Development of simulator-exercises on scrubber operation and environmental impact

Bachelor thesis for Marine Engineering Program

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CHALMERS UNIVERSITY OF TECHNOLOGY
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PREFACE

During the course Environmental impact from shipping which is given in the fourth year of the marine engineering program at Chalmers University of Technology, we felt that the education was missing a simulator exercise. The course examiner, when asked why there was none, simply answered that there was no exercise available to use. Thus, we decided to evaluate the possibility of using a simulator for environmental education and create an exercise that could be used in the future, as the topic for our bachelor thesis. Kongsberg Digital was kind to provide with a simulator software of a vessel with an installed scrubber installation, that Chalmers did not previously have access to. We want to extend our wholehearted gratitude to our supervisors Ida-Maja Hassellöv and Johan Eliasson, without their dedicated support and patience this thesis would have been stuck in a never-ending cycle of detours when trying to reach the end.

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SAMMANDRAG (in Swedish)

Sedan 2020, har det implementerats en global svavelbegränsning vad gäller tillåten mängd svavel i bränslet som får medföras ombord. Ett avgasreningssystem, som i daglig mun ofta kallas för en skrubber, tillåter ett fartyg dispens från denna begränsning, då avgaserna tvättasmed hjälp av vatten. Kortfattat, påverkar ett avgasreningssystem den marina miljön negativt, då påverkan från avgaserna omdirigeras överbord till havet direkt. Detta tvättvatten som pumpas överbord är försurat och ökar i sin tur försurningen av haven, därtill är de giftiga för marina organismer och skapar sammantaget en ny väg för föroreningar att nå den marina miljön. Teoretiska föreläsningar dels om hur ett avgasreningssystem funkar, dels om hur det påverkar den marina miljön, saknar idag relevanta simulatorövningar. För att kunna nyttja simulatormjukvara för detta ändamål behöver den först utvärderas. Det genomfördes genom att formulera olika lärandemål från relevanta informationskällor, såsom vetenskaplig forskning, rådande lagstiftning och industrins riktlinjer. Lärandemålen omvandlades sedan till frågor som var önskvärda att besvara i simulatorn. Den sammantagna bedömningen av hela utvärderingen är att simulatorn kan komplettera utbildning i några fall, såsom vakthållning, men saknar idag flera funktioner, vilket begränsar simulatorns kapacitet. Detta gäller särskilt frågor som ställer högre krav på simulatorn, exempelvis inom miljöpåverkan, som ej tillgodoses av simulatorn idag. Simulatorn fyller dock en funktion i att förevisa olika fall, såsom hur ett fartygs totala miljöpåverkan ökar då ett avgasreningssystem nyttjas. Det är fullt möjligt att visualisera mängden föroreningar som pumpas överbord under en resa exempelvis. Men nyckelfunktioner såsom vilka föroreningar som finns i tvättvattnet saknas. En annan begränsning är att de olika operativa scenariona som är möjliga att genomföra är få, exempelvis tvättvattnets reningsverk, möjliga fel på komponenter. Därutöver har en lista, över bristfälliga eller saknade funktioner, sammanställts som syftar till att rekommendera åtgärder som ger störst effekt för framtida utbildning.

Nyckelord: Sjöfart; skrubber; MARPOL, Annex VI, Regel 14; svaveloxider; miljöpåverkan; sjöfartsutbildning; simulatorövning; sjöingenjör.

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ABSTRACT

Since 2020 there have been a global limit on the sulphur content that is allowed in the fuel that is combusted onboard a vessel. An Exhaust Gas Cleaning System (EGCS), commonly known as a scrubber, allows a vessel to be exempt from this limit by cleaning the exhaust gases with water. In short, this system negatively affects the marine environment since it redirects pollutants from the exhaust gases released to the atmosphere and discharges it into the ocean. This discharge is acidic, significantly increases the acidification of the oceans, and is toxic for marine organisms, and creates a completely new path for pollutants to reach the marine environment. The theoretical lessons on how an EGCS and how it affects the marine environment today lack a relevant simulator exercise. To be able to use a simulator software for this topic, the software had to be evaluated. This was done by formulating learning outcomes from relevant information collected from the scientific community, regulatory requirements, and guidelines from the industry. The learning outcomes were formulated into questions that would be tried to be answered by usage of the simulator. The conclusion of this evaluation is that while the simulator can complement the education in some regards, mostly in watchkeeping, many features are missing that limits the simulator's capabilities for use in education outside the basic principles of environmental impact. It is useful for highlighting certain topics, such as on how a vessels total load onto the environment increases when using an EGCS and visualizing the number of pollutants that are discharged overboard during a voyage. Key features such as what the discharge water contains are missing. There is also a limitation in the amount of possible operational scenarios that is possible to investigate due to key components, such as the wash water treatment, are either not implemented or not possible to manipulate by introducing malfunctions into the system's components. A list containing recommendation of features to be implemented and what potential an implementation of these features could do for future education will also be presented.

Keywords: Shipping; scrubber; MARPOL, Annex VI, regulation 14; sulphur oxides; environmental impact; MET; simulator exercise; marine engineering.

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ACRONYMS AND TERMINOLOGY

AFM	Alkali Feed Module
Chalmers	Chalmers University of Technology
CO_2	Carbon Dioxide
DNV	Det Norske Veritas
EGCS	Exhaust Gas Cleaning System
EMERGE	Evaluation, Control and Mitigation of the Environmental Impacts of Shipping Emissions (an EU H2020 project)
ERS	Engine Room Simulator
FNU	Formazin Nephelometric Unit
HFO	Heavy Fuel Oil
MARPOL	International Convention for the Prevention of Pollution from ships
MDO	Marine Diesel Oil
MEPC	Maritime Environment Protection Committee
MET	Maritime Education and Training
MGO	Marine Gas Oil
SECA	Sulphur Emission Control Area
SO_x	Sulphur Oxides
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
PAH	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter

1. INTRODUCTION

In 2020 stricter global regulations entered into force, reducing the maximum allowed sulphur content in marine fuels (International Maritime Organization, 2016). Instead of switching to expensive low sulphur fuels, an increasing number of ships have installed Exhaust Gas Cleaning Systems (EGCS), also known as scrubbers, to be compliant. Statistics from the classification society Det Norske Veritas (DNV) Alternative Fuel Insight show that during the years 2016 to 2020, the total number of ships with EGCS (in operation and on order) rose from 312 to 4361 (DNV, n.d.).

A majority (85%) of the installed and on order EGCS in 2022 operates on an openloop principle (DNV, n.d.). If an open-loop system is used, the wash water containing the pollutants is discharged into the sea, and a large-scale use of EGCS will significantly increase the amounts of pollutants that will reach the marine environment (Turner et al., 2018). During the cleaning of the exhaust gases, the wash water will not just catch the sulphur oxides (SO_x) but also other pollutants in the exhaust gas. Measurements of the discharge water has found elevated concentrations of Polycyclic Aromatic Hydrocarbons (PAH) and metals such as vanadium, nickel, and iron (Lunde Hermansson et al., 2021; Ytreberg et al., 2021).

The increased use of EGCS creates a need for marine engineering students to understand this emission abatement technology. The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) stipulates the minimum criteria that all organizations that offer Maritime Education and Training (MET) must follow (International Maritime Organization, 2018b). These minimum criteria are specified in the STCW Code and does not demand any on-board training or usage of appropriate simulators for the education regarding shipping's environmental impact. By going beyond compliance and incorporating a simulator exercise and MEPC.340(77) se in the course Environmental impact from shipping at Chalmers University of Technology (Chalmers) would better prepare future students for working with a technology that may be a part of their future careers. With respect to any organization’s conditions (Aronsson et al., 2014), such as economical, technical, competence and manning, etc., often sets the limitations of what is possible to do. Here simulators are a cost-effective tool used to support learning in MET. Using a simulator allows a student the possibility to experiment on specific problems freely and improve their understanding, without risking potential loss of life, environmental and property damage (Kongsberg Digital, 2020).

The consensus of the marine environment scientific community is that a large-scale use of EGCS directly causes harm to the marine environment. There is untapped potential in using a simulator for education about this topic. Using a simulator exercise allows a student to learn how to operate and watchkeep an EGCS, while also allowing them to get better insight in how shipping affects the marine environment around it.

1.1 Background

Installed or on order EGCS have increased from 312 in the year 2016 to 4361 in 2020 (DNV, n.d). With the increase of installed EGCS a demand for competence is created, where having access to a simulator exercise would allow marine engineering students to be better prepared at operating the system, how an EGCS impacts the marine environment and get a better understanding of how loads onto the environment is created by shipping.

The idea of producing a simulator exercise for scrubbers first came about after having completed the course Environmental impact from shipping, in the fall of 2021, at Chalmers. A gap in a suitable, simulator-based practical exercise was identified. This thesis is aligned on evaluating how capable a simulator would be for MET versus regulatory requirements, classification societies technical guidelines and maritime environmental sciences research papers.

1.2 Aim of the study

The aim of this thesis is to evaluate the capabilities of a modern simulator and determine how suitable they are for MET when accounting for regulatory, environmental, and technical perspectives. This will be achieved through comparing the compiled theory derived from a literature study against the actual simulator performance. This in turn, should determine both adequate and inadequate simulator performance and give indications as to suitability for MET at Chalmers and present an example of how a simulator exercise could be done.

1.3 Research question

The overarching research question is: How credible and harmonized are a modern simulator for use regarding EGCS operation and environmental education? To answer that question, the following sub-questions will be answered:

- What is required of an EGCS simulator to meet STCW requirements?
- What is required of an EGCS simulator to adequately describe technical aspects of its operations?
- What is required of an EGCS simulator to adequately describe its related environmental impact?
- What opportunities and limitations are there in using an EGCS simulator today?
- What improvements are necessary if the EGCS simulator is not suitable for use today?

1.4 Delimitations

The following delimitations were taken to limit the scope of the thesis:

- All aspects other than regulatory, environmental impact and technical are disregarded, such as, but not limited to, economics.
- The paragraphs of MARPOL are limited to Annex VI, and further limited to Regulations 3, 4 and 14 regarding SO_x emission regulations, exemptions, and exceptions.
- Parts of the STCW Code are limited to parts related to education for engineers regarding environmental impact and operation of EGCS, Tables A-III/1 and A-III/2 are therefore amended to only include relevant excerpts.
- Only wet type EGCS will be discussed.
- Since the supply of Engine Room Simulators (ERS) versions available to the authors with a competent EGCS installed are low, as such only the 3.3.1.0181 version of the K-Sim ERS L11-6S70ME SCC software will be evaluated.

2. THEORY

The following chapters act as the theoretical framework that is needed to be able to answer the research question. These chapters summaries the current regulations related to an EGCS, guidelines produced by the industry, as well as the current research on an EGCS' environmental impact. The SCTW Code has been carefully studied, where the stipulated competence demands that relates to an EGCS has been separated and explained.

2.1 The simulator

The K-Sim ERS L11-6S70ME SCC (version 3.3.1.0181) is based on a Suez Max crude oil carrier. The requirements are that a simulator is stipulated by the STCW Code A-1/12, which says that a simulator must have an appropriate level of physical and behavioral realism to the intended training and assessment objectives (International Maritime Organization, 2018b). In 2017, a statement of compliance was issued by the classification society Det Norske Veritas Germanischer Lloyd (DNV GL) according to their own standard DNVGL-ST-0033 (DNV-GL, 2017). This standard aims to ensure that the simulator product comply with the simulator requirements.

Kongsberg Digital's concept of an ERS is to offer students training in both normal and abnormal engine room operations on-demand to improve safety, reliability, and economy (Hermansen, 2020). This is achieved by simulating both day-to-day operations and faults or deteriorations. In summary, the Kongsberg Digital simulator is certified for meeting the demands for basic operational training, troubleshooting and optimization studies (Hermansen, 2020).

The installed EGCS in the simulator is a hybrid (Figure 1) meaning that it can operate either as an open or closed loop system. After the scrubbing process, there is a pre-discharge treatment plant consisting of a sludge separator and an oil & soot separator that clean the used wash water prior to discharge overboard or for recirculation in closed loop, from residuals that in turn are led to a residue tank.

The ship is equipped with 2 Heavy Fuel Oil (HFO) tanks of approximately 228.2 m^3, 2 Low Sulphur HFO tanks of approximately 181.7 m^3 and 1 Marine Diesel Oil (MDO) tank of approximately 51.0 m^3 (Figure 2). This allows the vessel to comply with MARPOL regulations using HFO and their EGCS or by switching over to low sulphur content fuel without the EGCS.

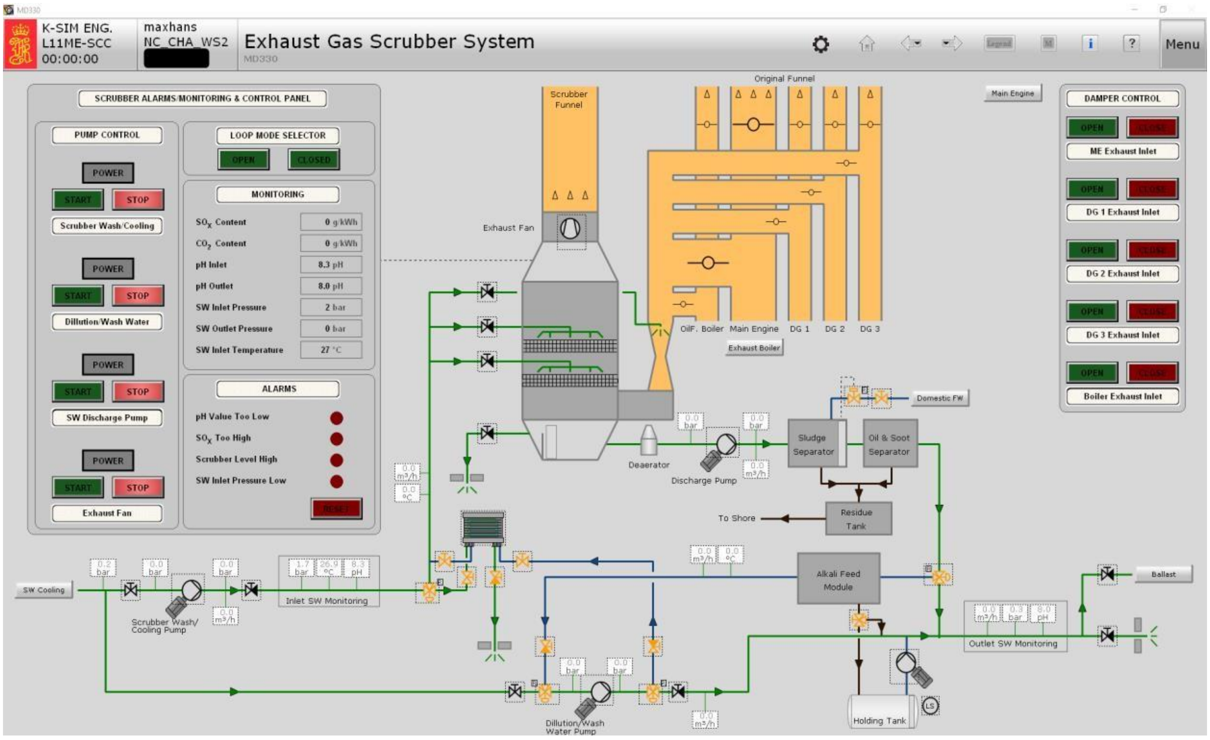

Figure 1: The simulator EGCS mimic, showing the alarms monitoring and control panel as well as the diagram lines with respective measurements such as temperatures, pressures, and flow rates.

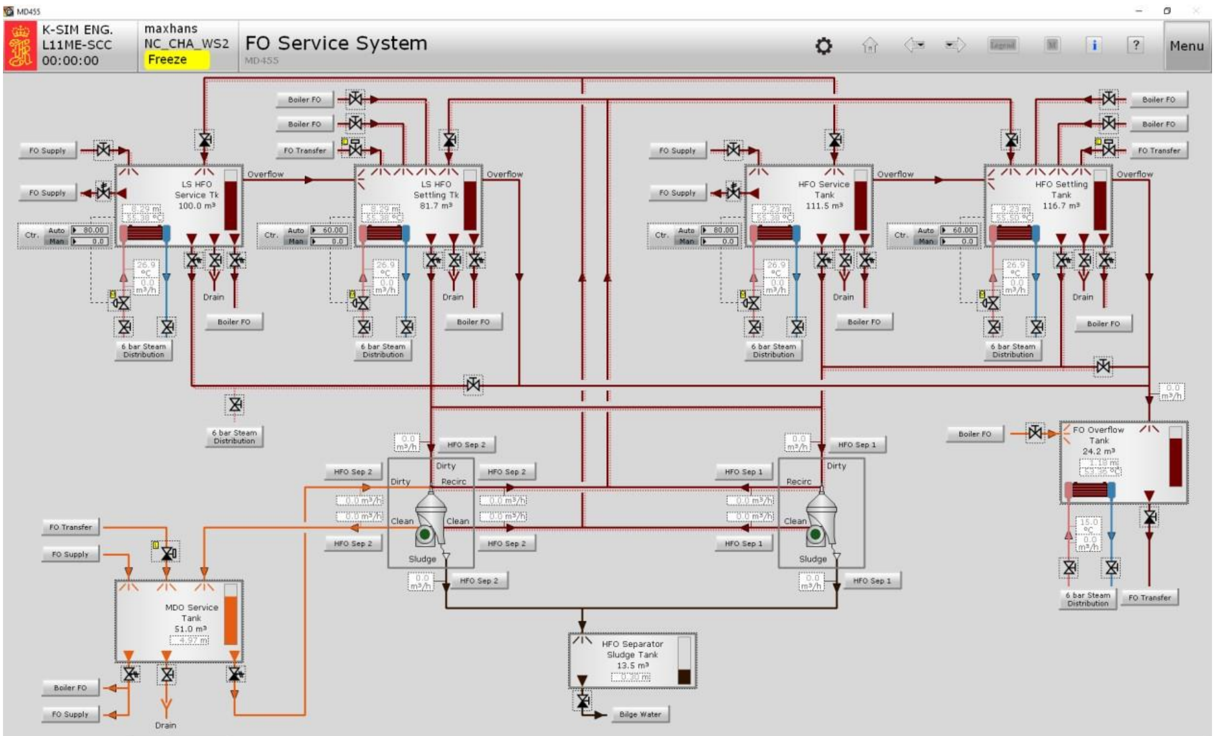

Figure 2: The simulator fuel oil (FO) service system, showing the various settling and service tanks.

2.2 STCW Convention and Code related to environment and usage of simulators as educational tools

The STCW Convention aims to standardize the education and certification of seafarers all over the world (International Maritime Organization, 2018b). The purpose is to guarantee a minimum standard of competence in seafarers. In Sweden, the governmental entity that regulates education on seafarers is the Swedish Transport Agency, who with the use of the Swedish Maritime Administration, control the course plans created by the existing MET given in Sweden, according to the STCW demands, which is stipulated by specifics in the STCW Code (Aronsson et al. 2014). A course plan, and in extension the MET, is approved for certification only if approved by the Swedish Transport Agency.

