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The enforcement of the global sulphur cap in maritime transport

Master Thesis

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Abstract

A regulation regarding the restriction of the sulphur emissions from ships was introduced by the International Maritime Organization (IMO) and will be put in force in 2020. The enforcement of a regulation that sets a new global limit of 0.5% sulphur content in fuel needs to be strict in order to ensure a high level of compliance in the high seas and a level playing field. This thesis presents the available and potential enforcement schemes that can be used in the ECA zones and more particularly in the high seas. The advantages and restrictions of each method are analyzed combined with cost evaluation for the tested technologies. In addition, there is an extensive presentation of the problem examined, along with the implications and consequences that this change will provoke to the demand and prices of the marine fuels.

The penalty policy for the non compliant ships is reviewed and a method for the calculation of the fines issued is developed and proposed. An easy tool that customizes the fine according to the ship has not been developed yet and time consuming procedures are followed in most countries before fines are imposed. This estimation method developed can help the authorities decide the fine on the spot using limited input data. The main engine specifications and sailing route of the ship are the main particulars used for the calculation of fuel consumption, whereas data provided by the company are not needed for the estimation of the suggested fines.

In the first part of the thesis an overview of the sulphur regulations around the world is presented and an assessment of the enforcement of the existing sulphur regulations in the ECA zones helps picture the extent of the problem that will be faced in 2020.

Περίληψη

Ο νέος κανονισμός για τις αέριες εκπομπές πλοίων που εισήχθη από τον International Maritime Organization (IMO) αφορά τον περιορισμό των αέριων ρύπων οξειδίων του θείου (SO_x) και θα τεθεί σε ισχύ την 1η Ιανουαρίου 2020. Ο κανονισμός ορίζει το ανώτατο παγκόσμιο όριο περιεκτικότητας θείου στο καύσιμο του πλοίου στο 0.5%. Ο έλεγχος των πλοίων από τις αρμόδιες αρχές για τη διαπίστωση της συμμόρφωσης με τον κανονισμό θα πρέπει να είναι αυστηρός προκειμένου να εξασφαλίσει υγιή ανταγωνισμό στον τομέα της ναυτιλίας σε όλα τα μέρη του κόσμου. Η παρούσα διπλωματική εργασία έχει ως στόχο να παρουσιάσει τα διαθέσιμα και μελλοντικά μέσα ελέγχου συμμόρφωσης με τους κανονισμούς τόσο εντός των περιοχών ECA (Emission Control Areas) αλλά κυρίως στους ωκεανούς εκτός αυτών. Οι μέθοδοι που χρησιμοποιούνται ή προτείνεται να χρησιμοποιηθούν βασίζονται σε υπάρχουσες τεχνολογίες ή τεχνολογίες υπό μελέτη και ανάπτυξη και αναλύονται ως προς τη λειτουργία τους και την οικονομική τους βιωσιμότητα. Μια εκτενής παρουσίαση του προβλήματος και των συνεπειών του στις τιμές των καυσίμων περιέχεται σε αυτή τη διπλωματική εργασία.

Το ύψος των προστίμων που επιβάλλεται στα πλοία που παραβαίνουν τον κανονισμό αναλύεται και συγκρίνεται με τα πρόστιμα που προτείνεται να επιβληθούν ώστε να αποτρέψουν μελλοντικές συμπεριφορές μη συμμόρφωσης. Τα εν λόγω πρόστιμα υπολογίζονται σε αυτή τη διπλωματική εργασία με βάση το οικονομικό όφελος που προκύπτει από τη χρήση απαγορευμένου καυσίμου. Η μεθοδολογία που αναπτύχθηκε χρησιμοποιεί δεδομένα για τον κινητήρα και τη διαδρομή του πλοίου, ενώ ακριβή δεδομένα που παρέχονται μόνο από την πλοιοκτήτρια εταιρεία δεν είναι απαραίτητα.

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Summary

Climate change in the past decades has become a major problem and regulations aiming to protect the environment are imposed in different sectors of industry. The last few years shipping is required to comply with new regulations preventing pollution of the marine environment from operational or accidental causes. Conventions like the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) were created in order to minimize water and air pollution from ships. The global sulphur cap, which targets the sulphur emissions, refers to the reduction of the sulphur content of marine fuel to 0.5%. The current limit is 3.5% and the sharp change will affect not only shipping but the global energy system as well.

The main objective of this project is to assess the alternatives for the enforcement of the global sulphur cap, set to be implemented in 2020, not only for the ECA zones but also for the high seas. Enforcement in the ECA zones of the existing regulations has been challenging in the previous years and many problems have occurred. On top of these, many difficulties in operating in the high seas are acknowledged and new methods have to surface and allow a cost effective enforcement even in the middle of the ocean. An assessment of the existing and future methods for implementation in the high seas are presented in this thesis and cost parameters are also examined. The authority responsible for the enforcement is a highly debated topic as the distinction between territories of jurisdiction is complicating the enforcement procedure.

The fines imposed in the ECA zones so far is doubtful whether they correspond to the profits that non-compliance can offer or if they create a

satisfying incentive for shipowners to pay for such an expensive regulation. More research is needed towards this direction in order to decide the fines that will be enough to force compliance and deter ship operators from taking the risk of getting caught with non-compliant fuel. This project deals with this issue and suggests fines corresponding to the needs of a specific vessel and the gravity of the violation.

Εισαγωγή

Η ρύπανση του περιβάλλοντος και οι συνέπειές της στον ανθρώπινο οργανισμό έχουν προκαλέσει τη λήψη μέριμνας από πολλά κράτη αλλά και διεθνείς οργανισμούς με σκοπό την προστασία του περιβάλλοντος και τη μείωση των αρνητικών επιπτώσεων στην καθημερινή ζωή του ανθρώπου. Η ναυτιλία έχει μπει στο στόχαστρο των νομοθετών μόνο τα τελευταία χρόνια όπου μια προσπάθεια να την εκσυγχρονίσουν, να βελτιώσουν την απόδοση και κατ' επέκταση να μειώσουν την επιβάρυνση του περιβάλλοντος από τους ρύπους που παράγει, έχει ξεκινήσει από τον IMO αλλά και από μεμονωμένες κυβερνήσεις κρατών. Κανονισμοί όπως η MARPOL (International Convention for the Prevention of Pollution from Ships) επικεντρώνονται στη μείωση της θαλάσσιας και αέριας ρύπανσης από τα πλοία. Ο κανονισμός για τη μείωση των εκπομπών οξειδίων του θείου από τα πλοία υπάρχει ήδη από το 2012 όπου έχει θέσει το όριο του 3.5% και θα ανανεωθεί το 2020 με το όριο να μειώνεται στο 0.5%.

Το νέο όριο που θα επιβληθεί επηρεάζει όχι μόνο τον κόσμο της ναυτιλίας αλλά και της παραγωγής και διανομής καυσίμου. Οι πλοιοκτήτριες εταιρείες ενδιαφέρονται να εξασφαλίσουν ίσους όρους προκειμένου να καταφέρουν να παραμείνουν ανταγωνιστικές. Πλοία που δε θα συμμορφωθούν με τον νέο κανονισμό θα έχουν ένα σημαντικό πλεονέκτημα σε σχέση με τις αντίπαλες εταιρείες λόγω των υψηλών κερδών που θα εξασφαλίσουν καίγοντας φθηνότερο καύσιμο. Η εξάλειψη τέτοιων φαινομένων είναι βασική προτεραιότητα της πλειοψηφίας των εταιρειών που σκοπεύουν να επενδύσουν σε ακριβότερο καύσιμο ή τεχνολογίες αφαίρεσης του θείου από το καύσιμο όπως τα scrubbers. Ο μόνος τρόπος για να εξασφαλιστεί αυτό είναι να πιέσουν τις αρχές να επενδύσουν σε τεχνολογίες και νέα νομοθετικά πακέτα με τα οποία η επιτήρηση των ωκεανών θα γίνει τόσο αυστηρή ώστε να μην παρατηρούνται συχνές παραβάσεις.

Η εμφάνιση ενός νέου καυσίμου στην αγορά με περιεκτικότητα σε θείο $<0.5\%$ και η αυξημένη ζήτηση για ένα τέτοιο καύσιμο θα επιφέρει αλλαγές στην ναυτιλιακή αγορά και την αγορά καυσίμων. Αύξηση της τιμής των καυσίμων με χαμηλή περιεκτικότητα σε θείο και μείωση της τιμής του πολύ διαδεδομένου HFO (Heavy Fuel Oil) που χρησιμοποιείται κατά κόρον στη ναυτιλία αναμένεται να παρατηρηθεί το 2020. Οι μεταβολές αυτές θα πραγματοποιηθούν σε πολύ σύντομο χρονικό διάστημα, καθώς η εφαρμογή του κανονισμού δεν έχει μεταβατικό στάδιο. Η διαθέσιμη ποσότητα ενός καυσίμου με χαμηλή περιεκτικότητα σε θείο και η τιμή αυτού ανησυχούν πολύ τους πλοιοκτήτες οι οποίοι θα πρέπει να πληρώσουν σημαντικά μεγαλύτερα ποσά για ακριβότερο καύσιμο αλλά και για αλλαγές στη λειτουργία του κινητήρα ώστε να αποφευχθούν καταστροφές των επιμέρους στοιχείων λόγω των διαφορετικών ιδιοτήτων των καυσίμων.

