D5.8 Report on working prototype of online sensor with cloud-based algorithm

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1 Document status

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1.2 Document History

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1.3 Review

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Table of Contents

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

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2 Executive Summary

The culmination of three years of participation in the H2020 project EfficienSea2 is the installation and field testing of the LITEHAUZ Sulphur Reporting System (LSRS) for vessels with continuous emission monitoring system (CEMS) installed. The LSRS is designed to allow the shipowner to access the full data package while allowing other Parties, such as the PSC, to inspect the latest subset of data relevant for the voyage and port call in question.

For the task of design and field testing, LITEHAUZ engaged with DFDS Seaways A/S and DANELEC Marine A/S. DFDS A/S was one the first major operators to install scrubbers and now has a number of ships that utilise scrubbers. DANELEC is a leading manufacturer of VDRs (Voyage Data Recorders) with more than 5,500 installations worldwide. Ship-based testing took place at the DFDS vessel 'Optima Seaways' operating a Ro-Pax route in the Baltic Sea. Dansk Analyse's Ship CEMS was used in the field test on an EGCS from AlfaLaval. A software architecture for the "land-based" data management, i.e. the storage facility, the data access, retrieving and display mechanism was developed and specified by Litehauz and programmed by a subcontractor. BIMCO and DMA provided the industry's and the authorities' sides of the application's use.

The successful field test was prepared through bench tests during 2017 and finally after some nail-biting delays carried out in March 2018 during voyages between Karlshamn in Sweden and Klaipeda in Lithuania. Data were automatically obtained from the CEMS onboard, transferred via the installed Voyage Data Recorder to the LSRS software compatible with the standards of the Maritime Connectivity Platform. The full dataset were available to the shipowner and a 72h dataset could be queried by authorities for decision support on compliance and prioritisation of PSC resources. Thus, the efforts of the engaged participants of Task 5.3 – 'Emission monitoring solution' resulted in the establishment of a fully functional mechanism for automated compliance monitoring suiting the needs of both shipowners and authorities.

The following recommendations are made regarding the Sulphur reporting mechanism based on the experiences gained by LITEHAUZ through the Maritime Connectivity Platform project supported by Horizon 2020:

- Invite EMSA to initiate a workshop on real-time monitoring in environmental issues of shipping, e.g. Sulphur emissions, and how to expand a voluntary industry reporting scheme such as the proposed into a versatile mechanism for PSC Decision Support. This may include interaction with requirements of THETIS-EU and MRV.
- Invite participants for a full-scale test in the existing SECAs involving a minimum of 3-4 Competent Authorities, 2 or more shipowners with 5 to 10 vessels operating in the short sea shipping sector to gain experiences on the true multi-authority queries to data and decision support regarding PSC on Sulphur.

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- Invite participants for a full-scale test in EU waters outside the existing SECAs (e.g. the Mediterranean Sea) involving a minimum of 3-4 Competent Authorities, 2 or more shipowners with 5 to 10 vessels operating in the short sea shipping sector, where the value of the business model is tested regarding delivering data to mandatory emission reduction schemes in EU ports.
- As previous, but with inclusion of Barcelona Convention Parties through REMPEC to ease accession of MARPOL Annex VI by demonstrating reduced administrative burden.
- Allowing for the development of similar real-time self-monitoring and reporting mechanisms for PMs, NOx, ballast water, fuel-S etc. will reduce administrative burdens in PSC. The inclusion of data of more pollutants and performance indicators of the ship, primarily speed, load, fuel consumption, will facilitate data mining and pattern recognition leading towards digitization and the development of autonomous or remotely controlled vessels.

The LSRS is a low-cost system using mainly existing infrastructure onboard, i.e. the CEMS, a well-proven and readily available Voyage Data Recorder (VDR) and a bespoke software built on applications already applied in the ballast water treatment sector. The total daily ba from bandwidth use from individual data transfers will amount to approximately 310 kilobytes. If the communication were to be transmitted by a 256 kilobit per second (32 kilobytes per second) satellite connection, it would occupy such for 10 seconds per day. It is expected that the existence of a simple application will allow shipowners to consider a faster technology uptake than is sometimes seen in the shipping sector.

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3 Introduction

The introduction of sulphur emission reduction in shipping has led to both global targets coming in 2020 from the International Maritime Organization and to the establishment of regional IMO Sulphur Emissions Control Areas (SECAs), e.g. the North Sea and Baltic Sea SECAs. Both SECAs cover predominantly EU member states' waters and are governed[1] by the Directive (EU) 2016/802, known as the 'Sulphur Directive' which implements the MARPOL Annex VI regulation 14 on Sulphur. Port and Coastal states have an obligation to survey and inspect vessels for their compliance with the international and national law. While new regulation almost by default increases the administrative burden and the costs to the industry, it is the ambition of many entrepreneurs in the field of performance monitoring, including LITEHAUZ, that this can be completely automated, thus reducing or eliminating the hassle of operating highly sophisticated monitoring equipment and leaving the record-keeping and reporting to electronic systems.

The global focus on sulphur in fuel has led to a considerable number of initiatives that reduces the sulphur emissions:

Existing regulations		**Impacts**
EU Sulphur Directive	➡	≤0.1% S in all ports since 2010
IMO SECA in North Sea and Baltic Sea	➡	≤0.1% S since 2015
More 'low sulphur' jurisdictions globally	➡	American IMO ECAs (North American and US Caribbean Sea)
		Several Chinese domestic ECAs (≤0.5% S)
		Mandatory ≤0.1% S for cruise ships in New South Wales Ports (Australia)
		Voluntary S reduction in many ports though local or international mechanisms (ESI, CSI)
Coming soon		
IMO Global Fuel Sulphur Cap	➡	≤0.5 % S in 2020

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. The LITEHAUZ Sulphur Reporting System (LSRS) is designed to allow the shipowner to access the full EGCS CEMS data while allowing other Parties, i.e. specifically the PSC, to inspect the latest subset of data relevant for the voyage and port call in question.

[1] Russia is not an EU member and the Russian part of the Baltic Sea is Russian jurisdiction. The Norwegian part of the North Sea is governed by Norwegian law implementing the EU Sulphur Directive.

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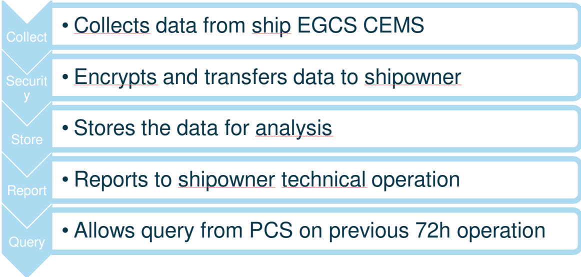

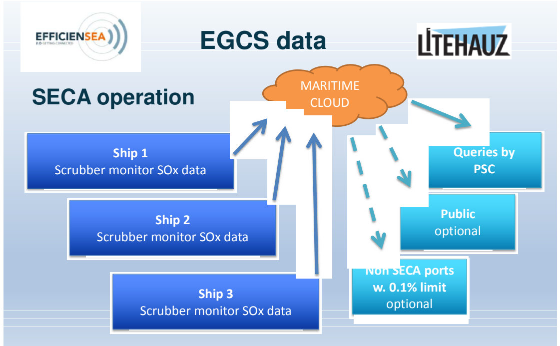

The LSRS in brief

The applicability of the LSRS

The LSRS is a low-cost system using mainly existing infrastructure onboard, i.e. the CEMS, a well-proven and readily available Voyage Data Recorder (VDR) and a bespoke software built on applications already applied in the ballast water treatment sector. The total daily ba from bandwidth use from individual data transfers will amount to approximately 310 kilobytes. If the communication were to be transmitted by a 256 kilobit per second (32 kilobytes per second) satellite connection, it would occupy such for 10 seconds per day. It is expected that the existence of a simple application will allow shipowners to consider a faster technology uptake than is sometimes seen in the shipping sector.

<u>The data transfer for Shipowner's use and for Port State Control queries</u>

The LSRS provides an economical incentive in the EU ECAs, although it may only be stronger for the short sea shipping sector with frequent port calls, and which may avoid a number of PSC for sulphur. In the remaining non ECA seas of EU member states the adherence to 0.1% S in ports and the low sulphur port schemes globally provides a stronger incentive for installing an automatic reporting mechanism, especially where reduction on tariffs and port fees are tied to low emissions of sulphur or fuel sulphur content. It was therefore decided early in the process to focus the effort on a reporting and analytical mechanism that would allow the shipowner or a service provider to store and mine the full dataset(s) for one or more ships. The data made available for PSC is a rolling 72h subset

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accessible on-line for PSC Decision Support. This dataset can be made available for all Parties with credentials matching those set by the shipowner, and while designed for Authorities, this may include NGOs and the public.

Decision Support for Port State Control

In the full vision of the implemented system the vessels operating in SECAs, and those operating in non-SECAs where low sulphur incentives are applied e.g. in ports, may all find the applicability of the LSRS beneficial to their reporting requirements. This includes both the pre-arrival 72h dataset for PSC, the possible reduction in port fees with low S-emissions, and the availability of the full dataset both for EGCS performance analysis and, if necessary, the submission of detailed datasets for a full inspection by PSC.

Shipowners may use LSRS to submit full datasets

The full dataset of a CEMS for an EGCS must be found onboard and the copy in LSRS is merely a back-up and it is currently not the intention to support on-line queries from PSC to obtain full datasets.

Shipowners may use LSRS to analyse performance of EGCS

Within the shipowner’s own fleet or if one common data repository is used for several owners thorough a third party, detailed analysis of collated scrubber operational performances is possible for the purpose of assessment of brand and model compliance performance. Also, one may identify suspicious non-compliance in certain areas/jurisdictions related to e.g. bunker quality. Once a dataset’s critical mass is met pattern recognition and predictive capacity is readily achievable through big data approaches.

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4 Objectives

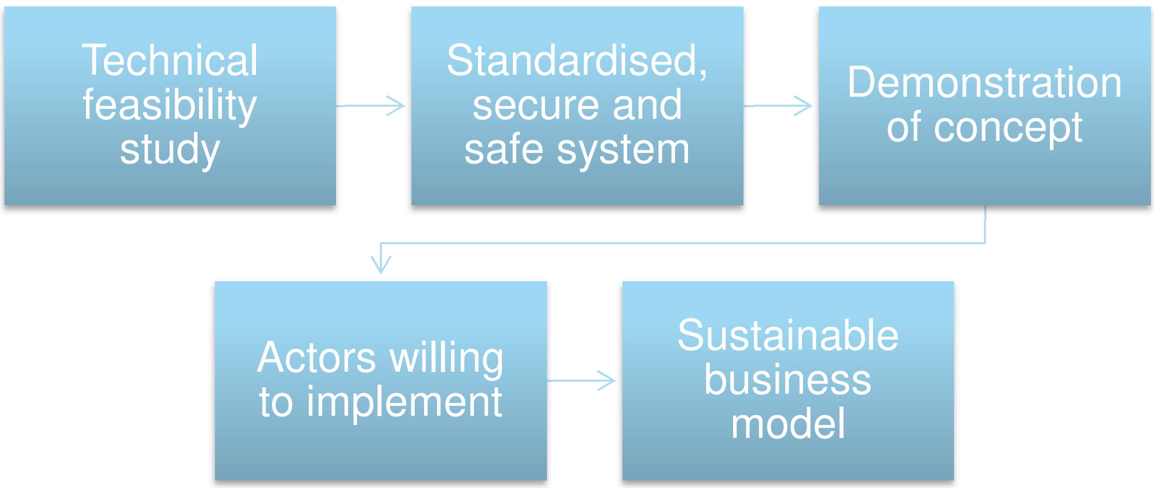
In the sister activity in work package 5 on "Development of a new common port database concept and structure" it is said that "Good nautical and commercial port information is the foundation for efficient and safe port calls". The same can be said of the environmental monitoring data which will form an increasingly larger part of the data exchange with maritime authorities and port administrations due to both mandatory and voluntary reporting requirements.

The objectives of work package 5.3 were to:

- investigate new sulfur emission monitoring concepts to be used by both shipowners and authorities;
- improve the exchange of information with port state authorities and possibly public stakeholders by enhancing the automatic flow of information sea-to-shore;
- standardised templates and reporting forms should ensure an efficient exchange of data by streamlining the information flow.

The information collected should allow shipowners to voluntary join a pre-arrival notification programme and to submit data to be used as a basis for Port State Control purposes. This will reduce the administrative burden, will help level the competitive playing field between shipping companies and will assist the shipping industry in remaining competitive compared to other modes of transport.

The overall digitisation project process is shown below.



The availability of a simple and versatile reporting system will encourage shipowners to fully comply with emission regulations compared to a setup with relatively rare occasional PSC inspections. For the righteous shipping line, automated and continuous emission reporting will contribute to fairer competition, by making fuel/emission fraud more difficult.

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5 The work covered

This report provides information on the Subtasks 5.3.4 *Field testing, demonstration and evaluation* and 5.3.5 *Recommendations*. This is the final report demonstrating the prototype of online sensor programming and summing up the final phase of the project:

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

LITEHAUZ is lead on WP5.3 and the field testing has been completed with input from the following partners:

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

5.1 Subtask 5.3.4 Field testing, demonstration and evaluation

Field tests were carried out on land-based lab/full-scale facilities as well as on a vessel where the monitoring device has been installed. During the tests, the monitoring efficiency, data transfer and analysis was demonstrated and evaluated.

5.2 Subtask 5.3.5 Recommendations

The system will allow shipowners to store and analyse data, and PSC authorities to screen the volunteers for sulphur regulatory compliance. The recommendations for the framework to be applied is presented in the report.

The data submission and analysis mechanisms were prepared for SO_2 emission and may (in future applications) be developed for emission data of many more pollutants and for correlation of the performance indicators of the ship, primarily speed, load, fuel consumption, etc., but may also include geoposition as well as hydrological and meteorological parameters. This unique collection of data will facilitate data mining, pattern recognition algorithms and the options for other business models through subscriptions.

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6 Working prototype of online sensor

6.1 Identification of WP collaborators and subcontractors

For the task of design and field testing, Litehauz engaged with companies that either participate in the EfficenSea2 project or Litehauz has previously worked with. 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. In detail 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 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 was 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

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talented and creative professionals. BlueBrick has provided their service to develop the software solution that will handle the onshore data handling and processing.

- BIMCO
  - The shipowner organisation has been involved in identifying the business case and through testing of the concept delivered many valuable stakeholder comments to the system development.
- DMA
  - The Danish Maritime Authority has been involved in identifying the authority role and the practical needs thus influencing the concept development allowing the WP to address both sides of the application's use.

6.2 Concept of Emission Report System

The general idea was 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 is initially implemented on-board M/S 'Optima Seaways', but Litehauz has taken steps to make the solution easily transferrable and scalable to other ships.

The technical data transmittance is, in short: the analogue signal is delivered by the exhaust gas analyser (CEMS) to the analogue data interpreter and 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 shipowner's office. A client PC at the shipowner's office will be running an application that will retrieve the data from the SFTP server for processing. Upon finalisation of data processing the data is transmitted to a cloud application. In the cloud, the processed data will be available to the shipowners and 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. Report D5.7 gives a detailed description of the hardware and software involved in the individual steps. The following section sums up the important details of the hardware and software.

