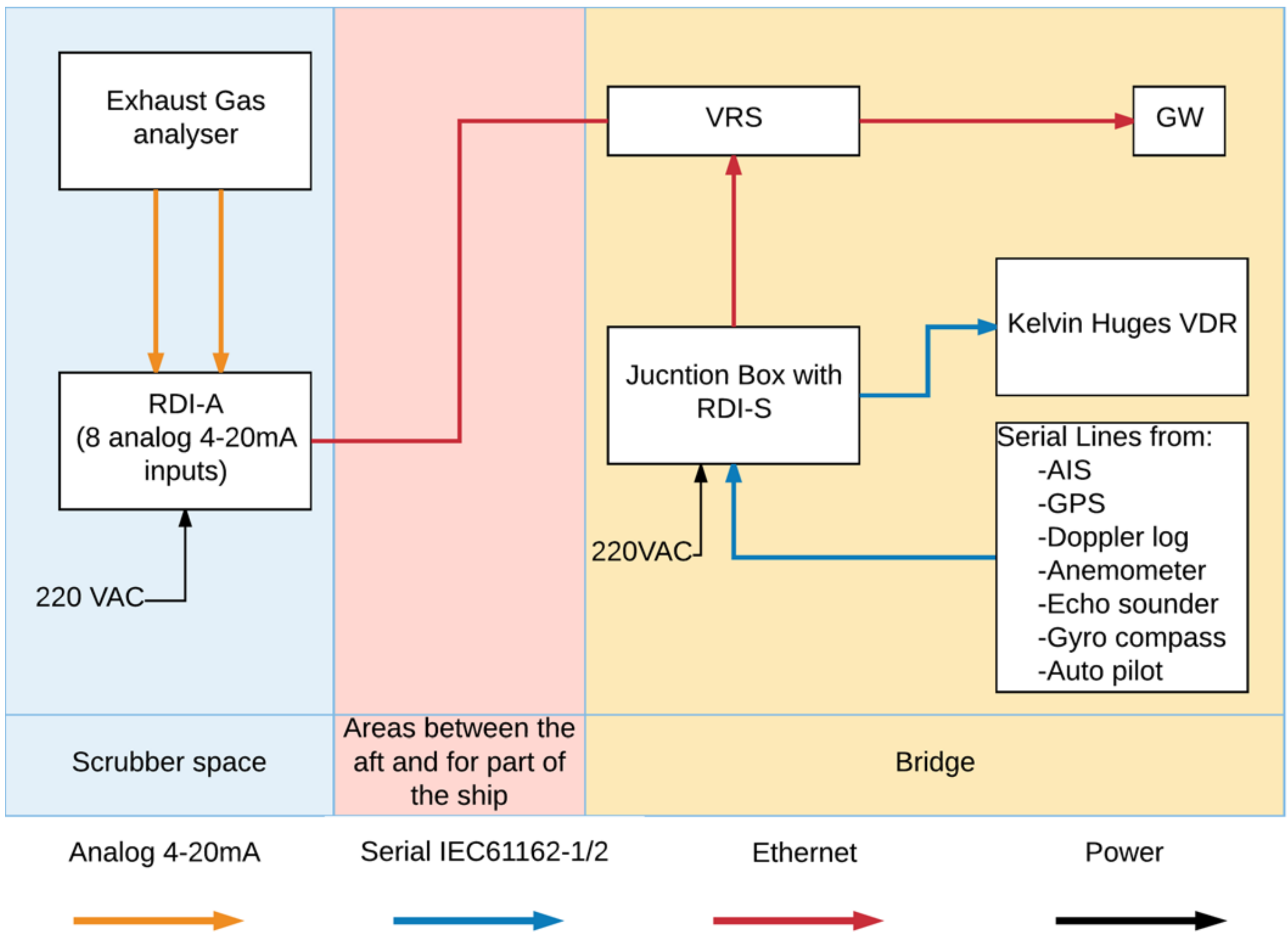

Figure 8: Principle drawing of DANELEC hardware installations

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During-installation

During initial stage of installation DANELEC Marine's hardware was mounted and cable connections were fitted. After the installation of the junction box with RDI-S the functionality of the VDR was verified. As shown in the flow chart in Figure 8 the different components of hardware have to be connected. Before commissioning cable connections between the exhaust gas analyser (ShipCEMS) and RDI-A as well as between RDI-A and VRS has to be mounted on the Optima Seaways, meaning that a second installation trip is be performed. However, do to difficulties in implementing changes to the ship's network infrastructure, the second installation trip is yet to be performed.

Commissioning

The last phase is the commissioning phase. After finalising the missing installations, the full functionality of the whole systems will be tested and possible problems will be adjusted. The data should be collected, packed and transmitted as XML-files from the ship to the already in place on-shore server.

5.3.4 Software and onshore networking solutions

During the project programming script and data handling algorithms have been developed to accommodate the emission data transmitted from the ship via the DANELEC Marine supplied hardware. Standards describing the format of the received data have been utilised to keep progression of the software development in sync with the hardware implementation.

Algorithm design

Prior to developing a standalone software application for transferring, storing and displaying sulphur emission data, a python[2] based data processing script was developed in-house to investigate how such an application should be built. Initially the scope was for the python-script to be able to handle inputs of CO_2 and SO_2 arrays in text- or csv-format, and provide the SO_2 (ppm) to CO_2 (% v/v) ratio values in a separate file. As this was achieved other relevant steps were added to the python-script, along with several sub-processes for evaluating and displaying the evaluated data. A total overview of the in-house developed algorithm can be seen in Figure 9.