Για να αποφευχθούν περιστατικά παράβασης η συχνότητα των ελέγχων και οι ποινές που θα επιβληθούν πρέπει να είναι αυστηρές. Από το 2015, οπότε άρχισαν οι έλεγχοι για τους αέριους ρύπους εντός των ζωνών ECA, έχουν επιβληθεί πρόστιμα σε πλοία που βρέθηκαν να ξεπερνάνε το ανώτατο όριο και πολλές υποθέσεις έχουν παραπεμφθεί στη δικαιοσύνη. Το δικαστήριο έχει επιδικάσει άλλες φορές υψηλά και άλλες αρκετά χαμηλά πρόστιμα, που δεν αντιστοιχούν ούτε στα κέρδη του πλοιοκτήτη από το φθηνό καύσιμο. Η δε καθυστέρηση των διαδικασιών και εκδίκαση των υποθέσεων δημιουργεί μια χαλαρότητα που επιτρέπει σε κάποιες εταιρείες να συνεχίσουν να παραβαίνουν τους κανονισμούς. Χρησιμοποιώντας την εμπειρία από τις ζώνες ECA θα πρέπει να αναπτυχθεί μια γρήγορη και εύκολη στην εφαρμογή μέθοδος για την απόφαση της ποινής που να λαμβάνει υπόψη τα χαρακτηριστικά κάθε πλοίου, το χρόνο λειτουργίας και τα λιμάνια τα οποία επισκέπτεται με τους περιορισμούς που μπορεί να έχουν. Τα πρόστιμα που θα επιβληθούν σε όσους δεν συμμορφωθούν με τον κανονισμό θα πρέπει να είναι τόσο υψηλά ώστε να καταστήσουν την παράβαση μη συμφέρουσα οικονομικά και να αποτρέψουν τυχόν επανάληψη του περιστατικού. Το ύψος των προστίμων συνεπώς θα πρέπει να είναι μεγαλύτερο του χρηματικού οφέλους του πλοιοκτήτη σε περίπτωση που καίει φθηνότερο καύσιμο. Για το συγκεκριμένο σκοπό θα πρέπει να ληφθούν υπόψη τυχόν μετασκευές στον κινητήρα, απαραίτητες για την καύση ενός νέου καυσίμου με διαφορετικό ιξώδες και άλλες φυσικές και χημικές ιδιότητες. Σε περίπτωση που χρησιμοποιούνται τεχνολογίες αφαίρεσης του θείου από το καύσιμο, ειδικές συσκευές συνεχούς παρακολούθησης των καυσαερίων εφαρμόζονται σύμφωνα με το νόμο και τα δεδομένα που καταγράφουν μπορούν να μας πληροφορήσουν για το είδος και την ποσότητα καυσίμου που χρησιμοποιήθηκε εν πλω. Πλοία που θα αλλάξουν καύσιμο προκειμένου να συμμορφωθούν με τον κανονισμό δεν διαθέτουν τέτοιο μηχανισμό και ένας διαφορετικός τρόπος υπολογιμού θα πρέπει να εφαρμοστεί.

Στα πλαίσια της παρούσας διπλωματικής εργασίας αναπτύχθηκε ένα εργαλείο για τον υπολογισμό των προστίμων που θα μπορούσαν να επιβληθούν σε πλοία που λειτουργούν σε διαδρομές έξω από τις ζώνες ECA. Ο υπολογισμός χρησιμοποιεί τα κύρια χαρακτηριστικά του κινητήρα και στοιχεία για το δρομολόγιο που ακολουθεί το εκάστοτε πλοίο και τα λιμάνια που επισκέπτεται. Η κατανάλωση καυσίμου ανά ταξίδι και το κόστος καυσίμου μπορούν να δώσουν μια καλή προσέγγιση για το πρόστιμο που θα πρέπει να επιβληθεί σε κάθε περίπτωση. Τα δεδομένα που χρησιμοποιήθηκαν για την ανάπτυξη του κώδικα δεν είναι εμπιστευτικά αλλά δημόσια, και μπορούν να χρησιμοποιηθούν από τις αρχές χωρίς την εμπλοκή της ναυτιλιακής εταιρείας για να παρέχει εμπιστευτικά δεδομένα. Ακριβή νούμερα και χαρακτηριστικά του κινητήτρα θα έδιναν πιο ακριβείς υπολογισμούς, που όμως στη συγκεκριμένη περίπτωση δεν επηρεάζουν ιδιαίτερα το τελικό αποτέλεσμα. Έτσι, διευκολύνεται το έργο των αρχών στο γρήγορο υπολογισμό των προστίμων, διαμορφωμένα για κάθε πλοίο και κάθε παράβαση.

Η εφαρμογή του κανονισμού απαιτεί όχι μόνο αυστηρά πρόστιμα αλλά και συνεχή επιτήρηση και έλεγχο των πλοίων στον ωκεανό όπως έχει γίνει στις ζώνες ECA τα προηγούμενα χρόνια. Η αυξημένη δυσκολία αυτού του έργου έγκειται στη μεγάλη έκταση που πρέπει να καλυφθεί προκειμένου να ελεγθούν πλοία σε όλα τα μήκη και πλάτη της γης και στον αριθμό των πλοίων που αυξάνει τον αριθμό των ελέγχων και το ύψος των επενδύσεων για εξοπλισμό που θα υπηρετεί αυτό το σκοπό. Οι τεχνολογίες που χρησιμοποιούνται ήδη για τον έλεγχο εντός των ζωνών ECA δεν είναι αρκετές για να καλύψουν την έκταση των ωκεανών. Νέες τεχνολογίες ή περαιτέρω μελέτη και εξέλιξη των υπαρχόντων είναι απαραίτητες για την εφαρμογή του νέου κανονισμού ο οποίος δεν προβλέπει τον τρόπο και τα μέσα που θα πρέπει να χρησιμοποιηθούν.

Η παρούσα διπλωματική εργασία παρουσιάζει τα διαθέσιμα μέσα αλλά και τα μέσα υπό μελέτη και μέσα που θα μπορούσαν να κατασκευαστούν για να εξυπηρετήσουν τον έλεγχο που θα διεξαχθεί από τις αρχές το 2020. Η τεχνολογία μπορεί να παράσχει πολλές λύσεις για έλεγχο από αέρα, στεριά ή θάλασσα. Υψηλές επενδύσεις για εξοπλισμό θα χρειαστούν προκειμένου να επιβλεφθεί μια τόσο μεγάλη περιοχή. Η επένδυση μπορεί να καλυφθεί από τα πρόστιμα που θα επιβληθούν, εφόσον μια αποτελεσματική πρακτική τεθεί σε ισχύ. Μια συντονισμένη προσπάθεια από τις αρχές όλων των παράκτιων κρατών είναι απαραίτητη προκειμένου να εξασφαλιστεί ένα υψηλό ποσοστό συμμόρφωσης.

Chapter 1

Introduction

Marine pollution reduction has been one of the main objectives for International Maritime Organization (IMO) during the past years. The MARPOL Convention was created to tackle with every kind of marine pollution including airborne emissions from ships. The upcoming global sulphur cap is part of Annex VI of MARPOL and targets sulphur emissions from ships not only close to the coast but also in the high seas. The limit in the sulphur content of the fuel used for the vessel's propulsion is currently 3.5% m/m (where m/m stands for the mass of sulphur dioxide gases in the total mass of emissions) and from 2020 it will drop to 0.5%. Several methods for compliance exist but the main problem that needs to be dealt with before 2020 is the enforcement of this regulation. The decision to implement the cap was taken before deciding the enforcement schemes that will be available in 2020 and the limited time before the limit is put in force concerns the experts and responsible authorities even more.

The objective of this thesis is to identify and assess the existing and potential methods to monitor and control sulphur emissions in a way that will ensure a level playing field for the maritime world. Many of these methods have not been used and tested in the past and some of them have been effectively used in the ECA zones but require further development that will make enforcement in the high seas feasible. The penalty policy that needs to be developed is a major topic of discussion for the authorities.

An evaluation of the penalty policy in the Emission Control Areas (ECA) is included in this project along with case studies that will help identify and introduce a method for issuing fines adjusted to a particular case and violation.

1.1 Objectives

The main learning objectives of this thesis project are:

- To study the legal framework of the sulphur regulations in shipping and the upcoming global sulphur cap
- To make an assessment of all the possible enforcement methods not only in the SECA zones but specifically in the high seas where various problems occur
- To define the responsible authority for the inspections and enforcement of the regulations both in SECA zones and the high seas
- To learn and present extensively the compliance methods available for all ship types
- To evaluate the situation regarding the fuel availability and the level of compliance expected in 2020
- To assess the current penalty policy in the ECA zones and propose a policy adjusted to the needs of every situation

1.2 Structure

The thesis is dealing with two main topics. The first one concerns the enforcement schemes that we will probably see operating from 2020 and on, not only in the ECA zones but mainly in the high seas, where a lack of possibilities and equipment is setting the implementation of this regulation at risk. The second topic deals with the penalty policy that is developed in the areas designated as ECA and a suggested method that can be potentially used to punish the non compliant ships and motivate shipowners to invest in the, rather expensive compared to HFO, compliance options.

The rest of this thesis is structured as follows:

- **Chapter 2**: This chapter introduces the action and regulatory role of the International Maritime Organization. The structure of the organization and the background of the regulations imposed are presented in this chapter.

- **Chapter 3**: The regulations in place or upcoming ones regarding the sulphur emissions all around the world, either global regulations or regional control, are explained thoroughly. An overview of the available compliance options for the shipping companies is entailed in this chapter.

- **Chapter 4**: In chapter 4 the responsibilities of the port and flag state are explained and their jurisdiction is analyzed. The jurisdiction of these authorities plays a crucial role in the enforcement of the sulphur cap.

- **Chapter 5**: The compliance in the ECA zones is researched and presented in this chapter in order to create a solid base for comparison of the compliance levels and variation of the levels and methods used in European countries.

- **Chapter 6**: In chapter 6 one of the main objectives of this thesis is analyzed. An overview of the enforcement schemes in the ECA zones and all the methodologies and technologies that can be potentially used to control the emissions in the high seas is presented. Assessments of the current and future technologies, as well as suggestions for further research and development that can facilitate the enforcement in the high seas is the primary goal of this chapter.

- **Chapter 7**: The scope of this chapter is to evaluate the marine fuel availability and prices, as they are projected for 2020. A comparison with the current fuel prices is necessary in order to create a complete picture of the situation as it is expected to be in 2020.

- **Chapter 8**: Chapter 8 contains the case studies that were developed in the context of this thesis and an explanation of the methodology used to evaluate the savings and fines proposed for every ship.
- **Chapter 9**: The 9th chapter concludes in the penalty policy that should be developed and is suggested in order to improve the compliance rates all around the world.
- **Chapter 10**: The conclusions of this thesis project are presented in the last chapter

Chapter 2

Organizational structure and regulatory role of the IMO

2.1 Brief history of the IMO

The International Maritime Organisation is a specialized agency of the United Nations established in 1948 in an international conference in Geneva. The convention did not enter into force until 1958 and one year later began its regulatory work. The initial purpose of this convention originated from the need to ensure safety at sea and impose regulations that would be followed by all shipping nations. National laws would only create frustration in operations because of the international nature of the shipping industry,so the need for an international body responsible to introduce and implement regulations was imperative.

The first convention adopted by the IMO was a revised version of the International Convention for the Safety of Life at Sea (SOLAS) [18]. The following years IMO focused its attention to matters related to pollution emerging from ships in the context of developing a greener and more sustainable shipping industry. A whole series of measures for tanker safety, oil and waste disposal or accidental pollution were introduced. The most significant was the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78),which includes measures against all different types of pollution, accidental or operational. It was first introduced in 1973 and revised in 1978 but did not enter into force until October 1983. The convention has been updated many times since, and regulations have been added.

IMO continues its regulatory work by introducing new measures but the past few years the attention has been mostly on updating the existing legislation and making sure it is adopted and implemented by most countries around the world.