In Section A-III/1, of the STCW Code, mandatory minimum requirements for certification of officers in charge of an engineering watch are established. Specifically in Table A-III/1, see table 1, the criteria for junior and Table A-III/2, see table 2, for senior engineers. These two tables show the competence criteria that are relevant to the marine environment (International Maritime Organization, 2018b).

Table 1: Amended Table A-III/1 from the STCW Code section A-III, describes the specification, function as well as various demands for junior officers in charge of an engineering watch at the operational level

Function: Controlling the operation of the ship and care for persons on board at the operational level			
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Ensure compliance with pollution- prevention requirements	*Prevention of pollution of the marine environment* *Knowledge of the precautions to be taken to prevent pollution of the marine environment* *Anti-pollution procedures and all associated equipment* *Importance of proactive measures to protect the marine environment*	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved training	Procedures for monitoring shipboard operations and ensuring compliance with MARPOL requirements are fully observed Actions to ensure that a positive environmental reputation is maintained

Table 2: Amended Table A-III/2 from the STCW Code section A-III, describes the specification, function as well as various demands for senior officers in charge of an engineering watch at the operational level when related to the marine environment and operation of an EGCS.

Function: Controlling the operation of the ship and care for persons on board at the management level			
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Monitor and control compliance with legislative requirements and measures to ensure safety of life at sea, security and protection of the marine environment	Knowledge of relevant international maritime law embodied in international agreements and conventions. Regard shall be paid especially to the following subjects: .4 responsibilities under the International Convention for the Prevention of Pollution from Ships, as amended .7 methods and aids to prevent pollution of the environment by ships .8 knowledge of national legislation for implementing international agreements and conventions	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate	Procedures for monitoring operations and maintenance comply with legislative requirements Potential noncompliance is promptly and fully identified Requirements for renewal and extension of certificates ensure continued validity of survey items and equipment

This creates a demand for all personnel where EGCS is part of their work duties. Junior engineers, as required by Table A-III/1, should be able to follow the relevant checklists for operation and maintenance of the system and its auxiliary equipment to keep the EGCS in compliance with The International Convention for the Prevention of Pollution of Ships (MARPOL). Furthermore, they should know what to do when equipment or recordings deviate from normal operations, to remove or minimize the potential harmful impact a fault could have on the environment. Concerning senior engineers, as required by Table A-III/2, they should know what performance of EGCS is necessary to be able to be exempt from regulation 14. As well as making sure that all procedures concerning the EGCS are factual and correct so that adequate performance is achieved.

2.3 MARPOL Annex VI Regulation 4 and 14

The emission of sulphur oxides into the atmosphere is regulated by MARPOL, Annex VI, Regulations for the Prevention of Air Pollution from Ships (International Maritime Organization, 2018a). The amount of sulphur oxides emitted is directly correlated to the amount of sulphur content in the fuel, therefore the global maximum allowed content (0.5% m/m) is defined in MARPOL Annex VI, Regulation 14.1 (International Maritime Organization, 2018a). Regulation 14.1 entered into force in 2020 after MEPC.280(77) was published, following an investigation to assure that the worldwide supply was satisfactory (International Maritime Organization, 2016). Earlier, restrictions regarding sulphur content have entered into force under regulation 14.4 inside Sulphur Emission Control Areas (SECA) since 2015, where 0.1% (m/m) or less is required (International Maritime Organization, 2008). The SECAs are geographically defined under regulations 14.3.1-4 (International Maritime Organization, 2018a), two examples of such areas are the Baltic Sea and the North Sea.

Exemptions to regulation 14, can be granted to a vessel by a flag states administration, under regulations 4.1 and 4.4 (International Maritime Organization, 2018a). According to these regulations, if the sulphur emission reduction created by any method that is equal to, or better than, the reduction created by using a fuel with low sulphur content, exemptions can be allowed. One such method is an EGCS, which cleans the gas exhaust with wash water to reduce pollutants released into the atmosphere.

Although exemptions can be granted to regulation 14 to a vessel by its flag state administration, it does not guarantee that all ports tolerate EGCS operation and especially so open loop ones. The North of England Protecting and Indemnity Association (North P&I Club), have released a consolidated a list for guidance only as these are subject to change, where allowance of, prohibition of or restrictions on EGCS are in effect totaling 52 different countries (North P&I Cub, n.d.). The countries included in the list, span across the globe with examples from Argentina to Hong Kong, all with some sort of variations from permitted without conditions or exceptions such as in Hong Kong to local, regional or nationwide ban on the discharge of wash water. The North P&I Club states that discharge of wash water into Argentinian jurisdiction, sea or river waters was prohibited in 2020 and three months later temporarily allowed. This showcases how quickly the tolerance of respective states or local authorities may change. Australia is a state that allows discharge of wash water if conditions such as following the IMO 2015 Guidelines for Exhaust Gas Cleaning Systems (resolution MEPC.259(68) are met. There are exceptions locally such as the port of Hastings disallowing discharge. North P&I Cub states that the Australian Maritime Safety Authority are investigating the environmental impact. Meanwhile Belgium does not permit discharge of wash water closer than 3 nautical miles from their coast under federal law and in regional law a ban on discharges in ports or inland waters are in effect (North P&I Club, n.d.).

2.4 EGCS principle of action

The objective of the scrubbing process is to remove most of the sulphur oxides (SO_x) and particulate matter (PM) contained in exhaust gasses, by spraying wash water that absorbs the water-soluble SO_x and other PM, before releasing the gasses to the atmosphere (Lloyd’s Register, 2012). When SO_x react with water, it forms sulphuric acid and lowers the pH of the water used for the scrubbing process (ABS, 2018):

$$\text{Eq. (1): } SO_2 + H_2O \rightarrow H_2SO_3 \text{ (Sulphureous Acid)}$$

The most common type (85%) onboard vessels are an open loop system (DNV, n.d), here sea water is continuously pumped into the EGCS, and the acidic wash water is simply discharged back overboard (ABS, 2018). The discharged water of an open loop EGCS normally reaches a pH below 3 prior to dilution (Ytreberg et al., 2021). In a closed loop system, the scrubbing water is recirculated. To keep a closed loop EGCS able to continuously operate in compliance to MARPOL, the wash water is treated chemically by adding a base (often NaOH) to raise pH to maintain a balance (ABS, 2018). The wash water bled-off, at an approximate rate of 0.1m3/MWh and replenished by adding new water into the loop (Lloyd's Register, 2012).

The waste streams produced from the scrubber process pass through a pre-discharge treatment plant if one is fitted onboard (Lloyd's Register, 2012). The overall idea with installing a pre-discharge treatment plant is that harmful residues are separated and not discharged overboard and instead pumped to a sludge holding tank so that it can be sent ashore. Furthermore, for an open loop, if one is fitted, it is usually designed to be able to process a wash water flow rate of 45 m^3 MWh^{-1} normalized (Lloyd's Register, 2012). The flowrate of a majority of the available EGCS data shows that vessels tend to have higher flows, typically 90 m^3/MWh (Lunde Hermansson et al., 2021) thus exceeding the limits of the general treatment plant design (Lloyd's Register, 2012).

2.5 The discharge water

The wash water accumulates pollutants in the scrubbing process that necessitates treatment prior to discharge overboard (International Maritime Organization, 2021).

The exact concentrations of pollutants in the discharge water might be hard to evaluate for any given ship (Ytreberg et al., 2021), trends can be found of the wash water's quality, such as pH and contaminants, metals, and PAHs, in the wash water. For example, when comparing data from discharge water samples from 41 different ships using an open loop EGCS and HFO, the wash water was on average 110 times more acidic than the inlet water (Lunde Hermansson et al., 2021). Ytreberg et al. (2021) averaged 36 open-loop EGCS samples to be 3.85 $\mp$ 0.33 pH, and 11 closed-loop EGCS samples as 4.54 $\mp$ 0.51 pH. Meanwhile the pH of 29 open loop inlet water data points were averaged to be 7.72$\mp$ 0.15, which is in fact lower than the 8.08 $\mp$ 0.07 pH of what they averaged the ambient seawater, sampled from primarily marinas and ports.

Mostly the same metals were found in discharge water samples taken (Lunde Hermansson et al., 2021; Teuchies et al., 2020; Ytreberg et al., 2021) while the exact averaged concentrations of the studies differed, the trend of elevated concentrations could be found in all of them. Metals commonly found in the discharge water were arsenic, cadmium, copper, lead, mercury, zinc, and iron. Mercury, cadmium, lead, and nickel are considered priority substances by the EU directive Water Framework Directive (Official Journal of the European Union, 2013).

A study on the wash water's ecotoxicological effect on pelagic copepods, where both open- and closed-loop samples were used showed that EGCS discharge water was more toxic to the copepods than crude oil (Thor et al., 2021). In a separate study, two samples, taken from open loop systems, were also found to be acutely toxic to marine organisms (Teuchies et al., 2020).

Thor et al., (2021) explains that no single substance may be attributed alone to the toxicity. They point out that the exact composition of the discharge water is hard to estimate, the expected homogenous trend regarding concentrations of PAHs, could not be found in their samples. Due to this, they argue that the many different metals, PAHs, and organics, combined with the pH and temperature of the wash water can result in what they call a "witch's cauldron" where the substances of the wash water mix, react, and create undesired toxic compounds. Synergetic effects in copepods have already been seen in the following combinations between metals: Cadmium and zinc, copper and nickel, zinc and nickel, zinc and lead, nickel and chromium, and lead and chromium (Verriopoulos and Dimas, 1988).

These are all metals that have been found in wash water samples from both open loop and closed loop EGCS (Lunde Hermansson et al., 2021; Teuchies et al., 2020; Ytreberg et al., 2021)

2.6 Alkalinity and EGCS performance efficiency

The EGCS performance is reliant on the wash water's alkalinity, since the acids created during the EGCS process, react with the alkaline water (ABS, 2018; Lloyd's Register, 2012).

Performance design should be weighed against optimization (Lloyd's Register, 2012). Lloyd's Register (2012) also advocates for minimum adequate wash water flow to remove enough SO_x to comply with Regulation 4 and argues instead for overall efficiency, in terms of pumping power, size, and weight of components. Lloyd's Register (2012) states that performance of an open-loop system is vulnerable to changes in natural alkalinity and pH of seawater. They continue to argue that the only way that an open-loop system could attempt to mitigate the resulting acidic wash water discharge is by diluting with more seawater, which in turn, would result in more pumping losses. Lloyd's Register (2012) then compares this to a closed loop, stating that is not as vulnerable to changes in ambient alkalinity or pH, since they operate on recirculating wash water that is continuously treated with a chemical base to maintain the alkaline quality. Furthermore, since control over alkalinity and pH is achieved, less wash water flow rate is required to achieve the same SO_x removal compared to an open loop, thereupon minimizing pumping losses (Lloyd's Register, 2012).

Furthermore, the performance design should include seawater temperature as SO_2 solubility is reduced at higher temperatures (Lloyd's Register, 2012). Lloyd's Register (2012) states that continuous monitoring of alkalinity onboard is impracticable and instead recommend measuring pH (normally between 8.0 and 8.4) and salinity to indirectly reference the current alkalinity. If their simplification is used, low salinity and or pH indicates low alkalinity. Due to alkalinity's effect on the scrubbing performance, Lloyd's Register (2012) explicitly excludes the Baltic Sea from recommended areas of operation, and even goes so far as to state that adequate open-loop EGCS performance is not expected within the Baltic Sea. Although both open- and closed loop EGCS activity has increased dramatically from 2012 to 2018 (Jalkanen et al., 2021). Meaning that just because Lloyd's Register (2012) advised in 2012 against open loop EGCS in the Baltic Sea, it doesn't necessarily mean that their recommendation is followed.

2.7 MEPC.340(77), 2021 guidelines for EGCS

MEPC resolution MEPC.340(77) concerns the 2021 guidelines for EGCS, its purpose is to specify various criteria, for example what is needed for an approval of exemption and the quality of the discharge water (International Maritime Organization, 2021). This resolution is voluntary guidelines until the respective flag state implements them. It states that pH, PAH, turbidity, and temperature should be continuously monitored and recorded, at the discretion of the flag states implementation of these guidelines, whenever the EGCS is in operation. The only time it is allowed to cease monitoring and recording is for maintenance purposes where the monitoring device is taken out of service.

According to resolution MEPC.340(77), to prove that the EGCS is equivalent to using fuels compliant with Regulation 14.1 (global limit) and 14.4 (local limit). The corresponding emission ratio limits, regardless of operating load point or transient operation, must be satisfied:

Regulation 14.1: fuel oil sulphur content 0.5 (% m/m) ↔ emission ratio of 21.7 SO_2 ppm/CO_2 (% v/v)
Regulation 14.4: fuel oil sulphur content 0.1 (% m/m) ↔ emission ratio of 4.3 SO_2 ppm/CO_2 (% v/v)

The first criterion for discharge water in MEPC.340(77) is pH, where it is stated that there are two options to comply with the guidelines and as such should be documented onboard. The first option requires that the measured discharge water pH never goes below 6.5. With the only exception being in case of maneuvering and transit, at which point, a ΔpH may never be greater than 2 between inlet and discharge. The second option requires the determination of an overboard pH discharge limit, either measured or calculated, to be >6.5 pH at a 4m distance from the discharge outlet. This discharge limit should be documented onboard. If calculated, it must consider conditions, such as highest practicable load, maximum allowed sulphur content in fuel, seawater alkalinity of 2.2 mmol/L and pH 8.2. The allowed deviation due to accuracy of monitoring equipment is 0.2 pH units. Thus, the pH meter should have a resolution of 0.1 pH units with temperature compensation.

The second criterion is about PAH. In MEPC.340(77), a new definition concerning PAH, is the establishment of phenanthrene equivalent (PAH_{phe}). According to MEPC.340(77), PAH_{phe} is the signal produced by a PAH monitor versus a known reference value, namely phenanthrene, to measure the concentration and range of different chemical groups of PAH contained in the wash water. The concentration of allowed PAH compared to PAH_{phe} in the discharge water is <50 µg/L prior to dilution. Where the limit 50 µg/L PAH correlates to the normalized water flow rate of 45 m^3/MWh (IMO, 2021). The PAH monitoring equipment is allowed a deviation of 5% and should have twice the range of the noted discharge concentration limit. If the discharge flow rate deviates from the normalized 45 m^3/MWh following a linear ratio presented in figure 3 is applicable for quick referencing.

Table 5: Criteria for discharge water PAH concentration

Specific Discharge Water flow rate (before dilution for pH control) (t/MWh)	Discharge concentration limit (µg/L PAH_{phe} equivalents)	Measurement technology
0-1	2250	Ultraviolet light*
2.5	900	– " –*
5	450	Fluorescence[3]
11.25	200	– " –
22.5	100	– " –
45	50	– " –
90	25	– " –

*Alternative measurement technologies may be used with the agreement of the Administration.

Figure 3: A screenshot of "Table 5: Criteria for discharge water PAH concentration", from MEPC.340(77) (International Maritime Organization, 2021). It shows the linear ratio of PAH discharge concentration limits as wash water flow rate changes.

The third criterion concerns turbidity, used as a rough proxy for the number of particulate matter, heavy metals and ash suspended in a fluid or volume. MEPC.340(77) recommends that the continuous water discharge should be measured after treatment and before dilution. Water treatment should be designed so that measured turbidity is <25 Formazin Nephelometric Units (FNU) or another equivalent unit used. What unit is used should be documented onboard. For example, if the inlet is 10 FNU, the discharge must be <35 FNU. The accuracy of turbidity monitoring equipment should not deviate more than 2 FNU and be able to identify whenever it is unable to reliably quantify measurements. This is for the turbidity monitoring equipment to record for the allowed 20% deviation for 15-minute period every 12 hours.

The fourth criterion relates to the prevention of discharging nitrates (NO_3^-). There are two options to determine what limits to adhere to; either the number of nitrates collected in the wash water must never exceed 12% of the total nitrogen oxides (NO_x) produced in the exhaust gasses during combustion, or the nitrate concentration in the wash water should never exceed 60 mg/l at the normalized wash water flow rate of 45 t^3/MWh, where the MW should always be considered to operate at 80% of its maximum continuous rating, as follows:

$$<60 \text{ mg/l @ } 45 \text{ t}_3\text{/MWh, MW} = 0.8 \times \Sigma \text{MW}_{\text{max, combustion units}}$$

Where wash water flow rate depends on the sum of power output of all exhaust gas sources that enter the EGCS.

The fifth criterion concerns primarily EGCS' that make use of non-standard chemicals, e.g., other than NaOH, Na_2CO_3 or approved flocculants for oily-water separators, and refer the reader to MEPC.169(57). If the standard chemicals are used, the only requirement is that the wash water discharge pH is <8.0.

The sixth criterion covers guidelines for discharge of any EGCS wash water that has been temporarily stored, in for example a holding tank. The three main considerations for discharge of temporarily stored EGCS wash water are pH, PAH, and turbidity. It is to follow the same pH (>6.5), PAH (<50 µg/L) and turbidity (<25 FNU) criterions as previously mentioned, although independent of any flow rate. If demonstration of compliance, for whatever reason, is impossible the wash water is to be regarded as EGCS residue. Concerning bleed-off when operating in closed-loop is subject to the same requirements. If the bleed-off water fails to meet either pH, PAH, or turbidity criterions it is to be considered as EGCS residues.

The seventh and final criteria is about residues from the EGCS water treatment process. The EGCS process, regardless of an open- or closed-loop system, generates residues from its treatment process. These residues should not be discharged or incinerated but delivered ashore to a qualified reception facility (International Maritime Organization, 2021).

2.8 Redundancy

Compliance to Regulation 14 of MARPOL Annex VI is expected to be kept all times, no matter what technology under regulation 4 is used (International Maritime Organization, 2018a). This means that for an EGCS, it must always operate adequately, and this raises concerns for redundancy. Lloyd's Register (2012) urges consideration for an adequate risk analysis, in terms of likelihood and consequences of failure within an EGCS, as it is unclear how flag and port states might react to a non-compliant ship. An EGCS without redundancy might suffer commercial consequences, such as embargo. There are no explicit redundancy requirements for the components in an EGCS system (ABS, 2018). Non-compliance is tolerated if the vessel or equipment is damaged or faulty according to Regulation 3.1.2 (International Maritime Organization, 2018a). This does not include damage resulting from negligence or poor design, so ABS (2018) recommend due diligence in design, operation, and maintenance so that breakdowns are avoided.

In 2019, MEPC produced the circular MEPC.1/Circ.883 for guidelines in case a vessel's EGCS fails due to malfunctions to meet the guidelines produced by MEPC (International Maritime Organization, 2019) This document recommends that when a malfunction is detected, immediate actions are to be taken to locate and rectify the fault. An EGCS operator should also have experience with and knowledge of the system, including access to the class approved technical manuals and troubleshooting procedures. If the lost compliance is unable to be regained within one hour, MEPC.1/Circ.883 recommends that the vessel change over to MARPOL compliant fuel. In the case a vessel does not carry compliant fuel onboard or is unable to carry out the fuel changeover, the vessel is recommended to come to an agreement with relevant authorities for a plan of action. All details during the EGCS malfunction, no matter if the fault was fixed or if an alternative plan was taken, shall be recorded (International Maritime Organization, 2019).