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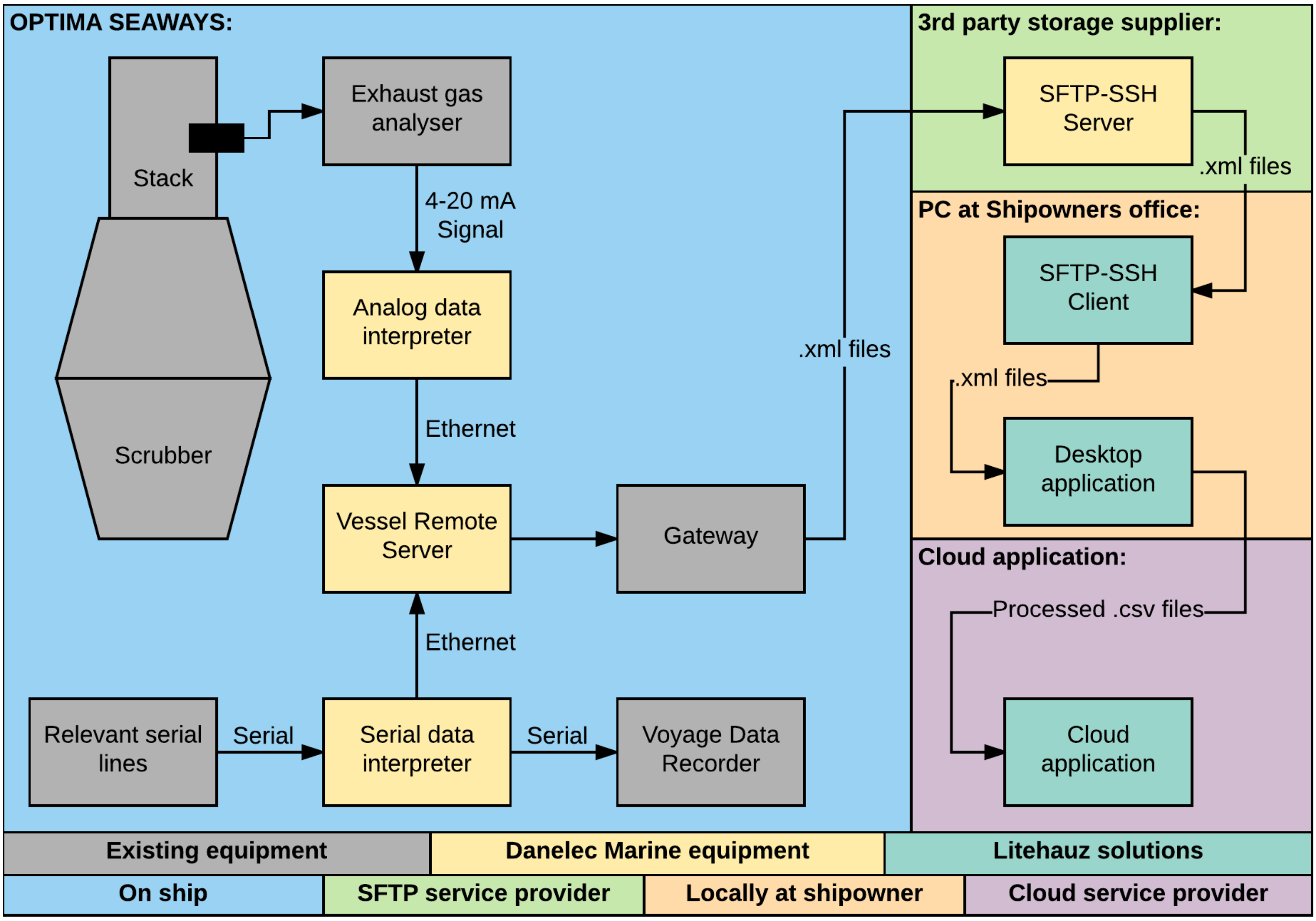

Figure 1: Monitoring concept for Optima Seaways with colour codes for source

6.3 Hardware

The current status of existing SO_x measurement technologies was a part of the initiating work on defining sensor and monitoring concepts. Report D5.6 provides a full description of the existing SO_x sensor technologies. The sensor used in the ship-based testing was the ShipCEMS.

6.3.1 Continuous Emission Monitoring System

From the range of companies that offer sensor technologies in package deals or as turn-key application for continuous emission monitoring, the ShipCEMS sensor was used for field testing as this was already a part of Optima Seaways scrubber installation. ShipCEMS is a Dansk Analyse A/S product, which is type-approved for continuous emission measurements. The system 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. Report 5.7 gives a detailed description of the working principles of the system.

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Figure 2:Gas conditioner from Dansk Analyse A/S

Figure 3:Gas analyser from Dansk Analyse A/S

6.3.2 ShipCEMS Analogue Data Extraction

Litehauz used the electrical diagrams of the ShipCEM system provided by Dansk Analyse A/S to establish how it would be possible to interface with the system. As these diagrams are proprietary to Dansk Analyse A/S, only simplified representations of these are available in this report, see Figure 4. The full diagram further provides numbering of the actual physical terminals where analogue signals are available.

The diagram showed the interface consists of two analogue 4-20mA outputs that are individually tasked with providing a signal for CO_2 and SO_2 concentration in the exhaust gas. As seen from Figure 4 the span in which the sensors are able to measure is respectively 0-10mol% and 0-100ppm. In case the exhaust gasses in the stack contains 10mol% CO_2 the CO_2 analogue output should produce a current of 20mA, while a concentration of 0mol% CO_2 should produce 4mA at the resistor marked by R in the figure below. Correspondingly, the concentration of 100ppm SO_2 should produce an analogue output for SO_2 with a current of 20mA, while 0ppm should produce 4mA at the resistor R.

The analogue signals, are already logged locally and used in adjusting the scrubber's performance and for proof of compliance in the event of a PSC inspection. Litehauz installed a secondary current loop and made the signal available to the analogue data interpreter

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provided by DANELEC Marine A/S, without interfering with transmission to the original recipient of the signals.

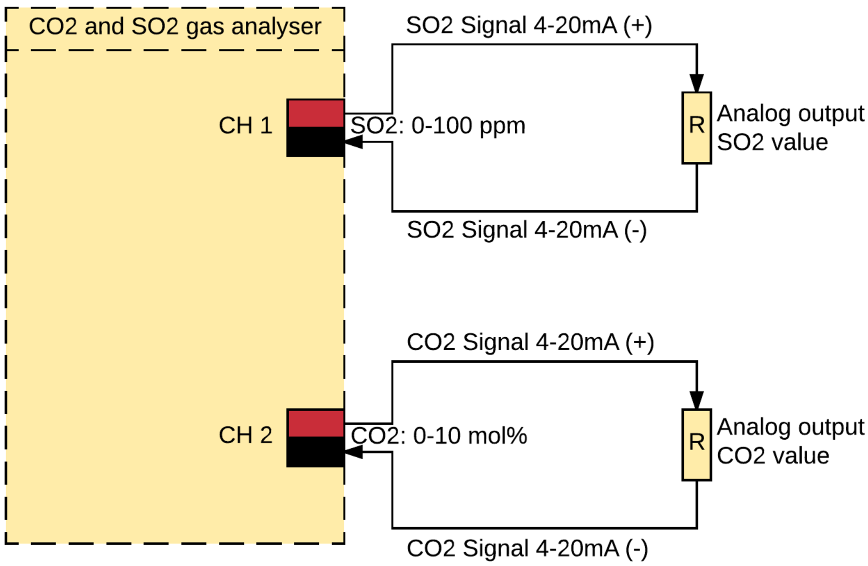

Figure 4: Electronic diagram of the present analogue interface on ShipCEMS equipment

6.3.3 Remote Data Interface

DANELEC Marine A/S provided two Remote Data Interfaces (RDI) for installation on Optima Seaways. One RDI for analogue signal input and one RDI 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 ShipCEMS, 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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6.4 Software and onshore networking solution

6.4.1 Algorithm Design

Prior to the development of a standalone software application for transferring, storing and displaying sulphur emission data Litehauz developed a Python[2] based data processing script to investigate how such an application should be built. In the first step the python-script had 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. Step by step relevant measures were added to the Python -script, along with several sub-processes for evaluating and displaying the evaluated data. Figure 5 shows a total overview of the developed algorithm.

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.
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 5 along with compliance percentages, i.e. how much of the time the ship is the emission criteria dictated by MEPC 256(68).

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

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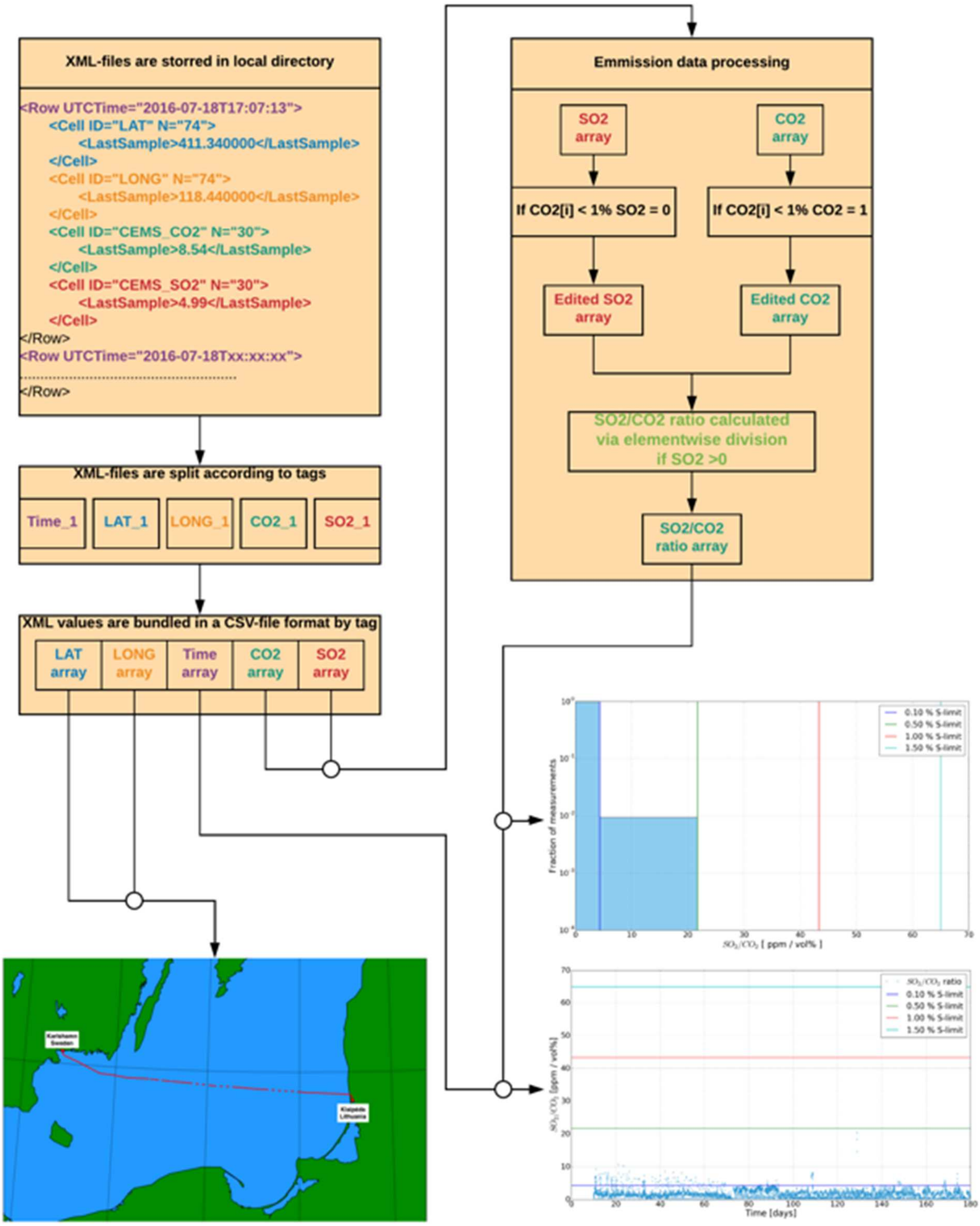

Figure 5: A flowchart describing the data processing carried out by the algorithm implemented in the automatic sulphur emission monitoring application

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6.4.2 Software Solution

The subcontractor BlueBrick was approached during the initial phase of the project to produce an application based on the specifications developed by Litehauz including 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 was also requested. In this project, BlueBrick has delivered their first beta version. Below is given an introduction to the local application and the cloud application is presented.

6.4.3 Data Transfer Overview

Figure 6 below provides an overview of the different data transmission steps performed post logging of the data on the ship. Progressing chronologically through the individual steps of the figure the following can be summarized:

1. Initially the XML-file containing logged data is transferred from the ship to a data repository. This communication is facilitated via a SFTP-SSH server, to perform the data transfer as securely as possible. Dependant on the shipowner's preferences the data may be transferred via satellite, GSM (3/4G) or Wi-Fi provided in the ports. Considering a scenario where data is sampled once per minute and reported every 24 hours the following applies to bandwidth usage and data consumption:
   - The equipment itself needs to perform TLS authentication prior to a data transfer. Such will produce a data consumption of *10-20 kilobytes*
   - An entity logged every 1 minute produces a data amount equal to 15 kilobytes per day. For the purposes of logging SO_2 and CO_2 emissions along with position data, i.e. latitude and longitude this amounts to 60 kilobytes per day. Further data entities like course and speed over ground are also logged. The total number channels logged amount to 18, meaning a *total daily data transfer of 270 kilobytes*.
   - Lastly, as the VRS's configuration may be updated remotely this may entail a data transfer of approximately *20 kilobytes per day*.

   Summing up the individual data transfers the total daily consumption will therefore amount to approximately 310 kilobytes. If the communication were to be transmitted by a 256 kilobit per second (32 kilobytes per second) satellite connection, it would occupy such for 10 seconds per day.

2. On the SFTP server the files are stored in two individual folder structures. One for back-up purposes and one for communicating with the shipowner's office and the local PC application.
3. The local PC application uses a SFTP-client to transfer newly received XML-files from the folder structure purposed with communicating with the shipowner's office. If new files are present on the SFTP-server, the PC application synchronises the local folder structure on the PC to resemble that of the SFTP-server.

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4. Received files are processed as described earlier in the section on algorithm design. As, the emission data belong to the shipowner only summed data, calculated values hereof and latitude and longitude coordinates are transmitted to the cloud application. The summed data describe the number of times a certain SO_2 to CO_2 ratio has been measured by the CEMS, while calculated values hereof is the average fuel Sulphur content equivalent and the compliance percentage. This is used for presenting frequency diagrams and provide decision support in relation to inspections.
5. On the cloud application the summed data is stored and made available for registered users, i.e. PSC or other relevant authorities. Only summed data from the last 72 hours is made available to the PSC control, while the shipowner can see historical data as well.

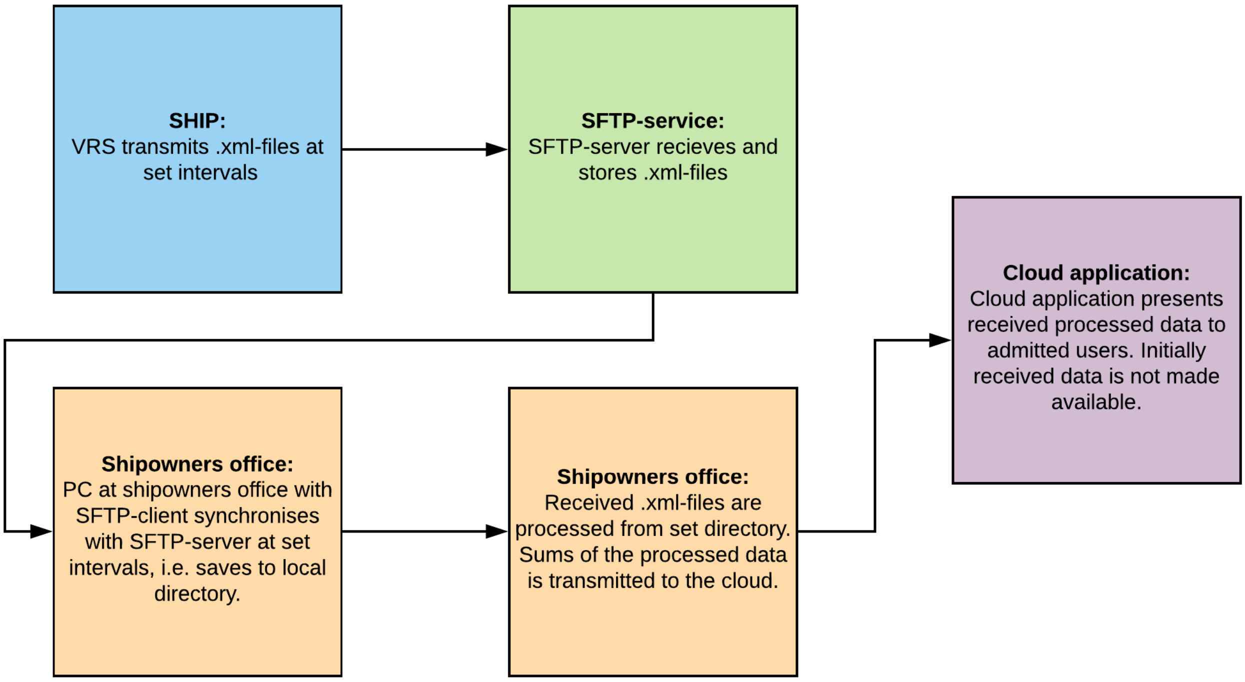

Figure 6: Data transmission scheme

6.5 Presentation of the Local Application

The local application at the shipowner's office is tasked with retrieving and processing the emission data. On the start-up screen, shown in Figure 7, the user can choose between two sheets, “Most recent data (72h)” and “Historical results”.