2.2 Structure of the IMO

The main purpose of these regulations is to create a level playing field and prevent shipping companies from lowering safety and security standards or violating environmental policy in order to increase profits and become more competitive. For that goal to be achieved, the regulations need to be ratified by the member states and adopted by every government separately in the national legislation.

The tasks of the organization are divided in the various bodies, each one with a specific objective according to IMO's constitution[18]. The major bodies are the Assembly, the Council and five main Committees and some subcommittees which form the rest of the organization. The highest in hierarchy is the Assembly which consists of all member states and its duties include arrangement of the financial matters of the organization, determining the work plan and electing the council which comes second in the hierarchy. The effective operation of the organization is assigned to the Council which, among other tasks, coordinates all the activities and is responsible of submitting the reports from all the committees and other organs of the organization to the Assembly. The council members are divided in three categories consisting of a number of countries depending on the interests of the member state. The first category includes states with interest in providing international shipping services, the second consists of states with interest in international seaborne trade and the third involves countries with interests in maritime transport or navigation. The committees are charged with different tasks according to their objectives and are responsible of proposing new conventions and other measures or updates to the existing ones. The main committees are: the Maritime Safety Committee (MSC) which deals with safety procedures and equipment of the vessels and matters related to maritime safety, the Marine Environment Protection Committee (MEPC) responsible for the prevention of pollution from ships, the Legal Committee with duties involving any legal matter of the organization, the Technical Co-operation Committee that operates in the technical cooperation field and the Facilitation Committee working on maritime traffic issues and procedures. These bodies of the organization are actively taking part in deciding the new developments in conventions and implementing any updates.

The new conventions or the amendments to existing ones are processed by the committees or subcommittees. After the need for a change has surfaced, the proposal has to be accepted and ratified by the member states with a written consent. This process is usually time-consuming and could even last several years and as a result many conventions entered into force a long time after they were first presented by the committees. The number of member states required to accept the convention before it enters into force depends on the importance of the subject in discussion. Important conventions have to be widely recognized and implemented so that confusion is avoided and the results are evident. By the time a convention is adopted, the national governments are obliged to decide the enforcement policy and the penalties for every violation.

The conventions and amendments introduced by the IMO compose a long list and concern subjects as the prevention of marine pollution, maritime safety and security, liability and compensation and other major subjects. The MARPOL (International Convention for the Prevention of Pollution from Ships) and SOLAS (International Convention for the Safety of Life at Sea) conventions are two of the most important that were first adopted in 1973 and 1974 respectively. The SOLAS convention dates back to 1914 after the Titanic disaster when a need for protection of the life at sea arose. Later it was replaced by newer versions in 1929, 1948, 1960 and 1974 which is the latest version. The SOLAS 1974 entered into force in 1980 and has been amended many times since, in order to follow the progress of the shipping sector and the current needs. It consists of Articles about general obligations and procedures and an Annex with 12 chapters where the details of the regulations are stated. SOLAS concerns structural requirements, navigation and communication equipment, life-saving appliances, cargo safety rules and special regulations for certain types of ships that ensure the safety of passengers, crew and ships.

2.3 The MARPOL Convention

The MARPOL convention was first adopted on November 2, 1973 resulting from the disastrous accident of the tanker Torrey Canyon in 1967 but this version was not implemented as it was absorbed by the Protocol of 1978 which was created after a series of tanker accidents in the years 1976-1977 [18]. The new version entered into force in 1983 and it was amended regularly in the following years. The aim of this convention is the elimination or minimization of marine pollution provoked by routine operation of ships or marine casualties and involves either oil or other hazardous chemicals. MARPOL consists of six annexes and each one targets a different problem. The last annex was added in 1997 and deals with the air pollution from ships.

Annex I refers to the pollution by oil, either accidental or operational discharge. It specifies the certificates and oil or oily waste discharge procedures for the vessels in special areas and in high seas, the structural requirements of the hull and tanks for the prevention of oil spillage, cleaning of the engine room, cargo and ballast tanks.

Annex II concerns pollution by noxious liquid substances and contains regulations about certificates, discharge and unloading of noxious liquid and oil-like substances in special and other areas. The substances are categorized in four categories according to the hazard for the marine environment if discharged into the sea and the area and quantity of discharge are defined in detail.

The problem anticipated in Annex III is the pollution that derives from harmful substances carried in packages. The regulations aim in identifying the harmful substances, marking them and packing them in a way that they do not pose a threat for the ship or the marine environment. The harmful substances are determined in the International Maritime Dangerous Goods Code (IMDG Code) and their labeling and stowage are clearly explained in the regulations.

Annex IV concerns the hazards that may appear from the discharge of sewage from ships directly into the sea. The problem exists mainly in coastal areas and as a result discharge of sewage is prohibited in a certain distance from the nearest land unless the ship is equipped with an approved sewage treatment plant.

In Annex V the requirements for the disposal of garbage are set, and the distance from land and special areas is defined. This annex prohibits the disposal of all plastics in the sea and distinguishes garbage and the way they should be disposed of.

The last and most recent annex of the convention, Annex VI, concerns the air pollution caused by ship operation [1]. It deals with the emission of ozone-depleting substances, nitrogen oxides (NO_x), sulphur oxides (SO_x) and volatile organic compounds. Special areas with specific limits regarding nitrogen and sulphur oxides are designated and the limits for the emission of such pollutants are strictly mentioned. The type of engine and the operation are described by different levels of control according to the ship construction date (Tier I, II, III) in order to clarify the regulations for nitrogen oxides as well as the type of fuel or the approved systems that can be used to reduce the emission of sulphur oxides respectively. The emission of volatile organic compounds from tankers has to be controlled and for that reason, vapor emission control systems are required. An amendment to this annex contains requirements for the control of emission of greenhouse gases and the limits for CO_2 emissions [1].

Chapter 3

Regulatory framework for sulphur emissions from ships

3.1 Description of the sulphur regulations

Global trade is highly dependent on shipping as, the biggest part, almost 90 percent of the global cargo, is transported by ships. The most widely used fuel in the shipping industry is the residual fuel oil, which is a low quality product of crude oil, one of the first fractions in the refining process. It is characterized by high viscosity that requires heating before the injection in the engine and might need increased injection pressure, depending on the type of fuel, in order to prevent volatile components from vaporizing after heating. The most popular residual fuels are RMG and RMK which differ mainly in the viscosity and are usually delivered in 380 and 700 cSt respectively or less. The low price of these crude oil products has established them as the main marine fuels and all marine engines are able to burn such fuels after the necessary preheating.

Bunker fuel when burned releases important amount of pollutants, the most significant of which are sulphur and nitrogen oxides (SOx and NOx), carbon monoxide and dioxide (CO and CO_2 respectively), black carbon (BC) and various kinds of particulate matter (PM) [35], [24]. Carbon and sulphur contained in the bunker oil are oxidized to CO_2 and sulphur oxides, mainly sulphur dioxide, SO_2. In the engine of the ship, nitrogen (N_2)is oxidized to nitrogen oxides (NO_x), which, along with the sulphur oxides, when they reach the atmosphere, are converted into fine particles, sulfate and nitrate aerosols [21].

The most dangerous of sulphur oxides, sulphur dioxide (SO_2), alone or absorbed in particulate matter, is the main cause for acid rain, which can destroy forests, harm the marine life and even corrode buildings. Areas with heavy industry or crowded ports have higher chances of experiencing the phenomenon of acid rain. These sensitive areas have proven to have higher percentages of population dealing with respiratory problems, and especially people who suffer from asthma or chronic bronchitis and become particularly sensitive to the effects of SO_2 [38].

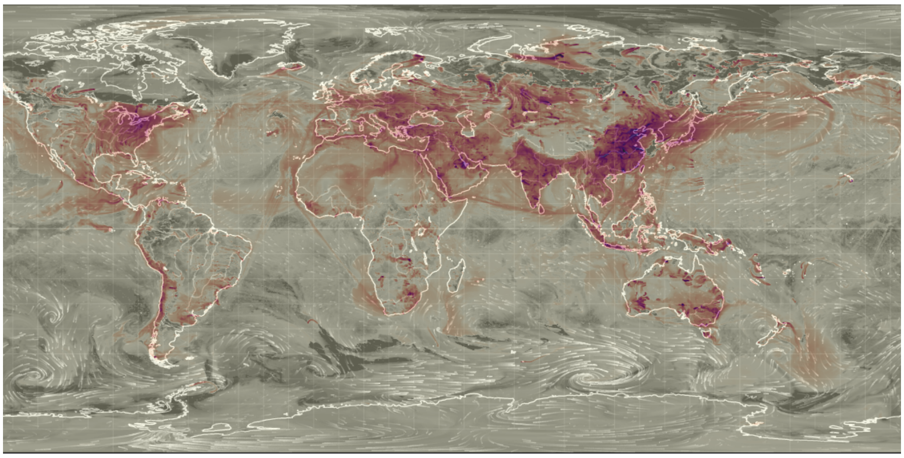

Figure 3.1: Highly polluted areas from sulphur, Source: https://earth.nullschool.net/

The sulphur content of the fuel is highly dependent on the crude oil it is produced from and the refining process. High sulphur content is damaging for the engine as the oxides released are corrosive unless they are neutralized by the cylinder lubricant. Marine lubricants have managed to cope with this problem and the sulphur content does not pose a threat to the engine parts anymore. The environmental impact however, was not anticipated for many years and maritime transport has a big share of responsibility for the global

SO_x emissions. The shipping industry started an effort to keep up with the developments in road transport, where strict regulations are already imposed, in 2005 when IMO set into force the MARPOL Annex VI for the first time.

MARPOL Annex VI aims in reducing the amount of these emissions globally and especially in targeted areas with increased maritime traffic that suffer from atmospheric pollution [17]. Such areas are designated as Emission Control Areas, known as ECAs, and currently they are the following: the Baltic Sea; the North Sea; the North American area, 200 nautical miles offshore USA and Canada, including Hawaii, St. Lawrence Waterway and the Great Lakes, and the United States Caribbean Sea area. They are often referred to as Sulphur Emission Control areas (SECAs) or Nitrogen Emission Control areas (NECAs) because of the sulphur and nitrogen regulations imposed. Every regulation of this annex sets the requirements for the type of fuel, engine and the acceptable levels of emissions.

MARPOL Annex VI was first set into force in 2005 and revised in 2008. According to the revised edition of 2008 any fuel used on board ship could not exceed a sulphur content of 4.5% m/m prior to 1 January 2012. The global limit was further reduced to 3.5% m/m after January 1, 2012 which is still in force. A new global cap will be imposed as from January 1, 2020 that will limit the sulphur emissions to 0.5% m/m.