To give a short introduction to the chronological process within the in-house algorithm:

1. Initially relevant files are stored in a local directory on the PC, from the where the programming script is to be executed. The XML-file format contains the values of the individually logged input, i.e. the CO_2-contration is denoted by the tag "CEMS_CO2".
2. Post execution of the python script, data files are interpreted and split according to the tag they have been provided with during logging.

[2] Python is widely used high-level programming language for general-purpose programming

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3. Values from the XML-files are then bundled into a CSV-formatted file containing the values of the relevant tags, i.e. time, longitudinal- and latitudinal coordinate, CO_2 concentration and SO_2 concentration
4. SO_2 and CO_2 data are then processed and evaluated, meaning that these arrays are sorted through and:
    a. Elements where the CO_2-concentration is lower the 1mol% the CO_2 value is set equal to 1 and the corresponding SO_2-value is set equal to 0. Effectively removing the relevance of set value.
    b. Elementwise division of corresponding SO_2- and CO_2-values is performed to determine the ratio and thereby the current level of compliance towards the SECA regulations.
5. Lastly the script produces figure allowing for graphical interpretation of the data, meaning a:
    a. map displaying the route sailed during logging of the emission data
    b. time series plot showing the individually measured emission ratios
    c. histogram showing the frequency of data measured within set intervals as seen in Figure 9 along with compliance percentages, i.e. how much of the time the ship is the emission criteria dictated by MEPC 256(68).

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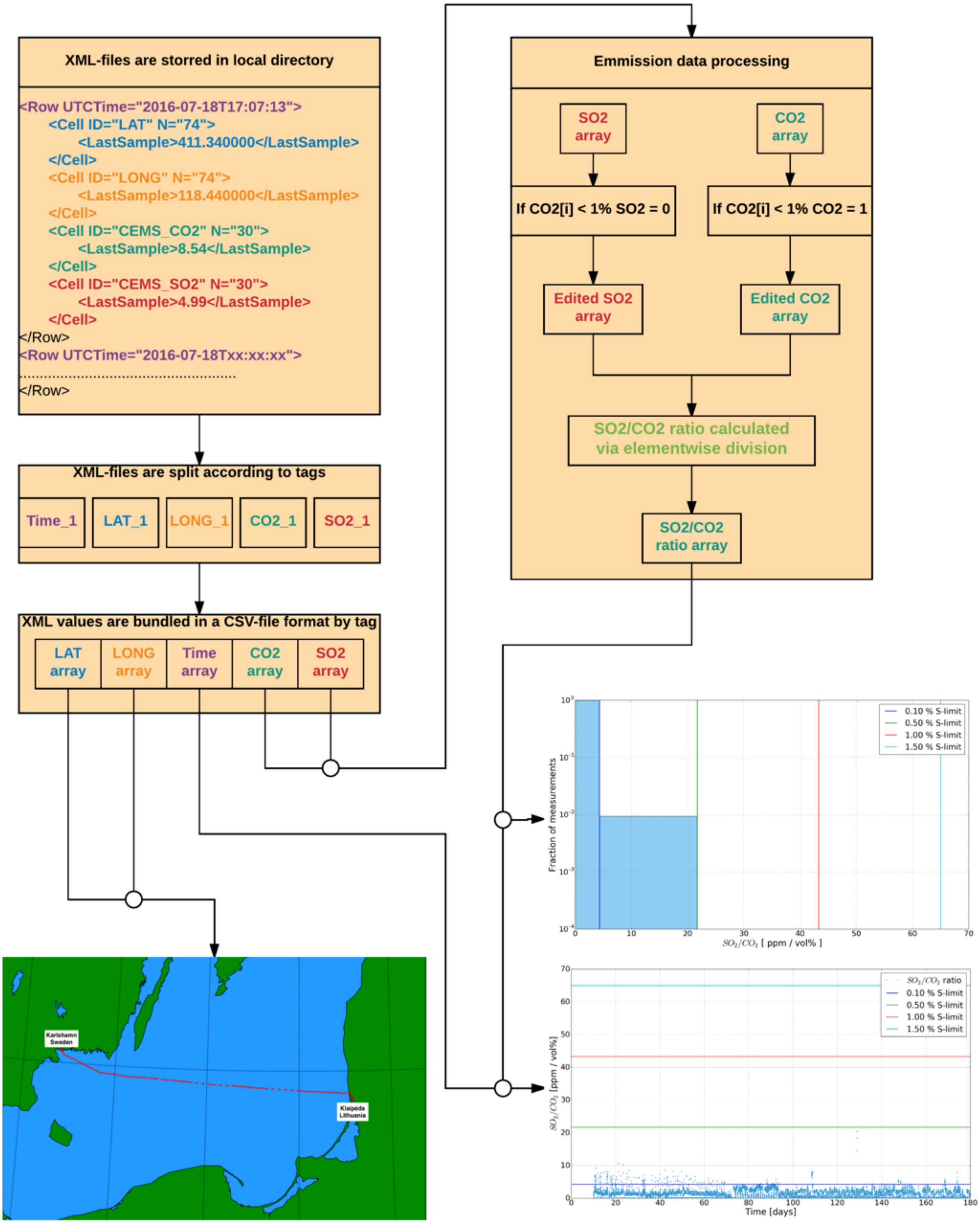

Figure 9: A flowchart describing the data processing carried out by the algorithm implemented in the automatic sulphur emission monitoring application

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5.3.5 Software

The subcontractor BlueBrick was approach during the initial phase of the project to assess whether they would be able to produce an application using the Python script and perform data transfer operation between the SFTP-server (initial data repository) and the local PC application. Further, a cloud platform for displaying processed emission data relevant to the PSC. BlueBrick accepted the request and has currently delivered their first beta version. Below an introduction to the local application and cloud application is presented.