2.9 Shipping's impact on acidification and alkalinity changes of the ocean

Acidification of the oceans occurs due to the ocean's uptake of carbon dioxide (CO_2) reach approximately 0.002 pH decrease per year (Rhein et al., 2013). This happens due to CO_2 increased partial pressure in the atmosphere and the amount of dissolved CO_2 in the ocean. This process does not reduce the total alkalinity of the water and is reversible in the case where diluted CO_2 is released when the partial pressure of CO_2 decreases (Stips et al., 2016).

$$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^{-} + H^{+} \leftrightarrow CO_3^{2-} + 2H^{+}$$ (Stips et al., 2016).

SO_x created by the combustion are converted to sulphuric acid in the atmosphere. The processes regarding nitric and sulphuric acids do, in contrast to CO_2, affect the total alkalinity of the water and are non-reversible without the addition of a strong base (Turner et al., 2017). By reducing alkalinity of an ocean, the ocean's resistance to future pH changes is also reduced (Stips et al., 2016).

Two studies that modelled acidification from sulphur in smokestack emission, resulted in a global annual average pH decrease of 0.0004 (Doney et al., 2007) and 0.00037 (Hassellöv et al., 2013). This global estimation might seem small when compared to the annual decrease of approximately 0.002 pH due to CO_2, not all areas of the ocean are affected equally by SO_x emissions from shipping (Stips et al., 2016). Most of the North Sea saw hardly any pH decrease due to shipping, the most heavily trafficked areas had an average annual decrease of over 0.0025 pH. These areas include the Danish straits, the Belgian, German, and Dutch coasts (Stips et al., 2016). The acidification rate significantly varies depending on factors such as seasonal changes, periodically the ocean will be affected by a higher local acidification compared to the annual average (Hassellöv et al., 2013).

Wash water discharge from an EGCS is an even more direct and effective way of transferring NO_x and SO_x into the water than smokestack emission (Turner et al., 2017). Their modelling shows that acidification due to shipping of the Baltic Sea with a fleet consisting of 20% open-loop EGCS, and 80% using 0.1% sulphur fuel, is the same as if 100% of the merchant fleet used 1.0% sulphur fuel. Results from their modelling, which can be seen in figure 4, shows that when more vessels install an open loop EGCS, a higher predicted annual pH and alkalinity decrease will be reached. The acidification was also studied by (Teuchies et al., 2020), their results shows that if 20% of the vessels comply with MARPOL sulphur regulations by using an open loop EGCS instead of using a fuel with less sulphur content, the pH of the surface water in the docks of Antwerp will decrease by 0.015 pH units in one year.

Teuchies et al. (2020) also present data that shows that the alkalinity will annually decrease in the same area by 6 µmol/liter, a reduction of 0.18%.

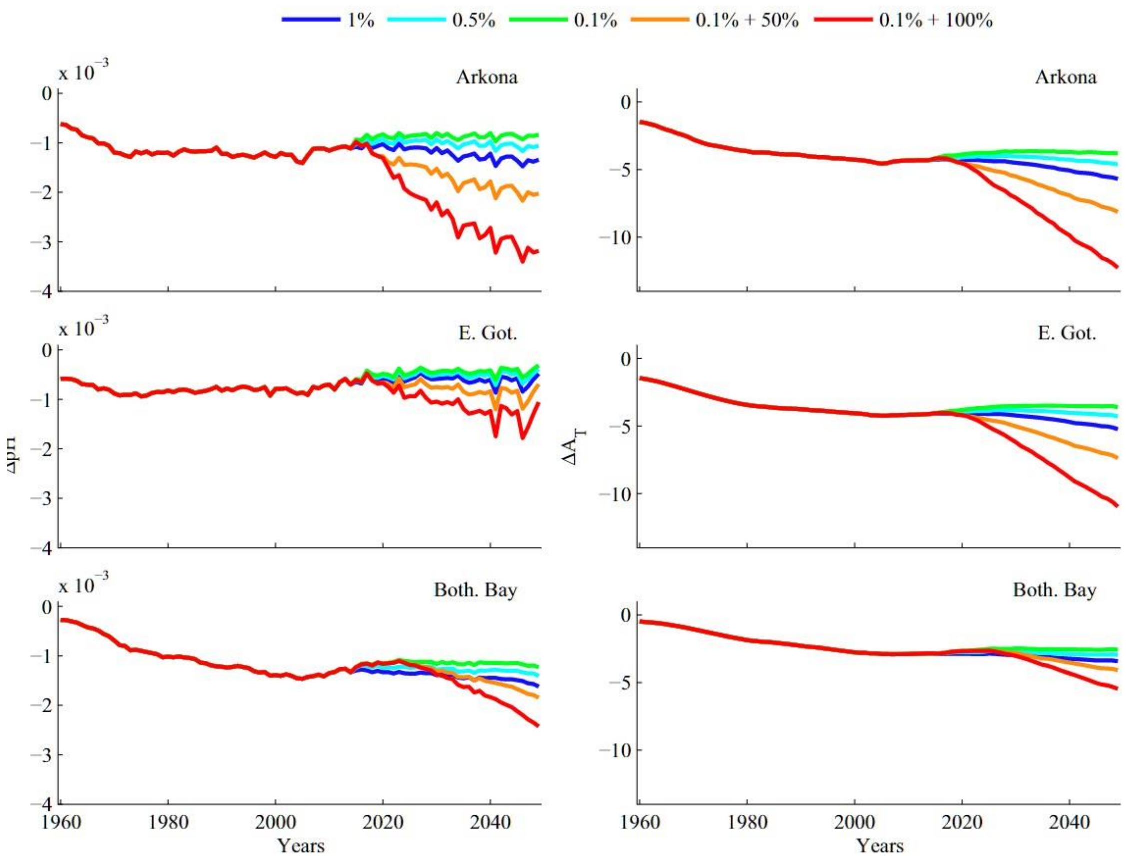

Figure 4: Results from modelling of five different scenarios. Predicting future annual decrease of pH and alkalinity from shipping in the areas of Arkona Basin, East Gotland Basin and the Bothnian bay, where all three areas are part of the Baltic Sea. Created by Turner et. al (2018) Used with permission without any changes according to https://creativecommons.org/licenses/by/4.0/

2.10 Increased environmental load by installation of an EGCS

A result of the European Union (EU) funded project named "Evaluation, control and Mitigation of the EnviRonmental impacts of shippinG Emissions" (EMERGE) shows that when an open-loop system EGCS is used onboard, the vessel's total environmental load, concerning metals and PAHs, increase (Ytreberg et al., 2021). When modelling the different load sources, their results show that 100% of the total measured vanadium, chromium, cadmium and nickel being transferred into the sea from a model ship originated from openloop EGCS. Ytreberg et al., (2021) also estimated that an open-loop EGCS, contributed to 90% of zinc, 53% of copper and 99% of arsenic of the total load. A secondary source for metals was anti-fouling paint, which contributed to 45% of total copper load and 8% of total zinc load. Furthermore, their results regarding PAHs, showed that the only notable sources from the vessel was bilge water and EGCS discharge water. Where once again EGCS is the largest source, where all but one PAH had above 99.95% contribution from EGCS. The outlier was naphthalene, where EGCS contributed to 99.87% of the total load (Ytreberg et al., 2021).

Another study, from Lunde Hermansson et al., (2021), demonstrated through calculations, a similar trend of EGCS usage impacting the environmental load. According to their results, if a vessel used an EGCS to comply with MARPOL Annex VI regulation 14, it would generally have an increased load when compared to using Marine Gas Oil (MGO) or MDO as a fuel. Since an EGCS allows the vessel to keep using HFO (IMO, 2018a), this results in a larger number of contaminants being emitted per power output (Lunde Hermansson et al., 2021). Results from their calculations, show that emission factors from HFO are on average 175 times higher for vanadium and 150 times higher for nickel. Similarly, but in a lower magnitude, iron had a 20 times higher emission factor for HFO. Emission factors regarding PAHs were also found to always be higher, with a varying degree of magnitude between two and 20 (Lunde Hermansson et al., 2021). Moreover, their calculations also resulted in a 10 times higher total sum of PAHs from EGCS using HFO when compared to using MGO/MDO without an EGCS. Concerning their findings, regarding an increased concentration of chromium, Lunde Hermansson et al. (2021) argues that the auxiliary systems an EGCS uses can create new sources of loads onto the environment. Their argument is that the hot and acidic sea water passing through stainless-steel pipes, which contains chromium, will be due to corrosion introduce an additional source of chromium that without the EGCS would not exist (Lunde Hermansson et al., 2021), an argument that (Teuchies et al., 2020) also propose in their study.

3. METHOD

To evaluate the suitability of the simulator software and be able to create a simulator exercise relevant to EGCS operation and its environmental impact, an assessment framework was constructed. The assessment framework was based on three different perspectives of EGCS: regulatory (both with respect to environmental and educational regulatory frameworks), environmental impact and technical/operations, and composed of three different modules (Figure 5). These modules included in the assessment framework are:

Module 1 (Figure 6), literature review.
Module 2 Figure (Figure 7), categorization of theory.
Module 3 (Figure 8), evaluation of simulator harmonization and credibility.

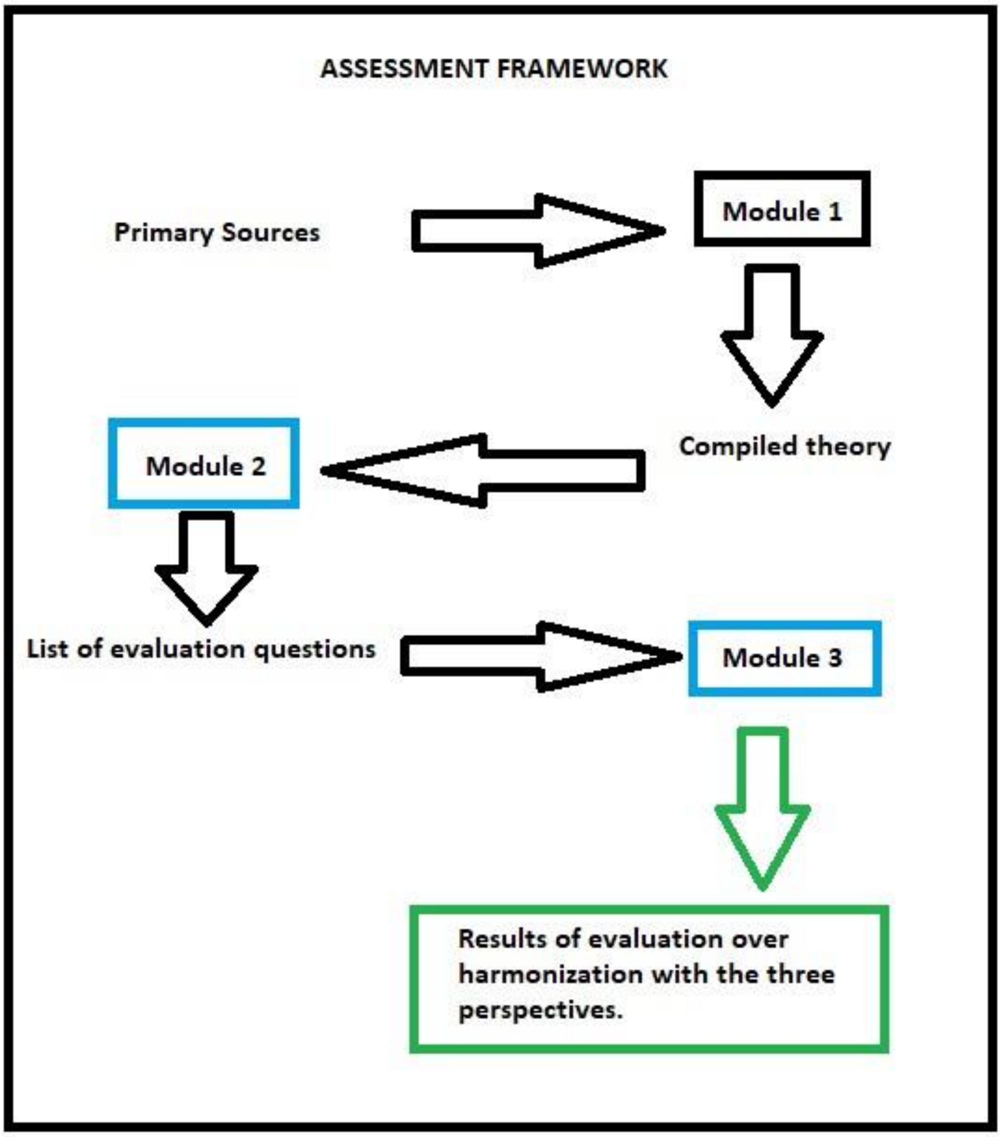

Figure 5: A simplified flowchart of the assessment frameworks modules, and their input and outputs.

Module 1 consisted of a collection of literature. This collection was done by with regards to the three respective perspectives, where the primary sources were regulatory documents, scientific literature, industrial guidelines, and the simulator manual. The collected literature was filtered and referenced to relevant competence demands as stipulated by the STCW Code. An explanation of how these demands were interpreted are presented in chapter 3.1.

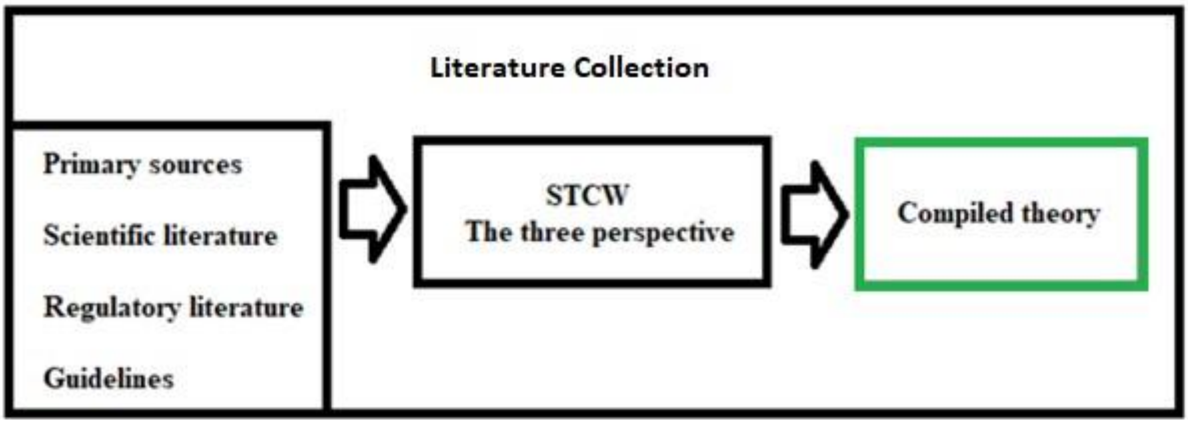

Figure 6: Module 1 of the assessment framework. Literature collected from the primary sources were referenced to the competence criteria from the STCW code and the three chosen perspectives.

After the literature filter in Module 1, the resulting compiled theory were brought over into Module 2. The compiled theory was split into excerpts and where each excerpt was categorized according to which STCW criterion (Table 1 and Table 2) and overall topic an excerpt could be summarized into. To be able to reference and identify the excerpts, they were given an individual identification code. The excerpts, their assigned identification number, and which STCW criterion and topic they refer to, can be found in Appendix 1. To evaluate what a simulator exercise should teach; the table were analyzed both from the perspective of STCW criterion and by the perspective of topic. This allowed the creation of learning outcomes, when related to EGCS operation and environmental impact, that included what a marine engineering student should know referenced from both the STCW competences' (Appendix 2) and the topics' (Appendix 3), point of view. These lists of learning outcomes were formulated into a list of possible exercise memorandum questions. The full sets of questions, their question number, and excerpt reference can be found in Appendix 4 and 5.

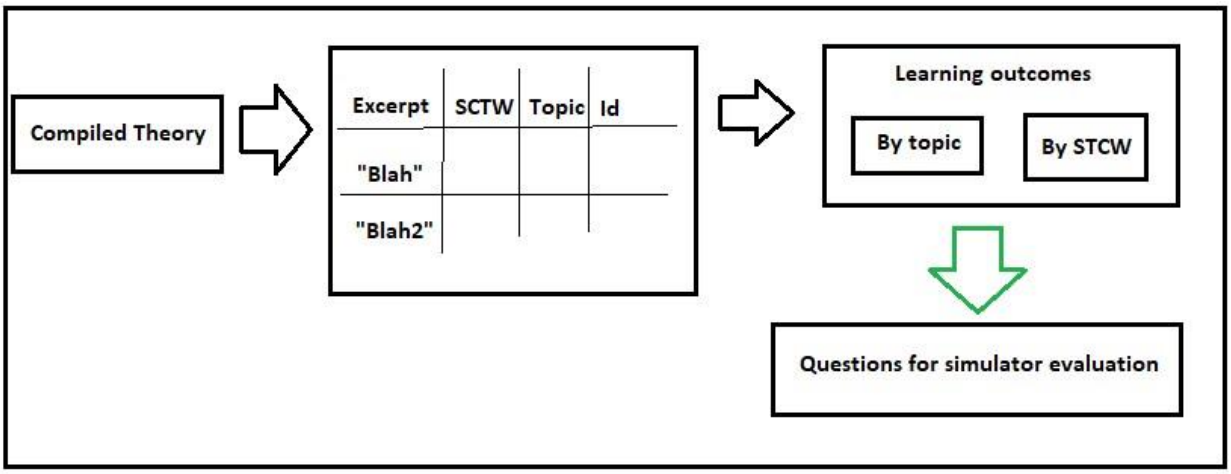

Figure 7: Module 2 of the assessment framework. Categorization of excerpts taken from the compiled theory created during Module 1. The excerpts were categorized according

to overall topic and competence criterion demanded by the STCW Code. Results of this module were a list of questions derived from the theory. The list of questions was used in Module 3.

In module 3, the simulator was challenged by trying to answer the questions produced during Module 2. The STCW Code requires that a simulator must have an appropriate level of physical and behavioral realism to the intended training and assessment objective. The results able to be produced during the evaluation were marked according to credibility and harmonization. After the evaluation of theory versus simulator, the results were categorized according to Yes (Y), Possible (P) and No (N). To be able to consistently differentiate between the different results, the following definitions were taken.

Yes: The simulator is capable to present a realistic enough answer and suitable for use in education.

Possible: The simulator is capable to present an enough realistic answer, if assumptions or outside sources/information used, is only used to such a degree that the simulator contribution is still deemed adequate and suitable for MET.

No: The simulator is not capable to present a realistic answer. The extra steps, assumptions or outside sources that are needed are so large that the simulators contribution is little to none. The simulator is not suitable in its current state.