The limits imposed for the ECA zones are different. The limit until July 1, 2010 was 1.5% m/m and it was reduced to 1.00% m/m after July 2010. The current limit for the sulphur content is 0.1% m/m and it is in force since January 1, 2015.

3.2 Regional emission control areas

Apart from the international regulations imposed by the IMO some countries have decided to create their own regulatory framework which will be enforced in their waters. The European Union and China have already set into force their own regulations regarding sulphur emissions in their ports.

The European Union introduced the Directive 2005/33/EU which corre-

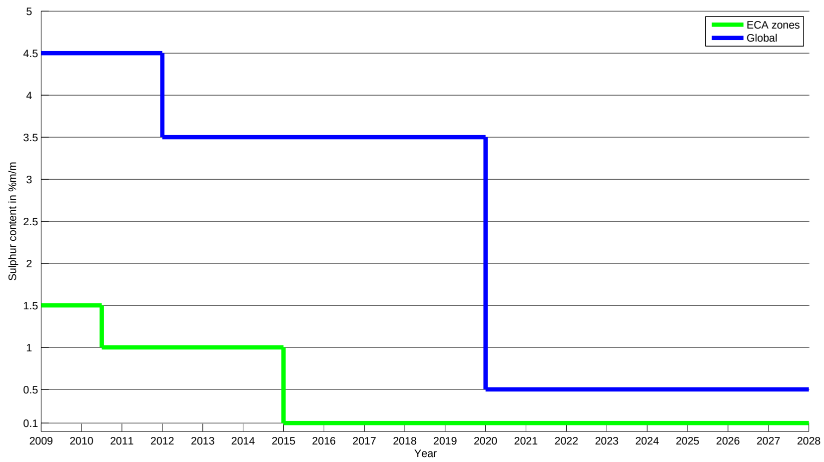

Figure 3.2: Sulphur emissions limits

sponds to the MARPOL Annex VI but with an additional provision that requires all ships at berth in European ports and not only in SECAs to reduce their sulphur emissions to 0.1% m/m, applied from January 1, 2010. The directive also contains a regulation that obliges passenger ship operators to use fuel with a sulphur content no more than 1.5% m/m when sailing in European waters. This regulation will be in force until 2020, when it will be replaced by the global sulphur cap with a limit of 0.5% m/m [37].

High air pollution levels along the coast of China have led the Chinese government in adopting measures. Given that the shipping sector contributes in a considerable degree to air pollution, the Chinese Ministry of Transportation has designated some coastal areas as Emission Control Areas (ECAs) [14]. The new regulations were announced in 2015 and designated the areas near the Pearl River Delta, Yangtze River Delta and the Bohai Sea as ECAs. Eleven ports included in these areas were recognized as key ports: Guangzhou, Shenzhen, Zhujiang, Shanghai, Ningbo-Zhousan, Suzhou, Nantong, Tianjin, Qinhuangado, Tangshan and Huanghua. The new requirements oblige all ships sailing inside ECAs or certain ports inside these areas to reduce emissions of sulphur oxides to 0.5% m/m. The enforcement of the regulation for ships at berth in the key ports was optional during 2016 and the ports had the opportunity to choose whether to enforce it or not, but it became mandatory since January 1, 2017 for all key ports. Key ports in the Yangtze River Delta set the enforcement date on April 1, 2016, followed by the key ports in the Pearl River Delta on October 1, 2016. The rest of the key ports did not enforce the requirements before January 1, 2017.

On January 1, 2018, the requirement will be extended to all ports within the designated areas and on January 1, 2019, sailing anywhere inside an ECA area will require sulphur emissions up to 0.5% m/m. The Chinese government will re-evaluate the situation and decide whether a stricter regulation of 0.1% sulphur should be imposed in the future. Compliant fuel and alternative abatement methods such as exhaust gas cleaning systems or use of shore power are accepted measures for compliance by the Chinese authorities.

Australia's biggest state, New South Wales, has also adopted a relevant framework for sulphur emissions in the port of Sydney [27]. As from October 1, 2015 the allowed limit for cruise ships at berth in the port of Sydney was set to 0.1% and from 1 July 2016 the measure was extended to all cruise ships sailing in Sydney harbor and requested fuel changeover before entering the harbor. The NSW authorities have restricted the regulation in Sydney harbor only because of the high percentage of visits by cruise ships in comparison with other NSW ports, but a possible extension of the regulation to other ports will be considered.

In an effort to improve air quality California has taken additional measures although it is already part of the North American ECA as recognized by the MARPOL Annex VI and lower sulphur limits are in force. Ships operating within 24 nautical miles of the coastline have to comply with California's regulation and use only marine distillate fuel (marine gas oil or marine diesel oil) not exceeding 0.1% sulphur content.

Turkey has adopted a regulation imposed by the European Union in all EU ports which obliges all passenger ships to burn fuel with maximum sulphur content 1.5% when sailing in Turkish waters [33]. Furthermore, all ships at berth in Turkish ports must burn fuel with less than 0.1% sulphur as well as crafts sailing in Turkish inland waters.

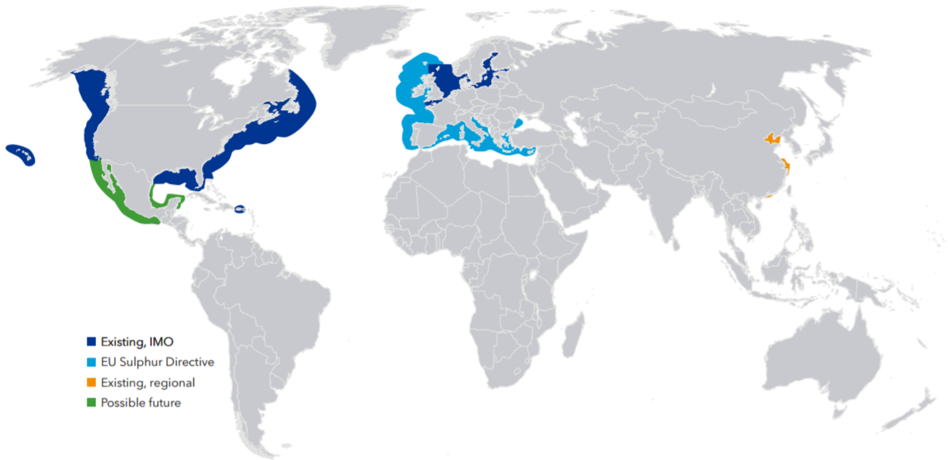

Figure 3.3: IMO, regional and possible future sulphur emission control areas, Source: DNVGL, 2016, Managing Sulphur Limits

Action towards a cleaner environment has been taken by other countries as well, that are trying to establish an ECA in their coastal areas. Mexico, Hong Kong and Turkey are preparing ECA designation proposals. Mexico is working in collaboration with the US and Canada for the ECA proposal, Turkey is planning to designate the Turkish straits and Marmara Sea as ECA and Hong Kong has imposed regulations in the Pearl River Delta aiming in establishing the area as an ECA.

3.3 The global sulphur cap in 2020

The imposition of the global sulphur cap will reduce the allowed sulphur content in fuel to 0.5% m/m worldwide. The current regulation allows a percentage of 3.5% sulphur in fuel and the residual fuels available in the market usually contain approximately 2.7% m/m sulphur. Therefore, compliance with the regulation in the high seas has not been an issue for the ship owners. As expected, the upcoming global sulphur cap has been for a very long time a much debated topic in the shipping world that was waiting for

IMO's critical decision regarding the implementation date of the cap. The shipping and refining industry have shown a phenomenal interest in the date the cap would be set in force, as their actions are highly dependent on the timing of the regulations.

The IMO would decide about the implementation date based on the results of the fuel availability study that was assigned to CE Delft[9]. The aim of the study was to assess the ability of the refining industry to produce enough low sulphur fuel for the shipping industry that could cover the demand once the regulations are set in force. The decision was first announced that it would be taken in 2018 but the need to provide the refining and shipping industry with enough time to adapt to the new regulations forced an earlier decision. Therefore, in October 2016, the MEPC 70 met to examine the results of the fuel availability study and decide the final date the cap will be set in force.

The study carried out by CE Delft came to the conclusion that the refining industry has enough time to adapt the production to the new requirements and serve the needs that will arise with the global sulphur cap. Alternative methods of compliance were taken into account for the calculations of the expected demand of compliant fuel in 2020. The study examined three scenarios of the fuel demand that depend on the amount of ships that will turn towards scrubbers and the newbuildings that will enter the market with an LNG installation. There is a base case, a high-demand case for marine fuels with sulphur content less than 0.5% and a low-demand case in which more ships will be equipped with alternative compliance options and less are going to use low-sulphur fuel.

The model created by CE Delft takes into account a variety of factors for the most realistic calculation of the amount of compliant fuel that will be needed for the switch in 2020. With a time frame almost four years ahead for the prediction of demand, the study had to consider every kind of change in the world fleet. Improvements in the fleet can occur not only due to new regulations imposed by the IMO or national authorities but also due to efficiency developments initiated by companies aiming to improve the fleet's effectiveness. Factors like the vessel's size, speed and cargo load can also affect the energy demand worldwide.

The use of exhaust gas cleaning systems in the future had to be predicted by analyzing the economic growth and the capability of the shipping companies to equip their ships with costly systems for the desulphurization of the fuel. At the same time, the restrictions concerning the discharge of wash water in specific ports or close to the shore can considerably increase the cost of acquisition and installation and may hinder many ship owners form investing in them. Scrubbers are not a viable solution for every type and size of ship, and that may restrain the expansion of their use. On the other hand, the industry is not expected to supply the market with an overflow of scrubbers, which means that a sudden high demand of scrubbers by the shipping industry cannot be anticipated and many ships may end up missing the deadline before the new regulatory context is put in motion.

For the LNG it is assumed that the price differential from the heavy fuel oil will be significant, with the LNG maintaining the advantage of a price lower than the conventional fuels. It is estimated that an average of 13% of the world fleet will use LNG, that is a growth in demand by 60% to 80% compared to 2012 [9]. The main problems that will prevent the rapid development of the LNG installations is the long payback period and the lack of infrastructure in the ports around the world that makes refueling hard or even impossible in certain routes.

CE Delft's study estimates that marine fuel demand will increase by approximately 8% in the time period from 2012 to 2020. The demand of HFO with a sulphur content of more than 0.5% m/m is expected to drop dramatically, namely from 228 to 36 million tonnes per year in average while for HFO of sulphur content less than 0.5% it is expected to grow after 2020. Marine fuel supply is also dependent on the global fuel, and more specifically the non-marine fuel demand, and the refinery capacity to produce the necessary volume of low sulphur fuels. The increase in global energy demand is estimated to be around 13% and the increase in marine fuel about 5% in the base case, 21% in the high case and decrease of 8% in the low case, which shows a significant fluctuation and uncertainty in the assessment of energy demand.