Data transfer overview

Below Figure 10 provides an overview of the different data transmission steps performed post logging of the data at the ship. Initially the XML-files containing logged data is transferred from the ship to a data repository. This communication is performed via a SFTP-SSH server, to perform the data transfer as secure as possible. On the SFTP server the files are stored in two individual folder structures. One for back-up purposes and one for communicating with the shipowners office and the local PC application. The local PC application uses a SFTP-client to transfer newly received XML-files from the folder structure purposed with communicating with the shipowners office. Received files are processed as described earlier, and the processed data is transmitted to the cloud application as CSV-files.

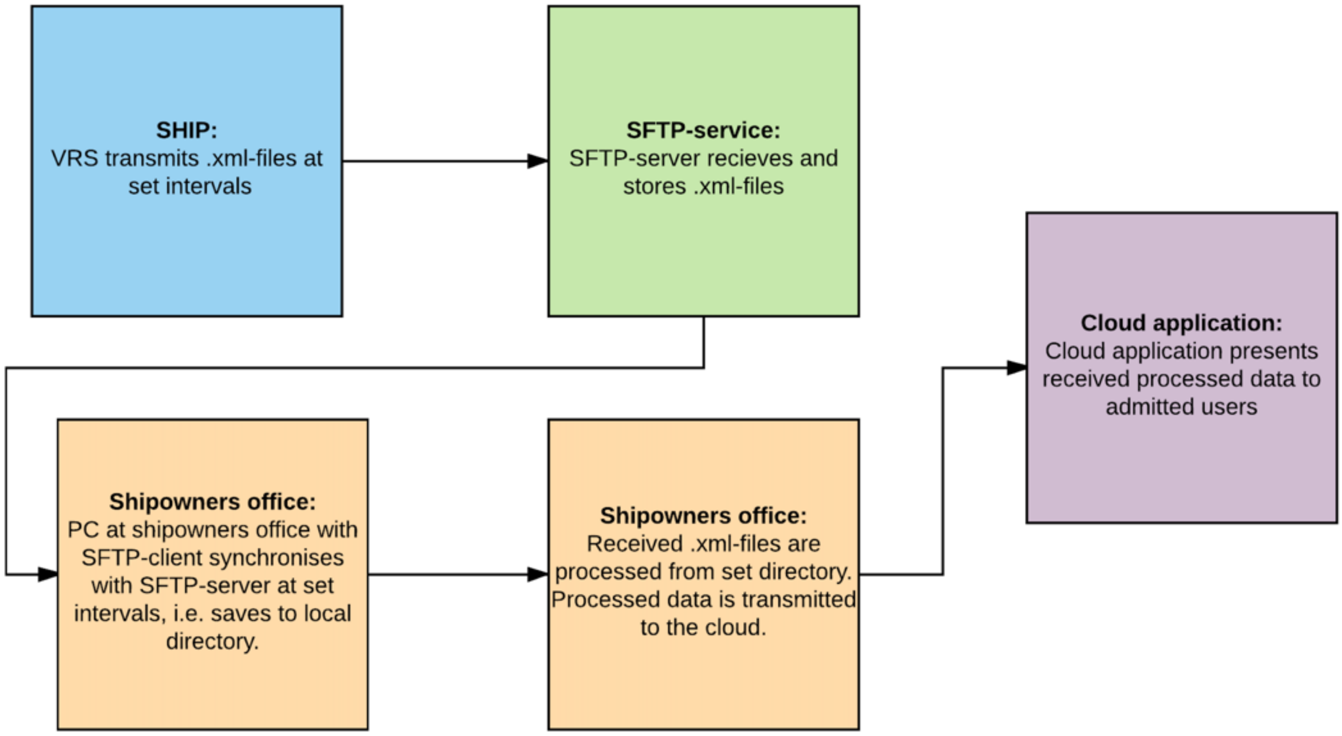

Figure 10: Data transmission scheme

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Presentation of the local application

As previously described the local application is tasked with retrieving and processing the emission data. Upon initialising the application, the user is presented with the screenshot shown in Figure 11, where it is displayed what data is currently available for the different ships. Also, the overall sulphur emission compliance ratio is presented to the user, i.e. what fraction of the measurements are within compliance. To clarify, the below presented data are not real measurement data, therefore these compliance ratios should be disregarded by the reader.