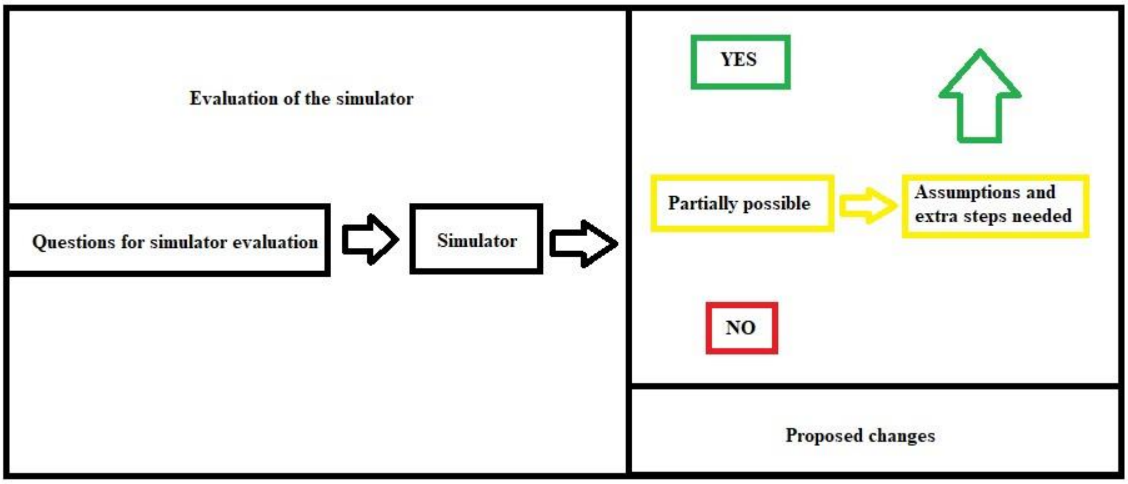

Figure 8: Module 3 of the assessment framework. Questions produced during Module 2 were tried to be answered by usage of the simulator. Where the resulting answer were divided into three categories: Yes, Possible, and No.

3.1 Collection of literature

The collection of literature was based on the STCW Code, where information that was relevant to the requirements and fell within the scope of this thesis were studied. To build a library of trustworthy references, Currency Relevance Authority Accuracy Purpose (CRAAP) tests were initially used as a basic filter to create a list of potential sources (Herrero-Diz et al., 2019). The literature was then analyzed again in-depth, by looking through the details, for example examining their method, if their conclusion contradicted or agreed with other papers. If they contradicted it was determined why so. The author's expertise, workplace, and previous list of publications were also examined for any signs of competing interests. The publishers were also investigated, for regular publication of papers regarding the environment or maritime technology.

To find sources, different databases and keywords were used (together in different ways with different Boolean operations):
Scrubber; EGCS; environmental impact; concentration; wash water; acidification; maritime environment; IMO; MARPOL, Annex VI, regulation 14; operation of EGCS; simulator education; PAH

These keywords were used to search in the following databases:

- Web of science, an abstract- and reference database with citation index for papers in all fields.
- Regs4ships, a database containing maritime regulations.
- Scopus, an abstract- and reference database with a tool for making citation searches for papers in all fields.

3.2 Reliability

Each step of the assessment framework was designed in such a way that reliability concerns are addressed. Each step is traceable backwards, this ensures that any concern regarding the reliability of a result can be traced, from discussion all the way back to the primary sources that were used as a foundation for that assessment. Any person, with access to the K-Sim ERS L11-6S70ME SCC (version 3.3.1.0181) simulator can reproduce what topic was assessed. That person should pay attention to their level of confidence and expertise in using ERS simulators, as this should be comparable to a last year marine engineering student enrolled at Chalmers. Any future replications should take special notice of what version is used, since future updates and implementations to the software may lead to eventual changes in results. Another important fact to point out is the fact that the subjectiveness of the division between the three different results (Y/P/N) could cause concerns. To limit these concerns, each result is combined with explanatory notes where the thought process for each result is described.

3.3 Validity

Kongsberg Digital, the producer of the simulator software used during this thesis, is a dominant company in the maritime simulator market. Their products are also the primary simulators used in education at Chalmers as of 2022. The K-Sim ERS L11-6S70ME SCC (version 3.3.1.0181) is classed according to DNVGL-ST-0033 and carries a statement of compliance, where what specific STCW Code competences are meant to be learnt in the simulator. However, none of these are directly related to the environment, which raises concerns around the validity of the usage of this simulator. But this is in fact part of the aim of the thesis, to identify adequate and inadequate simulator performance to determine its suitability for MET at Chalmers.

3.4 Ethical aspects

This thesis poses no risks to individuals. The simulator was used with permission. However, there is an ethical aspect that needs to be addressed and that is the risk of challenging or damaging the reputation and trademark value of the Kongsberg Digital company. Therefore, it is important to highlight that this thesis intends to offer constructive criticism and not defaming or discrediting their product that was used to complete this thesis. Kongsberg Digital’s involvement has been minimal, all contact has been through a supervisor and there has never been any specific terms or restrictions that has been forced to be followed.

4. RESULTS

The following results (Table 3) were obtained, to maintain transparency all results have been listed. For the entire worksheet, where additional notes to supplement why a question was assigned a certain result, see Appendix 4 and 5. Out of the total 63 questions, 28.5% were marked with Yes-result, 24% marked with Possible-result, and 47.5% marked with No-result (Table 4). In general, overall trends could be found in the different results. Questions that resulted in “No” demanded a more detailed and specific answer regarding to discharge water content and environmental load while the Possible-results is found on questions that ask a more general and broad question. The topics of watchkeeping, maintenance studies, and the overall purpose of an EGCS system, resulted in Yes.

Table 3: Shows the results obtained. The question number (no.) is a rolling number. The identification code (id. Code) shows what excerpt is referenced (Appendix 1). Result (Y/N/P) denotes if the evaluated question was found to be Yes, No, Possible.

No.	**Id. code**	**Question**	**Result (Y/N/P)**
1	B7-1, B7-3	What is Regulation 14 and why does it exist?	Y
2	B7-1, B7-3	Where does Regulation 14 apply and what limits does it stipulate?	N
3	B7-2, B7-3	Explain why a vessel could be exempt from regulation 14, who allows the exemption?	P
4	C3-1	How does an EGCS work? Explain the different components.	Y
5	C3-2	Introduce a malfunction, what changes in the operation and fix it	Y
6	C8-3	How could the above be prevented? Write a procedure for fixing above in case your prevention failed.	Y
7	C7-3	Chief tells you to empty the residue tanks and the holding tank, where are these allowed to go?	N
8	C7-4	What chemicals are used to treat the wash water, and explain briefly why rules could be different for different chemicals?	N
9	C8-1, C8-2	How does the alkalinity of the inlet water change the performance of the ECGS in open and closed loop?	N
10	C9-1	Are the MEPC criteria for discharge water legislative?	N
11	C8-4	Examine the system, what could affect the quality of the discharge water?	P
12	D2-1, D4-1	How does an open loop system work? Why is the pH of the outlet lower than the inlet?	Y
13	D8-1	Lloyd’s register does not recommend open loop in Baltic Sea, why could this be important to keep in mind?	N
14	E3-1, E4-1, E7-1	How does a closed loop system work? What purpose does the bleed-off serve, and when are you allowed to discharge it overboard?	N
15	E8-1	How come closed loop EGCS is not as (in general) affected by alkalinity as an open loop?	Y

16	F3-1, F3-2	What pH values of the open loop outlet water is expected? Suddenly the pH starts to increase, give some possibilities of what could have happened? Suddenly the pH starts to decrease, give some possibilities of what could have happened?	N

No.	**Id. code**	**Question**	**Result (Y/N/P)**
17	F4-1, F4-2, F4-5, F4-6	Why would pH of the outlet water be important? What impact could discharge of too much acidic water into a body of water have?	P
18	F7-1	What is the pH discharge limit and how is it defined?	N
19	F4-6	What pH does the closed loop wash water have? What of the bleed off/discharge?	N
20	F4-2, F4-5	Why is there a need for a dilution pump?	Y
21	F4-3, F4-4	How come shipping and the EGCS does not cause the same effects globally and locally, how does the input of contaminants into the marine environment change when comparing smokestack emission versus discharge of the wash water?	P
22	F7-2	What is the discharge limit of PAH, why is it important to measure and minimize the amount being discharged?	N
23	F4-8	What kind of pollutants could be found in the discharge water? Examine the system and discuss what could be found and what the different sources are.	P
24	F4-9, F410, F4-7	How does the mixture affect the discharge water toxicity?	P
25	F8-5, F8-6, F8-7	A vessel equipped with EGCS introduces new types of load and substances into the environment when compared to non-EGCS vessels, what could the substances and the source be?	N
26	F8-5, F8-6, F8-7	Compare EGCS compliance with compliance with other methods, which of the types creates the highest load onto the environment?	P
27	G7-1, G7-2	Measurements are allowed to deviate from MEPC limits. Why and how much?	N
28	H6-1, H63, H6-4	MARPOL compliance is mandatory, but exceptions are allowed. When and under what circumstances?	Y
29	H6-1, H6-2	What consequences could there be to non-allowed noncompliance?	N
30	H6-2	Investigate the system, identify vulnerabilities to the availability and reliability of the system.	Y
31	H3-1, H63, H6-4	Introduce component malfunction/failure. Explain the consequences and fix it. How could you as an operator prevent malfunctions, and why is it important?	Y
32	H3-1, H63, H6-4	Write a procedure for identifying and fixing this component malfunction/failure.	P
33	C3-1, D3-1, E3-1	How is the principle of EGCS? What is the difference between a closed and open loop? Examine all components and explain their purpose.	Y
34	F3-1, F3-2	Why does the pH value of inlet and outlet differ?	Y

35	F3-1, F3-2, H3-1, C3-2	How can a changing pH value indicate effectiveness of the system?	N
36	H3-1	Introduce a malfunction, what changes in the operation and fix it	Y
37	C3-2	How could above be prevented? Write a procedure for fixing above, in case your prevention failed	Y
38	D4-1, F4-1	Why is the pH of the discharge water monitored, recorded and limited?	Y
39	F4-2	What can the pH do onto the environment?	P

No.	**Id. code**	**Question**	**Result (Y/N/P)**
40	F4-3, F4-4	How come the load onto the marine environment increase when contaminants are discharged compared to smokestack emission?	P
41	F4-1, F4-2, F4-8	There are contaminants in the discharge water, what substance are they and where do they come from? Analyze the system and discuss what the different sources could be.	Y
42	F4-8, F4-9, F4-10	Why would someone care about the different contaminants? Briefly explain the threat they pose.	P
43	F4-7, F4-9, F4-10	Does the mixture of the many substances, at varying temperatures and pH values, change the toxicity of the discharge water?	P
44	C5-1	The pre-discharge treatment plant creates residues and sludge, which you are not allowed to discharge overboard, where should they end up?	N
45	B7-1, B7-3	There are two limits given by MARPOL Annex VI regulation 14, what number and where do they apply?	N
46	B7-2	How come there are alternative ways of complying with regulation 14?	P
47	C7-1	If you want to comply using an EGCS, what performance of sulphur elimination from the scrubber process is needed?	N
48	C7-3	Discharge from the holding tank, what criteria of the wash water is needed to be followed?	N
49	C7-5	What is in the residues, and where are you allowed to discharge it?	N
50	E7-1	What is the point of the bleed off water while running CL, what does it contain and when are you allowed to discharge it?	N
51	E7-1	How is the pH discharge limit decided, and what does an operator have to keep in mind during operation, for example if the geographical operation will change?	N
52	F7-1	How and why is PAH recorded, why is there a limit of allowed PAH content?	N
53	F7-3	What is turbidity, why should it be measured and what consequences could there be from high turbidity?	N
54	G7-1, G7-2	When are some deviations from limits in measurements allowed, and why?	N
55	H6-1, H6-2	Regulation 14 is mandatory compliance, no matter what compliance method is used, what consequences could there be from non-compliance?	N
56	H6-1, H63, H6-4	Non-compliance is allowed in special cases, what are they and what responsibilities does the crew have onboard?	Y

57	H6-1, H6-2	Identify a few different vulnerabilities of the systems availability and reliability, how can these be addressed?	Y
58	C8-1, C8-2, D8-1, E8-1	The geographical area of operation is about to change, the vessel will travel north in the Baltic Sea. The vessel is currently operating in open loop mode, which Lloyd's register does not recommend in the Baltic Sea. Why do they recommend this, and how could you prepare for entry into the Baltic Sea?	N
59	C8-3	How could you prepare the crew for future maintenance, preventive or corrective, of the EGCS? And why is speed and accessibility extra important in this case?	Y
60	C8-4	Analyze the system, what could affect the quality of the discharge water and how could unnecessary pollution be made possible?	P
No.	**Id. code**	**Question**	**Result (Y/N/P)**
61	F8-1, F8-2, F8-3, F8-4	The scientific community agrees that a large-scale use of EGCS will significantly increase the impact onto the marine environment, why? Compare the EGCS to other contamination sources and discuss.	N
62	F8-5, F8-6, F8-7	How does compliance with an EGCS compare to other compliance methods, are there any loads being added or removed?	P
63	B9, C9	How come an EGCS is allowed and who allows the exemption, and what regulations are there regarding performance? Are there any legislations regarding EGCS discharge water? Discuss briefly, by using your previous education regarding international law and shipping.	N

Table 4: Results in %, for Perspective, STCW, and in total.

	Yes [% approximately]	**No** [% approximately]	**Possible** [% approximately]
Perspective Question no. 1-32	31%	44%	25%
STCW Question no. 33-63	26%	51.5%	22.5%
Total (63 questions)	28.5%	47.5%	24%

5. DISCUSSION

In the following chapters, the different results (Y/N/P) will be separated and discussed. The questions in each result-group have been further divided up by their common topic. This way, two similar topics can have different results depending on how the question was phrased.

5.1 Y-results – Adequate simulator performance

The following questions were marked as "Yes", this means that for these questions, the simulator was deemed to be capable of producing an answer that harmonized enough with the compiled theory and the behavior of the simulator was realistic enough to simulate a real

EGCS. Most of the Y-results came from questions that handled the topics of how an EGCS works, what purpose it fills, how to watch keep and operate it.

A common denominator in these results is a limitation in the number of malfunctions that is possible to insert into the operation in the simulator. This limits the harmonization and depth of knowledge that is possible to achieve in deeper understanding in specific cases, but overall, the behavior of the simulator is close enough to what is expected.

5.1.1 Regulation 14 and the principle of an EGCS

For identified common denominators for adequate simulator performance, regarding MARPOL Annex VI Regulation 14 and the principle of an EGCS see question no. 1, 4, 12, 15, 20, 33, 34, 38 (Table 3). Where adequate explanation of EGCS principle of action, both closed and open loop, were found in the simulator manual. This combined with the system diagrams and operational menu should be sufficient to understand how the two different types works. Since the closed loop simulator uses onboard freshwater as wash medium, the fact that ambient sea water alkalinity does not affect the operation can be understood. This could be used for education regarding the operational limitations of an EGCS and discuss what to keep in mind when the area of operation is going to be changed. The components of the system are clearly named, and purpose should be easily identified by the name alone. Although there is a lack of information given besides the components name. The pre-discharge treatment plant, for example, cannot be manipulated in any way. There is no malfunction, or variable that is possible to be introduced/changed within the treatment plant. Thus, it is not possible to get any deeper knowledge how to watchkeep or service the plant or know what eventual consequences can be created from a malfunction.

Since the sulphur in the fuel is shown, it should be possible for a student to be able to reach a conclusion about the purpose of Regulation 14. By changing the sulphur content and analyzing the SO_x emission without the EGCS in operation and comparing these numbers to what is emitted when the EGCS is operating while running on high sulphur fuel. By discussing the SO_x emission, a student should also be able to reach conclusions regarding why the discharge pH is lower than the inlet pH.

5.1.2 Watchkeeping, redundancy and compliance.

Another identified common denominator concerning adequate simulator performance is subject of watchkeeping, redundancy and compliance, see question no. 5, 6, 28, 30, 31, 36, 37, 56, 57 and 59 (Table 3). Results show that the EGCS in the simulator lacks component redundancy which would have been a good tool to aid a student in understanding how vulnerabilities in a system's availability and reliability can be minimized. For example, either by installing redundancy or having effective maintenance planning and increased preparedness, to make sure that the system does not fail or must be overhauled when the EGCS operation is needed. This could be done by inducing faults into the operation, analyzing what in the operation changes. This topic is somewhat limited due to a limitation in possible faults and consequences to the overall operation. The components that could be manipulated were the valves, pumps, regulation, and the measurement systems. No malfunction is possible to introduce in the scrubbing tower, with aim to limit the scrubbing process performance. For example, there are no nozzle clogging or uneven water spray. A user can only reduce the scrubbing performance (SO_x emission reduction) by limiting wash water flow into the tower or reducing the pH of ambient sea water if operating on open loop.

For watchkeeping, an understanding of the threat an EGCS poses to the marine environment, acts as a safeguard. If one understands the potential consequences, it is easier to motivate work to proactively mitigate them. A deeper understanding could for example benefit everyone, as to what actions are to be taken when entering various geographical areas of operation. As national or regional regulations might differ from what is explicitly stipulated in MARPOL or guidelines published by IMO.

Combined with roleplaying different cases and situations, the simulator can be used as a teaching aid for discussing how and when non-compliance is allowed. An example of a situation: After a complete failure in the wash water pump, which is a critical component, the EGCS operation stops. Unable to overhaul the pump until port, which is two days away, the engineer shuts of the scrubber and bypasses it completely. Even though there are LFSO and MDO available for switch over. Here the crew has not done the utmost possible, which regulation 3 of Annex VI demands is a must for non-compliance to be allowed when induced by component failure. These scenarios do not just create a discussion about legal cases, when non-compliance is allowed, but can also lead into investigations regarding environmental consequences from the actions taken during an allowed non-compliance. Should the engineer change over to MARPOL compliant fuel, or can they feed the EGCS with the dilution pump instead of the sea water pump to keep feeding the scrubbing process water, albeit with a lower flow?

5.2 P-Results – Adequate simulator performance if complemented

Overall, the questions that were marked as "Possible" are missing the key feature of having discharge water content implemented, measurable and changeable. If assumed, or calculated, averaged are used, the simulator can perform a credible P-result in answering question regarding to the following topics. These topics also cover areas that are hard to achieve by simulator usage alone, the simulator can complement the education and positively affect the learning outcomes.

5.2.1 EGCS legality

The first common denominator where, with complements such as assumptions, the simulator performance was adequate is EGCS legality, see question no. 3 and 46 (Table 3). To begin, Regulation 4 states that, any method that is equivalent to reduction of sulphur content of the fuel, in reducing SO_x emission can be allowed exemption to regulation 14. The exact legal framework of how IMO conventions are implanted into national law, is difficult to achieve in a simulator setting and will need complementary lessons. Despite the limitations the simulator can still present a very clear visualization of what is meant when a legal code demands equivalent or better technology, such as in the case of regulation 4. The simulator allows the sulphur content of the fuel to be changed from the simulator standard of 3% sulphur content. This allows a user to be able to reduce the sulphur content to such a point where the EGCS is no longer needed for SO_x emission to comply to regulation 14.

5.2.2 Discharge water content

Another common denominator is the discharge water content, see question no. 11, 17, 21, 23, 39, 40 (Table 3), where the amount of sulphur being scrubbed into the wash water was possible to calculate as previously mentioned EGCS and with the EGCS in operation. If this is combined with education regarding acidification, calculation of how much sulphuric acid is being discharged over a voyage, could present an understandable, or "real", case for the dangers of acidic discharge from an EGCS. To be able to get any relevant knowledge regarding the other pollutants, the content needs to be calculated based on assumptions. The simulator presents a very detailed fuel consumption which varies depending on load, this combined with assumptions of the fuel contents, from bunker reports or scientific papers can be used to calculate an estimation of exhaust gas pollutant content. Efficiency of the predischarge treatment plant is not known by using the simulator or from reading the manual, which creates a need for further assumptions regarding treatment efficiency. If this is done it is possible to calculate an estimation of what pollutants the discharge water will contain and at what concentrations.