With a number of assumptions and formulas for the use of the scrubbers, alternative fuels, LNG and compliant fuel based on the consumption of the previous years, from 2012 and on, the current trends and the predicted economic growth, the study of CE Delft has concluded that every case scenario can be anticipated in 2020. According to the assessment, the refining industry will be capable to adjust the production of fuel for the maritime industry and anticipate the needs that will arise by the 1st of January in 2020 along with the demand of the market outside the shipping world.

In October 2016, MEPC 70 came to a decision to implement the global sulphur cap in 2020 rather than 2025 based on the positive results of the fuel availability study by CE Delft. An alternative study conducted by EnSys Energy and Navigistics Consulting was submitted to the organisation on behalf of various stakeholders, among them BIMCO and IPIECA[12]. This supplemental study came to a different conclusion regarding the fuel availability in 2020 and provided a different view of the matter. The EnSys/Navigistics study claims that most operators will not have equipped their ships with exhaust gas cleaning systems by 2020 and the only way of compliance will be low sulphur fuel. If that is the case, the refining industry does not have enough time to prepare for the high demand of such fuels that will occur overnight. It is not expected that owners will use low sulphur fuels prior to the implementation date, leading us to the conclusion that the shift will happen overnight. Some blended fuels have a questionable performance for the marine engines and there is no or little experience regarding the use of these fuels. An overnight shift will deprive us the chance to test their performance and correct any problems that may occur.

An important argument of stakeholders against the IMO's decision is that an overnight switch will cause an abrupt increase of the demand for low sulphur fuel oil and of the corresponding prices. The resulting strained market will need months to recover and assure a high compliance level. The annual volume of fuel with a sulphur content less than 0.5% that the cap will require, is projected to be around 210 million mt more than before the cap. This is a much more significant change than the switch in 2015 with the ECAs, and compliance is not possible to happen overnight [12]. Demand will rise suddenly and the refining industry cannot increase the production in a very short period of time. Adapting the production long before the implementation of the cap, does not bring any profit to the bunkers as owners will not opt for low sulphur fuel before the implementation date. Moreover, it has to be ensured that the refining industry has incentive to increase the supply volume to the maritime industry, as other markets might provide bigger profits.

The lack of available distillate or blended fuel, if the industry does not manage to meet the expectations of the IMO, will provide some operators with the perfect incentive not to comply with the regulations and profit from the strained market conditions. The recovery of the market could require a few weeks or even months and create a situation favorable to violations to the detriment of compliant companies, which could lose market share because of the higher operation costs and freight rates. Many shipping companies are in favor of a transitional period that will allow the market to adapt and will ensure a level playing field.

3.4 Compliance options

Compliance with the current regulations can be achieved with a range of options approved by the IMO. Sailing in ECA zones is permitted only with emissions of 0.1% m/m sulphur or less, which can be achieved with either compliant fuels or emission abatement methods. A third option of burning LNG fuel is available mainly for newbuildings, as retrofitting is very costly for older ships.

3.4.1 Compliant fuels

The majority of the world fleet uses compliant fuel when entering an ECA zone. The available low sulphur fuels are distillate oils like MGO, hybrid fuel oils that were recently developed and made available in the market as an alternative to distillates and we usually refer to blended fuels. Distillates are priced higher than residual fuel oil that is normally used in shipping and have different properties that require different handling. The low sulphur fuel has to be kept in separate fuel tanks and due to the reduced viscosity, unlike heavy fuel oil, it does not need heating before injection. According to MARPOL regulations, the changeover from high to low sulphur fuel should be done prior to entering the ECA zone and the opposite procedure has to be applied when exiting the ECA.

The price fluctuation of fuel oil boosted the uptake of marine distillate and hybrid fuels in the detriment of other compliance methods as it is the most cost effective way for complying with the ECA requirements and no alterations in the ship's engine or operation are needed. The absence of the need for capital investment renders this option the most appealing, especially for the older ships. A retrofitting and installation of any emission abatement system is costly, takes up a lot of space and entails a series of alterations in the engine room and arrangements of the ship's systems.

The fuel costs per voyage in shipping usually are 50%-60% but can be as high as 70% of the total operational costs depending on the type of vessel, which accounts for a considerable amount of money that shipowners or charterers have to invest. Because fuel is the biggest operational cost, the shipping industry is not flexible in changing to alternative, "greener" fuels unless a regulation requires such a change. Compliance with the new regulations represents an important investment from the shipowners' view for compliant fuel or exhaust gas cleaning systems and retrofits in case of older ships. Even though fuel prices have significantly dropped the past years, the regulations have obliged shipowners to turn to cleaner fuels, resulting in an overall increase in operational costs. However, the shipping sector is going through a crisis that does not provide the ship operators with a reasonable margin to absorb the cost increase. Consequently, it leaves them no option but to pass the additional costs to the shippers and cargo owners by increasing the freight rates. It is estimated that freight rates from the Middle East to

Singapore could increase up to US $1 per barrel according to Sushant Gupta, research director for Asia refining at Wood Mackenzie. Part of the cost is expected to be passed to the consumer, who will notice an increase of the goods' prices. Given that 90% of the world's production is transported by ships, an increase in the transportation costs will result in a corresponding increase in the prices of traded goods.

Since 2015 compliant vessels need to be equipped with both heavy fuel oil and marine gas oil or marine diesel oil with a sulphur content less than 0.1% m/m for the time spent in ECA zones. The cost increase was substantial, as the market had to switch from 1% sulphur fuel and consequently use higher quality fuels like marine gas oil (MGO) or the cheaper, blended fuel oil with a sulphur content of 0.1%. In the past years a decrease in demand of the high sulphur fuels has been observed and an anticipated increase in MGO and blended, hybrid fuels of almost 50%. Although a higher demand would normally mean a price increase, the price of MGO remained almost unchanged.

This fuel requirement has increased the transportation costs and burdened the shipowners or the charterers depending on the type of contract. In time/bareboat charters the fuel cost and the responsibility to comply with the regulations lies with the charterer. Further details about the responsible party in case of fines, delays, and losses should be clarified beforehand in the contract between the owner and the charterer.

The use of low sulphur fuel instead of the bunker fuel is estimated to increase the fuel costs by 50% in the shipping industry. The current price of the MGO is about US$500 and the projections of the price increase in 2020 for all products and not just marine fuels is about US$10 to US$20 per barrel [12], [29]. A change from HFO to MGO in 2020 is calculated to cost the marine industry almost US$60 billion annually with a considerable margin because of the uncertainty of the predictions of the fuel prices in 2020. Some less optimistic estimations add an even larger bill to the shipping industry according to the demand of low sulphur fuels and the refining capacity.

The current limitations of sulphur emissions in the ECA zones affect mostly vessels that spend significant time sailing in ECAs. That applies in passenger vessels with an itinerary inside these zones or cargo vessels that transport products between ports in ECAs. Ocean-going vessels typically spend 5-6% of their operating time in ECAs. The majority of the world fleet are ocean-going vessels and consequently the cost of operating on low sulphur fuel in ECA zones is of little importance compared to the fuel costs of the whole journey. The introduction of the new regulation will add a big bill to the fuel costs of every vessel around the world no matter the route or the destination.

Apart from petroleum products, other alternative fuels can be used provided they are compatible with the engine type or the necessary alterations in the engine are made and the right fuel treatment systems are used. The most common ones among them are Liquefied Petroleum Gas (LPG), biofuels, dimethyl ether, ethane and methanol. These fuels have limited availability in ports around the world which, by extension, limits their use. Alternative fuels do not have a considerable market share and have little or no influence in market trends and maritime economy.

3.4.2 Emission abatement systems

A popular alternative to low sulphur fuels for the compliance with the regulations are the emission abatement systems, commonly known as scrubbers. The scrubber is a device that treats the exhaust gases with a chemical solution through seawater or freshwater aiming in removing part or the total of SO_x from the gases and reducing particulate matter. The cleaner exhaust is then released to the atmosphere and the neutralized SO_x and PM along with the solution used are released as waste in the sea.

Two types of scrubbers are currently available in the market for ship installation:

- dry scrubbers
- wet scrubbers

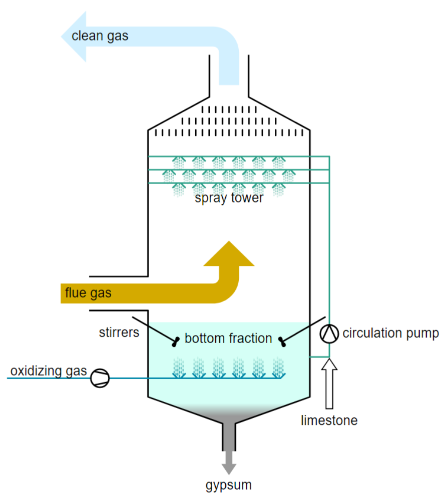

Figure 3.4: Layout of scrubber operation

Dry SO_x scrubbers are most commonly used in land based industry and use dry chemical substances to neutralize sulphur. In a dry scrubber, calcium hydroxide ($Ca(OH)_2$), commonly known as hydrated lime, reacts with sulphur and produces solid calcium sulfate ($CaSO_4$), commonly known as gypsum. The sludge produced has to be stored on board and discharged on shore as discharge in the sea is not allowed according to the IMO regulations [3]. Water is not used in dry scrubbers and therefore the exhaust gases are not cooled before reaching the ambient air. Dry scrubbers usually operate in temperatures between 240°C and 450°C which allows them to be installed before waste heat recovery or selective catalytic reduction (SCR) systems to reduce NO_x at the same time [32].

Wet scrubbers are further divided in three sub-categories:

- open loop
- closed loop
- hybrid

In wet scrubbers, the sulfurous gases are dissolved in the water where they form strong acids and react with the alkalinity of the seawater or the added sodium hydroxide in the freshwater. Sodium sulfate salt is formed by this reaction which can be discharged in the sea as it is a natural salt. The whole system comprises of a scrubber unit, usually placed in or around the funnel, a washwater treatment plant, a residue handling facility and an emissions monitoring system as imposed by the IMO for the continuous monitoring of sulphur emissions. Evidently, the scrubber system takes up a remarkable space on the ship as it is accompanied by the necessary pumps, coolers and tanks. This space is reserved from cargo space, especially in retrofits where the arrangement may not allow an easy installation of the system. The size of the scrubber affects highly the overall cost of the installation and the manufacturing costs. The efficiency of the scrubber and consequently the amount of SO_x removed from the flue gas, can be adjusted according to the fuel used and the limitations of the region the ship is sailing. The alkalinity of the water used and the function of the scrubber will decide the final percentage of SO_x in the gases emitted in the atmosphere. Apparently, the higher the amount of SO_x removed, the higher the energy consumption of the scrubber.