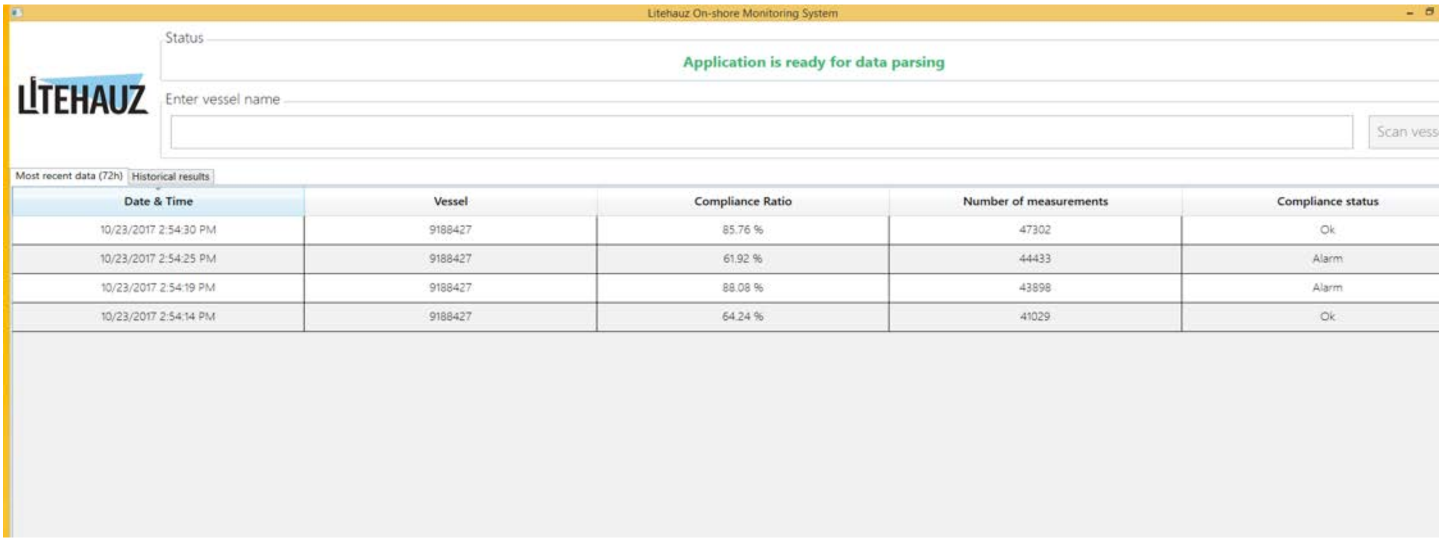

Figure 11: Screenshot of the starting when opening the local application

From the initial window the user can take a more detailed look into the emission data by clicking the relevant ship. This provides the user with a histogram, showing how the ship is performing emission-wise, at intervals relating to corresponding fuel oil sulphur content.

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Also, if the user wants to examine the original data file, this is possible through the “view original file” button.

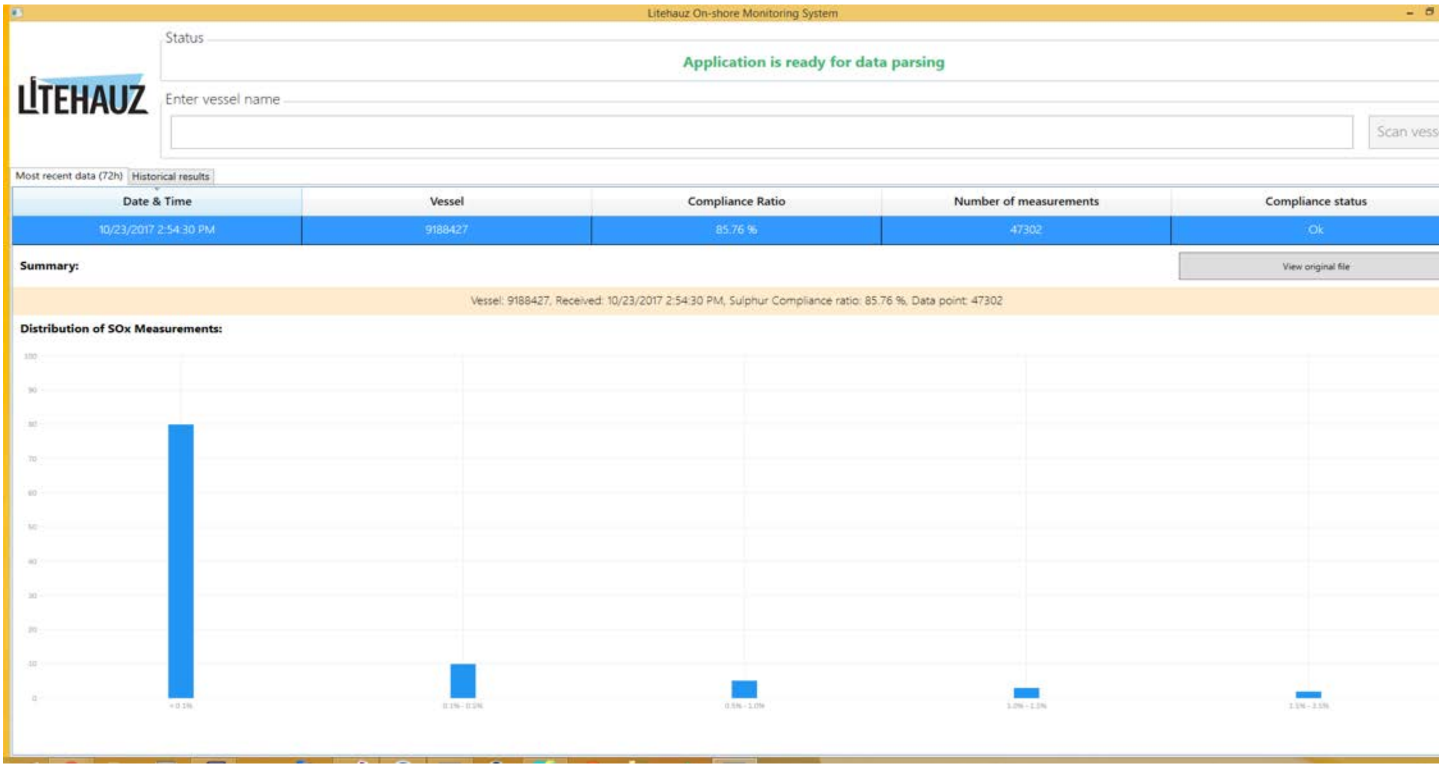

Figure 12: Screenshot of graphical presentation of emission data

The above parts of the application only provide an insight to the emission data received within the last 72 hours, as this is the data also available to the PSC, via the cloud application. To provide a user with the appropriate credentials with an indication of how the ship has been performing historically, it is a possibility to get data presented as seen in Figure 13 (the dummy data are the same, but note the new sheet in upper left corner), where stored data from earlier periods will be found.