Another way to reach this step, is to simply estimate average concentration from recorded analysis of real-world discharge water samples, such as Lunde-Hermansson (2021) or results from the EMERGE-project (Ytreberg et al., 2021). While these calculations will be an estimated average, the exact numbers themselves do not have to be the focus of the exercise. Discussion regarding environmental impact could be based on these averages, and supplement theoretical education on the topic of this can be used to estimate what a vessel will discharge over a voyage and supplement the theoretical education on the topic.

Furthermore, since the fuel consumption can be varied, different load points can be studied and incorporating a moment of optimization study of engine room operation and allows an understanding of how a vessel’s impact on the marine environment can change depending on how well the vessel is being operated.

5.2.3 Increased load, toxicology, and synergetic effect

The topics on toxicity and synergetic effect, see question no. 24, 26, 42, 43 and 62 (Table 3), were not possible to do solely with the simulator. Concentration calculations regarding pollutants can be used to strengthen the theoretical education by visualizing how much is estimated being discharged overboard by a vessel over a voyage. By presenting a realistic case to study, the topic could become more understandable than just academic theory. By using a system that is relevant to their career, the education on synergetic effect and toxicology could be strengthened, instead of being felt distant and too theoretical and thusly unnecessary to understand even after the exam is done. The limitation here is the large step in assumptions that is needed to be taken, which could limit how realistic the exercise feels.

5.2.4 Redundancy and maintenance planning

About redundancy and maintenance planning, see question no. 32 (Table 3), it was found that the exact type of component is not explicitly described in the simulator. Nominal data of the pumps, curve and effect is visible and changes depending on system load, what the component is (type and maker) not visible. This forces a student or teacher to assume a realistic component, but if this is done, there is a good opportunity to teach about the importance of having correct and understandable overhaul procedures. This is something that has been done in other courses during the MET at Chalmers, but here, this educational moment can be combined with discussions regarding operational, legal, and environmental impacts. This topic is also relevant to education regarding availability and readiness which is also taught at Chalmers. A worst-case loss of operation in an EGCS could not only result in massive legal consequences for the vessel if not handled correctly, but also create an unnecessary significant threat to the marine environment. The system as presented by the simulator is very vulnerable to component failures as it does not have any componentredundancy. The importance of the topic and the vulnerable system could increase the students understanding of the importance of correctly planned maintenance and preparedness. If a malfunction is introduced slowly, the operational impacts can be observed. The number of possible scenarios is limited by a limited number of malfunctions possible in the simulator. If, for example, a pump slowly gets more and more wear, the flow rate of the wash water will be reduced. At first, the flow rate will still be sufficient for the scrubber process, but eventually as the wear gets worse and worse, MARPOL compliance will be lost due to insufficient scrubbing. By giving the student a task where they should write up how this fault can be detected, and how to do the maintenance or overhaul, and when it should be planned, a student can get an increased competence in watchkeeping a critical system such as the EGCS and preventing a failure.

5.3 N-results – Inadequate simulator performance

Questions marked as a “No”, can’t be answered from using the simulator to the degree that assumptions render the benefits of using the simulator low to none. The discussion of the Nresults is accomplished by analyzing the results and finding common denominators.

The N-results obtained ranges from simply no implementation to either inadequate realism or unclear harmonization with the parties involved, as named in the theory, for example the MEPC. The credibility and harmonization of the simulator overall, in terms of EGCS operation and environmental education suitability isn’t necessarily inadequate if indicated as such by N-results. What the overall N-results indicate is that in some areas, depending on how a question is posed, the resulting simulator performance is inadequate at the time (version 3.3.1.0181). The identified N-results also serve as highlights for areas where implementation of or changes to the simulator may reflect positively on its performance.

5.3.1 MARPOL Annex VI Regulation 14

One identified common denominator for inadequate simulator performance is the MARPOL Annex VI Regulation 14, see question no. 2 and 45 (Table 3), where there is a mass and volume discrepancy. The simulator shows SO_x emissions to air in the unit’s g/kWh. But to prove that an EGCS is equivalent under Regulation 4 so that the ship is compliant with for example Regulation 14.4 (inside a SECA), the following emission ratio must be complied with:

$$<4.3\ SO_2\ \text{ppm}/CO_2\ (\%v/v)$$

This means that, although there is a limit and alarm for high SO_x emissions, it does not give a credible answer to, nor is it harmonized with either Regulation 14.1 or 14.4. This complicates the task of checking if a ship is compliant or not.

5.3.2 Alkalinity and the Alkali Feed Module

Another common denominator that was identified was alkalinity and the Alkali Feed Module (AFM), see question no. 8, 9, 13, 14, 19, 50 and 58 (Table 3). To begin with, EGCS performance is dependent on the alkalinity of the wash water used. In open loop this is dependent on the ambient alkalinity of the seawater intake. Although the subject of alkalinity is a short one it is relevant to the AFM since it works by the same principle to ensure that the wash water remains alkaline. In closed loop, treatment or dosing of the wash water is necessary and, in the simulator, this is achieved by the AFM. That should monitor pH and dose a named chemical to maintain this balance versus the acidification of the scrubbing process.

However, in the simulator, alkalinity is not implemented at all and instead the variable ambient seawater pH is used to dictate the simulator EGCS performance. Effectively, it is not possible to affect EGCS performance through changes in alkalinity, such as transit through the Baltic Sea. The reason might be that the continuous monitoring of alkalinity is not reasonable according to Lloyd's Register (2012) who then instead suggests that alkalinity be indirectly referenced by measuring pH and salinity. Although salinity is also not implemented so this argument is weak. Furthermore, variations in pH of the wash water are predictable as indicated by any attempts to adjust the ambient seawater pH intake, according to this function:

$$pH_{out} = pH_{in} - 1.7 \text{ if } pH_{in} > 6.4$$

Alkalinity is not implemented, so by default its credibility to realistically show how alkalinity affects EGCS performance or possible geographical limitations are low and not harmonized with classification societies guidelines (ABS, 2018; Lloyd's Register, 2012) or scientific papers on shipping's impact on acidification and alkalinity changes of the ocean (Doney et al., 2007; Hassellöv et al., 2013; Rhein et al., 2013; Stips et al., 2016; Teuchies et al., 2020).

Furthermore, there are two interesting results concerning the AFM and the fifth discharge water criterion under MEPC.340(77), where it is stated that if NaOH, Na_2CO_3 or other approved flocculants for oily-water separators are used the pH must be <8.0. If nonstandard chemicals are used one must confer to MEPC.169(57). To begin, the simulator manual and the AFM as implemented in the simulator fails to specify what chemicals are used. This means that it is impossible to ascertain what chemicals are used in a credible way as well as showing harmonization to MEPC.340(77). Additionally, there is no way to measure pH of the circulating wash water in the EGCS if operated in closed loop. Also, since the implemented AFM lacks any form of control systems, the dosage rate is unknown. This means that the system can't show in a credible way how the pH is maintained to ensure adequate performance. This is important, because the dominant factor dictating the recirculating wash waters pH in the system should be the AFM, where only a minor amount is bled-off at approximately $0.1m^3$/MWh and replenished. Making it difficult to show, in a credible way, how the EGCS is kept continuously operated in compliance with MARPOL Annex VI Regulation 14 requirements of equivalent or better SO_x reduction when operating in closed loop (International Maritime Organization, 2018a).

This is not to conclude that the simulator is impossible to understand. The simulator manual explains the process and there are visualizations of how the systems work, e.g., diagram lines and graphical boxes. So, the purpose of the AFM is understandable but any meaningful learning outcomes are limited, as little is written, and much is assumed.

5.3.3 Discharge water criteria

About discharge water criteria, see question no. 11, 14, 16, 18, 22, 27, 35, 44, 48, 51, 52, 53, 54 and 60 (Table 3), the simulator performance was found to be inadequate. Where no pertinent information on discharge water criteria was found, either in the simulator or its manual. This indicates that the simulator is a poor complement to teaching in this topic or to foster an understanding of consequences to using an EGCS compared to, for example MARPOL compliant fuels or alternative ones. Although the manual describes the process, it fails to explicitly specify how efficient the pre-discharge treatment plant is. This might lead a student to assume that the plant removes residues and other pollutants completely and that there is no need for any discharge water monitoring other than a pH sensor. An assumption that runs counter to scientific papers already addressed in the theory chapters above.

The simulator, however, does serve a purpose in visualization of where contaminants enter the wash water and where they are removed in the pre-discharge treatment plan. However, what exact composition of pollutants are unknown in the simulator. No sources of pollutants besides pH and unnamed residues are indicated in the simulator, where residues are cleaned from the wash water prior to discharge overboard and pH measured. So, in short, the simulator is not credible when compared to nor is it harmonized with the MEPC.340(77) discharge water criteria.

To exemplify, the only two discharge water criteria that is reasonably complied with is the first concerning pH and last concerning incineration of wash water residues. But it fails to mention which option was chosen when determining their pH discharge limit. It is also not mentioned at all in the simulator manual. There is an alarm, but why it was set to a certain value is not explained in either the manual or simulator. Worth to mention, although it is discussed previously is that the inlet and outlet pH seems to follow a predictable function $pH_{out} = pH_{in} - 1.7$ if $pH_{in} > 6.4$ that is difficult to interfere with so far that insufficient EGCS performance is hard to obtain. This makes the simulator almost too efficient to provide any insight into how alkalinity (which is not implemented at all) and pH fluctuations might affect performance. Furthermore, the simulator manual explains that no residues should be pumped overboard or incinerated but pumped ashore to a receiving facility. Although this is impossible to do in the simulator, even if one tried, because it's a simple graphical box without any functionality. The other criteria, such as PAH, turbidity, nitrites, what chemicals are uses if operating in closed loop, if stored in the holding tank are not described at all in the simulator manual. Also, in the simulator there are no PAH or turbidity sensors nor is there a method for measuring nitrates prior to discharge overboard. As discussed previously about the AFM the chemicals used to maintain an alkaline wash water is unknown and so does not comply with the fifth criterion. So, conclusively, it is impossible to comply with the guidelines and is not harmonized with MEPC.340(77). Following that same tangent, since it’s hard to comply with guidelines that are not explained or implemented, the simulator serves as a poor platform. At least if the goal is to achieve adequate learning outcomes, such as why the guidelines exist, what they are and above all else why they should be followed out of an environmental load perspective.

It could be argued that if one assumes the concentrations of various pollutants accumulated in the wash water, it is possible to complete calculations as to the environmental load. This is probably true as all necessary flow rates are given, but it requires a great deal of assumptions and know-how. This argument falls however, since there is no point in using a simulator if all, but one variable is assumed. Making it a calculation exercise with extra steps, namely using the simulator. The same is true for knowledge of the EGCS as a process, it is an understandable concept, but yields no great knowledge gain, since most of the sub-systems, e.g., pre-discharge treatment plant and AFM, offer little to no functionality in operating the simulator EGCS overall.

5.3.4 Knowledge of EGCS and its performance

Concerning inadequate simulator performance on knowledge of EGCS and its performance, see question no. 9, 13, 14, 16, 19, 22, 25, 35, 50, 58 and 60 (Table 3), it was found that no new environmental loads was shown that are necessary to be aware of or limitations that would reduce the EGCS performance of the simulated ship. Instead, one would have to calculate with a great deal of assumptions so far that the point of using a simulator no longer serves a point.

This is unfortunate as Lunde Hermansson et al. (2021) have shown that using an EGCS results in a greater environmental load. Something that is unreasonably difficult to showcase in the simulator. Since for example, it is unable to give any resulting environmental impact because of using a dirtier fuel with an EGCS than MGO or MDO without one. The simulator does provide sulphur and ash content in the fuel being used if one examines the service tanks. However, since the pre-discharge treatment plant is underdeveloped, it is impossible to observe a difference since it removes all residues regardless. This was demonstrated by attempting to raise the sulphur content to an extreme level (maximum allowed in the simulator software was 10%) and operate fully loaded with the EGCS in service. No change was observed, as the pre-discharge treatment plant just works at a presumably assumed 100% efficiency in removing residues. This disallows any realistic or credible learning outcomes in understanding the threat that an EGCS pose to the marine environment.

This is expected and as already discussed, the absence of a PAH sensor, as required by MEPC.340(77), makes it impossible to show that the measured pollutants per power output should have increased like how Lunde Hermansson et al. (2021) observed a factor of 10 in emitted PAH compared to operating on MGO or MDO without an EGCS. Another interesting point that Lunde Hermansson et al. (2021) showed, was the increased concentration of chromium. Where it was argued that hot and acidic seawater passing through stainless-steel piping, that was built to withstand the working atmosphere of an EGCS, would corrode and introduce this as an additional environmental load, namely chromium. This too is impossible to show in the simulator, as the piping are exempt to malfunctions, something that pumps, and other components are not. Then again, the malfunctions that one can introduce in the simulator are at a basic level. It would've been interesting however, to be able to showcase, that the working environment in the EGCS is a hot and acidic one, with a discharge of chromium. For example, it must be an implemented monitoring system that measures a variable like the pH outlet does in the simulator. Just the pollutant concentrations and rate would be interesting to add to exemplify that although this technology exempts the ship and might appear to solve all the problem. There is in fact drawbacks as there are with most systems. Then a student could better learn and understand their potential impact on the environment, for example, why it is important to keep the pre-discharge treatment plant in good order so that the residues escaping into the discharge piping are minimized.

5.3.5 Environmental load

The final common denominator that will be discussed is environmental load, see question no. 22, 25, 35 and 61 (Table 3), where inadequate simulator performance was observed when attempting to show how an EGCS increase the impact on the marine environment.

During the attempts, no information on environmental load was ascertained. Instead, one would have to calculate these loads with such extensive assumptions and manual calculations that the simulator at this point serves little to no use. For example, mostly the same metals, such as, but not limited to, arsenic, cadmium, and copper was found in discharge water samples taken (Lunde Hermansson et al., 2021; Teuchies et al., 2020; Ytreberg et al., 2021). Although the measured concentrations differed, an average trend was still shown of elevated concentration in all of them. Given the fuel oil data used for combustion and flow rate of the wash water, it is not improbable to calculate the resulting environmental load. The point is however that these concentrations need to be assumed.

The fact of the matter is that it is difficult to show how an EGCS might increase a ships environmental load without these sources, in some way or another, implemented into the simulator, such as PAH and metal variables. It is difficult, if not impossible, to realistically show that an EGCS is the largest pollution source to a student by solely using the simulator. Since, from reading the simulator manual and looking at the system itself, it appears that the pre-discharge treatment plant works at an incredibly high efficiency to the point where discharge wash water monitoring systems other than for pH is unnecessary. This shuts down the potential learning outcomes to see how, for example, 99.95% of PAH originates from the EGCS rather than the bilge system. Or how 90% of zinc, 53% of copper and 99% of arsenic, as an environmental load originates from the EGCS, rather than antifouling paints. In summary, such assumptions and manual calculations would have to be conducted to show how an EGCS increase the ships environmental load, to a point, where the simulator is no longer of any use.

5.4 Method

The method was designed to build a systematic review of where information was collected, what it is about, what STCW requirement it is comparable to and ultimately formulated into a question that could challenge the simulator to gauge its performance.

This leaves some concern for subjectivity as the questions are created by the authors themselves and so is the grading of a question. This is an unavoidable decision, by choosing this method and although this might be seen as a liability concerning reliability, it has been actively mitigated by working systematically with full transparency. Another argument, to support the use of this method is that strictly objective assessment is a poor choice, due to the available tools and expertise in doing any credible code analysis of the simulator software. The authors are enrolled in the marine engineering program at Chalmers and so, that would be a poor fit as simulator training is done and should be assessed by how a user or student works in the simulator.

As previously described in the method chapters, the process with its respective modules is shown in detail and if one has read Appendix 1 and 2, it is abundantly clear how the questions were formulated as to minimize subjectiveness, such as bias. In Appendix 1, respective parts of the compiled theory, text excerpts were taken and systematically categorized according to either perspective or STCW requirements. These were then assigned an identifier for use in Appendix 2. In Appendix 2, each identifier with their excerpt, were formulated into questions and then assigned a number in a rolling order. The purpose of this was to create a list of relevant questions to be tried to answer using the simulator alone and then graded according to Y/N/P, see method chapter for definitions. To further mitigate reliability issues, as the grading, can be seen a subjective liability from teste to tester, an additional note was left to motivate why a question was assigned a certain result. This makes the process open to scrutiny as should be.

The advantages to using this method is that it results in questions that are answerable today, for example Y-results, in the simulator software. These could be used already today for MET at Chalmers without any further implementation or work. Something that probably wouldn’t have been done if another method was chosen. Even the P-results, who require some form of compliment, could also be used. Meanwhile the N-results should be avoided as they serve little to no benefit for MET today although as already mentioned, it still provides values in pointing out specific areas where changes to the simulator should reflect positively. Summarily, the fact that a total of 63 questions have been systematically created and tested in the simulator provides value. The Y-results and if complimented the P-results, could be integrated into the current curriculum, and used in in laboratory memorandums if one wanted. If a different method had been chosen, such as investigating the code, the questions would never have been created in a way that is synchronized with, for example STCW requirements or scientific papers.

In summary, while there are two concerns for subjectivity that could affect reliability negatively, these have been actively worked with so that the margin of error is decreased. Since each step of the process is shown and motivated throughout the thesis, it is safe to assume that while there might be some subjectivity left to affect the result, actions to minimize them have been taken. So that the results, aimed to measure the simulator performance, could answer the research question.

6. CONCLUSION

In its present state, a simulator exercise using the K-Sim ERS L11-6S70ME SCC (version 3.3.1.0181) can only present a visualization of key topics that is being taught. A visualization could support a student to reach educational qualities demanded at Chalmers, but it is of question if the time it takes to produce anything of value in the simulator would not be better spent on improving the current curriculum. The purpose of this thesis was to evaluate how capable and compatible the simulator software would be for MET at Chalmers after accounting for the stated perspectives, e.g., regulatory requirements, environmental papers, and technical guidelines. The simulator was designed to be applied to the STCW Code competencies involving basic ER operations, such as maintaining a safe engineering watch or operating main- and auxiliary machinery. It is therefore not a surprise that whenever required simulator performance is raised beyond those design criteria, it often resulted in inadequacy or in need of complementation from outside sources. This raises concerns for suitability for qualified maritime environmental impact studies at Chalmers.

The historical trend of maritime regulations shows that they tend to get stricter. However, today there are currently no set regulations for what the EGCS discharge water quality must be. The guideline on discharge water that has been produced by IMO, are simply guidelines and have clearly been ignored by the simulator manufacturer since not even most of the basic criteria, outside of pH, are presented in a credible way. Currently, there are no regulatory reasons to not install an EGCS to operate on cheaper HFO fuels. Even if local ports prohibit EGCS usage, the vessel can change over to MDO or another compliant fuel. This is of course a good thing for any vessel to do, but the moment the vessel leaves that geographical area, they can swap over to HFO again. This combined with the statistics regarding the number of EGCS installed onboard, shows that this technology arguable is here to stay for the coming years, which facilitates a need for knowledge, understanding and competence.