Open loop wet scrubbers

In open loop scrubbers operating in the sea, a seawater circulation system is used to wash the sulphur off the gases. The water is pumped from the sea and after reacting with the gases and removing the sulphur, it is cleaned by separating the residuals and storing them in the sludge tank in order to dispose of them in a reception facility onshore. The seawater is then discharged in the sea and it is not recirculated in the system. The flow rate is approximately 45 m^3 /MWh. A usual removal rate is 98% -99% with full alkalinity seawater, which will be able to reach a 0.1% m/m sulphur from a fuel with sulphur content 3.5%. In case the scrubber is running in less alkaline waters the efficiency will be drastically reduced and the requirements will not be reached. The manufacturer of the scrubber is obliged to provide information about the maximum level of sulphur in the fuel used and any limitations about the seawater temperature [32].

Closed loop wet scrubbers

For operation in enclosed waters where the alkalinity of the water is much lower than the sea, a closed loop scrubber is suggested. The closed loop scrubbers operate with freshwater treated with sodium hydroxide (NaOH). The resulting chemical solution reacts with sulphur and the sludge produced is kept in a separate sludge tank. The low in sulphur content gases evade in the atmosphere and the wash water is not discharged in the sea but cleaned and recirculated. A holding tank is used for the storage of the clean water that will be reused for scrubbing and allows the system to operate in zero discharge mode. Zero discharge refers to the situation where discharge of the scrubbing water is not permitted according to the regional regulation. However, a certain amount of wash water has to be discharged in the sea after the operation is completed so that sodium sulphate will not be encountered in high concentrations. Manufacturers suggest a discharge flow rate of 0.1 m^3 /MWh.

The pH of the wash water can be modified with the amount of sodium hydroxide, leading to smaller quantities of fresh water needed for the scrubbing. The flow rate in a closed loop scrubber is estimated to be almost half of that an open loop system requires, approximately 20 m^3 /MWh. The caustic soda used for removing the sulphur is corrosive to aluminium, brass, bronze, tin, zinc and glass, limiting that way the options for the materials to be used for the piping of the system [32].

After the main scrubber tower a hydroclone or separator is installed in order to capture the water droplets that evaporate because of the exhaust and scrubbing water temperatures. The droplets captured can be used in the re-circulation system to reduce the fresh water consumption [3].

Closed loop scrubbers generally take up more space on the ship because multiple tanks are required and storage of the caustic soda could occupy a significant amount of space. Consequently, closed loop systems could lead in bigger cargo losses and greater operation costs even in areas where freshwater scrubbing is not necessary and wash water discharge is available. These needs have forced the industry to develop hybrid scrubbers that can operate in both open and closed loop mode.

Hybrid wet scrubbers

Hybrid scrubbers are a combination of the aforementioned systems and are able to operate in any alkalinity or in areas where water discharge is prohibited. Fresh water is only used when open loop system is regulated or inefficient, resulting in smaller quantities of sodium hydroxide needed, smaller storage tanks and fresh water consumption and reduced operation costs in general. The technology is more complex than the previous systems but the flexibility they provide have allowed them to become more and more popular in the maritime world.

Regulatory requirements for scrubbers

The installation of a scrubber has to be approved by the flag Administration according to the standards set about its operation. It has to be confirmed that it can reach the expected limits and it will provide an equivalent to the fuel requirement. The updated Guidelines for Exhaust Gas Cleaning Systems that were released by the IMO in 2015 include all the requirements the Administrations need to take into account for the approval although they do not consist regulations and therefore are optional. The approval can be done on behalf of the flag Administration by a recognized classification society. The Guidelines permit two schemes:

- Scheme A which is accompanied by a unit certification along with a continuous parameter check and daily exhaust emission monitoring

- Scheme B which needs a continuous exhaust emission monitoring system

Scheme A needs to be certified for being able to meet the emission limit for continual operation with fuels with the maximum sulphur content. On the contrary, Scheme B scrubbers do not need to be certified by the manufacturer but a continuous emissions monitoring system need to be installed to monitor the gases at any given time. A SO_2/CO_2 ratio is measured after the scrubber and the sulphur content can be then derived and checked. The data has to be monitored at a rate of 0.0035 Hz or more. Both schemes have to be accompanied by the EGC Record Book [16]. Scheme B is preferred compared to Scheme A on board vessels and monitoring systems are installed in every vessel carrying a scrubber. The emissions in ships with abatement systems can be monitored throughout the journey, given that the scrubber is operating normally, either in ECA zones or in the high seas, when the regulation is put in force.

The wash water could contain some residue from the scrubbing like nitrogen oxides, sulphur oxides and particulate matter, but also traces of oil, polycyclic aromatic hydrocarbons, heavy metals and nitrogen [10]. Discharge of these substances in the sea is prohibited according to MARPOL Annex VI, Regulation 14, Paragraph 2.6. Wash water monitoring has to be continuous in sensitive areas like ports or estuaries and the following values need to be measured[16]:

- pH: Should be no less than 6.5, measured at a distance of 4m from the overboard discharge point

- PAH: Polycyclic aromatic hydrocarbons should not have a concentration of more than 50 ţg/L PAHphe (phenanthrene equivalence) above the inlet water PAH concentration.

- turbidity: Should be less than 25 formazin nephlometric units (FNUs) or 25 nephlometric turbidity units (NTUs) above the inlet water turbidity. Turbidity is related to the amount of particulate matter, metals and ash minimized by the wash water treatment system.

- nitrates: Prevention of discharge of nitrates beyond a level equivalent to 12% removal of NO_x from the exhaust or 60mg/l normalized for a discharge flow rate 45t/MWh should be achieved by the wash water treatment system.

Effluent discharges from exhaust gas cleaning systems are reviewed regarding their impact in the marine environment and there is an ongoing discussion to regulate the discharges in some coastal areas within the European Union. Such restrictions will make the open loop scrubbers obsolete in ships operating in routes including European waters and ports as the continuous discharge of wash water will not be allowed and its storage will be necessary for a certain amount of time.

Installation costs

The cost for the installation of a scrubber varies according to the type of the ship and the cargo transported, the size of the ship, the ship plans and existing piping equipment and the type of scrubber and its energy demand. An approximate estimation of the scrubber costs is presented in the following Table 3.1, where data was obtained from the Fuel Availability Study submitted to the IMO in October 2016 by CE Delft[9].

Table 3.1: EGCS investment costs, Source: Assessment of fuel oil availability 2016 by CE Delft

EGCS Type	**Fixed investment costs (million USD)**	**Variable investment costs (USD per kW of installed engine power)**
Open loop, retrofit	2.3	55
Open loop, newbuild	1.9	38
Hybrid, retrofit	2.8	58
Hybrid, newbuild	2.4	44

Additionally, the operational costs have to be considered in the assessment and according to the stakeholders taking part in the Fuel oil availability study they are the ones presented in Table 3.2.

Table 3.2: EGCS Operational costs, Source: Assessment of fuel oil availability 2016 by CE Delft

EGCS Type	**Operational costs**
Open loop	1% additional fuel + USD 13,000 + 0.4*P(kW)
Hybrid	0.5% additional fuel + USD 25,000 + 0.4*P(kW)

3.4.3 LNG as fuel

Compliance with the new regulations and the ones currently in force can be achieved with LNG powered ships. LNG is the greener solution available in shipping for the time being with a reduction of sulphur emissions almost 100%, of CO_2 emissions 20%-25%, of particulate matter 98%-100% and NO_x removal up to 80%-90% [31]. The number of LNG fueled ships is constantly increasing, with a number of more than 75 operating ships and another 80 expected to be built in the next three years [34]. LNG provides compliance with all the existing and future regulations without any additional investments but the original cost of the installation is high with a usually long payback period that does not work in favor of its expansion. The LNG installation is profitable in newbuildings and usually vessels with a fixed route that spend a lot of time in ECA zones.

The low prices of LNG compared to low sulphur fuel oil and the fluctuating prices of fuel oil can explain the uptake of LNG ships the last years in new buildings. Ships with fixed routes and high fuel consumption like containerships are ideal for such an investment due to the smaller payback period. Although there is bigger uptake of the LNG fueled ships with the global cap approaching, the shipping industry has not yet embraced this sustainable technology. This is due to a number of limitations that LNG is paired with.

Figure 3.5: LNG ship layout

The large amount of space the LNG installation occupies on a ship is an important drawback as it limits significantly the cargo space and the revenues for the ship owner. It is a rather costly installation, 10%-25% more expensive to build than vessels operating on fuel oil, that requires not only special engine arrangements but special storage tanks as well [8]. The energy density of LNG is 30% - 40% lower than diesel and gasoline and consequently it requires almost three times the volume of a normal fuel oil tank on the ship. Additionally, LNG is stored liquefied in a temperature of -162°C in specially designed tanks with good insulation or under high pressure in order to remain in liquid state. The membrane tank design occupies 50% of the market and the spherical tank design the 45%, leaving a 5% for other types of tanks. The two predominant types are designed to have sufficient insulation, integrated in the double-walled steel or external, able to carry LNG for long distances in low temperatures[39]. These tanks are expensive to obtain and install and take up too much space as their weight does not allow to be installed anywhere on the ship without creating stability problems. Currently, they are designed to fit in cargo spaces and they are accompanied by the necessary piping and steelwork that necessarily reduces cargo space.