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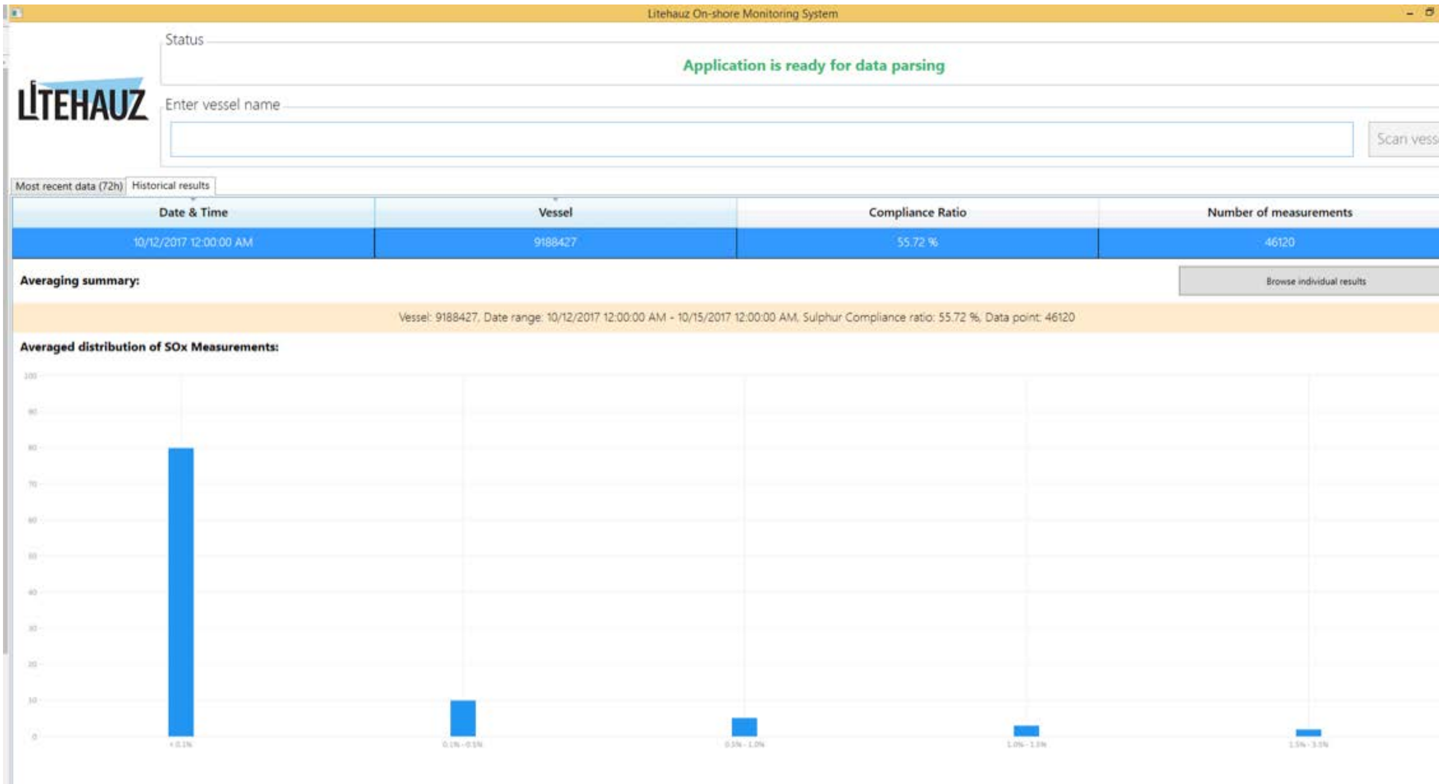

Figure 13: Graphical presentation of historical emission data in local application

Presentation of the cloud application

In continuation of the local application a cloud application was created to provide a platform for automatic publication of emission data. The processed data along with graphical presentations of the data will be accessible via an internet browser and user login. Initially, the user will be presented with an overview of ships with emission data present in the cloud, their compliance ratio and upon clicking on a specific ship the user will be presented with a histogram of the emission data.

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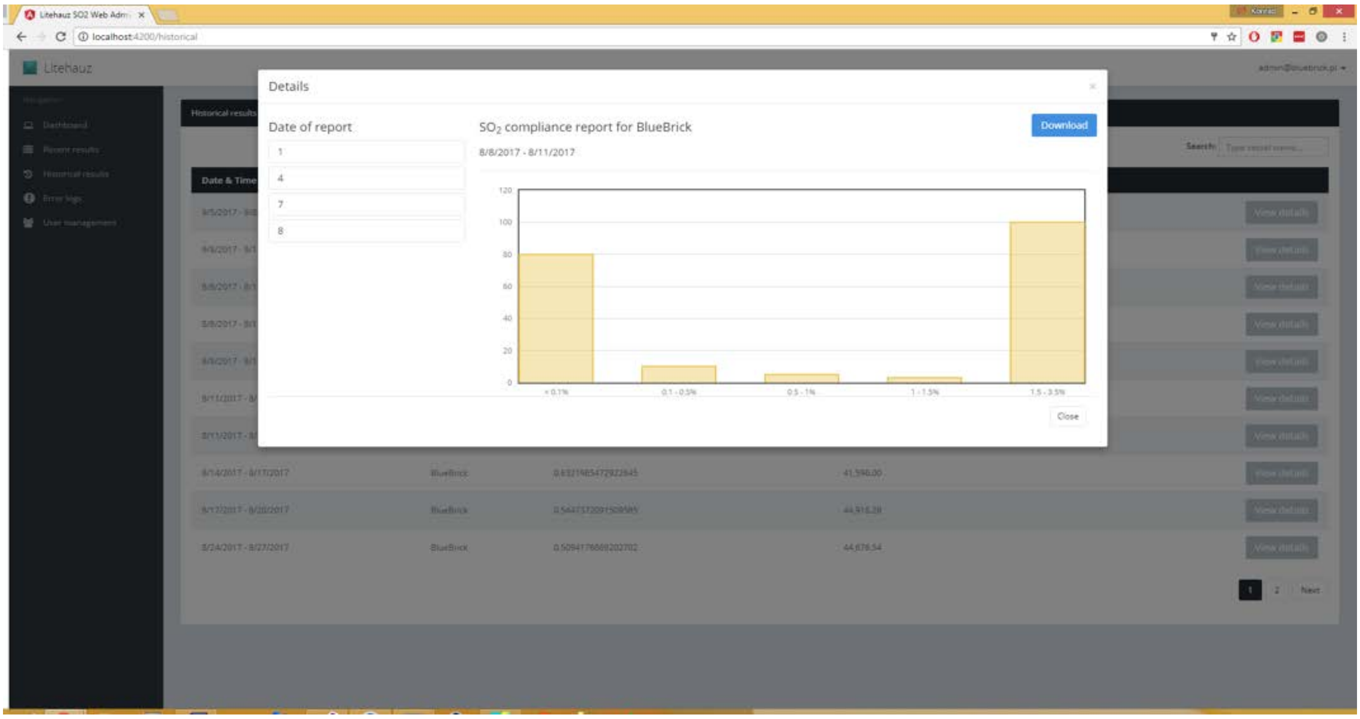