6.5.1 Data from the last 72-hour period

As displayed in Figure 7, the first sheet, called “Most recent data (72h)” presents the user with a list of currently available ship data from the last 72-hour period. For each vessel, identified by the IMO number, the measurement count and the overall sulphur emission

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compliance ratio is displayed, i.e. what fraction of the measurements are within compliance. The second sheet, called “Historical results”, gives excess to data older then 72 hours. This function will be explained later.

If the ship of interest is on the list the user can click on it and will get more detailed information of the emission data. In case the ship of interest is not on the list the user can search for a specific vessel in the available search function above the list. This local ‘shipowner’s’ function is currently also available to users with credentials matching the authorities’ through the cloud application (see later).

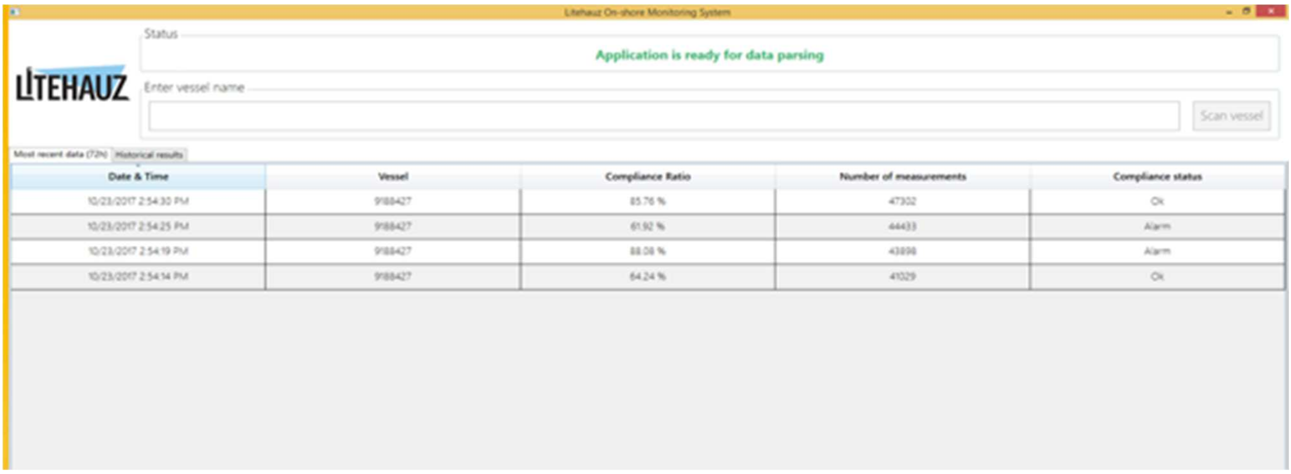

Figure 7: Screenshot of the user interface when opening the local application with a list of available ship data from the last 72-hour period. - Full size of the screenshot is available in Appendix I

By clicking on one of the ships from the list, a new window presenting a histogram plot will open as displayed in Figure 8. The histogram plot shows how the vessel was performing emission-wise at intervals relating to corresponding fuel oil sulphur content, e.g. <0.1%, 0.1%- 0.5%, 0.5%-1.0%, 1.0%-1.5%, and 1.5%-3.5%. The user can examine the original data file by clicking the “view original file” button on the right corner shown in Figure 8. A new window will open up showing the original data in .xml format, as displayed in Figure 9.

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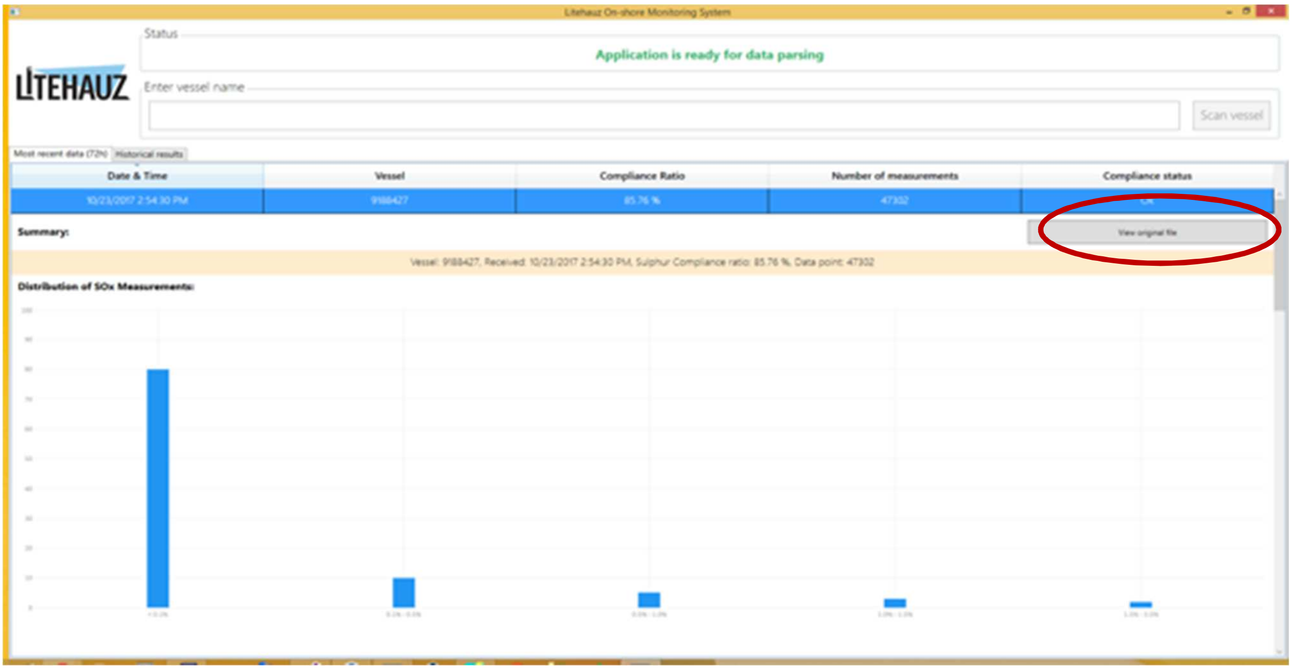

Figure 8: Screenshot of graphical presentation of emission data - Full size of the screenshot is available in Appendix II

```
<?xml version="1.0"?>
- <DataCollection Format="DANELEC-0.9" EndTime="2017-04-29T08:48:31" StartTime="2017-04-29T04:48:31">
    <DeviceConfig Vesselname="MS_Danelec" Mmsi="123456789" Imo="1234567" Time="2017-02-24T11:38:50" ID="4216-00011-c30f3028"/>
  - <LogData EndReason="COMPLETE">
      <DataLoggerConfig Time="2017-04-28T10:30:42" ID="DataProcessor2"/>
    - <SyncData>
      - <RowsSegment SamplingWindow="300000">
          <ReportConfig Time="2017-04-28T10:27:09" ID="TelemetryReport"/>
        - <Row UTCTime="2017-04-29T04:53:31">
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              <Deviation>0.735778</Deviation>
              <LastSample>4.500000</LastSample>
              <Max>6.600000</Max>
              <Mean>5.499404</Mean>
              <Min>2.100000</Min>
              <Trend>-0.000313</Trend>
            </Cell>
          - <Cell ID="AIS_DRAFT" N="73">
              <LastSample>7.400000</LastSample>
            </Cell>
          - <Cell ID="WIND_DIR_R" N="300">
              <LastSample>110.000000</LastSample>
            </Cell>
          - <Cell ID="STW" N="300">
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              <LastSample>0.000000</LastSample>
              <Max>0.000000</Max>
              <Mean>0.000000</Mean>
              <Min>0.000000</Min>
              <Trend>0.000000</Trend>
            </Cell>
          - <Cell ID="DPT_KEEL" N="300">
              <LastSample>28.000000</LastSample>
```


Figure 9: Screenshot of the original file. - Full size available in Appendix III

6.5.2 Historical data

It is possible for the user to access the performance data of the ship beyond the last 72 hours. This is currently reserved for a user with credentials matching the shipowner's. By clicking on the sheet "Historical results" stored data from earlier periods will be available. In accordance with the 72-hour period sheet, the user will see a list of available ship data, shown in Figure 10. The user can click on a ship to get the detailed information of that ship.

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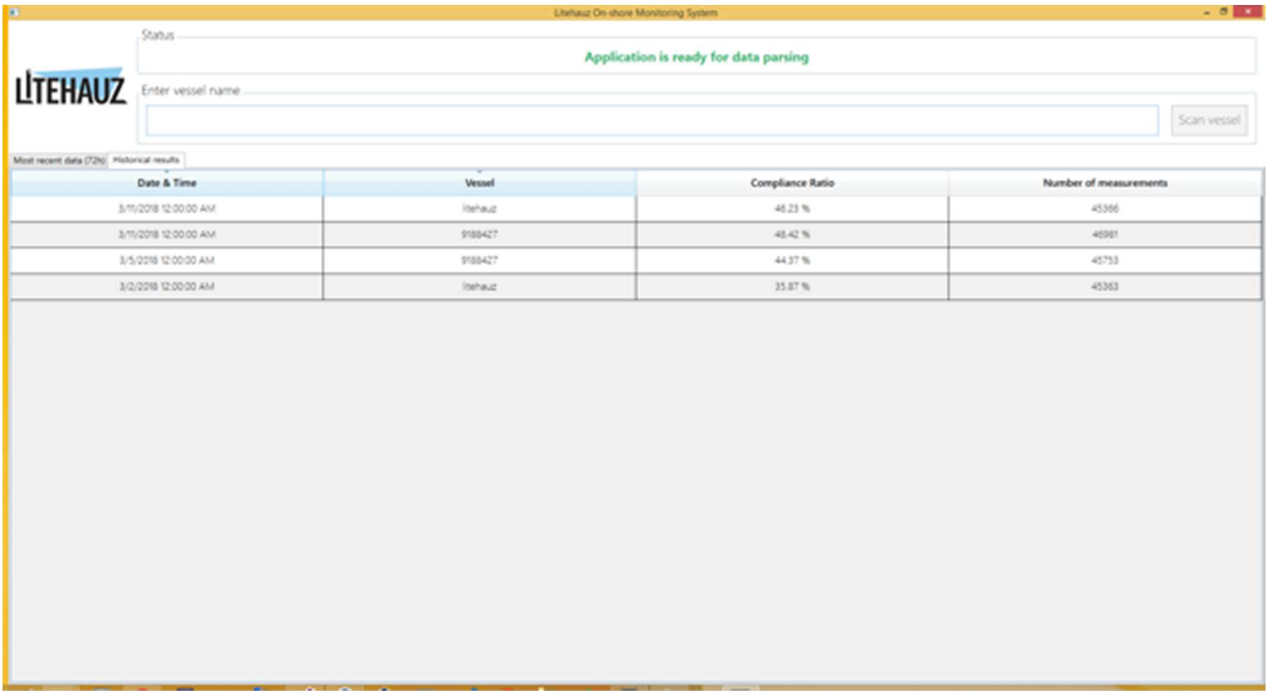

Figure 10: Screenshot of listed historical data - Full size of the screenshot is available in Appendix IV

As seen in Figure 11, a histogram of the emission data from the chosen vessel over a specified period is displayed. All relevant information, e.g. vessel number, date range and compliance ratio are shown in the orange header of the plot.

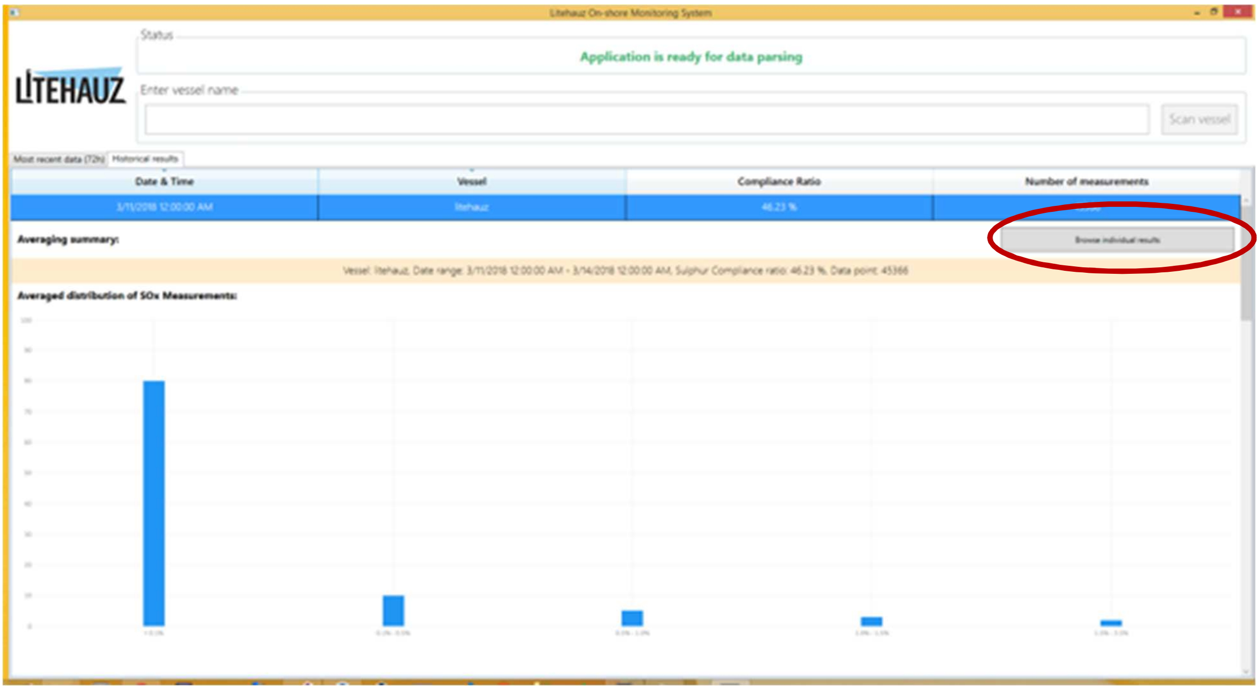

Figure 11: Screenshot of graphical presentation of historical emission data in local application. Red circle shows the button "Browse individual results" - Full size of the screenshot is available in Appendix V

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By clicking on the button “Browse individual results” in the red circle, a new window opens showing a list of reports, one of which can be selected, as displayed in Figure 12.

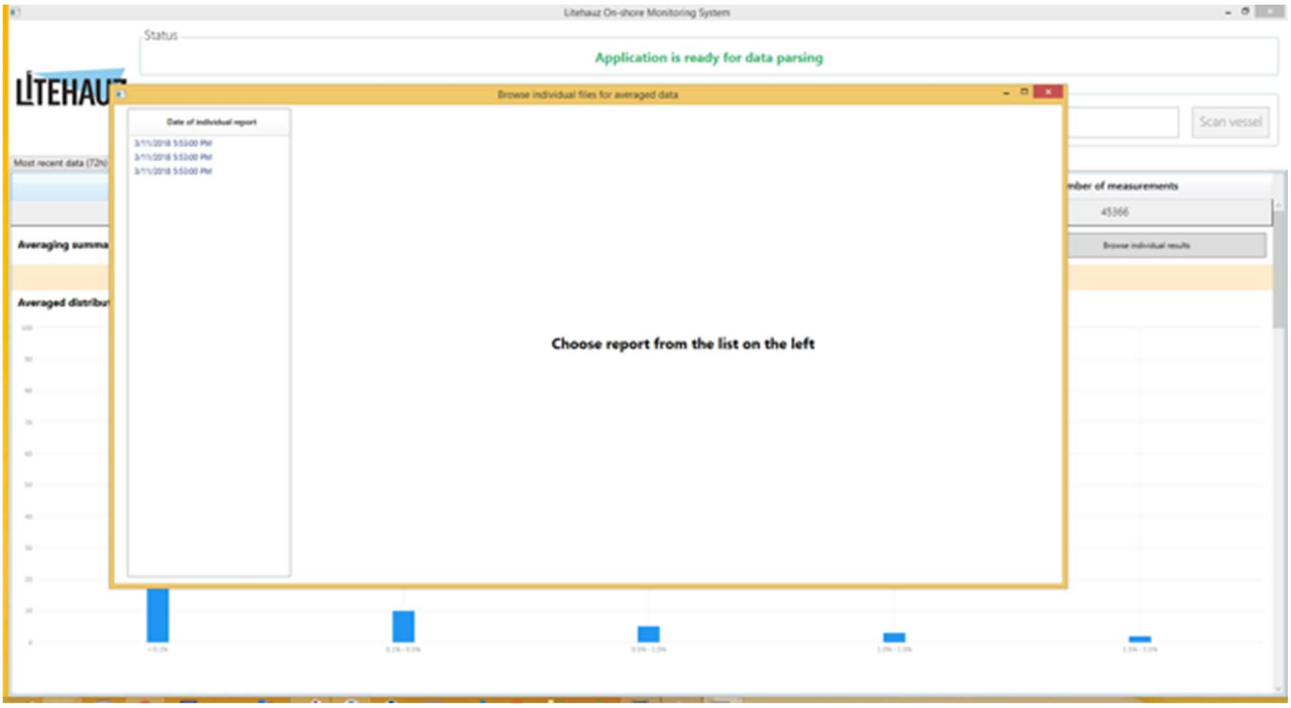

Figure 12: Screenshot of browseable individual files for average data - Full size of the screenshot is available in Appendix VI

Figure 13 displays the histogram plot of the emission data of the selected report. Parallel to the 72h application described in section 6.5.1 the user can now look at the original data by pressing the button “View original file”, marked with a red circle in Figure 13. Figure 14 illustrates an example of the raw data from the selected emission data.