Outside operational understanding and increased watchkeeping ability, the simulator can at best be used as a visualizing aid for environmental impact. The current build of the simulator does not provide a credible behavior that is worth studying regarding environmental impact. Any studies on environmental impact are limited by the lack of presented data. But if pollutants and emissions, in all systems, were given the same dedication and quality of implementation as for example the fuel management has been given, the opportunities for environmental impact in MET would be different. For example, if pollutants were implemented properly, they could also be translatable to most engine room systems such as, the bilge water and its discharge or the stern tube with its leakage. This would overall improve the credibility of the simulator to mimic a real like ship. Where the possibilities to anchor its harmonization to regulations, technical guidelines and the scientific community would be coherent. Summarily lifting the achievable learning outcomes from basic engine room operations that have been repeatedly manufactured to date.

6.1 Recommendations for further implementation

The following features lack proper implementation, and needs to be rectified if the simulator should be suitable for MET regarding EGCS operation and its environmental impact:

- Increasing the amounts of possible scenarios that is available for study. This can be done by introducing new, more diverse, malfunctions. For example, inside the scrubber tower, such as clogged nozzles, uneven spray, etc. would introduce more interesting faults for a student. Furthermore, the malfunctions should be more descriptive than a percentage, as this is difficult to understand, especially when there is no mention of what this means in the simulator manual.

- Realistic defining of a component's type and make, this would further enhance learning outcomes, as there are different kinds of pumps, fans, and valves; all with their benefits and drawbacks. Especially so if one attempts to conduct maintenance studies.
- Discharge water content measurements should be implemented according to MEPC.340(77), for example turbidity- and PAH measurement devices and some way to measure nitrates prior to dilution. Additionally, to enhance environmental load studies, overall concentrations of pollutants, such as heavy metals should be implemented.
- Proper implementation of the pre-discharge treatment plant to be able to see how the treatment is done. As previously mentioned above, more malfunctions are necessary here as well, to gain the ability to introduce faults to this plant. So that the performance of wash water treatment is observable and manipulatable.
- Proper implementation of AFM and an adequate control system, to allow for changing of dosage, etc. The chemical used should also be named and described in more detail in the simulator manual.
- Wash water quality should be possible to affect, and the quality should be affecting the scrubber process.
- Residue tank should be filled during operation, as well as measurements of content. Furthermore, a way to discharge these residues ashore should be implemented.
- Implementation of waste streams (PAHs, metals etc.) to the EGCS should enable the same principles to be shown from other sources, such as anti-fouling paint, black and grey water, and bilge.

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APPENDIX 1

Table 5: Categorization of compiled theory. Excerpts were categorized according to the relevant STCW criterion and overall topic. Ultimately assigned an identification code.

Text extract [Theory chapter]	**STCW criterion [identification no]**	**Topic [identification letter]**	**ID-Code**
“The objective of the scrubbing process is to remove most of the sulphur oxides (SO_x) and particulate matter (PM) contained in exhaust gasses, by spraying wash water that absorbs the water-soluble SO_x and other PM, before releasing the gasses to the atmosphere (Lloyd’s Register, 2012).” [2.4]	[3]"Anti-pollution procedures and all associated equipment"	[C] General EGCS operation/principle of action and performance	C3-1
“This document recommends that when a malfunction is detected, immediate actions are to be taken to locate and rectify the fault. An EGCS operator should also have experience with and knowledge of the system, including access to the class approved technical manuals and troubleshooting procedures. If the lost compliance is unable to be regained within one hour, MEPC.1/Circ.883 recommends that the vessel change over to MARPOL compliant fuel.” [2.8]	[3] "Anti-pollution procedures and all associated equipment"	[C] general EGCS operation/principle of action and performance AND [H] redundancy/compliance lost	C3-2 AND H3-1
“The most common type (85%) onboard vessels are an open loop system (DNV, n.d), here sea water is continuously pumped into the EGCS, and the acidic wash water is simply discharged back overboard (ABS, 2018).” [2.4]	[3] "Anti-pollution procedures and all associated equipment"	[D] OL EGCS operation/principle of action	D3-1
In a closed loop system, the scrubbing water is recirculated. To keep a closed loop EGCS able to continuously operate in compliance to MARPOL, the wash water is treated chemically by adding a base (often NaOH) to raise pH to maintain a balance (ABS, 2018). [2.4]	[3] "Anti-pollution procedures and all associated equipment"	[E] CL EGCS operation/principle of action	E3-1
“With the only exception being in case of manoeuvring and transit, at which point, a ΔpH may never be greater than 2 between inlet and discharge. The second option requires the determination of an overboard pH discharge limit, either measured or calculated, to be >6.5 pH at a 4m distance from the discharge outlet.” [2.7]	[3] "Anti-pollution procedures and all associated equipment"	[F] Threat from discharge water	F3-1

"The overall idea with installing a pre-discharge treatment plant is that harmful residues are separated and not discharged overboard and instead pumped to a sludge holding tank so that it can be sent ashore." [2.4]	[4] "Knowledge of the precautions to be taken to prevent pollution of the marine environment " AND "Importance of proactive measures to protect the marine environment"	[C] General EGCS operation/principle of action and performance	C4-1

Text extract [Theory chapter]	**STCW criterion [identification no]**	**Topic [identification letter]**	**ID-Code**
The discharged water of an open loop EGCS normally reaches a pH below 3 prior to dilution (Ytreberg et al., 2021). [2.4]	[4] "Knowledge of the precautions to be taken to prevent pollution of the marine environment " AND "Importance of proactive measures to protect the marine environment"	[D] OL EGCS operation/principle of action AND [F] threat from discharge water	D4-1 AND F4-1
The wash water bled-off, at an approximate rate of 0.1m3/MWh and replenished by adding new water into the loop (Lloyd's Register, 2012). [2.4]	[4] "Knowledge of the precautions to be taken to prevent pollution of the marine environment " AND "Importance of proactive measures to protect the marine environment"	[E] CL EGCS operation/principle of action	E4-1
The processes regarding nitric and sulphuric acids do, in contrast to CO_2, affect the total alkalinity of the water and are non-reversible without the addition of a strong base (Turner et al., 2017). By reducing alkalinity of an ocean, the ocean's resistance to future pH changes is also reduced (Stips et al., 2016). [2.9]	[4] "Knowledge of the precautions to be taken to prevent pollution of the marine environment " AND "Importance of proactive measures to protect the marine environment	[F] threat from discharge water	F4-2

Two studies that modelled acidification from sulphur in smokestack emission, resulted in a global annual average pH decrease of 0.0004 (Doney et al., 2007) and 0.00037 (Hassellöv et al., 2013). This global estimation might seem small when compared to the annual decrease of approximately 0.002 pH due to CO_2, not all areas of the ocean are affected equally by SO_x emissions from shipping (Stips et al., 2016). [2.9]	[4] "Knowledge of the precautions to be taken to prevent pollution of the marine environment " AND "Importance of proactive measures to protect the marine environment"	[F] threat from discharge water	F4-3

Text extract [Theory chapter]	**STCW criterion [identification no]**	**Topic [identification letter]**	**ID-Code**
Wash water discharge from an EGCS is an even more direct and effective way of transferring NO_x and SO_x into the water than smokestack emission (Turner et al., 2017). [2.9]	[4] "Knowledge of the precautions to be taken to prevent pollution of the marine environment " AND "Importance of proactive measures to protect the marine environment"	[F] threat from discharge water	F4-4
For example, when comparing data from discharge water samples from 41 different ships using an open loop EGCS and HFO, the wash water was on average 110 times more acidic than the inlet water (Lunde Hermansson et al., 2021). [2.5]	[4] "Knowledge of the precautions to be taken to prevent pollution of the marine environment " AND "Importance of proactive measures to protect the marine environment"	[F] threat from discharge water	F4-5
Ytreberg et al. (2021) averaged 36 open-loop EGCS samples to be 3.85 $\mp$ 0.33 pH, and 11 closed-loop EGCS samples as 4.54 $\mp$ 0.51 pH. [2.5]	[4] "Knowledge of the precautions to be taken to prevent pollution of the marine environment " AND "Importance of proactive measures to protect the marine environment"	[F] threat from discharge water	F4-6

A study on the wash water's ecotoxicological effect on pelagic copepods, where both open- and closed-loop samples were used showed that EGCS discharge water was more toxic to the copepods than crude oil (Thor et al., 2021). In a separate study, two samples, taken from open loop systems, were also found to be acutely toxic to marine organisms (Teuchies et al., 2020). [2.5]	[4] "Knowledge of the precautions to be taken to prevent pollution of the marine environment " AND "Importance of proactive measures to protect the marine environment"	[F] threat from discharge water	F4-7
Text extract [Theory chapter]	**STCW criterion [identification no]**	**Topic [identification letter]**	**ID-Code**
Mostly the same metals were found in discharge water samples taken (Lunde Hermansson et al., 2021; Teuchies et al., 2020; Ytreberg et al., 2021) while the exact averaged concentrations of the studies differed, the trend of elevated concentrations could be found in all of them. Metals commonly found in the discharge water were arsenic, cadmium, copper, lead, mercury, zinc, and iron. Mercury, cadmium, lead, and nickel are considered priority substances by the EU directive Water Framework Directive (Official Journal of the European Union, 2013). [2.5]	[4] "Knowledge of the precautions to be taken to prevent pollution of the marine environment " AND "Importance of proactive measures to protect the marine environment"	[F] threat from discharge water	F4-8
Thor et al., (2021) explains that no single substance may be attributed alone to the toxicity. They point out that the exact composition of the discharge water is hard to estimate, the expected homogenous trend regarding concentrations of PAHs, could not be found in their samples. Due to this, they argue that the many different metals, PAHs, and organics, combined with the pH and temperature of the wash water can result in what they call a "witch's cauldron" where the substances of the wash water mix, react, and create undesired toxic compounds. [2.5]	[4] "Knowledge of the precautions to be taken to prevent pollution of the marine environment " AND "Importance of proactive measures to protect the marine environment"	[F] threat from discharge water	F4-9
Synergetic effects in copepods have already been seen in the following combinations between metals: Cadmium and zinc, copper and nickel, zinc and nickel, zinc and lead, nickel and chromium, and lead and chromium (Verriopoulos and Dimas, 1988). These are all metals that have been found in wash water samples from both open loop and closed loop EGCS (Lunde Hermansson et al., 2021; Teuchies et al., 2020; Ytreberg et al., 2021) [2.5]	[4] "Knowledge of the precautions to be taken to prevent pollution of the marine environment " AND "Importance of proactive measures to protect the marine environment"	[F] threat from discharge water	F4-10

The amount of sulphur oxides emitted is directly correlated to the amount of sulphur content in the fuel, therefore the global maximum allowed content (0.5% m/m) is defined in MARPOL Annex VI, Regulation 14.1 (International Maritime Organization, 2018a). Regulation 14.1 entered into force in 2020 after MEPC.280(77) was published, following an investigation to assure that the worldwide supply was satisfactory (International Maritime Organization, 2016). [2.3]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[B] reg 14	B6-1

Text extract [Theory chapter]	**STCW criterion [identification no]**	**Topic [identification letter]**	**ID-Code**
Click or tap here to enter text.Exemptions to regulation 14, can be granted to a vessel by a flag states administration, under regulations 4.1 and 4.4 (International Maritime Organization, 2018a). According to these regulations, if the sulphur emission reduction created by any method that is equal to, or better than, the reduction created by using a fuel with low sulphur content, exemptions can be allowed. One such method is an EGCS, which cleans the gas exhaust with wash water to reduce pollutants released into the atmosphere. [2.3]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[B] reg 14	B6-2
Earlier, restrictions regarding sulphur content have entered into force under regulation 14.4 inside Sulphur Emission Control Areas (SECA) since 2015, where 0.1% (m/m) or less is required (International Maritime Organization, 2008). [2.3]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[B] reg 14	B6-3
According to resolution MEPC.340(77), to prove that the EGCS is equivalent to using fuels compliant with Regulation 14.1 (global limit) and 14.4 (local limit). The corresponding emission ratio limits, regardless of operating load point or transient operation, must be satisfied: Regulation 14.1: fuel oil sulphur content 0.5 (% m/m) ↔ emission ratio of 21.7 SO_2 ppm/CO_2 (% v/v) Regulation 14.4: fuel oil sulphur content 0.1 (% m/m) ↔ emission ratio of 4.3 SO_2 ppm/CO_2 (% v/v) [2.7]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[C] General EGCS operation/principle of action and performance	C6-1

Text extract [Theory chapter]	STCW criterion [identification no]	Topic [identification letter]	ID-Code
The sixth criterion covers guidelines for discharge of any EGCS wash water that has been temporarily stored, in for example a holding tank. The three main considerations for discharge of temporarily stored EGCS wash water are pH, PAH, and turbidity. It is to follow the same pH (>6.5), PAH (<50 µg/L) and turbidity (<25 FNU) criterions as previously mentioned, although independent of any flow rate. [2.7]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[C] General EGCS operation/principle of action and performance	C6-2
The fifth criterion concerns primarily EGCS' that make use of non-standard chemicals, e.g., other than NaOH, Na_2CO_3 or approved flocculants for oily-water separators, and refer the reader to MEPC.169(57). If the standard chemicals are used, the only requirement is that the wash water discharge pH is <8.0. [2.7]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[C] General EGCS operation/principle of action and performance	C6-3
The seventh and final criteria is about residues from the EGCS water treatment process. The EGCS process, regardless of an open- or closedloop system, generates residues from its treatment process. These residues should not be discharged or incinerated but delivered ashore to a qualified reception facility (International Maritime Organization, 2021). [2.7]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[C] General EGCS operation/principle of action and performance	C6-4
Concerning bleed-off when operating in closedloop is subject to the same requirements. If the bleed-off water fails to meet either pH, PAH, or turbidity criterions it is to be considered as EGCS residues. [2.7]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[C] CL EGCS operation/principle of action	E6-1
. This discharge limit should be documented onboard. If calculated, it must consider conditions, such as highest practicable load, maximum allowed sulphur content in fuel, seawater alkalinity of 2.2 mmol/L and pH 8.2. [2.7]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[F] Threat from discharge water	F6-1
The concentration of allowed PAH compared to PAH_{phe} in the discharge water is <50 µg/L prior to dilution. Where the limit 50 µg/L PAH correlates to the normalized water flow rate of 45 m^3/MWh (IMO, 2021). [2.7]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[F] Threat from discharge water	F6-2

Text extract [Theory chapter]	**STCW criterion [identification no]**	**Topic [identification letter]**	**ID-Code**
The third criterion concerns turbidity, used as a rough proxy for the number of particulate matter, heavy metals and ash suspended in a fluid or volume. MEPC.340(77) recommends that the continuous water discharge should be measured after treatment and before dilution. Water treatment should be designed so that measured turbidity is <25 Formazin Nephelometric Units (FNU) or another equivalent unit used. [2.7]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[F] Threat from discharge water	F6-3
The accuracy of turbidity monitoring equipment should not deviate more than 2 FNU and be able to identify whenever it is unable to reliably quantify measurements. This is for the turbidity monitoring equipment to record for the allowed 20% deviation for 15-minute period every 12 hours. [2.7]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[G] Deviation allowed [discharge water]	G6-1
. The allowed deviation due to accuracy of monitoring equipment is 0.2 pH units. Thus, the pH meter should have a resolution of 0.1 pH units with temperature compensation. [2.7]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[G] Deviation allowed [discharge water]	G6-2
Compliance to Regulation 14 of MARPOL Annex VI is expected to be kept all times, no matter what technology under regulation 4 is used (International Maritime Organization, 2018a). This means that for an EGCS, it must always operate adequately, and this raises concerns for redundancy. Lloyd's Register (2012) urges consideration for an adequate risk analysis, in terms of likelihood and consequences of failure within an EGCS, as it is unclear how flag and port states might react to a non-compliant ship. [2.8]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[H] Redundancy/complianc e lost	H6-1
An EGCS without redundancy might suffer commercial consequences, such as embargo. [2.8]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[H] Redundancy/complianc e lost	H6-2

Text extract [Theory chapter]	**STCW criterion [identification no]**	**Topic [identification letter]**	**ID-Code**

There are no explicit redundancy requirements for the components in an EGCS system (ABS, 2018). Non-compliance is tolerated if the vessel or equipment is damaged or faulty according to Regulation 3.1.2 (International Maritime Organization, 2018a). This does not include damage resulting from negligence or poor design, so ABS (2018) recommend due diligence in design, operation, and maintenance so that breakdowns are avoided. [2.8]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[H] Redundancy/complianc e lost	H6-3
This document recommends that when a malfunction is detected, immediate actions are to be taken to locate and rectify the fault. An EGCS operator should also have experience with and knowledge of the system, including access to the class approved technical manuals and troubleshooting procedures. If the lost compliance is unable to be regained within one hour, MEPC.1/Circ.883 recommends that the vessel change over to MARPOL compliant fuel. In the case a vessel does not carry compliant fuel onboard or is unable to carry out the fuel changeover, the vessel is recommended to come to an agreement with relevant authorities for a plan of action. [2.8]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[H] Redundancy/complianc e lost	H6-4
All details during the EGCS malfunction, no matter if the fault was fixed or if an alternative plan was taken, shall be recorded (International Maritime Organization, 2019). [2.8]	[6] Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended	[H] Redundancy/complianc e lost	H6-5
The EGCS performance is reliant on the wash water's alkalinity, since the acids created during the EGCS process, react with the alkaline water (ABS, 2018; Lloyd's Register, 2012). [2.5]	[7]"Methods and aids to prevent pollution of the environment by ships"	[C] General EGCS operation/principle of action and performance	C7-1
Lloyd's Register (2012) states that performance of an open-loop system is vulnerable to changes in natural alkalinity and pH of seawater. [2.5]	[7]"Methods and aids to prevent pollution of the environment by ships"	[C] General EGCS operation/principle of action and performance	C7-2
An EGCS operator should also have experience with and knowledge of the system, including access to the class approved technical manuals and troubleshooting procedures. [2.8]	[7]"Methods and aids to prevent pollution of the environment by ships"	[C] General EGCS operation/principle of action and performance	C7-3

Text extract [Theory chapter]	**STCW criterion [identification no]**	**Perspective [identification letter]**	**ID-Code**

According to their results, if a vessel used an EGCS to comply with MARPOL Annex VI regulation 14, it would generally have an increased load when compared to using Marine Gas Oil (MGO) or MDO as a fuel. [2.5]	[7]"Methods and aids to prevent pollution of the environment by ships"	[C] General EGCS operation/principle of action and performance	C7-4
Due to alkalinity's effect on the scrubbing performance, Lloyd's Register (2012) explicitly excludes the Baltic Sea from recommended areas of operation, and even goes so far as to state that adequate open-loop EGCS performance is not expected within the Baltic Sea. Although both open- and closed loop EGCS activity has increased dramatically from 2012 to 2018 (Jalkanen et al., 2021). Meaning that just because Lloyd's Register (2012) advised in 2012 against open loop EGCS in the Baltic Sea, it doesn't necessarily mean that their recommendation is followed. [2.6]	[7]"Methods and aids to prevent pollution of the environment by ships"	[D] OL EGCS operation/principle of action	D7-1
Lloyd's Register (2012) then compares this to a closed loop, stating that is not as vulnerable to changes in ambient alkalinity or pH, since they operate on recirculating wash water that is continuously treated with a chemical base to maintain the alkaline quality. [2.6]	[7]"Methods and aids to prevent pollution of the environment by ships"	[E] CL EGCS operation/principle of action	E7-1
Their modelling shows that acidification due to shipping of the Baltic Sea with a fleet consisting of 20% open-loop EGCS, and 80% using 0.1% sulphur fuel, is the same as if 100% of the merchant fleet used 1.0% sulphur fuel. [2.9]	[7]"Methods and aids to prevent pollution of the environment by ships"	[F] Threat from discharge water	F7-1
When modelling the different load sources, their results show that 100% of the total measured vanadium, chromium, cadmium, and nickel being transferred into the sea from a model ship originated from open-loop EGCS. [2.10]	[7]"Methods and aids to prevent pollution of the environment by ships"	[F] Threat from discharge water	F7-2
Ytreberg et al., (2021) also estimated that an open-loop EGCS, contributed to 90% of zinc, 53% of copper and 99% of arsenic of the total load. A secondary source for metals was antifouling paint, which contributed to 45% of total copper load and 8% of total zinc load. [2.10]	[7]"Methods and aids to prevent pollution of the environment by ships"	[F] Threat from discharge water	F7-3
Furthermore, their results regarding PAHs, showed that the only notable sources from the vessel was bilge water and EGCS discharge water. Where once again EGCS is the largest source, where all but one PAH had above 99.95% contribution from EGCS. The outlier was naphthalene, where EGCS contributed to 99.87% of the total load (Ytreberg et al., 2021). [2.10]	[7]"Methods and aids to prevent pollution of the environment by ships"	[F] Threat from discharge water	F7-4

Appendix 1 P.