Figure 14: Initial login screen and data presentation

The current period visible to e.g. PSC users would be 72 hours, however this period may be changed to serve a desired purpose.

5.4 Land-based test

Before the whole system, hardware and software, is tested different segments are examined. The software for collecting and displaying scrubber self-monitoring data was developed and tested on real time data collected from a vessel operating a major manufacturer's scrubber system. The goal of the test was to apply the script described in the section Algorithm design, which is part of the local application. Emission and operation data was provided by DFDS and exported using TrendManager Pro, which is the software associated with the PureSOx system. The selected time span of the analysis is the first half of 2016, from 1/1/2016 to 29/6/2016, corresponding to 180 days. The reporting interval of the measured scrubber data is 4.5 minutes corresponding to a frequency slightly higher than the 0.0037 Hz required by MEPC. The only exception is the turbidity, which is reported on a 15-minute moving average, as recommended by MEPC.

The route in the test is between Karlshamn, Sweden and Klaipeda, Lithuania and is therefore entirely executed in the Baltic SECA. This is a route operated by AB DFDS Seaways (a Swedish DFDS subsidiary), and data containing GPS-coordinates with time-stamps were readily available from online providers of AIS-data. The ship's cruising speed could be established by using this data. A map of the route, generated from the data, is presented in Figure 15. Further details about the route has been specified in Table 1.

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Table 1: Route specifications

	Distance [nm]	Transit time [h]	Mean speed [knots]
Karlshamn-Klaipeda	207,7	12,5	16,6

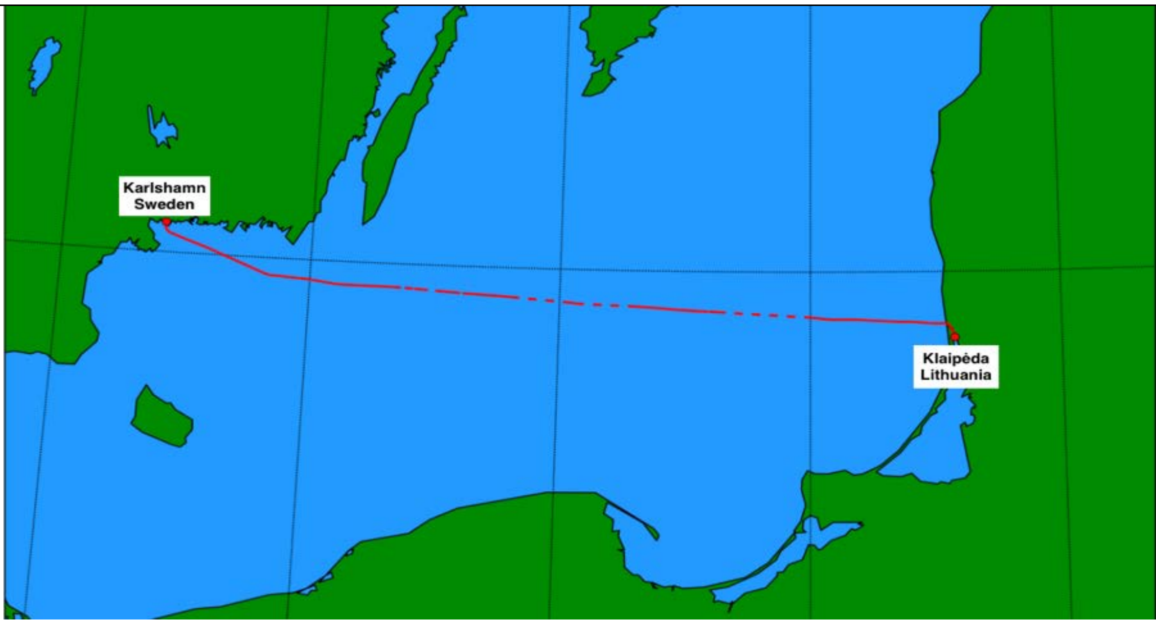

Figure 15: Map of the route between Karlshamn and Klaipeda

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Time series analysis of the sulphur emission data

MEPC, 2015[3] recommends that the sulphur emissions from scrubbers are reported as a ratio of SO_2 and CO_2 in units of ppm/vol%. Various limit values are established for this ratio based on the sulphur content of the fuel oil. According to EU regulation, the limit value for 0.1% sulphur fuel (corresponding to a SO_2/CO_2 ratio of 4.3 ppm/vol%) is not to be exceeded in the North Sea, Baltic Sea, and English Channel.