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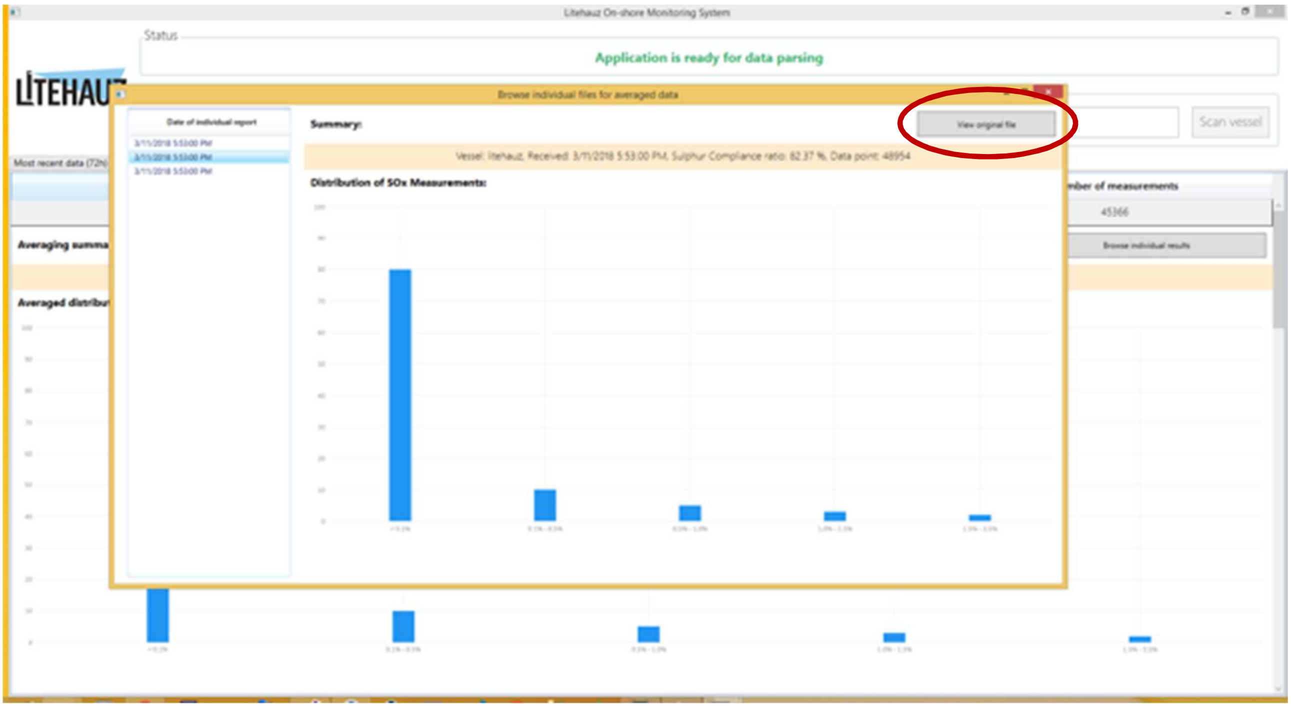

Figure 13: Screenshot of histogram of individual files. Red circle shows the button “View original file” - Full size of the screenshot is available in Appendix VII

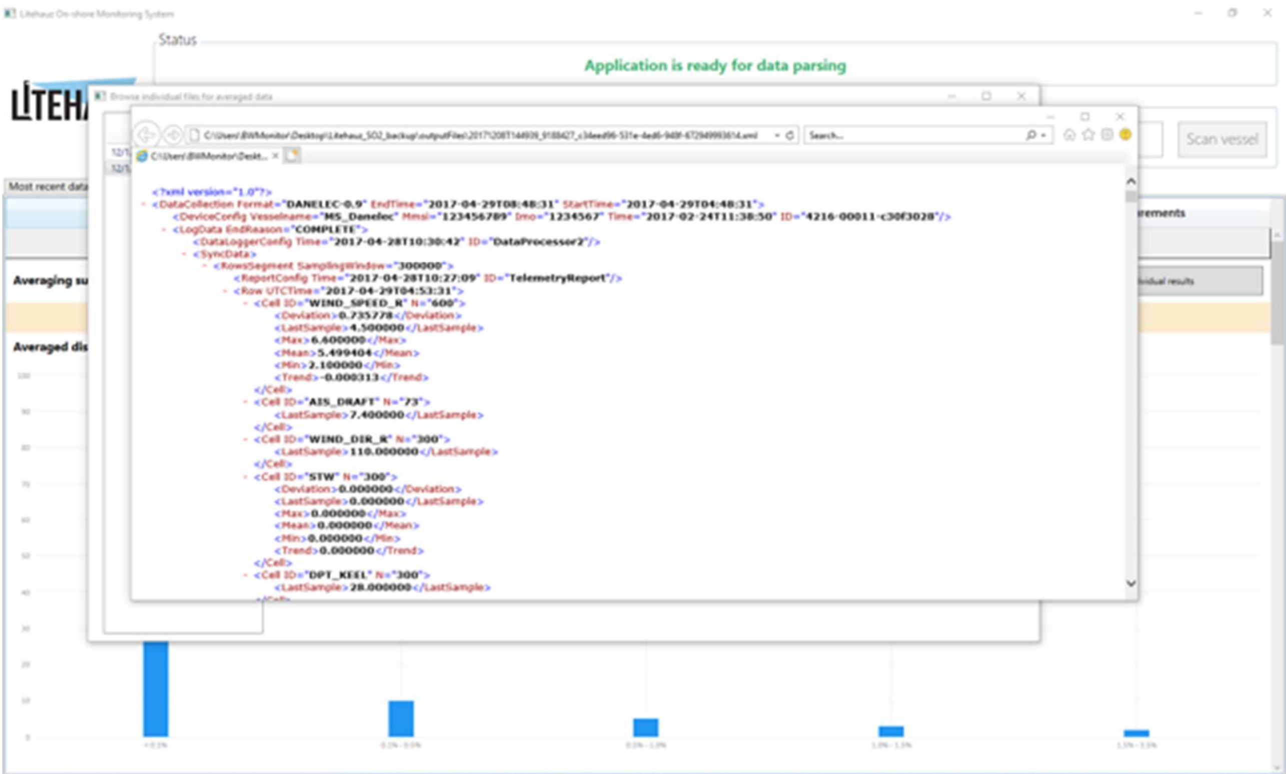

Figure 14: Screenshot of the original file from selected report of historical data - Full size of the screenshot is available in Appendix VIII

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6.6 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 (Figure 15). The level of accessibility depends on the appropriate credentials and will be as followed:

i. only to ships from single shipowners
ii. full data
iii. administrative relevant data

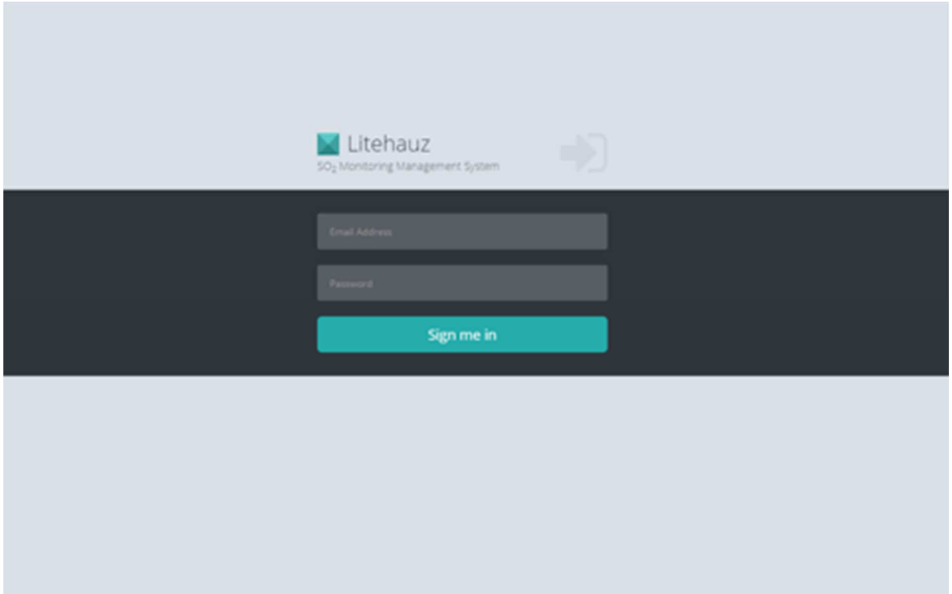

Figure 15: Screenshot of initial login screen to cloud application via internet browser - Full size of the screenshot is available in Appendix IX

When logged in, the user is presented with a browseable list of ships with emission data and their compliance ratio (Figure 16). In accordance with the local application a histogram of the emission data will open up by clicking on a specific ship on the list as illustrated in Figure 17.

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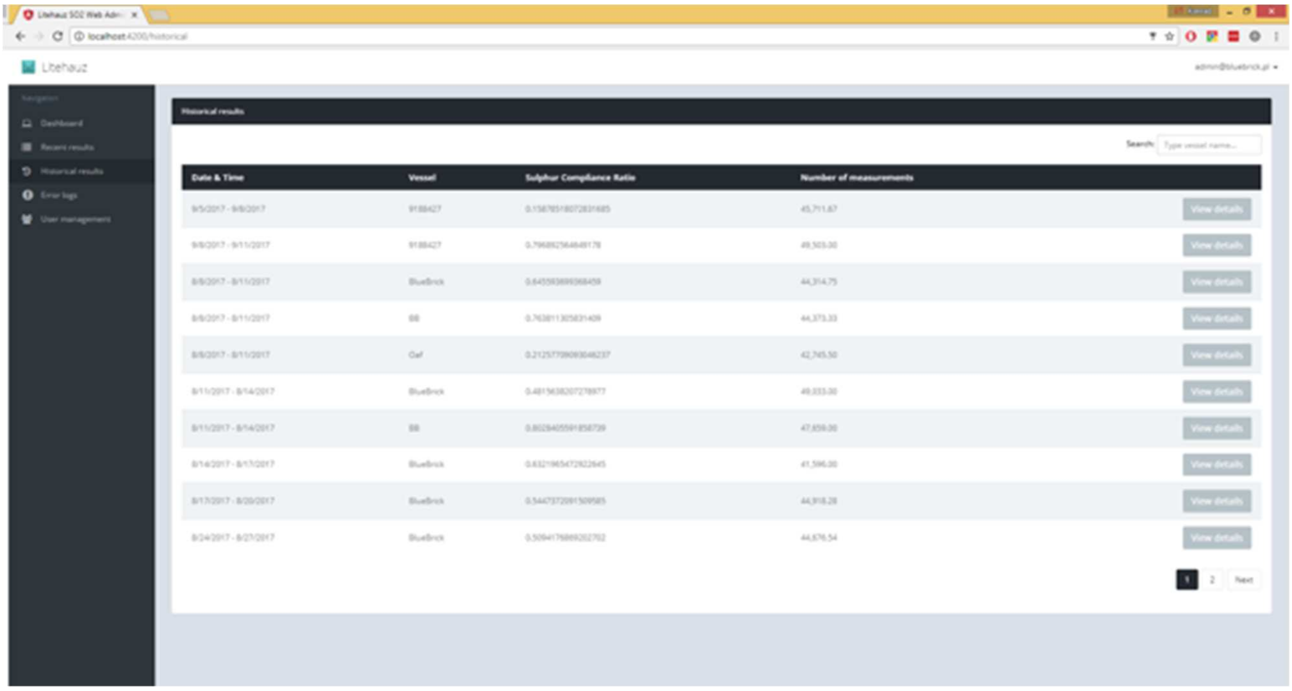

Figure 16: Screenshot of browsable list of available ships - Full size of the screenshot is available in Appendix X

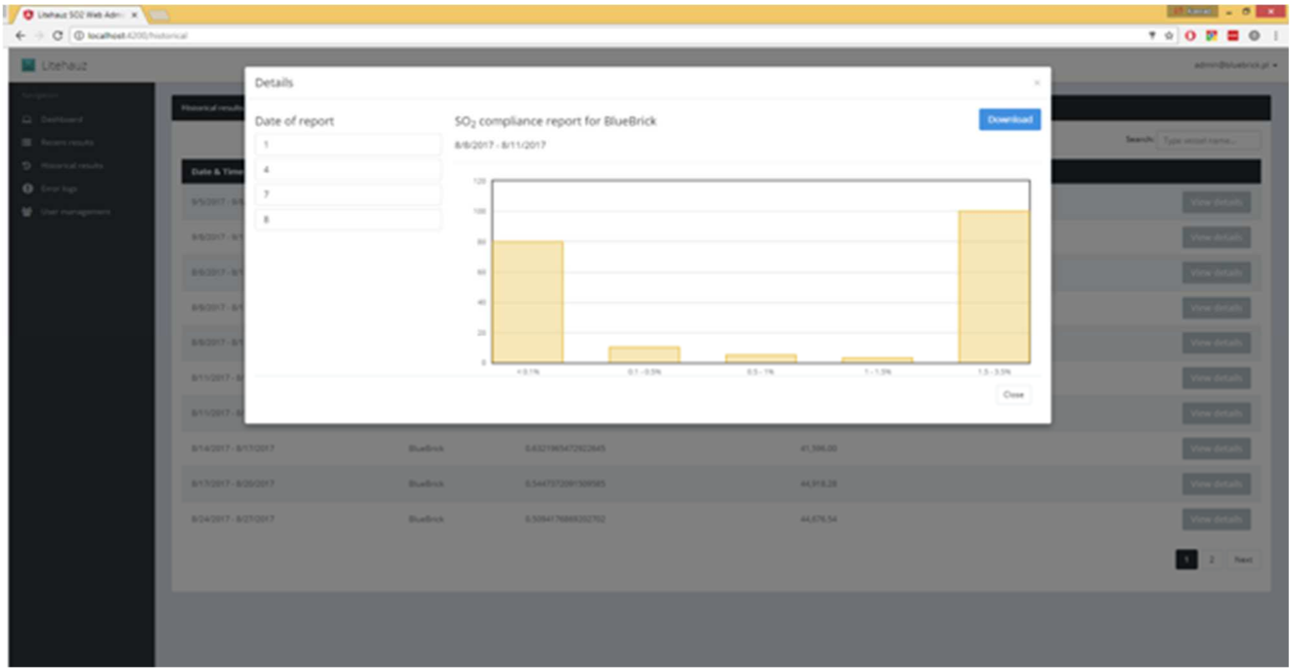

Figure 17: Screenshot of histogram plot of SO_2/CO_2 data - Full size of the screenshot is available in Appendix XI

The current period visible to e.g. PSC users would be 72 hours, however this period may be changed to serve a desired purpose. The shipowner or other authorised persons will have access to emission performance data of their vessels from desired periods.