Poor infrastructure for LNG bunkering around the world is an issue that troubles many stakeholders as not only does it hinder ship owners from investing in LNG ships but also ports that would probably invest in bunkering points due to low demand[31]. Europe has the majority of the LNG bunkering points and more points are under construction or planned to begin in the coming years. The ports of Rotterdam in the Netherlands, Turku in Finland, Zeebrugge in Belgium, Stockholm in Sweden and Oslo in Norway are only a few of the available LNG bunkering points in Europe along with port of Incheon in South Korea and Los Angeles in the U.S. [19]. The lack of infrastructure in other countries outside Europe makes the use of LNG fueled ships impossible in long routes as the autonomy of ships running in LNG will be limited. It goes without saying that a passenger ship operating in fixed routes in places with satisfactory infrastructure like the Baltic and the North Sea is easier and profitable to run on LNG as bunkering does not constitute an issue. On the contrary, a large ship traveling in the high seas and operating in places with poor or non-existent LNG infrastructure is impossible to maintain fuel autonomy and needs to run in fuel oil as well, by using a dual fuel engine. Ships operating in ECAs are most likely to run on LNG fuel in order to comply with the regulations rather than ocean-going

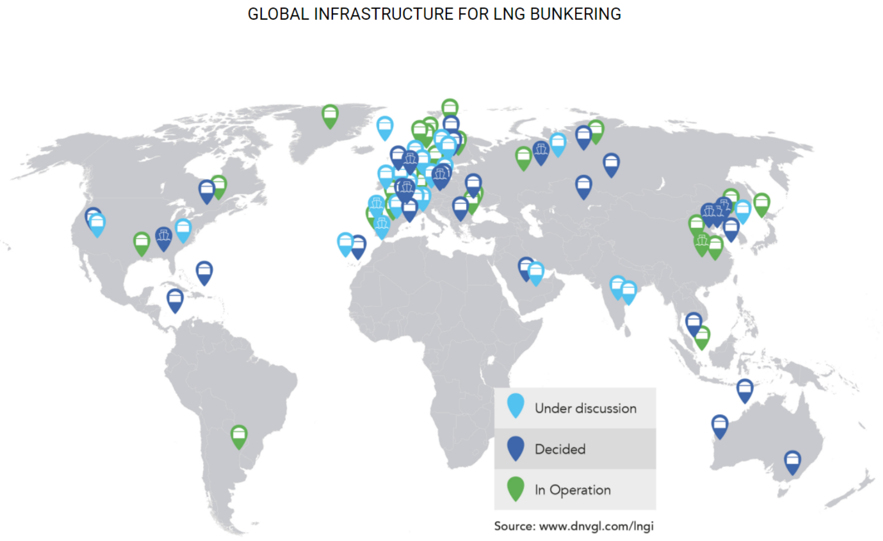

Figure 3.6: Global LNG bunkering infrastructure, Source: www.dnvgl.com/lngi/

vessels. Consideration about LNG is raised regarding the phenomenon called "methane slip" and refers to the unburned methane emitted from gas and dual fuel engines that are used in LNG fueled ships. Methane is a greenhouse gas responsible for global warming that is proved to have 28 times higher global warming potential than the CO_2 over a 100 year perspective. Low engine loads cause higher methane emissions compared to higher engine loads that show a level of 7g CH_4/kg LNG, with the highest percentage reaching approximately 23-36g/kg LNG observed at an engine load of 15%. This is due to incomplete combustion in the engine and it can be improved with alterations in the combustion process or with an oxidation catalyst [5]. The advantage of LNG against other fuels regarding greenhouse emissions is therefore reduced but is still less than any marine fuel.

The uniformity of the legislation is necessary for the expansion of LNG network. A ship owner needs to rely in regulations that have effect in every port the ship is sailing in the entire journey before they invest in an expensive technology. Regulations are usually referring to safety, which is a major issue in the case of LNG. LNG needs careful handling by trained crew as in certain concentrations and temperatures it becomes extremely dangerous. LNG is composed of mostly methane and stored in approximately -162°C. LNG in its liquid state is not explosive but when it vaporizes and is released in the air, a concentration of 5% to 15% by volume in an enclosed space is enough to produce a very flammable atmosphere. The odorless character of LNG makes it difficult to detect unless a visually detected, dense cloud is formed. Although LNG is not a toxic liquid and an eventual spillage at the sea is not considered dangerous, in the event of a collision or grounding a structure of the inner hull and leakage of LNG could create a pool fire that leads to further damage of the ship's strength and stability [39].

Chapter 4

Enforcement of the regulations

4.1 Port state jurisdiction and duties

The Port State has jurisdiction over all the vessels entering the state's ports. The port state has to be distinguished from the coastal state, although we refer to the same state. The legal context within these two differentiates the two terms. The coastal state has jurisdiction over the maritime zones of the state in general, as these are defined in the United Nations Convention on the Law of the Sea (UNCLOS) as internal waters, territorial sea and exclusive economic zone. The coastal state may apply its laws to any ship sailing within its waters and to those on board, crew and passengers.

The internal waters is the area where the coastal state has full jurisdiction over the vessel and the crew and usually include harbors, fjords and similar geographical formations. As stated in UNCLOS the internal waters can be anticipated by the state like its land territory where it is allowed to enforce its national regulations. Usually, ships do not enter the internal waters when traveling unless they need to reach a port. When entering a port, a ship could be inspected by the port state control in order to ensure that environmental and safety regulations are not violated. If a violation is recorded the ship might be detained or penalties may be imposed to the ship operator.

The territorial sea extends up to 12 nautical miles away from a state's coast as defined in UNCLOS [26]. Although this is not an extended area compared to the high seas, some main corridors and certain trades may require vessels to enter the territorial sea and the coastal state's jurisdiction. However, the sovereignty of the coastal state in the territorial sea is limited compared to the internal waters due to the principle of freedom of navigation and the vessel's right of innocent passage. Every vessel can sail in the territorial sea without being stopped by the port state control as long as their passage remains ordinary and no suspicious acts happen within these waters. The sovereignty of the coastal state in the territorial sea is clearly defined in Article 24 of UNCLOS [26]

More limited jurisdiction has the coastal state in the exclusive economic zone. The vessel can sail in this zone as if it was the high seas but it has to comply with the national regulations of the state. The state's rights are mostly limited to exploitation and exploration of the area as well as protection of the corresponding maritime environment.

The coastal state in an effort to enforce regulations has developed port state control (PSC), an authority that is responsible for the control of foreign ships that enter the coastal state's waters regarding compliance with safety and environmental regulations. Ships are inspected while at berth by trained inspectors employed by PSC that are allowed to go on board and conduct a detailed inspection. A detailed inspection requires targeting of the ships according to some criteria raised by the coastal state. One of these important criteria is the flag under which a ship is flying. A black listed flag renders the vessel more suspicious for possible violation and therefore may lead to more inspections by PSC when reaching a port.

In case of non compliance with a regulation, the port state control is often authorized to issue fines and detain ships in the port. However, the port state control has to comply with the regulation of the state regarding the penalty policy and therefore it is not always authorized to issue fines when violations are noticed. Authorization to the port state control would move the responsibility from the responsible authority, like the police, directly to PSC. This measure would facilitate the enforcement procedure and minimize delays and waste of resources.

Port state control is responsible for conducting all the inspections in the state's ports and therefore the past few years it has been very active regarding this responsibility in many parts of the world. As a result, it has gained experience and developed an equipment that has rendered inspections more effective and less time consuming. The expertise and knowledge that has been gained and developed these years will be useful for the implementation of the global sulphur cap.

4.2 Flag state jurisdiction and duties

The flag state duties and jurisdiction over the vessels are mainly laid down under Article 94 of UNCLOS 1982 and complemented by other articles. The flag state has jurisdiction over the registered ship regarding "administrative, technical and social matters" [26], which means that jurisdiction is not limited to operational and technical matters of the ship but the master and crew as well. Flag state's duties include the control of the ship's compliance with the regulations referred to marine pollution and ensuring that it is equipped with the necessary certificates that prove compliance. Many flag states lack the resources, expertise and technical knowledge to exercise their responsibilities and have delegated their duties to Classification Societies. Maritime law and the International Maritime Organization allow such delegation of duties but the responsibility for the seaworthiness and compliance of the ships flying their flags ultimately lies with the flag state. The relocation of duties to Classification Societies is constantly growing and flag states have attempted to relocate their responsibilities as well.

Apart from coastal states that are entitled to having vessels registered under their flag, landlocked states constitute flag states as well, since it is allowed by International Law.

Flag states have significant power over the vessels under their flag and are the main responsible authority for enforcing the regulations regardless of where the ship is sailing. In the high seas the flag state is the only responsible for the entity of the ship and no other authority has any jurisdiction over the vessels. High seas are fairly regulated and a lack of enforcement methods makes non compliance a very appealing practice for some ship operators. Flag states are obliged under the Article 217 (4) of UNCLOS 1982 to investigate a vessel when suspicions are raised regarding an alleged violation of regulations in a foreign port, territorial sea or exclusive economic zone of a foreign state. The penalties imposed should be adequate enough, so that ship operators are discouraged to violate the regulations again in the future [26]. The flag state has these obligations in the high seas where the port state cannot take any action against foreign vessels. Despite this obligation, irresponsible flag states have incentives to impose affordable penalties on the vessels registered under their flag or avoid imposing any penalties at all in order to attract more shipowners with substandard ships. Substandard ships are ships whose hull, machinery, equipment or operational safety is considerably below the international standards set [20].

Owners searching for low prices and having little interest in fulfilling high quality standards for their ships consider safety a matter of lower importance compared to maintaining a competitive price for potential shippers. Such owners try to register their ships under flags of convenience in their effort to minimize the costs despite the fact that lower standards will result in higher maintenance and operational costs. A flag of convenience in the maritime industry will reduce the market value of the vessel, increase the insurance fees and the possibilities to be caught more often by PSC at port for a thorough inspection that may also lead to detention. Flags of convenience are usually listed by the Memorandum of Understanding on Port State Control as black or grey flags and are targeted more often for inspections by PSC. Companies that wish to keep a high level profile and do not want to be delayed by PSC, choose to register under white flags as listed by PSC every year. On the other hand, ship owners that list their ships under flags of convenience will probably take advantage of a potential low enforcement of the global sulphur cap and use high sulphur fuel.

4.3 Flag State Control versus Port State Control

The duties and jurisdiction of the flag state and port state are not conflicting but complimentary and aim to ensure the compliance of the ships with the regulations in all the areas they apply. The absence of some flag states' willingness to control and punish the vessels registered under their flag and at the same time the lack of the necessary equipment and experience to accomplish such a complicated task like the enforcement of the new regulation in the high seas, has raised the question whether the port states should undertake the task of enforcement of the global sulphur cap. Port states have conducted numerous inspections regarding the monitoring of air pollution from ships and many campaigns have been successfully completed after regulating the ECA zones. The expertise, trained personnel and potentially useful equipment is owned by many port states but the most important is the motivation of port states to implement a relevant project in order to protect their coast and waters from every kind of pollution and finance the operations with the fines imposed and collected from violating ships.

Targeting of ships for the inspection of the sulphur content of fuel in ports will rely undoubtedly in the flag a vessel is flying as it will cut down the number of ships that need to be inspected in order to realize violations of the regulation. This criteria, however, can only be proven useful when the ship reaches the port as the ship cannot be stopped by any authority while sailing in the high seas or forced to change route for an inspection.

Chapter 5

Compliance with the regulations

5.1 Compliance with existing SO_x regulations

The emission levels are currently restricted only in the ECA zones and zones regulated by national law. The enforcement in the ECAs has been challenging for the authorities due to the lack of an enforcement policy that allows multiple inspections without demanding significant funding from governments. The shipping companies have important incentive not to comply with the regulations as the profit from burning high sulphur fuel and avoiding investing in new technologies as scrubbers or LNG in newbuildings is substantial. The non-compliant companies are rendered more competitive to the detriment of compliant companies which, in order to stay in business, need to increase freight rates proportionally to the higher operating costs.