It is common practice of CEMS to measure exhaust gas emissions even when the engines are not running. This may result in high measurements of SO_2 combined with low measurements of CO_2 of atmospheric air, resulting in elevated ratio values. When the engine is running, the exhaust CO_2 levels reach approx. 5 vol%, which is significantly higher than the background level of 0.04 vol% CO_2 in the atmosphere. For the purpose of this report, SO_2 measurements from periods in which the engine is not running have been discarded. These periods were identified by applying a threshold value of CO_2 = 1 vol% and below at which the engine is assumed to be off.

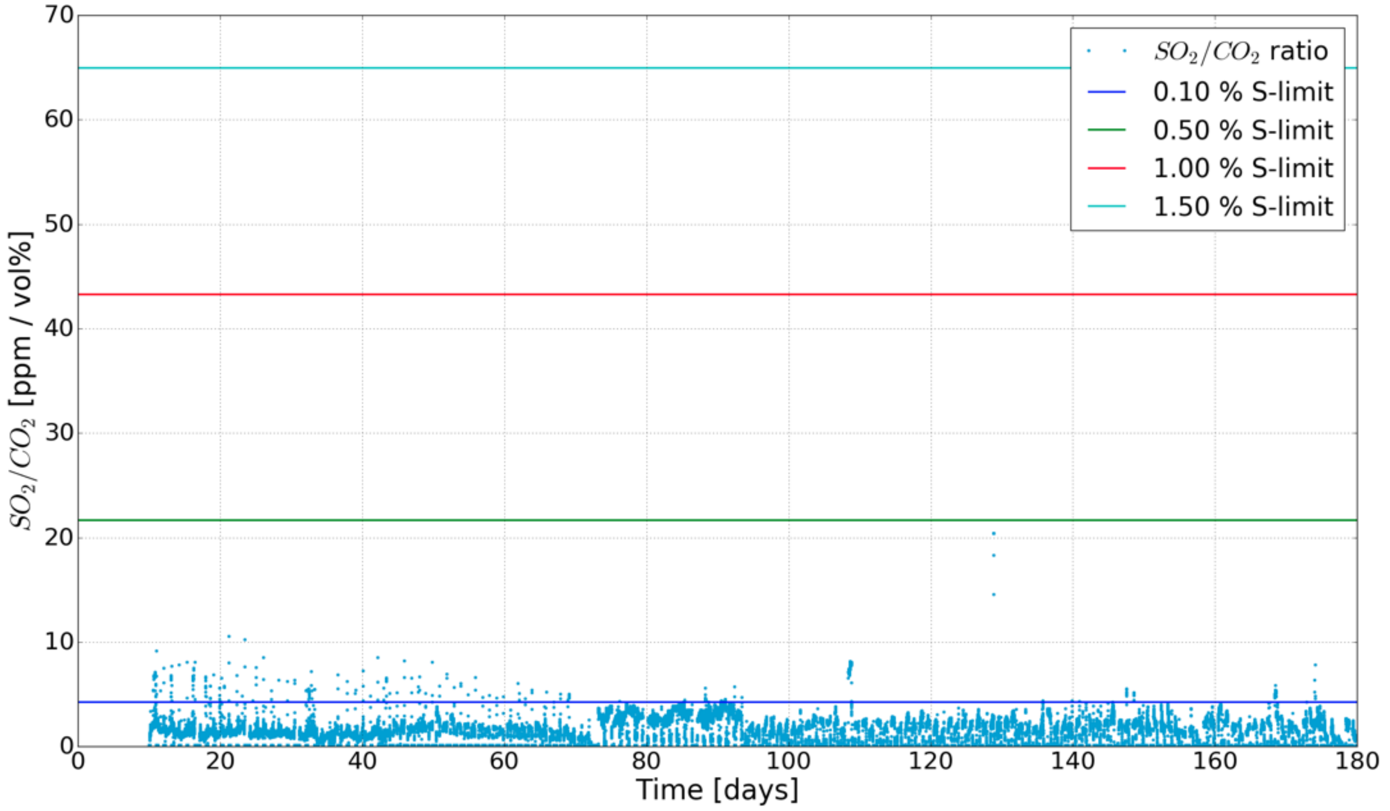

Figure 16: Time series plot of ratio of emitted SO_2 and CO_2

Figure 16 shows the SO_2/CO_2 ratio in ppm/vol% as prescribed by MEPC (actual scrubber data from a previous study by Litehauz) analysed and presented by the algorithm. Data for the first ten days of measurement are not available. The bulk of the data points are below the fuel oil sulphur limit of 0.1%, but during the first 75 days data points relatively

[3] MEPC (2015). Resolution mepc.259(68) - 2015 guidelines for exhaust gas cleaning systems.

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frequently exceed the 0.1% S-limit. However, none exceeds the 0.5% S-limit. After 75 days of measurements, only a few and irregular occurrences of emissions slightly above the 0.1% are seen for the remaining period.

The same data showing the SO_2/CO_2 ratio in Figure 16 has been plotted as a histogram in Figure 17, exactly the same way as emission data is present in the local and cloud application. The bins on the horizontal axis indicate the range of emissions corresponding to the sulphur content limits shown previously (from left to right: 0.1%, 0.5%, 1.0%, 1.5%, and >1.5%).