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6.7 Demonstration and Evaluation

6.7.1 Installation of the Field-based Test

As stated in the previous delivery D5.7 the installation was carried out on the DFDS A/S operated vessel OPTIMA SEAWAYS, serving a RO/PAX route between Karlshamn and Klaipeda. The installation was carried out through a 5-step plan, comprising the following steps:

1. Pre-installation inspection, where the installation scope was determined and plans for cable placement and cable penetrations were established
2. Cable installation, in which Ethernet cable and cable penetrations were placed in relevant locations of the ship to provide connectivity between later installed data acquisition and transmission equipment
3. Network configuration, for definition of external data transmission to shore and interconnectivity between the data acquisition devices
4. Equipment installation, including placement of the RDI-A/S, VRS and connectivity between the CEMS and RDI-A.
5. Commissioning, where the performance of the installed equipment was verified, and data was being transmitted to the on-shore SFTP-server

Figure 18: The structure inside the red circle houses the scrubber on the vessel Optima Seaways

6.7.2 Pre-installation

Throughout this initial phase relevant material, e.g. installation, performance manuals, were reviewed. As shown in Figure 19 and Figure 21 the three DANELEC components RDI-A, RDI-S and VRD had to be installed and RDI-A cable connection had to be fitted. An

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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 19 and Figure 20 the scrubber area is located at the aft part of the ship and the installed equipment had to be connected via cables to the hardware installed on the bridge which is located in the fore part of the ship. This of course posed 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 satisfying the ships' class. Further, as the VDR system aboard Optima Seaways is of Kelvin Hughes make, an external service technician had to run a performance test of the equipment post installation to verify that the new installation did not impaired its functionality.

Summarising on the pre-installation inspection, the following was found to influence the installation:

- Physical locations of the local area network (LAN) switches and their interconnectivity
- The condition and locations of bulkhead cable penetrations

OPTIMA SEAWAYS was built in 1999, as of such the ship has seen a number of retrofit projects. Especially the scrubber installation performed in 2014 has provided the ship with a series of updated cable penetrations in the aft part of the ship, that are reconfigurable. Thus, there was a limited need for installation of new cable penetrations, which are quite time consuming to implement. From the preinstallation inspection the intended cable routing between the CEMS and LAN switch 1, seen in Figure 19 was proposed and decided upon. On the bridge deck there were no reconfigurable cable penetrations available and the normal cable penetrations present were at full capacity. To realise the cable scheme seen in **Error! Reference source not found.** that would allow communication between the VDR, internet and the RDI-A located in the aft part of the ship, it was found that two cable penetrations would have to be installed for the Ethernet cable to exit the bridge.

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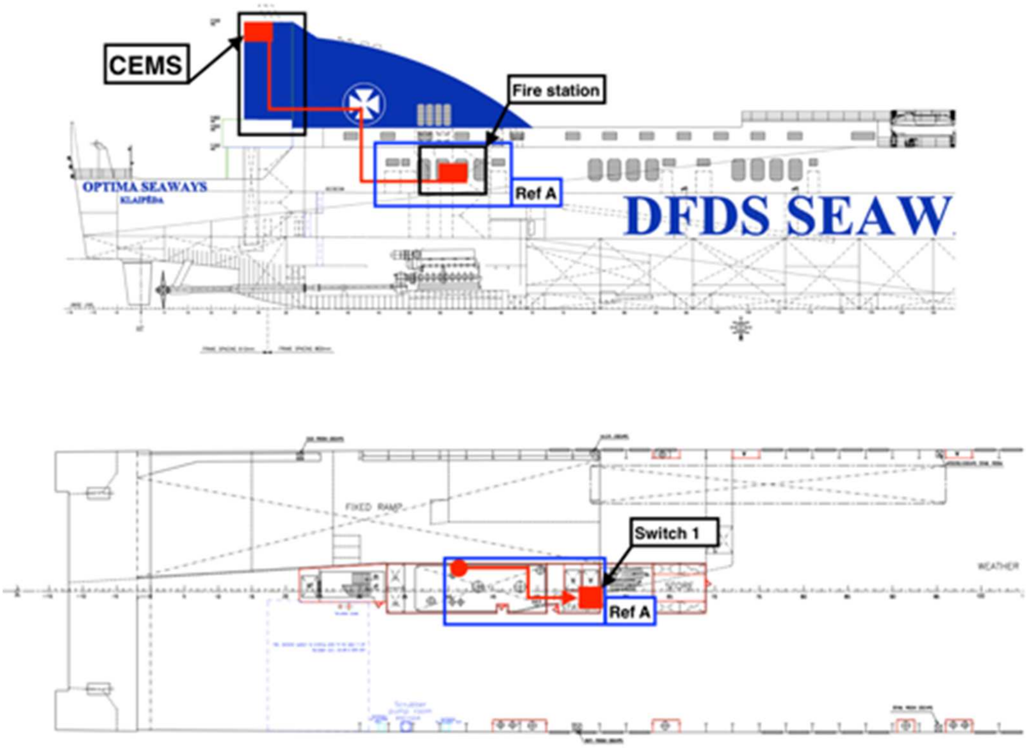

Figure 19: Schematics of cable connection between the CEMS and the LAN switch in the Fire Station onboard Optima Seaways

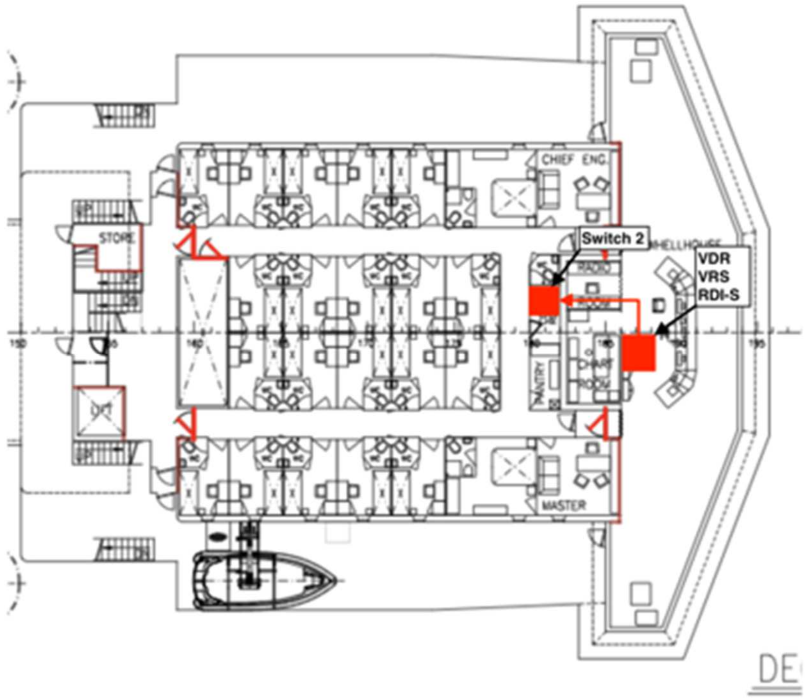

Figure 20: Schematics of cable connection between the VDR, VRS and the LAN switch in the Fire Station onboard Optima Seaways

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6.7.3 Cable installation

The interconnectivity between the hardware and specifications of the installed cables is described in Figure 21. Communication between the devices is performed over Ethernet cable. As the ship already had a good data infrastructure, Ethernet cables only had to be installed between the LAN switches described in the pre-installation section. The cables were installed over several visits to the ship, along with the cable penetrations located on the bridge.

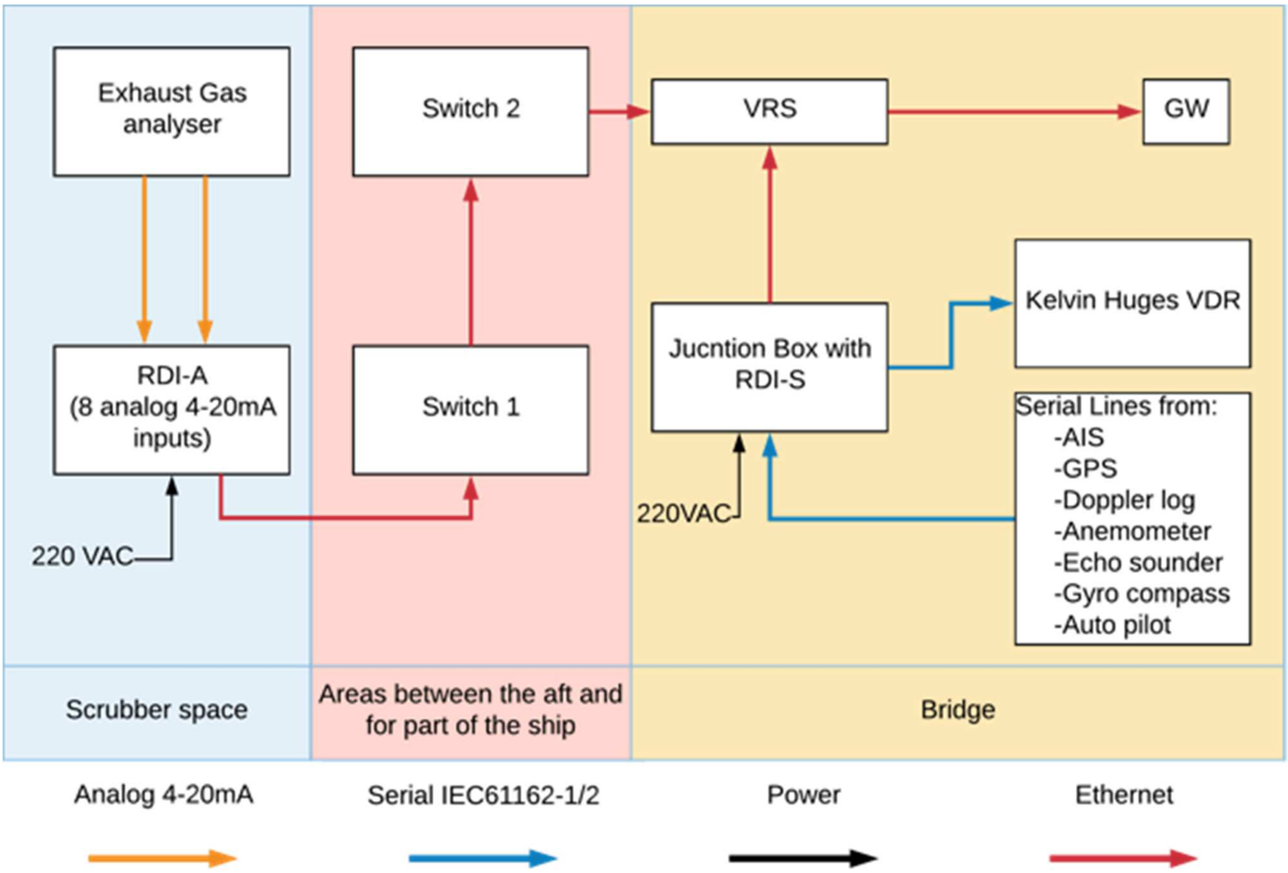

Figure 21: Principle drawing of DANELEC hardware installations

6.7.4 Network configuration

As it was decided upon to use the available network infrastructure of the ship, i.e. LAN switch 1 & 2, to transfer data between the RDI-A and VRS, it was necessary

6.7.5 Equipment installation

When the cable installation and network configuration was completed DANELEC Marine's hardware was mounted on the bridge and at the CEMS. Further, the Ethernet cables were fitted with RJ45 plugs and placed in their designated ports of switch 1 & 2. Subsequently of connecting the RDI-S and VRS to the VDR, the functionality of the VDR had to be verified by an authorised Kelvin Hughes service technician. This verification was performed without

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any issues and was therefore accepted. The VRS and RDI-S installation on the bridge can be seen in Figure 22.

Figure 22: The installed VRS on the left and RDI-S on the right

As the described the RDI-A had to be installed at the CEMS in the aft part of the ship. On Figure 23 the enclosure and its contents can be seen along with cable connecting data, power and the 4-20 mA signal.

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Figure 23: On the left marked by a circle is the RDI-A in its enclosure. On the right the contents of the enclosure are visible, i.e. the RDI-A

Internally in the CEMS cabinet the wiring has been altered to provide the RDI-A with the emission signal, as seen in Figure 24 and Figure 25.**Error! Reference source not found.**

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Figure 24: The internal wiring of the CEMS cabinet. The green cable is tasked with providing the 4-20mA signal to the RDI-A

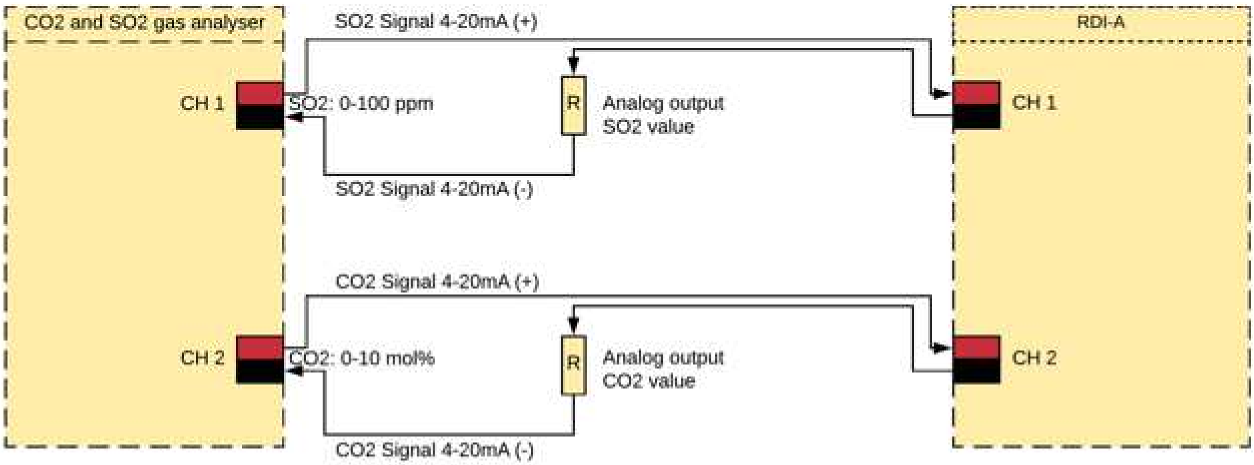

Figure 25: Altered signal loop. R indicates the old recipient of the analog signal

6.7.6 Commissioning Test

Concluding the installation on Optima Seaways, a commissioning test was carried out on the scrubber equipped vessel operated by DFDS A/S in the Baltic Sea. It was verified that the installed equipment e.g. hardware and cable connections was working correctly and did not interfere negatively with any of the ships equipment involved in the installation. A gapless data transfer was demonstrated as well as the undisturbed functionality of the Kelvin Hughes VDR.

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6.8 Demonstration of Data Transfer and Monitoring Efficiency

Emission and operation data from the scrubber retrofitted on Optima Seaways was made available in March 2018. During this time span Litehauz showed the successful transmission of xml-files from the ships VDR to the SFTP-server where it was stored. The transmission interval was set for xx. The local PC application at the shipowners office used the SFTP-client and synchronised the data. The interval for the synchronisation was set for xx. Hereafter the data was processed and transmitted to the cloud.

MEPC Res.259(68) demands a rate of at least 0.0035 Hz when SO_2(ppm) and CO_2 (%) data is continuously measured and recorded onto a data recording and processing device. The reporting interval of the measured scrubber data is 60 seconds corresponding to a frequency of approximately 0.016 Hz, more frequent than required by MEPC. It is common practice that the CEMS measures exhaust gas emissions even when main engines are not running. This may result in high measurements of SO_2 combined with low measurements of CO_2 of atmospheric air, producing artificially elevated SO_2/CO_2 ratios. For the purpose of reporting usable values, valid SO_2 measurements are considered as from the periods in which a threshold value of $CO_2 > 0.4$ vol% indicates that a main engine is running.

The time span of the analysis was from 24/03-2018 to 27/03/2018, corresponding to 3 days. Data are reported every 60 seconds leading to 4320 theoretical counts. The sensors used in ShipCEMS reports values recorded below detection limits as zero and occasionally a negative value may be recorded. Using artificial zero values will bias calculations of mean values and frequency distributions, and all data points below or equal to zero are considered non-valid. Some data may be invalid under more than one criterion. Table 1 gives an overview over the counts that were neglected.

Table 1: Breakdown of data points from AlfaLaval's PureSOx scrubber into categories

Theoretical counts	Valid counts	SO_2/CO_2 <0	SO_2/CO_2 =0	SO2 ≤ 0	CO2 ≤0.4
4320	2444	0	1876	0	1876

6.9 Demonstration of analysis

As described in section 6.4.1 Algorithm Design the PC application uses the algorithm to process the received xml-files. The recommendation made by MARPOL Annex VI MEPC Res.259(68) that the Sulphur emissions from EGC systems are reported as a ratio of SO_2 and CO_2 in units of ppm/vol% were taken into consideration. According to EU regulation, the limit value for 0.1% m/m Sulphur fuel corresponds to a SO_2/CO_2 ratio of 4.3 ppm/vol%.