Text extract [Theory chapter]	**STCW criterion [identification no]**	**Topic [identification letter]**	**ID-CODE**
Another study, from Lunde Hermansson et al., (2021), demonstrated through calculations, a similar trend of EGCS usage impacting the environmental load. According to their results, if a vessel used an EGCS to comply with MARPOL Annex VI regulation 14, it would generally have an increased load when compared to using Marine Gas Oil (MGO) or MDO as a fuel. [2.10]	[7]"Methods and aids to prevent pollution of the environment by ships"	[F] Threat from discharge water	F7-5
Emission factors regarding PAHs were also found to always be higher, with a varying degree of magnitude between two and 20 (Lunde Hermansson et al., 2021). Moreover, their calculations also resulted in a 10 times higher total sum of PAHs from EGCS using HFO when compared to using MGO/MDO without an EGCS. [2.10]	[7]"Methods and aids to prevent pollution of the environment by ships"	[F] Threat from discharge water	F7-6
Concerning their findings, regarding an increased concentration of chromium, Lunde Hermansson et al. (2021) argues that the auxiliary systems an EGCS uses can create new sources of loads onto the environment. Their argument is that the hot and acidic sea water passing through stainless-steel pipes, which contains chromium, will be due to corrosion introduce an additional source of chromium that without the EGCS would not exist (Lunde Hermansson et al., 2021), an argument that (Teuchies et al., 2020) also propose in their study. [2.10]	[7]"Methods and aids to prevent pollution of the environment by ships"	[F] Threat from discharge water	F7-7
Exemptions to regulation 14, can be granted to a vessel by a flag states administration, under regulations 4.1 and 4.4 (International Maritime Organization, 2018a). [2.7]	[8] "Knowledge for national legislation for implementing international agreements and conventions"	[B] reg 14	B8-1
The MEPC.340(77) resolution concerns the 2021 guidelines for EGCS, its purpose is to specify various criteria, for example what is needed for an approval of exemption and the quality of the discharge water. This resolution is voluntary guidelines until the respective flag state implements them (IMO, MEPC.340(77), 2021). [2.7]	[8] "Knowledge for national legislation for implementing international agreements and conventions"	[C] General EGCS operation/principle of action and performance	C8-1

APPENDIX 2

Table 6: Learning outcomes derived from excerpt categorization (Appendix 1) sorted according to STCW criterion.

SCTW criterion	Learning outcomes and identification code (Appendix 1)
"Anti-pollution procedures and all associated equipment"	How and EGCS work - C3-1 Be able to fix it - C3-2 How open loop work - D3-1 How closed loop work - E3-1 pH values to know immediately - F3-1+2 (if se other # = panic) Be able to fault find the system - H3-1
"Knowledge of the precautions to be taken to prevent pollution of the marine environment " AND "Importance of proactive measures to protect the marine environment"	Residue to land - C4-1 (don not drain into sludge etc.) Open loop pH = bad - D4-1 closed loop creates discharge as well - E4-1 Open loop pH = bad - F4-1 N + S = acid = acidification + reduce alkalinity = bad - F4-2 Impact higher closer - F4-3 Impact discharge > impact smokestack - F4-4 discharge pH = very bad - F4-5 open loop discharge pH + cl discharge pH = very bad - F4-6 Closed loop + open loop discharge = toxic - F4-7 Many metals + many concentration - F4-8 pH+temp+many subjects = synergetic - F4-9 Some metal combos have proven synergetic, F4-10
"Responsibilities under the International Conventions for Prevention of Pollution from Ships, as amended "	Reg 14 definition + SECA - B7-1 Reg 14 exemptions allowed according to Reg 4 - B7-2 sulphur in fuel decide sulphur in exhaust 0.5% mass globally, 0.1% SECA - B7-3 EGCS performance - C7-1 holding tank before discharge - C7-3 Usage of chemicals - C7-4 Residues - C7-5 CL bleed of water - E7-1 pH discharge limit - F7-1 PAH limits - F7-2 Turbidity limits - F7-3 Deviation in turbidity due to operation allowed - G7-1 Deviations in measuring due to the sensors - G7-2 MARPOL compliance mandatory but not really - H6-1 Redundancy good embargo not good - H6-2 non- compliance ok if not user made - H6-3 Non-compliance ok if done good - H6-4

"Knowledge for national legislation for implementing international agreements and conventions"	Exemption to 14 given by administration - B9-1 MEPC guidelines, not legislative but maybe - C9-1
SCTW criterion	**Learning outcomes and identification code (Appendix 1)**
"Methods and aids to prevent pollution of the environment by ships"	Alkalinity and performance - C8-1 OL alkalinity performance - C8-2 maintenance should be able to be done preferably quickly - C8-3 (person who responsible for procedures are responsible for it actually working and personnel using procedure is capable) Discharge depends on system quality, C8-4 Open loop no good Baltic sea, D8-1 Closed loop not so affected by Baltic sea - E8-1 EGCS significantly increases acidification higher than non EGCS ship - F8-1 EGCS only source of some metals - F8-2 EGCS largest source of other metals - F8-3 EGCS largest source of PAH - F8-4 EGCS significantly higher load than fuel compliance - F8-5 EGCS PAH significantly higher - F8-6 EGCS new sources of contaminants - F8-7

APPENDIX 3

Table 7: Topics derived from excerpt categorization (Appendix 1) sorted according to topic.

Topic	**Learning outcomes and identification code (Appendix 1)**
[B] reg 14	Reg 14 definition + SECA - B7-1 Reg 14 exemptions allowed according to Reg 4 - B7-2 sulfur in fuel decide sulfur in exhaust 0.5% mass globally, 0.1% SECA - B7-3 Exemption to 14 given by administration - B91

[C] General EGCS operation/principle of action and performance	How EGCS work - C3-1 Fix it quick - C3-2 Residue to land - C5-1 EGCS performance - C7-1 Holding tank before discharge - C7-3 Usage of chemicals - C7-4 Alkalinity and performance - C8-1 OL alkalinity performance - C8-2 maintenance should be able to be done quick - C8-3 (person who responsible for procedures are responsible for it actually working and personnel using procedure is capable) Discharge depends on system quality - C8-4 MEPC guidelines, not legislative but maybe - C9-1
[D] OL EGCS operation/principle of action	HOW open loop work - D2-1 Open loop pH = bad - D4-1 Open loop no good Baltic Sea, D8-1
[E] CL EGCS operation/principle of action	How closed loop work - E3-1 closed loop creates discharge as well - E4-1 closed loop bleed of water - E7-1 closed loop not so affected by Baltic sea - E8-1
[F] threat from discharge water	pH values to know immediately - F3-1+2 (if se other # = panic) OL pH)= bad - F4-1 N + S = acid = acidification + reduce alkalinity = bad - F4-2 impact higher closer - F4-3 impact discharge > impact smokestack - F4-4 discharge pH = very bad - F4-5 open loop discharge pH + cl discharge pH = very bad - F4-6 CL + OL discharge = toxic (copepods) - F4-7 (by knowing dangers, will be able to act preventive) Many metals + many concentration - F4-8 (above) ph+temp+many subjects = synergetic - F4-9 (above) Some metal combos have proven synergetic – F4-10 (above) pH discharge limit - F7-1 PAH limits - F7-2 Turbidity limits - F7-3 EGCS significantly increases acidification higher than non EGCS ship - F8-1

Topic	**Learning outcomes and identification code (Appendix 1)**

[F] threat from discharge water	EGCS only source of some metals - F8-2 EGCS largest source of other metals - F8-3 EGCS largest source of PAH - F8-4 EGCS significantly higher load than fuel compliance - F8-5 EGCS PAH significantly higher - F8-6 EGCS new sources of contaminants - F8-7
[G] deviation allowed [discharge water]	Deviation in turbidity due to operation allowed - G7-1 Deviations in measuring due to sensors - G7-2
[H] Redundancy/compliance lost	Be able to fix it - H3-1 MARPOL compliance mandatory but not really - H6-1 Redundancy good embargo not good - H6-2 non-compliance ok if not user made - H6-3 Non-compliance ok if done good - H6-4

Appendix 4

Table 8: Questions according to categorization of topics (Appendix 3) with respective result and additional notes. The notes serve as motivation as to why a result was assigned either Y/N/P. The identification code refers to where the question originates from (Appendix 1).

Id. Code	No.	Question	Result (Y/N/P)	Additional notes
According to learning outcomes by topics (Appendix 3)				
B7-1 B7-3	1	What is Regulation 14 and why does it exist?	Y	The simulator manual describes that the EGCS is aimed to reduce sulphur emissions. The EGCS in the simulator can visualize sulphur scrubbing and be used as a tool to show purpose. Sulphur content of fuel can be changed and correlates with sulphur emissions measured.
B7-1 B7-3	2	Where does Regulation 14 apply and what limits does it stipulate?	N	Although a limit can be shown since the system alarms when SOx emission is too high, it does not give specific information regarding compliance. Gives emission in g/kWh, which is not easily transformed into ppm SOx/volume CO2 and does not specify SECA compliant or not. The simulator manual does not explicitly describe Regulation 14, nor does it give an equivalent g/kWh for when non-compliance to the regulation.
B7-2 B7-3	3	Explain why a vessel could be exempt from regulation 14, who allows the exemption?	P	Visualization of scrubber procedure of effective reduction of SOx out, comparison of SOx emission with compliant fuel is possible. How allowance is given is not possible to be understood from the simulator. Manual does not explain why an EGCS is allowed legally.
C3-1	4	How does an EGCS work? Explain the different components.	Y	While the diagram of the system gives an understanding of EGCS operation, no information regarding the treatment (sludge/oil and soot separator), the residue tank nor what happens in the alkali feed module.
C3-2	5	Introduce a malfunction, what changes in the operation and fix it	Y	Faults/malfunctions that is possible: Pump and fan, wear faults and electrical faults. Signal malfunctions on measurements and measurements lost. Valves stuck and leakage and fail to return to position level switch. No faults on treatment plant or feed module. Dampers none. Monitoring sensors can’t be manipulated. No nozzle malfunctions or anything in the scrubber tower. No backpressure, cannot manipulate the travel of exhaust gas.
C8-3	6	How could the above be prevented? Write a procedure for fixing above in case your prevention failed.	Y	Fault finding moment possible, notice when numbers start to deviate, find the source. Although the limited possibilities are reduced. Prepare for what to do when deviation happens. Student to read manufacturers manuals and find what components are involved to write an overhaul procedure.

Id. Code	No.	Question	Result (Y/N/P)	Additional notes
According to learning outcomes by topics (Appendix 3)				
C7-3	7	Chief tells you to empty the residue tanks and the holding tank, where are these allowed to go?	N	The simulator disallows the emptying of residue tank because its interaction is not implemented. The simulator manual does explain that these residues must be sent ashore to a reception facility and that they are not to be incinerated onboard. However, since it lacks implementation more than a graphical box named residue tank doing any tasks concerning residue handling is impossible. The holding tank does have interaction implemented and it is possible to affect the pH sensor if operated in closed loop. The problem here is that the result that was obtained also had other irregularities, such as improbable flow rate, etc. question no. 7. The holding tank, does not generate any change in measured pH at the outlet SW monitoring, if having operated as either open or closed loop to collect different pH. This is exacerbated by the fact that the holding tank discharge pump has a nominal flow of approximately 2500 m3/h, where it is pumped overboard in a matter of seconds. If simulated at a 0.1 speed, no changes are observed by repetitive tests to generate a change in pH.
C7-4	8	What chemicals are used to treat the wash water, and explain briefly why rules could be different for different chemicals?	N	No information regarding Alkali Feed Module and its dosage/treatment is given.
C8-1 C8-2	9	How does the alkalinity of the inlet water change the performance of the ECGS in open and closed loop?	N	Not possible to change alkalinity. Cannot affect performance by alkalinity. The pH of the ambient sea water can be manipulated. While pH affects SOx scrubber efficiency, and pH and Alkalinity can correlate, it is not always true. The simulator does not add anything additional to theoretical education.

C9-1	10	Are the MEPC criteria for discharge water legislative?	N	No information regarding discharge water or criteria is presented, thus simulator does not complement teaching in this topic.
C8-4	11	Examine the system, what could affect the quality of the discharge water?	P	No information regarding what is found in discharge water is presented, but data regarding to fuel consumption exists and how much SOx, NOx, and CO2, is emitted with and without the EGCS in operation. Discussions, with assumptions of average fuel content, the combustion, and treatment plant efficiency, to discuss possible substances and concentrations in the discharge water. With an understanding of how hot acidic water affects the piping system, discussions regarding possible contamination from metal pipes can be carried out.

Id. Code	**No.**	**Question**	**Result (Y/N/P)**	**Additional notes**
According to learning outcomes by topics (Appendix 3)				
D2-1 D4-1	12	How does an OL system work? Why is the pH of the outlet lower than the inlet?	Y	Able to operate on open loop, information given in monitoring should be sufficient to understand the connection of sulfur, the scrubber operation, and pH. Simulator manual also describes the process.
D8-1	13	Lloyd's register does not recommend OL in Baltic Sea, why could this be important to keep in mind?	N	Not possible to change alkalinity, unable to simulate the EGCS efficiency changes when alkalinity of the water changes, such as traveling north in the Baltic Sea.
E3-1 E4-1 E7-1	14	How does a closed loop system work? What purpose does the bleedoff serve, and when are you allowed to discharge it overboard?	N	Simulation manual explains the process. Visualization of how the system works, purpose of why the system bleed of water is understandable if student understands the scrubber process and the system diagram. Purpose of bleed of is also explained in the manual. No information regarding what is found in the discharge water is visible, additional sources and calculations needed to such a point that the simulator does not contribute, and pH of the bleed-off can only be seen if directed to discharge overboard instead of the holding tank.

E8-1	15	How come closed loop EGCS is not as (in general) affected by ocean alkalinity as an open loop?	Y	If understanding of how alkalinity impacts scrubber, System diagrams show that while operating in closed-loop mode, the EGCS is not directly affected by the sea water alkalinity.
F3-1 F3-2	16	What pH values of the open loop outlet water is expected? Suddenly the pH starts to increase, give some possibilities of what could have happened? Suddenly the pH starts to decrease, give some possibilities of what could have happened?	N	A user is unable to change efficiency of the scrubbing performance by operating it differently. An operator is unable to lower or increase how much SOx is scrubbed without changing initial conditions. Sulfur content of fuel has no impact on pH out: 0% sulfuric fuel gives 6.6 pH, 10% (max allowed) sulfuric fuel also results in a discharge at 6.6 pH. pH of the discharge water appears to be a linear function of ambient sea pH. 8.3 in -> 6.6 out, 8.0 -> 6.3 out, 7.7 -> 6.0, 7.4 -> 5.7. f(pHin)=pHin-1.7 if pHin > 6.4 Dilution flow changes the pH. Can show signs of how wear in pumps and leaking valves can, by reducing dilution flow, reduce the pH of the discharge water. Increasing pH with fault in the scrubber tower (showcasing reduction of SOx scrubbing performance, less SOx -> less acidification) is not possible.

Id. Code	**No.**	**Question**	**Result (Y/N/P)**	**Additional notes**
According to learning outcomes by topics (Appendix 3)				
F4-1 F4-2 F4-5 F4-6	17	Why would pH of the outlet water be important? What impact could discharge of too much acidic water into a body of water have?	P	Visualization of the number of SOx being discharged, by comparing SOx emitted without EGCS and SOx emitted with EGCS. This combined with lessons can further increase understanding of the threat to the environment a large amount of acid being discharged can present.
F7-1	18	What is the pH discharge limit and how is it defined?	N	Discharge limit not possible to be viewed. Unable to change when monitoring alarms for pH too low, the pH always alarms at 6.0 pH. Unable to gain any information needed for either of the two pH measurements options given by MEPC 340(77).

F4-6	19	What pH does the CL wash water have? What of the bleed off/discharge?	N	Can only see the temperature and flow in the system while running on a closed loop mode. The only information presented regarding the wash water in closed loop, are the flow rate and temperature. No information of how or what treatment is being done. Although the pH of the bleed of can be visible if directed to overboard instead of the holding tank, it does not explain much of what happens to the wash water.
F4-2 F4-5	20	Why is there a need for a dilution pump?	Y	The pH of the discharge water varies with changes in dilution flow rate, and the system alarms for low pH if the dilution pump is not running, or with a large enough reduced performance, during open loop mode. During closed loop, valves around the dilution pump must be changed over so that the dilution pump becomes the wash water pump.
F4-3 F4-4	21	How come shipping and the EGCS does not cause the same effects globally and locally, how does the input of contaminants into the marine environment change when comparing smokestack emission versus discharge of the wash water?	P	Some emissions (SOx, NOx, and Co2) into the atmosphere is visible in the scrubber monitoring. Calculations of how many g/kWh in discharge water is possible to calculate with assumptions for treatment plant efficiency since no information is presented regarding the efficiency of the treatment. With complementary theory of how smokestack and discharge emissions impact different amount of area, it is possible to show that EGCS discharge are localizing the emissions into a smaller area using an EGCS.

Id. Code	**No.**	**Question**	**Result (Y/N/P)**	**Additional notes**
According to learning outcomes by topics (Appendix 3)				
F7-2	22	What is the discharge limit of PAH, why is it important to measure and minimize the amount being discharged?	N	No information regarding PAH concentration in the discharge water given by simulator. Nor how much PAH exists in the exhaust gases. Unable to gain conclusions regarding PAH load onto the environment.