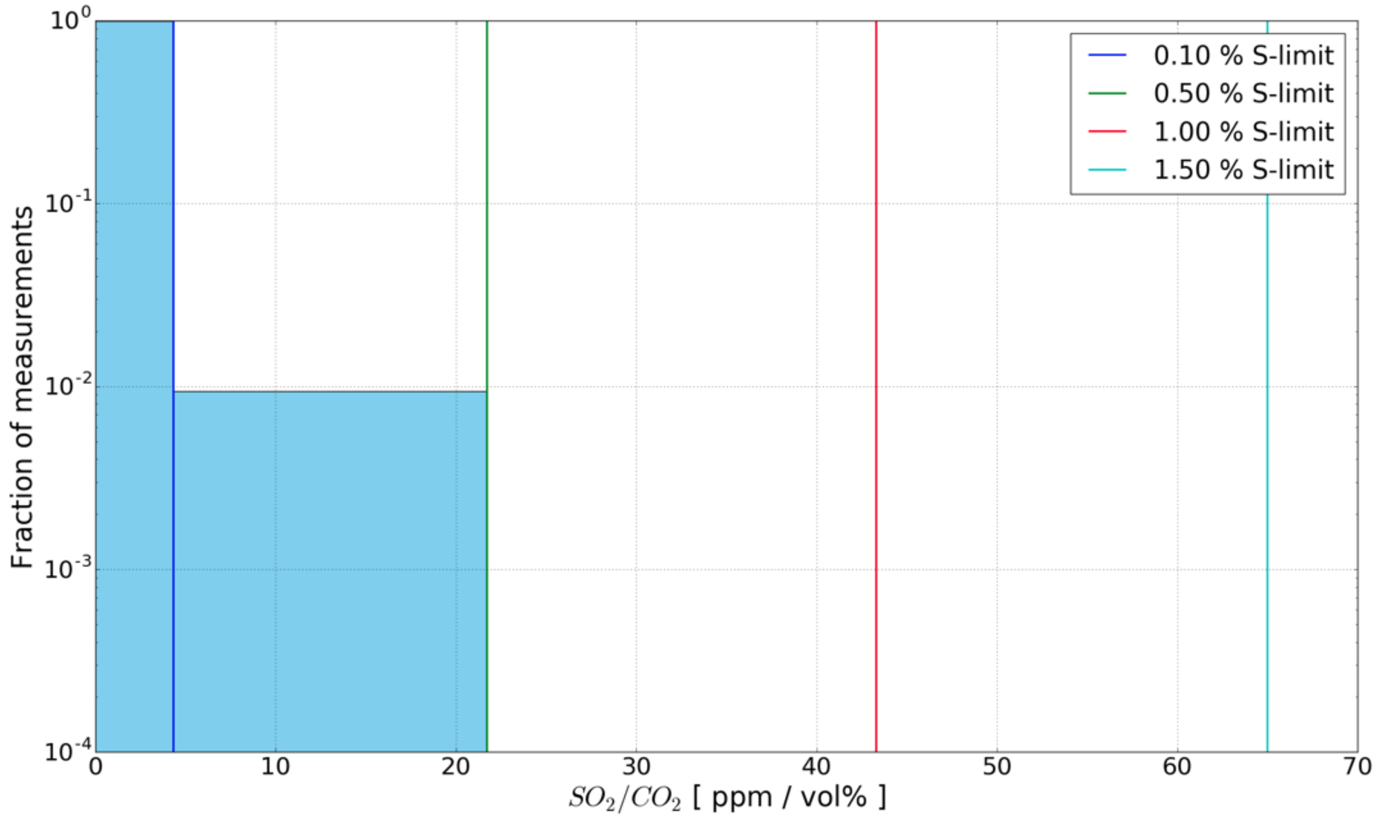

Figure 17: Histogram plot of SO_2/CO_2

The frequency diagram in Figure 17 (please note logarithmic scale on ordinate axis) shows that nearly all the measurements are below the 0.1% S-limit. The data points exceeding the limit make up just short of 1% of all the measurements. All in all, 99.1% of the data is compliant with the maximum 0.1% sulphur limit, as shown in Table 2. This feature of the in-house developed Python script has been applied 1:1 in the local application.

Table 2: Percent compliant and non-compliant sulphur emission, according to the 0.1% S-limit

	Percent
Compliant	99.1 %
Non-compliant	0.9 %

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With relatively simple revisions the algorithm may be also be used to analyse and present data received from the scrubbers washwater monitoring system of pH, turbidity, PAH.

The on-shore data management - software testing

To test the functionality of the software architecture randomised data was used to examine data transfer and processing of raw data. Data was successfully loaded from the SFTP-SSH server to the SFTP-SSH client and consequently processed. The following step of uploading the processed data to a cloud platform could not be tested since the could platform is not fully at this present time. Completion, documentation and implementation into the Maritime Connectivity Platform (former Maritime Cloud) will be concluded during the next couple of steps.

Commissioning test

Commissioning tests will be carried out over on one or two scrubber equipped vessels operated by DFDS A/S in the Baltic, one being Optima Seaways where the installation of equipment has been initiated, but not concluded. Secondarily, DFDS A/S has expressed interest in applying the same solution to the ship Athena Seaways, operating the same path as Optima Seaways. Whether this will occur depends on time and financial constraints. During the tests, the monitoring efficiency, data transfer and analysis will be demonstrated and evaluated.

5.5 Evaluation - Business case

Many of the difficulties in the business case of this project have been discussed and explained in delivery D.5.6, where it was concluded there would be limited financial incitement for at shipowner to implement the proposed solution. However, Jeppe Skovbakke Juhl (BIMCO) lead of WP5 has proposed that the shipowners organised in BIMCO utilising scrubbers, may have an interest in implementing the automated emission reporting tool into their automated port reporting tool, developed during the EffcienSea2 project.

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