The processed data is visualised in a histogram plot. The calculated SO_2/CO_2 ratio data is plotted in the frequency plot, seen in Figure 26. The bins on the horizontal axis indicate the range of emissions corresponding to the Sulphur content limits (from left to right: 0.1%, 0.5%, 1.0%, 1.5%, 3.5%, and >3.5%).

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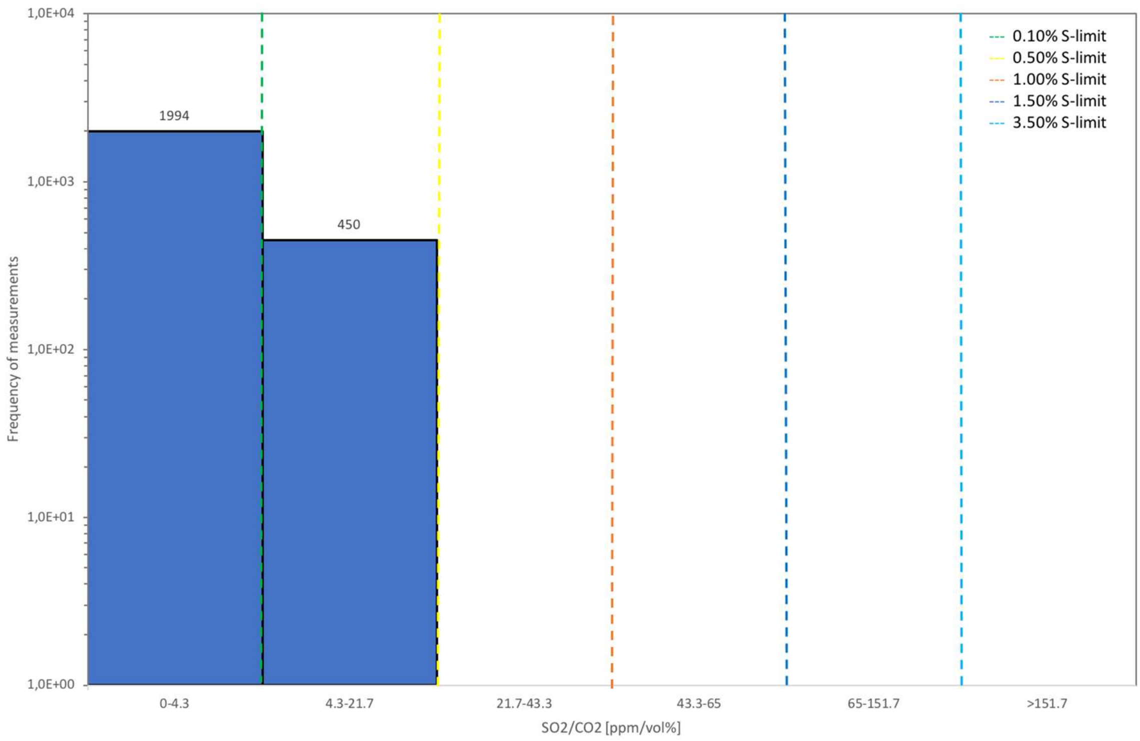

Figure 26:Frequency diagram of the SO2/CO2 ratio data with a logarithmic scale on ordinate axis shows that 81.5 % (1994 data points) of the valid measurements are in the limit of 0.1% Sulphur fuel. Approximately 18.4 % of the data exceed a ratio of 4.3 (0.1% fuel oil Sulphur content).

6.10 Recommendations

It is recognised that the PSC data on in the EU are already reported to THETIS-EU system maintained by EMSA. These are results of individual compliance verifications carried out by member States competent authorities under the Sulphur Directive and provide monitoring of sulphur on a daily basis across the EU. While THETIS-EU allow for prioritization of ship inspections based on risk identified through the recent reported PSCs (i.e. a timeline of months/weeks), the LSRS allows the PSC of a country to decide the inspection regime for all the vessels reporting on-line while they are approaching port based on the real-time indicative S-compliance during the last 72h. The LSRS is not replacing or duplicating THETIS-EU, but adding a true real-time component.

The following recommendations are made regarding the Sulphur reporting mechanism based on the experiences gained by Litehauz through the Maritime Connectivity Platform project supported by Horizon 2020:

- Invite EMSA to initiate a workshop on real-time monitoring in environmental issues of shipping, e.g. Sulphur emissions, and how to expand a voluntary industry reporting scheme such as the proposed into a versatile mechanism for PSC Decision Support. This may include interaction with THETIS-EU and MRV.

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- Invite participants for a full-scale test in the existing SECAs involving a minimum of 3-4 Competent Authorities, 2 or more shipowners with 5 to 10 vessels operating in the short sea shipping sector to gain experience on the true multi-authority call to data and decision support regarding PSC on Sulphur.
- Invite participants for a full-scale test in EU waters outside the existing SECAs (e.g. the Mediterranean Sea) involving a minimum of 3-4 Competent Authorities, 2 or more shipowners with 5 to 10 vessels operating in the short sea shipping sector, where the value of the business model is tested regarding delivering data to mandatory emission reduction schemes in Ports.
- As previous, but with inclusion of Barcelona Convention Parties through REMPEC to ease accession of MARPOL Annex VI by demonstrating reduced administrative burden.

Allowing for the development of similar real-time self-monitoring and reporting mechanisms for PMs, NOx, ballast water, fuel-S etc. will reduce administrative burdens in PSC. The inclusion of data of more pollutants and performance indicators of the ship, primarily speed, load, fuel consumption, will facilitate data mining and pattern recognition leading towards digitization and the development of autonomous or remotely controlled vessels.

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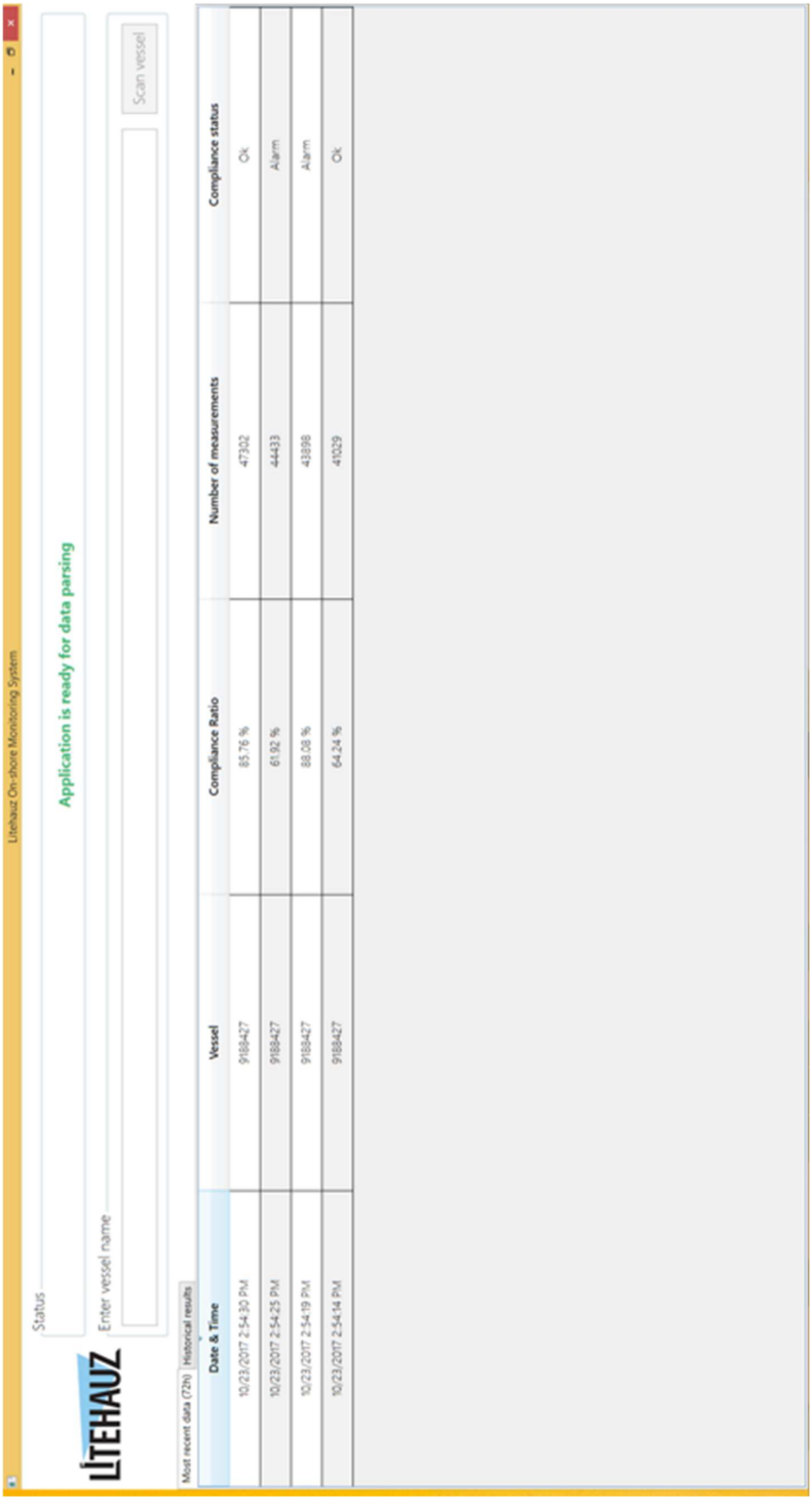
Appendix I



Screenshot of the user interface when opening the local application with a list of available ship data from the last 72-hour period

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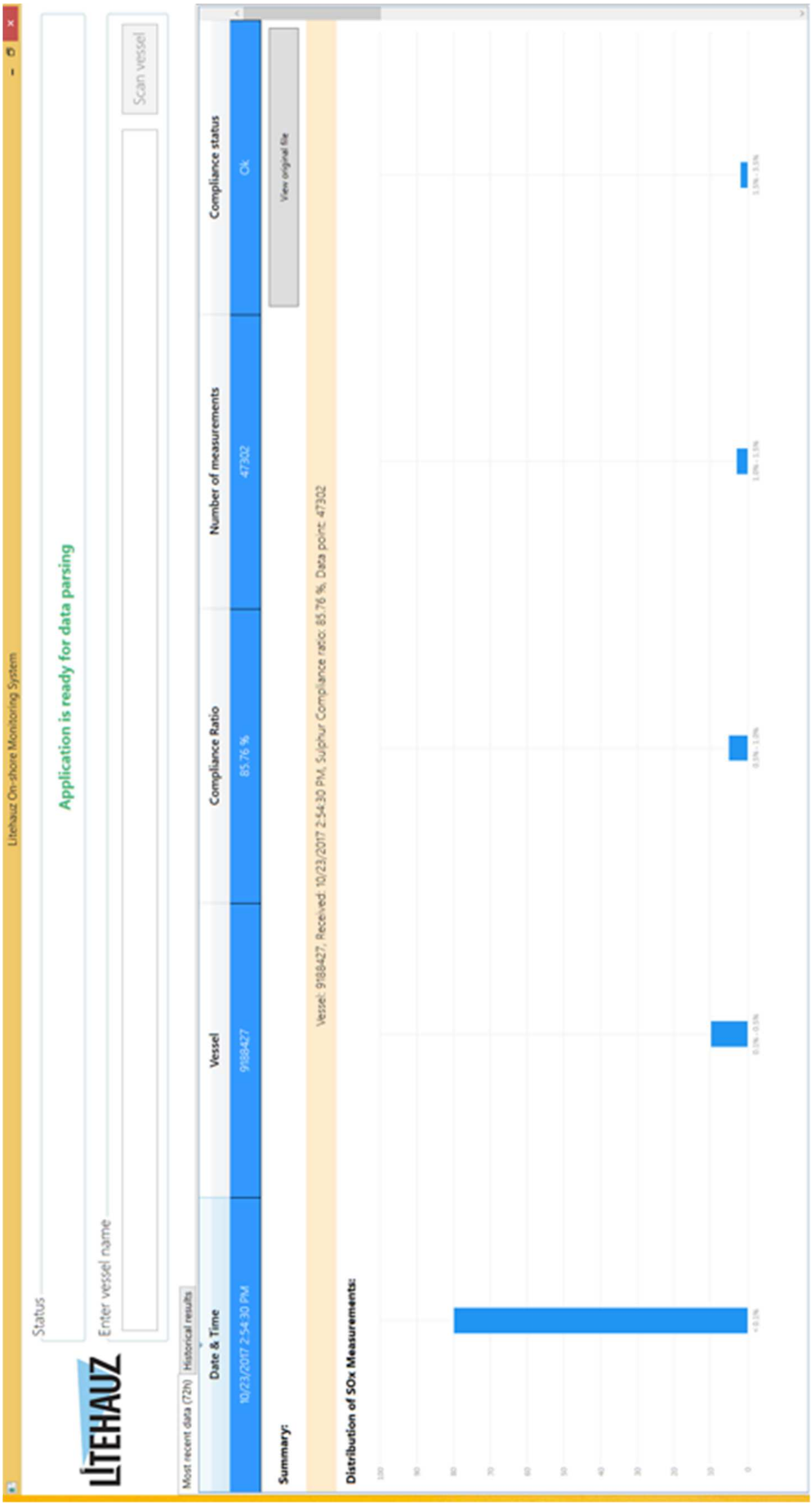
Appendix II