F4-8	23	What kind of pollutants could be found in the discharge water? Examine the system and discuss what could be found and what the different sources are.	P	No information regarding what is found in discharge water is presented, but data regarding to fuel consumption exists and how much SOx, NOx, and CO2, is emitted with and without the EGCS in operation. Discussions, with assumptions of average fuel content, the combustion, and treatment plant efficiency, to discuss possible substances and concentrations in the discharge water. With an understanding of how hot acidic water affects the piping system, discussions regarding possible contamination from metal pipes can be carried out.
F4-9 F4-10 F4-7	24	How does the mixture affect the discharge water toxicity?	P	No information regarding synergetic effect can be gained from the simulator. Although discharge concentrations, is possible to calculate with assumptions and data taken regarding fuel content and consumption, and from average discharge water samples, the simulator serves no real purpose in this subject.
F8-5 F8-6 F8-7	25	A vessel equipped with EGCS introduces new types of load and substances into the environment when compared to non-EGCS vessels, what could the substances and the source be?	N	Information around what load other load sources onboard the vessel creates is not visible/implemented. Must be calculated. So, comparison in the simulator is not possible without such a large assumptions, calculations and complementary sources that the simulator at this point serve no purpose.
F8-5 F8-6 F8-7	26	Compare EGCS compliance with compliance with other methods, which of the types creates the highest load onto the environment?	P	Able to comply with different methods, EGCS+HFO, LSFO and MDO. SOx emission is visible when running on all 3 states. With additional information/assumptions regarding fuel contents, calculations and comparison of what additional load and emission factors an EGCS creates is possible.

4.

Id. Code	No.	Question	Result (Y/N/P)	Additional notes
According to learning outcomes by topics (Appendix 3)				
G7-1 G7-2	27	Measurements are allowed to deviate from MEPC limits. Why and how much?	N	No measurements regarding turbidity or PAH are implemented. General inaccuracy in measurement equipment cannot be visualized, only explained and such the simulator does not contribute. The allowed deviation from criterion is turbidity, although since no measurement device is implemented, it is still impossible to learn this from the simulator.
H6-1 H6-3 H6-4	28	MARPOL compliance is mandatory, but exceptions are allowed. When and under what circumstances?	Y	If sufficient education regarding regulation is given beforehand, discussion regarding when and why non-compliance can be allowed is possible. By setting up different scenarios with a theoretical situation and a malfunction, the different scenarios can be discussed to evaluate if the non-compliance are allowed according to regulation 3 of Annex VI.
H6-1 H6-2	29	What consequences could there be to nonallowed noncompliance?	N	Theory, lessons. Not relevant to simulator operation. The simulator does not have a valuable impact on the education regarding this topic.
H6-2	30	Investigate the system, identify vulnerabilities to the availability and reliability of the system.	Y	No redundancy in system, very vulnerability to component failures, easy to see importance of redundancy and discuss how availability and reliability can be increased in different ways. For example, installing redundancy or increasing the occurrence of preventive maintenance and planning overhauls when the EGCS is not needed (such as in harbor or at anchor or when running on MARPOL compliant fuel).

H3-1 H6-3 H6-4	31	Introduce component failure/malfunction. Explain the consequences and fix it. How could you as an operator prevent malfunctions, and why is it important?	Y	Although the possible faults are limited. The importance of not having failure in the EGCS during operation when one component fails. With understanding of consequences (discharge/emission/legal), the simulator can present a good visualization of why not allow failures and the importance of good watchkeeping to notice before fault occurs, and planning of preventive maintenance.

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Id. Code	No.	Question	Result (Y/N/P)	Additional notes
According to learning outcomes by topics (Appendix 3)				
H3-1 H6-3 H6-4	32	Write a procedure for identifying and fixing this component failure/malfunction.	P	Although number of faults possible is limited. The components are defined, and such manufacturers manuals can be read after so that an overhaul procedure can be written. Indications for a coming fault in the operation is not clearly presented, but by using the manuals it is possible to theorizes cause and effect. Depending on fault, the EGCS can operate anyway in a different state, so depending on which fault there are more possibilities than just overhauling the component.

APPENDIX 5

Table 9: Questions according to categorization of STCW criterions (Appendix 2) with respective result and additional notes. The notes serve as motivation as to why a result was assigned either Y/N/P. The identification code refers to where the question originates from (Appendix 1).

Id. Code	No.	Question	Result (Y/N/P)	Additional notes
According to learning outcomes by STCW (Appendix 2)				
C3-1 D3-1 E3-1	33	How is the principle of EGCS? What is the difference between a closed and open loop? Examine all components and explain their purpose.	Y	It is possible to show the principle of an EGCS and the two different loop systems. Concerning components and their purpose, it is difficult to ascertain exactly what each component in for example the pre-discharge treatment system does. The same applies for the alkali feed module. The simulator itself has only implemented graphical blocks with a name to indicate the system. It would be advisable to add more functionality into these systems so that further learning outcomes could be achieved. The simulator manual would also need more information on each system as it describes most components in general and not specifically for these simulated ones.
F3-1 F3-2	34	Why does the pH value of inlet and outlet differ?	Y	It is possible to show that the wash water is acidified by absorbing the SOx out of the exhaust gases, although this needs further investigation as the f(x)=pHin-1.7 appears to be true for all operating conditions up until pHin<6.4. At that point some variations are observed. This means that it's impossible to learn more than the basic concept of acidification, since there's no realistic and or fine tuning of pH difference that could affect EGCS performance so showcase the importance of observing but above all else understanding why pH inlet and outlet differs. If finer reactions in pH outlet can be implemented as an effect to variations in ambient seawater pH it would improve on the learning outcomes of pH differences when operating an EGCS.
F3-1 F3-2 H3-1 C3-2	35	How can a changing measured pH value of the discharge indicate effectiveness of the system?	N	The scrubber process is not able to be changed except water flow rate and pH of the ambient seawater. Not possible to change pH of the discharge due to effectiveness of the scrubbing (nozzle clogged, uneven water spray) or the treatment plant (inadequate treatment). Possible to demonstrate that pH correlate with EGCS efficiency, reduced pHin increases the SOx emissions. Although f(x)=pHin-1.7, appears to be true if pHin>6.4, this limits the learning outcomes since the only way to affect pH discharge and EGCS performance is through manually adjusting the ambient seawater pH as an instructor and/or dilution flow either as user or instructor. This means that it is impossible to change the inherent variables in the scrubbing process and its improbable that the EGCS performance will be inadequate unless major faults are activated, or ambient seawater pH inlet is set to an unreasonably low level.

H3-1	36	Introduce a malfunction, what changes in the operation and fix it	Y	Malfunctions are possible in a range from either active or inactive or from 0-100% fault, but limited to: electrical and signal faults, wear and tear on pumps and fans or leakage and stuck valves. The simulator manual does not describe how the calculations for said fault are implemented and from testing the simulator not much changes in operation up until >80% in most cases. Whereas in some, for example the exhaust fan faults, doesn’t result in any changes to operation of EGCS or combustion engines (due to backpressure). In summary, only pumps, fans, valves and sensors are subject to malfunctions. This means that there are no malfunctions for the actual scrubbing process in the main scrubber tower, for example clogging the wash water nozzles just to name one.

5.

Id. Code	No.	Question	Result (Y/N/P)	Additional notes
According to learning outcomes by STCW (Appendix 2)				
C3-2	37	How could above be prevented? Write a procedure for fixing above, in case your prevention failed	Y	With the current implemented malfunctions, the information given is enough to identify faults from deviations in diagram lines providing information such as flow rate, pressure, temperatures and pH, etc. so that they can be located and fixed.
D4-1 F4-1	38	Why is the pH of the discharge water monitored, recorded and limited?	Y	It is possible to and should be monitored, recorded and limited according to MEPC.340(77). This is doable to teach in a simulator environment. Although no specific information as to what option was used and noted in onboard documentation, this leaves the user to make a qualified guess since the alarm indicates at <6.0 pH, it must be option 2, where >6.5 pH is required at a 4m distance from discharge point. This is not noted or described in the simulator manual.
F4-2	39	What can the pH do onto the environment?	P	Not able to affect the ambient seawater pH because of EGCS operation. Implementation of decreasing ambient seawater pH due to poor circulation would be an interesting in for example port if operated as an open loop. At the moment the only way to change ambient seawater pH in any way, shape or form is if an instructor manually inputs new ambient seawater pH values. But overall, a user should be able to deduce pH changes as cause and effect from using open loop with complimentary assumptions/theory/lectures.
F4-3 F4-4	40	How come the load onto the marine environment increase when contaminants are discharged compared to smokestack emission?	P	Need complimentary theory/lectures in order to understand that locally waterborne emission > smokestack emission. Also see above since it is hard to mimic realistic changes to ambient seawater pH without having an instructor do so manually and continually but also the fact that pHin and pHout relationship follows a linear function up until pHin<6.4 it becomes difficult to showcase increased environmental load in the simulator alone. And lack of discharge water contents.

F4-1 F4-2 F4-8	41	There are contaminants in the discharge water, what substance are they and where do they come from? Analyze the system and discuss what the different sources could be.	P	With basic understanding of fuel content and how pollutants are created during combustion, a student can conclude that the sum of contaminants in the fuel should come out in the discharge wash water. Contaminants such as SOx, NOx and CO2 are monitored in detail and one can showcase the difference between operating the EGCS in service or out to see the difference. Other contaminants, such as heavy metals or PAH are not monitored at all. But if one understands the basics, one can deduce other forms of contaminants that are discharged overboard, for example, if seawater passes through stainless steel pipes comprised of Ni to protect against corrosion (due to hot temperatures, low pH in scrubbing process) it is logical that it would result in traces of Ni in the wash water discharges due to corrosion. Furthermore, since the simulator ship is also equipped with a marine growth protection system and impressed current cathodic protection system where anodes are energized to protect against fouling on or in seawater pipes and corrosion of hull that might lead to oxidation to form hydrated iron oxides.

Id. Code	**No.**	**Question**	**Result (Y/N/P)**	**Additional notes**
According to learning outcomes by STCW (Appendix 2)				
F4-8 F4-9 F4-10	42	Why would someone care about the different contaminants? Briefly explain the threat they pose.	P	Need lesson, but if for example the threat of different contaminants is understood, the simulator can be used to calculate how much, if assumptions are made, is being discharged overboard per time unit or distance travelled in different states of operation. This could illustrate the need for understanding, especially if navigating in sensitive areas, such as the Baltic Sea with an open loop EGCS.
F4-7 F4-9 F4-10	43	Does the mixture of the many substances, at varying temperatures and pH values, change the toxicity of the discharge water?	P	See above, a lesson is necessary prior to using the simulator, to understand synergistic effect and lethal concentration, where the simulator again can be used to calculate and better guide the user/student as to how much contaminants are concentrated in the acidic wash water discharge.
C5-1	44	The treatment plant creates residues and sludge, which you are not allowed to discharge overboard, where should they end up?	N	The simulator shows an arrow to shore meaning that it is not implemented more than a graphical box and associated diagram lines. Simulator manual describes that residue collected should be sent ashore and not discharged overboard or incinerated. While the fact that residue goes to shore, no information of what the residues contain in the tank is given as well as overall lacking any manipulation of variables or information. For example, there is no level indicator, no temperature sensor or working pump; it is only a box named residue tank.
B7-1 B7-3	45	There are two limits given by MARPOL Annex VI	N	Simulator shows correlation between SOx content and %S of fuel, although since SOx content is given as mass (g/kWh) conversion to volume (ppm) as required by Regulation 14 is impossible. Thus, difficult to ascertain if SECA compliant or not, only indication of how mass is released to the atmosphere. Shows no limits nor anything regarding SECA or global.

		regulation 14, what number and where do they apply?		
B7-2	46	How come there are alternative ways of complying with regulation 14?	P	The simulator manual doesn't explicitly mention that Regulation 4 allows for equivalent or better methods of complying with Regulation 14. The simulator can showcase difference between running with or without the EGCS in service so that Sox pollution can be highlighted. However, difficulty to prove that regulation 14 is complied with due to g/kwh instead of SOX ppm/CO2 volume, also the simulator does not show if SECA or not.
C7-1	47	If you want to comply using an EGCS, what performance of sulfur elimination from the scrubber process is needed?	N	>6/kWh is set alarm limit in simulator EGCS, however since an exact comparison is difficult to do without assumptions and know how because mass (gram) is not conversable to volume (ppm). It is difficult to determine if >6g/kWh is equivalent or better (less) than mandated by Regulation 14.

Id. Code	**No.**	**Question**	**Result (Y/N/P)**	**Additional notes**
According to learning outcomes by STCW (Appendix 2)				
C7-3	48	Discharge from the holding tank, what criteria of the wash water is needed to be followed?	N	No information regarding PAH or turbidity. Unable to fill holding tank during open loop and system will not alarm when discharging closed loop bleed-off water from holding tank under any tried circumstance. When discharging from the holding tank, you can monitor pH (observe a difference at all) and flowrate if operating in closed loop. However, if operating in open loop, there are no changes to the monitored variables. Furthermore, it is impossible to monitor PAH and or turbidity due to lack of implementation in simulator. These measuring devices do not exist at all. Thus, it is possible to calculate although this requires a great deal of assumptions and know-how to a point where the simulator serves no point.
C7-5	49	What is in the residues, and where are you allowed to discharge it?	N	Cannot see and cannot discharge residues. It is mentioned that residues are removed from wash water (although failing to specify how much) and sent to residue tank to be sent ashore in the simulator manual. Where the manual also states that residues should not be incinerated according to Regulation 16, however, this is impossible to do since it is just a box named residues tank. It is possible to learn about residues although at a very limited scope, since they're not monitored or mentioned moreover than that the pre-discharge treatment plant cleans the wash water prior to discharge overboard. The system provides

				no level indicator, no temperature sensor or other information about the residues gathered here and so it is impossible to know what the residues are comprised of if not calculated with a great deal of assumptions.
E7-1	50	What is the point of the bleed-off water while running CL, what does it contain and when are you allowed to discharge it?	N	Purpose of the bleed-off water can be assumed, but only assumed since no information regarding what is being bled off is presented. Can monitor pH but again not PAH, turbidity or other criteria found in MEPC.340(77). It does serve a point to mimic a closed loop system although without a pH measuring device for closed loop it is unlikely that the system is realistically implemented as no control system can regulate a system it has no idea of actual variables of. Thus, implementing an adequate control system, showing dosage rate, pH in the closed loop section of the overall EGCS could improve so that the purpose of the bleed-off principle is understood.
E7-1	51	How is the pH discharge limit decided, and what does an operator have to keep in mind during operation, for example if the geographical operation will change?	N	Discharge limit of pH is not explicitly stated in manual, no information of what option used (also no alarm for delta pH=>2), but probably option 2, meaning dilution at 4m length from discharge point, since the alarm limit is <6.5 set at 6.0 in simulator. Meaning that it is expected to dilute to >6.5 at 4m from the discharge point. Furthermore, hard to mimic geographical change, since ambient seawater pH is set and only changeable by instructor and if so, follows a linear change as previously described.

Id. Code	**No.**	**Question**	**Result (Y/N/P)**	**Additional notes**
According to learning outcomes by STCW (Appendix 2)				
F7-1	52	How and why is PAH recorded, why is there a limit of allowed PAH content?	N	Not implemented.

F7-3	53	What is turbidity, why should it be measured and what consequences could there be from high turbidity?	N	Not implemented.
G7-1 G7-2	54	When are some deviations from limits in measurements allowed, and why?	N	Not implemented.
H6-1 H6-2	55	Regulation 14 is mandatory compliance, no matter what compliance method is used, what consequences could there be from noncompliance?	N	Need lesson of the regulations and potential consequences as these are a grey zone.
H6-1 H6-3 H6-4	56	Non-compliance is allowed in special cases, what are they and what responsibilities does the crew have onboard?	Y	Simulating different cases for non-compliance can help guide through different reasons for why compliance is allowed to be lost. Danger for vessel, component failure, etc. This can further be enhanced if roleplay scenario is incorporated into simulator training, where the user/student could argue with the instructor over radio, to handle non-compliance disputes. Summarily, all non-compliances differ from situation to situation, since it varies due to what flag state you're dealing with, if you report or not, etc..
H6-1 H6-2	57	Identify a few different vulnerabilities of the systems availability and reliability. How can these be addressed?	Y	The simulator has no double component redundancy, but the EGCS can be kept in service in special cases, such as when the sea water pump fails by realigning the system loop. Some components have no redundancy, such as the exhaust fan, but in the simulator, this doesn't result in any consequences at all (for example backpressure). This highlights the need for good procedures and planned overhauls to avoid failure in critical components.

Id. Code	**No.**	**Question**	**Result (Y/N/P)**	**Additional notes**

According to learning outcomes by STCW (Appendix 2)				
C8-1 C8-2 D8-1 E8-1	58	The geographical area of operation is about to change, the vessel will travel north in the Baltic Sea. The vessel is currently operating in open loop mode, which Lloyd's register does not recommend in the Baltic Sea. Why do they recommend this, and how could you prepare for entry into the Baltic Sea?	N	Alkalinity not implemented.
C8-3	59	How could you prepare the crew for future maintenance, preventive or corrective, of the EGCS? And why is speed and accessibility extra important in this case?	Y	Writing up procedures/checklists/overhaul reports/plan of the maintenance. Importance of accessibility and speed is possible to understand due to no redundancy and importance of the EGCS.
C8-4	60	Analyze the system, what could affect the quality of the discharge water? How could unnecessary pollution be made possible?	N	Simulator gives good overview of what the components does and where the main contaminants come from, although actual implementation of a wash water pre-discharge treatment plant is necessary to understand efficiency of removing residues from the wash water, otherwise a basic and too rudimentary level is kept in the simulator that is not realistic and counter to MEPC.340(77). Understand the concept, but no great knowledge gained.
Id. Code	**No.**	**Question**	**Result (Y/N/P)**	**Additional notes**

According to learning outcomes by STCW (Appendix 2)				
F8-1 F8-2 F8-3 F8-4	61	The scientific community agrees that a large-scale use of EGCS will significantly increase the impact onto the marine environment, why? Compare the EGCS to other contamination sources and discuss.	N	Information on increased environmental load must be calculated. So, comparison in the simulator is not possible without such large assumptions, calculations and complementary sources that the simulator at this point serve no purpose.
F8-5 F8-6 F8-7	62	How does compliance with an EGCS compare to other compliance methods, are there any loads being added or removed?	P	Simulator unable to prove that EGCS is equivalent with other compliance methods, but increased load is possible to visualize. Unable to ascertain if Regulation 14 compliant, due to mass not volume given in emission monitoring system. This means that the EGCS can't prove according to Regulation 4 to be equivalent or better. However, the simulator allows for the monitoring of mass released to the atmosphere, on all three different fuels such as HFO (3.0%S), LS HFO (0.6-0.7%S) and MDO (0.1%S) without generating a >2g/kWh alarm. If additional information/assumptions of fuel content are made, calculations and comparison of what additional load EGCS creates is possible.
B9 C9	63	How come an EGCS is allowed and who allows the exemption, and what regulations are there regarding performance? Are there any legislations regarding EGCS discharge water? Discuss briefly, by using your previous education regarding international law and shipping.	N	Simulator shows g/kwh out. Not directly linked to ppm/volume but comparison to SOX out when compared to using MARPOL compliant fuel is possible to show the "equivalent technology". But no information regarding discharge criteria is visible, no information of value regarding legality can be taken from simulator.

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CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2022
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