Screenshot of graphical presentation of emission data

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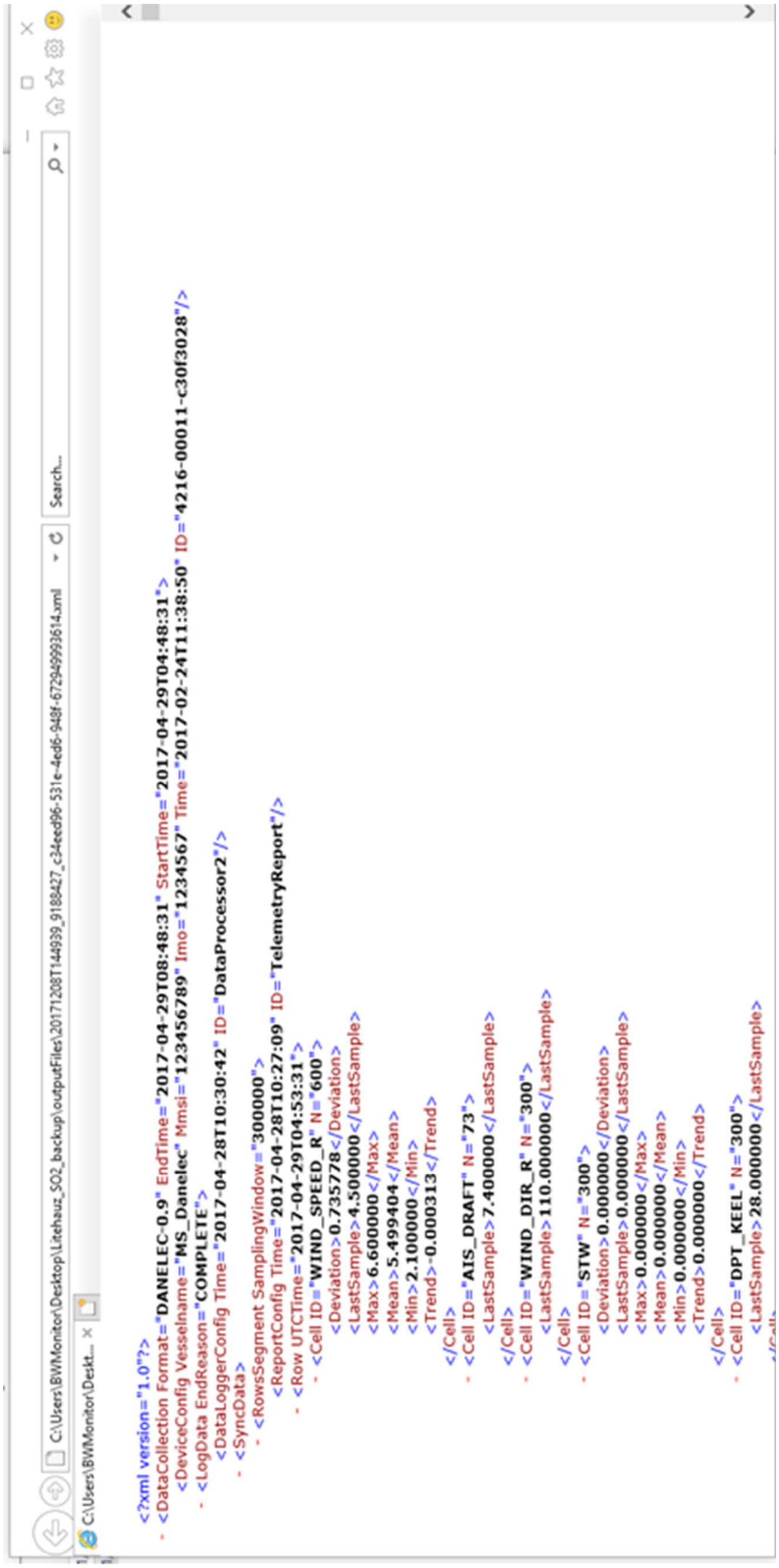
Appendix III




```xml
<?xml version="1.0"?>
- <DataCollection Format="DANELEC-0.9" EndTime="2017-04-29T08:48:31" StartTime="2017-04-29T04:48:31">
    <DeviceConfig Vesselname="MS_Danelec" Mmsi="123456789" Imo="1234567" Time="2017-02-24T11:38:50" ID="4216-00011-c30f3028"/>
  - <LogData EndReason="COMPLETE">
      <DataLoggerConfig Time="2017-04-28T10:30:42" ID="DataProcessor2"/>
    - <SyncData>
      - <RowsSegment SamplingWindow="300000">
          <ReportConfig Time="2017-04-28T10:27:09" ID="TelemetryReport"/>
        - <Row UTCTime="2017-04-29T04:53:31">
          - <Cell ID="WIND_SPEED_R" N="600">
              <Deviation>0.735778</Deviation>
              <LastSample>4.500000</LastSample>
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              <Mean>5.499404</Mean>
              <Min>2.100000</Min>
              <Trend>-0.000313</Trend>
            </Cell>
          - <Cell ID="AIS_DRAFT" N="73">
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            </Cell>
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            </Cell>
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Screenshot of the original file.

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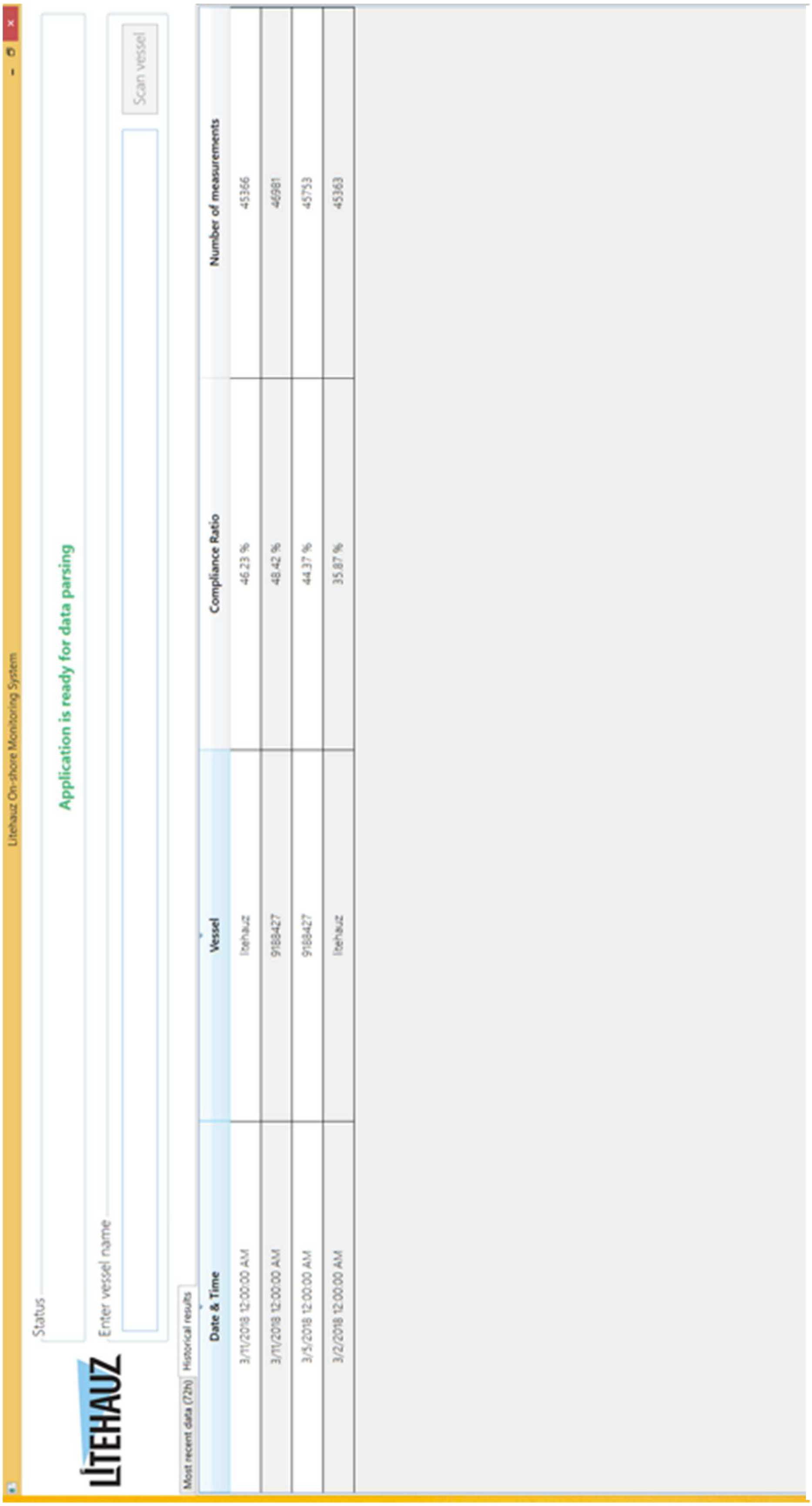
Appendix IV



Screenshot of listed historical data

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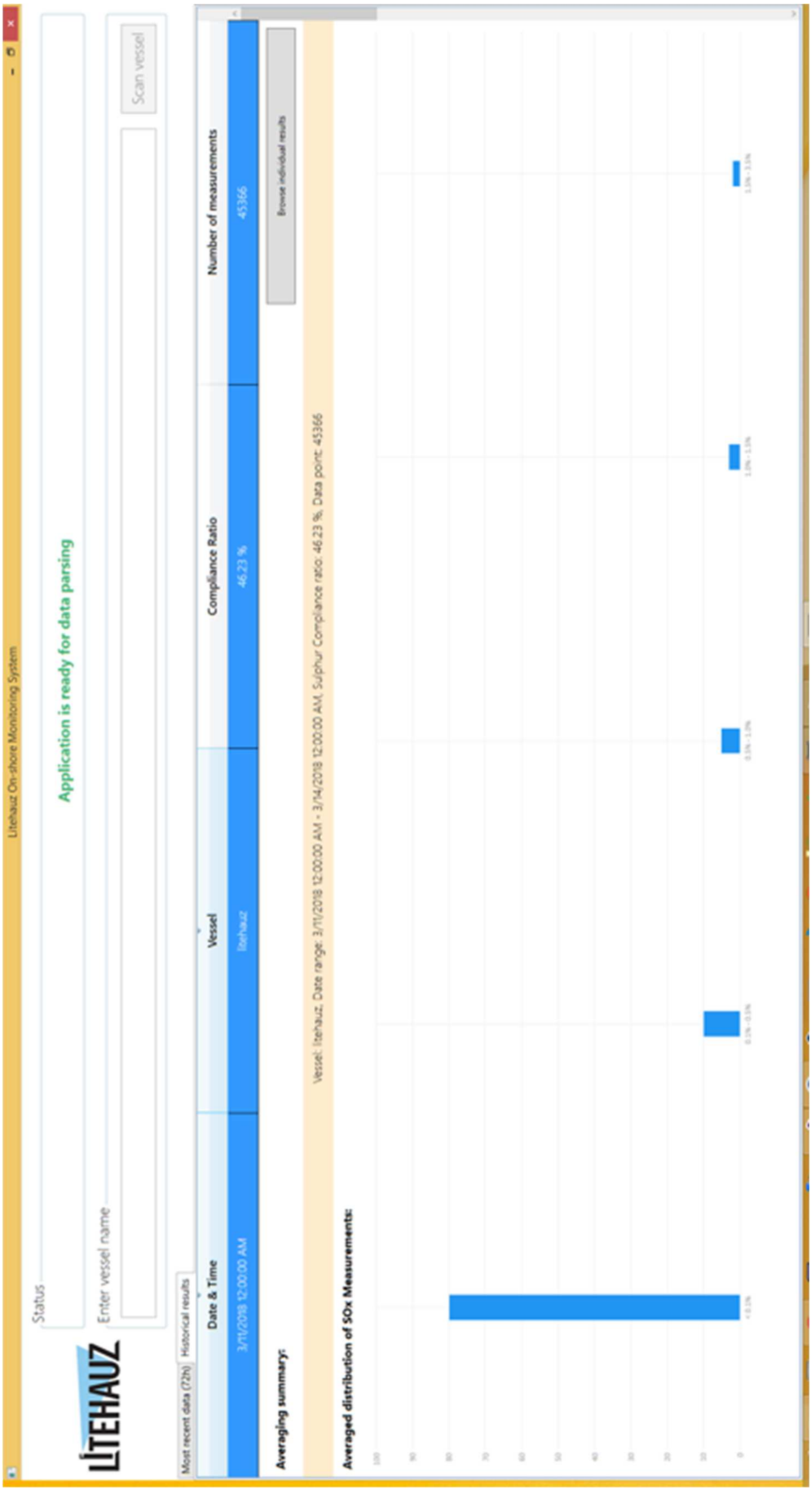
Appendix V



Screenshot of graphical presentation of historical emission data in local application. Red circle shows the button “Browse individual results”

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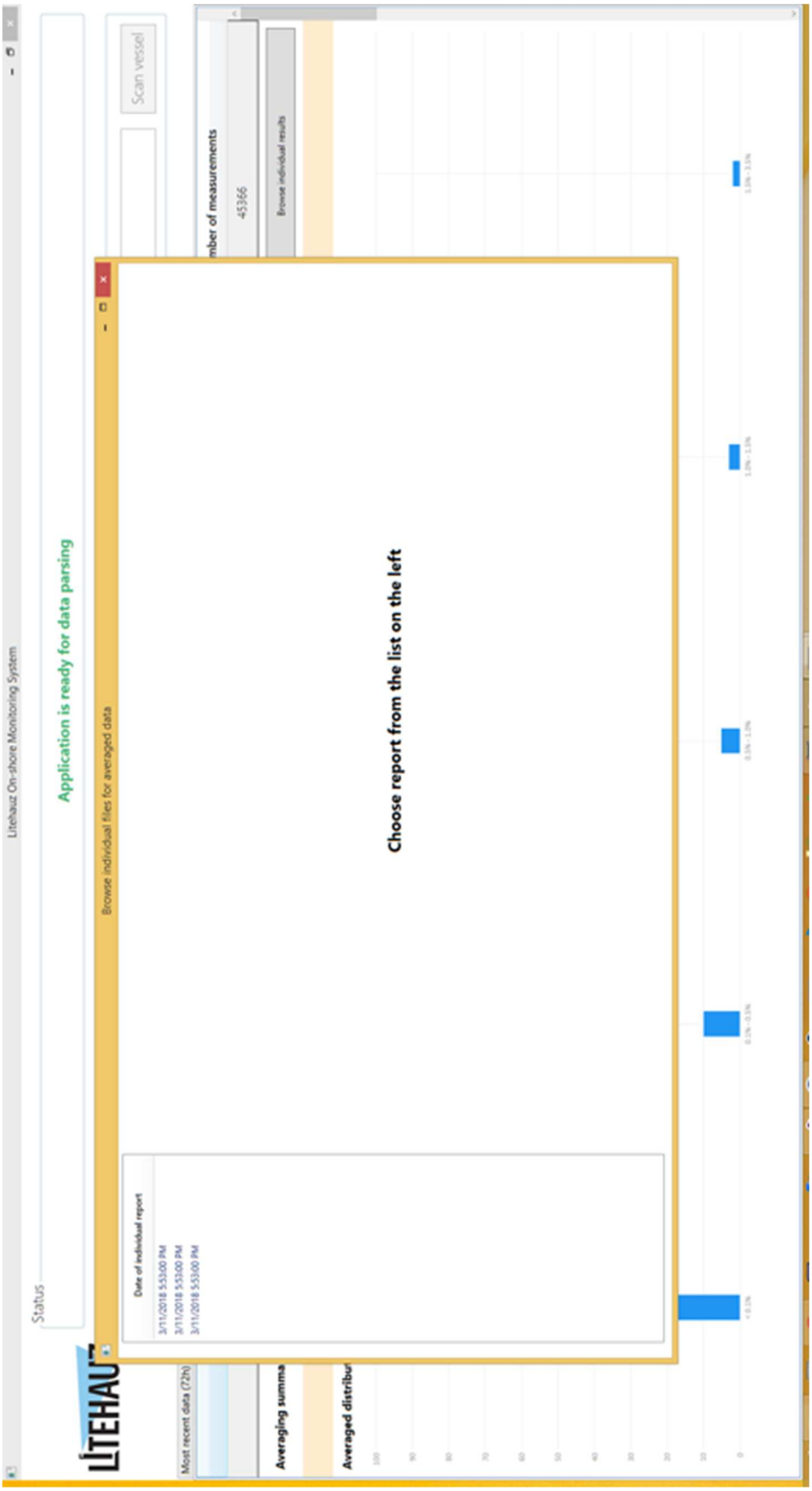
Appendix VI



Screenshot of browseable individual files for average data

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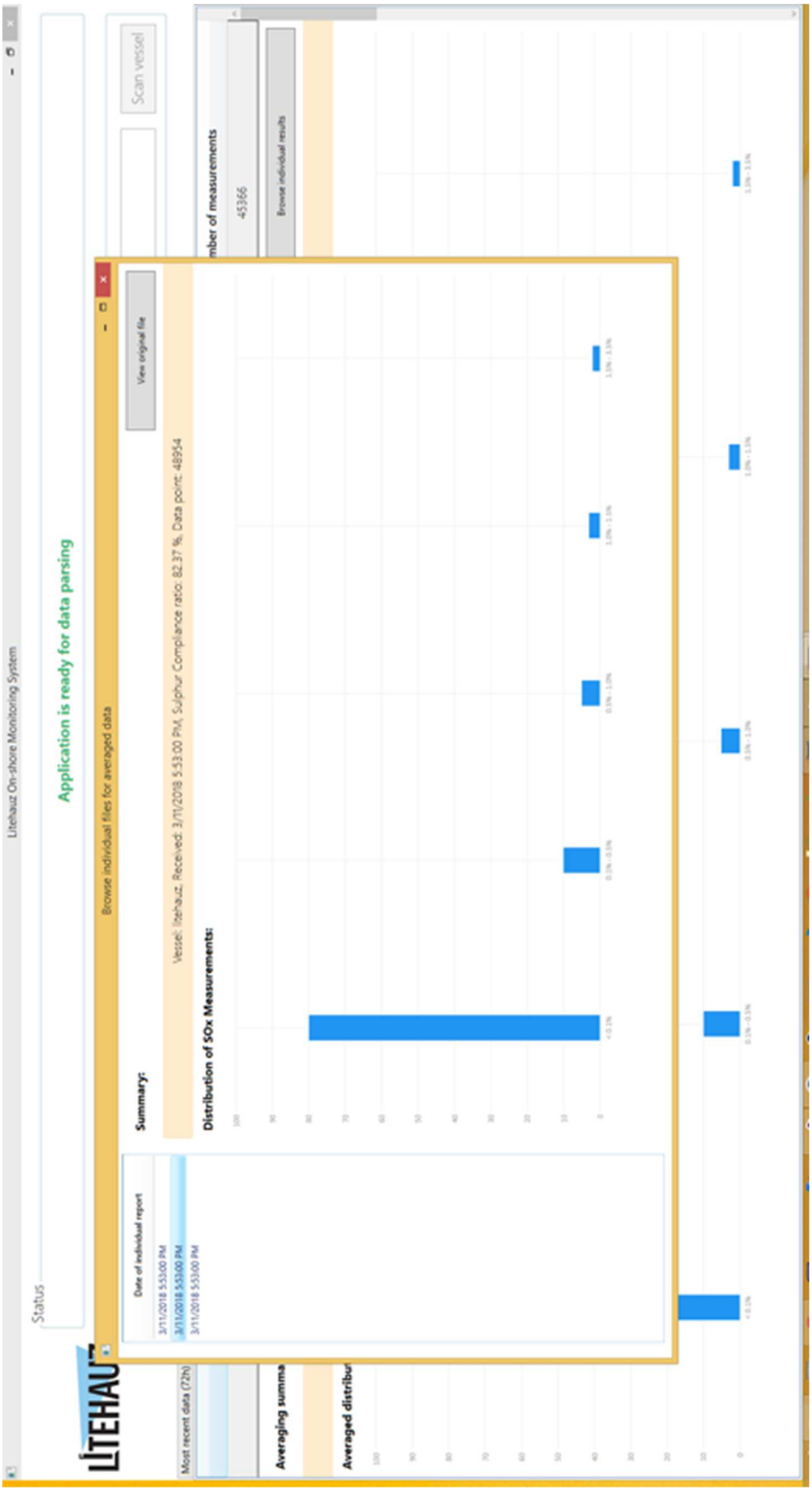
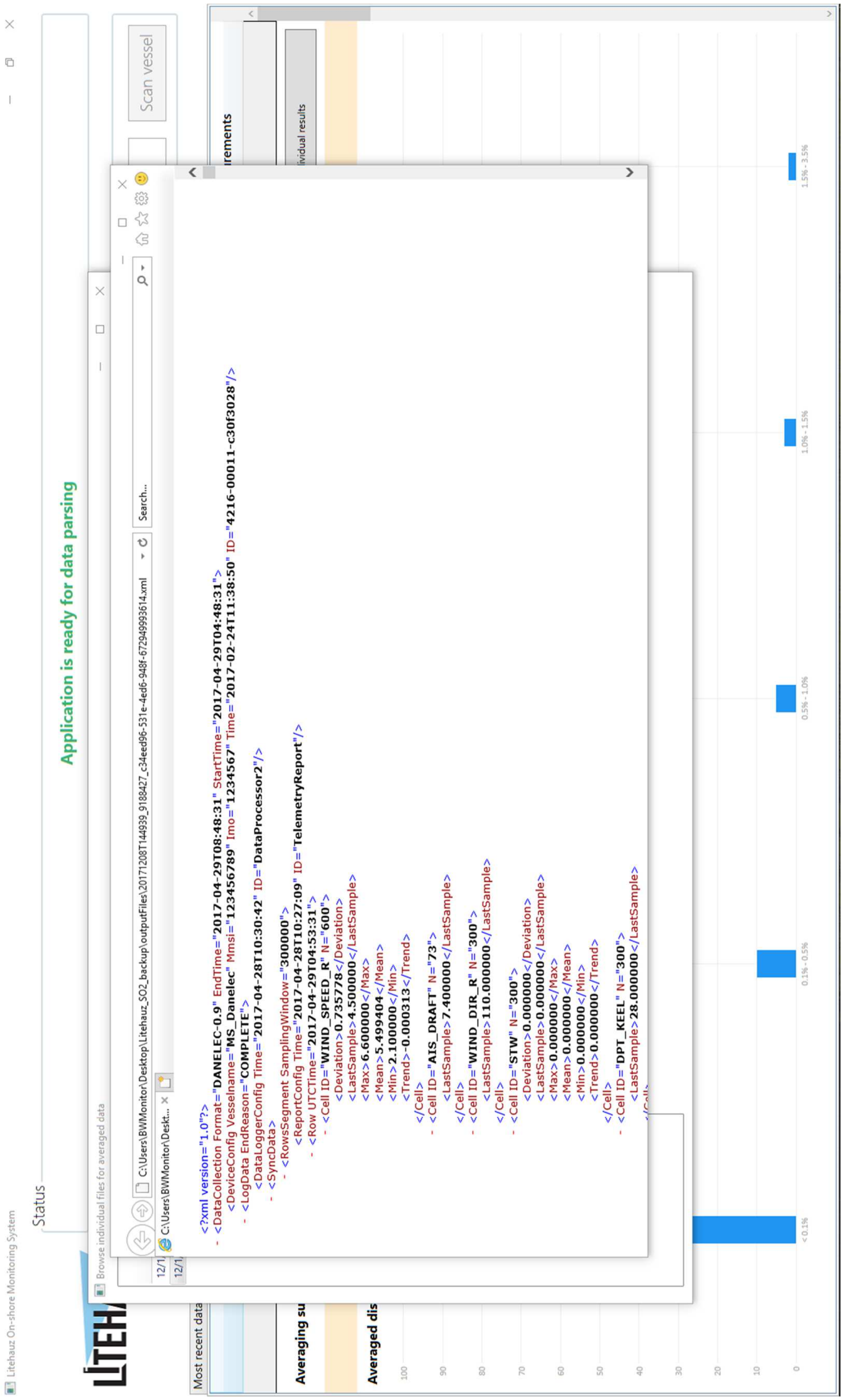
Appendix VII



Screenshot of histogram of individual files. Red circle shows the button “View original file”

“This project has received funding from the *European Union’s Horizon 2020 research and innovation programme* under grant agreement No 636329”.

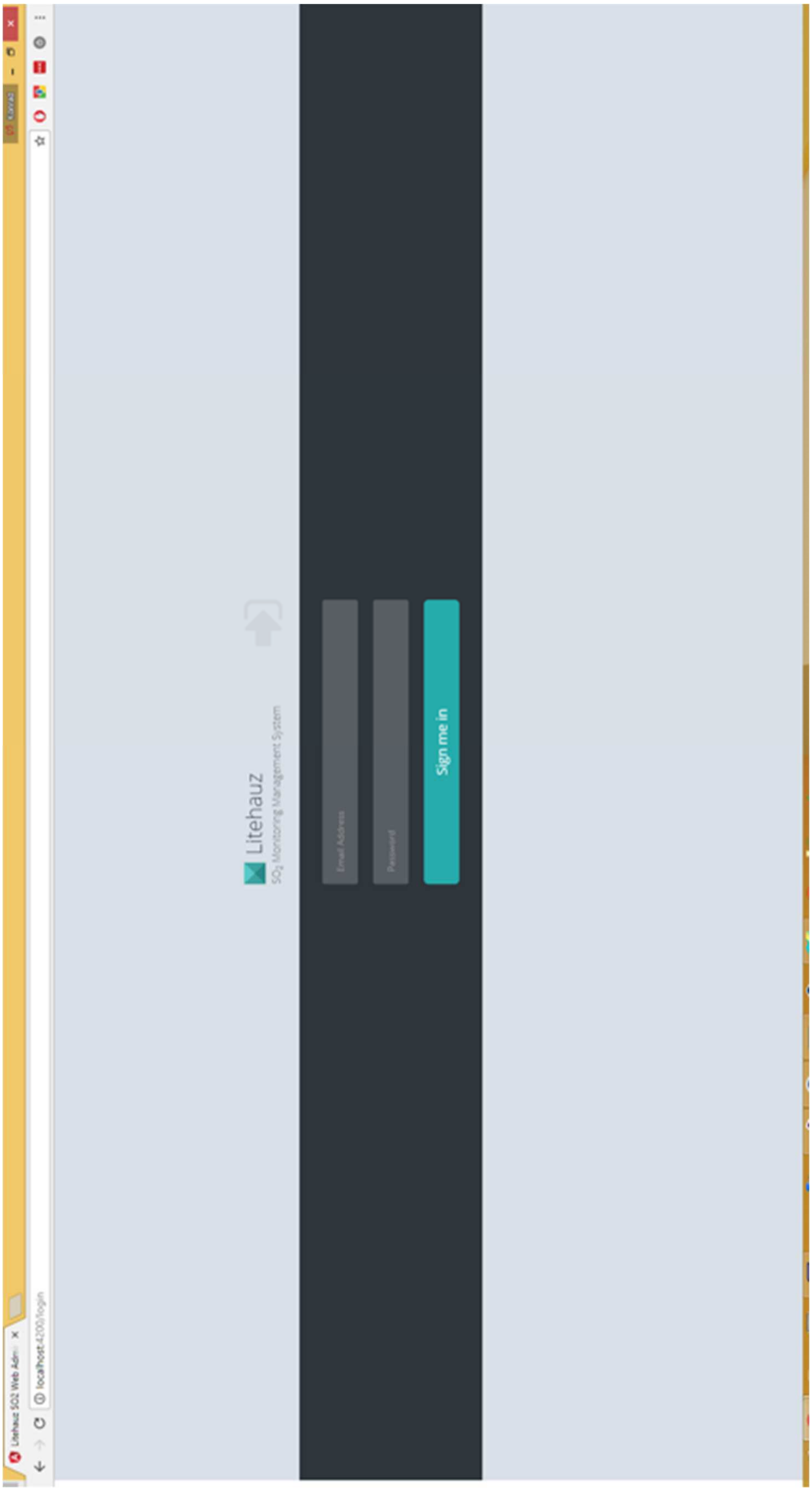
Appendix VIII



Screenshot of the original file from selected report of historical data

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

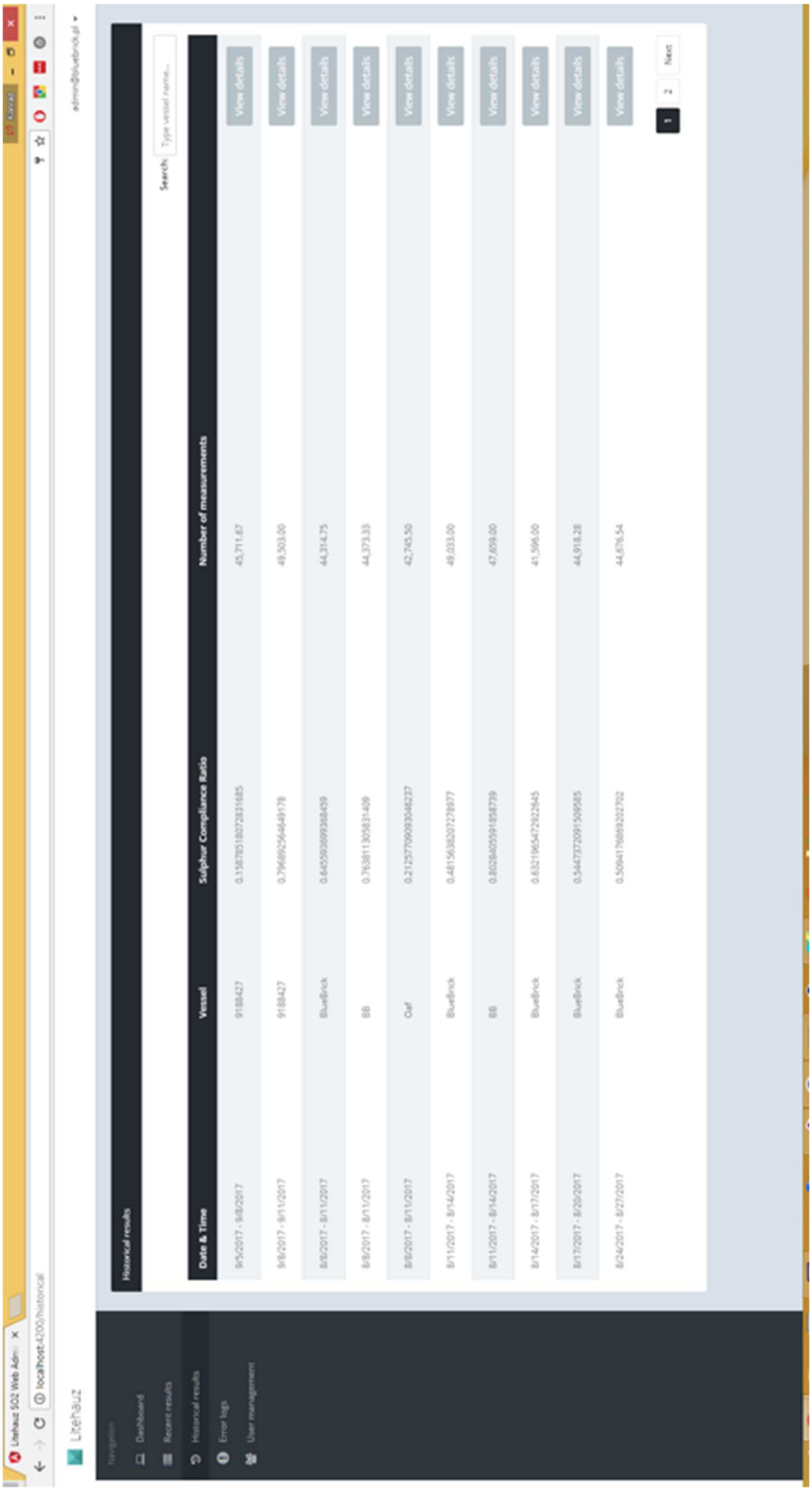
Appendix IX



Screenshot of initial login screen to cloud application via internet browser

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

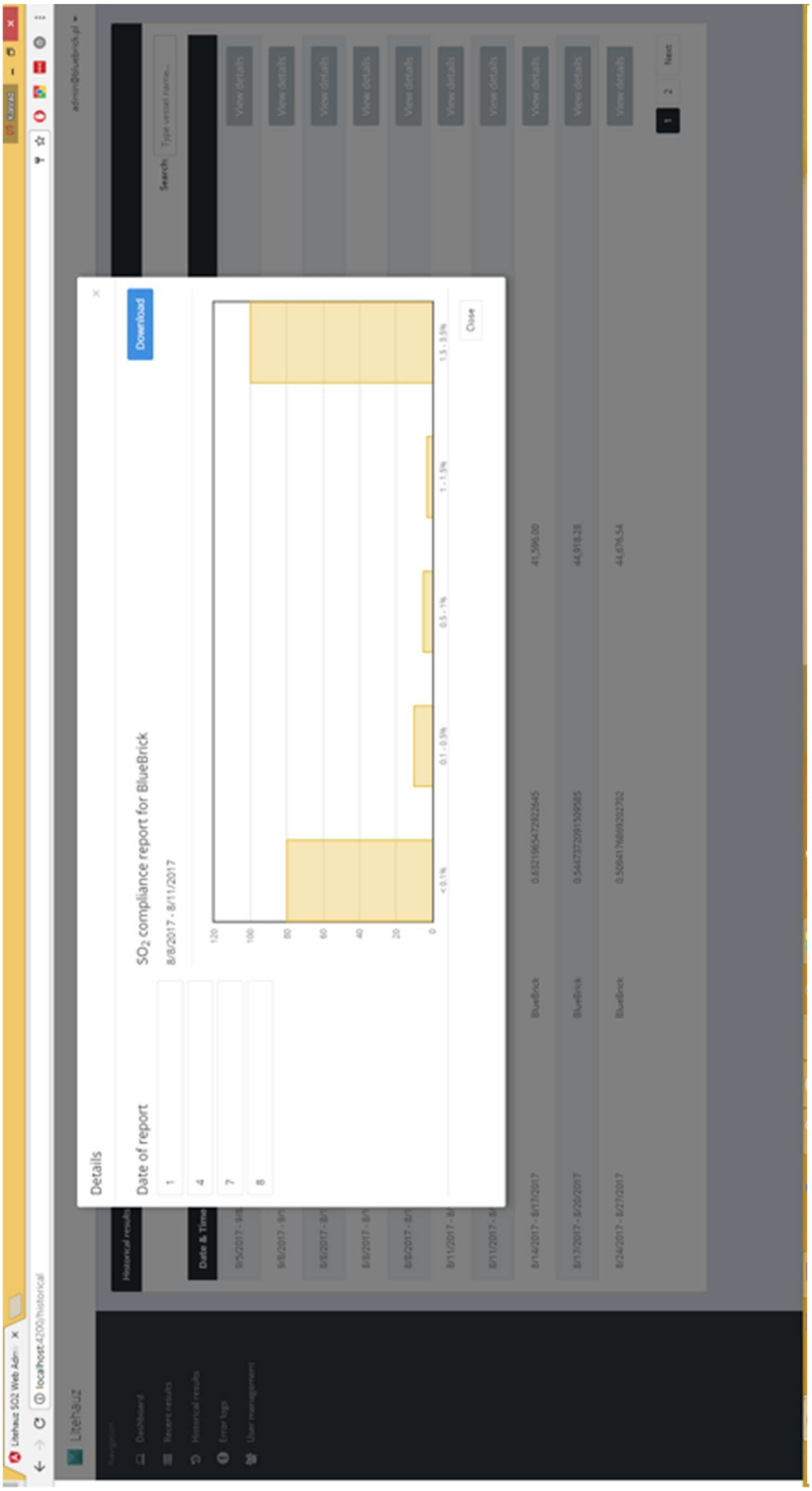
Appendix X



Screenshot of browsable list of available ships

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".

Appendix XI



Screenshot of histogram plot of SO_2/CO_2 data

"This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 636329".