Inspections in the ECA zones have provided an insight in the compliance rates after the limitations imposed in 2015. The inspections are usually conducted by port state control officers, specially trained to identify violations and misguidance. The inspection procedure includes document verification that mainly consists of bunker delivery notes and ship's log books but other documents that prove the ship's compliance as well. The port state control officer needs to examine the International Air Pollution Prevention Certificate (IAPP) that every ship is obliged to carry, any documents related to exhaust gas cleaning systems or other equivalent emission abatement methods used by the ship, the bunker delivery notes and the samples of the fuel bunkered. The bunker delivery note should display clearly the type of fuel used on board and the sulphur content. If a low sulphur content fuel is used prior to entering the ECA zone, the ship's log books should prove the time of the changeover and the volume of the compliant fuel in the corresponding tanks. Every similar changeover operation before entering and after exiting an ECA zone must be recorded in the log book. It is also required for ships sailing in ECA zones to maintain a representative fuel sample of the fuel oil delivered. The sample is to be kept sealed and signed by the supplier's representative and the master or officer in charge until the fuel is consumed [25], [11].

If any suspicion is raised regarding the compliance of the vessel, the port state control officer has the right to conduct a more detailed inspection. The clear grounds for such an inspection are clearly stated in the guidelines for the port state control under MARPOL ANNEX VI. If clear grounds exist, the port state control officer can take a sample of the fuel used on board at any part of the ship for further examination. Samples can be checked with handheld devices that are able to provide an approximate estimation of the fuel's sulphur content but for more detailed examination and higher accuracy, the samples have to be taken to the lab. Lab tests require significantly more time than tests with handheld devices but the higher accuracy they provide makes them necessary in case a punishment must be applied. A fine can be decided according to the gravity of the violation, which is determined usually by the lab results. If charges are about to be faced, the lab tests are necessary as evidence of the violation provided to the court. Handheld devices only provide an instant indication of whether the vessel is exceeding the sulphur limit or is within an acceptable or doubtful range.

This procedure established by the IMO for the inspection of ships at port is time consuming and costly to implement. The number of ships inspected is very limited and deduction of a compliance percentage of the global fleet is very difficult to be achieved. The complexity of the procedure gives the owners the opportunity to find ways to avoid fines and sanctions by using tricks to mislead the port state control officers.

Compliance in European waters can be monitored by the system developed for the EU member states named THETIS. All states of the Paris Memorandum of Understanding on Port State Control (Paris MoU on PSC), which consist of the EU member states, Canada, Iceland, Norway and the Russian Federation, have access to the THETIS system. THETIS is a database containing information about the compliance of the ships in the corresponding ports with the European directives and regulations. The port state control's inspection reports are made available to all member state authorities, which can have a full picture of the ship's compliance behavior. The system has been operational since January 1, 2011 and an average of 18,000 inspections per year by the 28 member states have been recorded since.

Nevertheless, the compliance rates measured in European waters and inside ECA zones were found rather satisfying. A study conducted by the European Commission and submitted to the IMO in the 70th session in 2016 has gathered data from about 12,000 inspections in European ports during the period January 1, 2015 to June 30, 2016. The inspections were carried out by trained inspectors in the European ports on behalf of the EU member states. A total number of 8,964 ships was inspected during that period with the vessel type varying between general cargo ships, tankers and bulk carriers. There has not been a difference in the compliance rates between vessel types, size, flag state or destination. It was observed though, that in a certain distance from the port entrance, the compliance tended to be lower. In the given period, 592 ships out of the inspected where found with some sort of non compliance, either non-filled or completely missing log books, sniffer measurements that showed a level of sulphur higher than 0.2% or fuel samples that clearly demonstrate non compliance. Out of the total number of samples taken from the ships tanks, only an average percentage of 3% to 4% has proved to be non compliant with the sulphur regulation, a fact that demonstrates a generally high level of compliance in the European ports. It has to be stated though, that not all cases examined were due to deliberate emission of a higher sulphur level but could be caused by equipment failure or failure to examine thoroughly the sulphur content of the fuel when bunkered, resulting to bunkering a non-compliant fuel.

Within the scope of monitoring of compliance and the need for new methods and technologies to detect the non-compliant ships, the EU initiated the CompMon project. The project aims in finding ways to spot non-compliance or increasing the legal value of some existing alternative methods as well as gathering information about the compliance levels in ports of the European states and analyzing them to come into conclusions about the compliance rates and the enforcement practices. One of the activities was the Belgian Sniffer Campaign, which was organized in two stages in 2015 and 2016. The first Campaign took place in the first two weeks of October 2015 and the second one from August to November 2016. During this period, airborne measurements of the emissions of ships sailing in Belgian waters were conducted and the conclusions were published. A sum of 17 flight hours during the first campaign and 135 hours in the second, formed the successful observation campaign.

A surveillance aircraft equipped with a SO_2 sniffer sensor was used for the measurements and the control of the sensor, while processing of the data was achieved with a tailored IGPS software. The sniffer constantly measures the sulphur content of the ambient air and automatically transmits the data to the connected software. When the sniffer approaches the plume of a ship, a peak appears in the software and this measurement is immediately connected to the ship, which is recognized by the AIS data used for the positioning of the ships. Every ship is marked as compliant or not after analyzing the data and an indication for the non-compliant ships is sent to authorities for further action. Compliance data is stored in a database along with the AIS data and comments from the operator and pilot of the aircraft.

Despite a small uncertainty in a number of measurements, the majority of them gave an accurate indication of the sulphur levels. Out of approximately 1400 ships inspected, 1300 measurements were of satisfying quality and almost 100 non-compliant ships were spotted. This amount corresponds to 8% non compliance in the Belgian waters. The percentage is rather low, showing that most of the ships comply with the ECA regulations regardless of their

Table 5.1: Compliance rates

Area/Method	**Period**	**No. of measurements**	**Ratio of non compliance**
Fuel samples in Denmark	2016	150	5%
Sniffer in Great Belt Bridge, Denmark	7/2015 - 12/2015	1167 of medium or high quality	4%
Surveillance aircraft in Danish waters	6/2015 - 10/2016	480 of medium or high quality	6%
Sniffer in fixed station in Gothenburg, Sweden	2016	483 of medium or high quality	1%
Finland (Fixed and Boat)	2016	2570 (Fixed) 430 (Boat)	0.6%
Hamburg port, Germany	11/2014 - 11/2016	6523	1.66%
Fixed platform in Rotterdam, Netherlands	2016	1229	7%
Helicopter in Dutch waters	09/2016	327	18%
Aircraft in Belgian waters	2016	1233	11%
Aircraft in SECA border	09/2016	74	16%

type, size, flag state or destination. Strict enforcement of the regulations will force even more ships to comply in order to avoid fines and sanctions.

The number of inspections in the European SECA and the corresponding number of the ships found non compliant gives a general impression of the level of enforcement in the European SECA, which has provided satisfying compliance rates. Table 5.2 presents the inspections conducted in the European waters in the years 2015-2016. It is very important to note that not all cases of non compliance have been severe violations but rather administrative problems regarding the relevant paperwork instead of non compliant fuel.

Table 5.2: Compliance in European SECA

Region	No.of inspections	Non compliant ships
Baltic Sea	3745	126
North Sea	6117	606

The total of the port inspections was not accompanied by a fuel sample, as only in a few cases a fuel sample was needed. The percentage of fuel samples taken was 16% in 2015 and 26% in 2016.

5.2 Enforcement in Denmark

Enforcement in Denmark has been done effectively since 2015 and the SO_x levels measured in the atmosphere have been reduced more than 50% after the sulphur regulation in 2015 was imposed. The Danish EPA is responsible for the control in the danish waters and has undertaken the inspection task with any available means. Enforcement is achieved with airborne measurements, fixed platform measurements and port inspections according to the MARPOL convention. The rates of compliance within the Danish waters are displayed in Table 5.3.

Table 5.3: Compliance rates in Denmark

Method	Period	No. of measurements	Ratio of non compliance
Fuel samples	2016	150	5%
Sniffer in Great Belt Bridge	7/2015 - 12/2015	1167 of medium or high quality	4%
Surveillance aircraft	6/2015 - 10/2016	480 of medium or high quality	6%

The Danish legislation defines as responsible for the issuing of fines and penalties in general the Danish Police and all violations must be evaluated by the police before any penalty is imposed to the ship. It has been noticed that the procedure is slow as the police needs to deal with a variety of cases and violations around the country. Police officers were not aware of the sulphur regulations until recently and the lack of previous similar cases made the issuing of fines and imposition of sanctions a difficult and time consuming task. Administrative fines could probably solve the problem of delays as they could be issued on the spot by the port state control. The same legislation is adopted in other European countries as well like Sweden.

The inspections in port for the content of sulphur in the fuel are carried out in combination with the port state control inspections about the compliance of the ship with all regulations regarding safety and environmental pollution. The Danish Maritime Authority is responsible for these inspections and the Danish EPA undertakes the sulphur inspections. Sulphur inspections are charged and payed by the EPA, while the rest of the cost for the inspections falls under the jurisdiction of the Danish Maritime Authority. Data about the inspection rates in Denmark and the cost of the inspections in Danish waters was provided by the Danish EPA. An average of 400 sulphur inspections per year are conducted by the Danish Maritime Authority and the EPA in the ports of Denmark and approximately 150 out of them required an oil sample to be taken and examined. The cost of these inspections is DKK 200,000 per year (approximately € 27,000) and the cost of the fuel samples that had to be taken to the lab is DKK 600 per sample (approximately € 80). This number includes the analysis in the lab and the postage fees by ordinary mail. Of course, in case of emergency the cost will increase due to higher postage fees. The sniffer installed at the Great Belt Bridge is deployed with a contract that cost to the Danish government DKK 1,300,000 (approximately € 175,700) per year, which results to an average cost per measurement taken of DKK 130 (approximately € 17). This cost refers to every measurement taken by the sensors installed on the bridge, but only some of them are of good or medium quality which can be analyzed and produce useful conclusions. If only the higher quality measurements are considered, the cost will rise up to DKK 200 per measurement (approximately € 27). The airborne monitoring is the most expensive campaign the Danish government has conducted and has cost DKK 5,000,000 (approximately € 675,700), leading to an average of DKK 2,500 per observation. In the Table 5.4 an overview of the costs of inspections in Denmark is available.

Table 5.4: Cost of inspections in Denmark

Surveillance method	**Cost per year (DKK)**	**Cost per inspection/ measurement (DKK)**
Port inspection (incl. fuel samples when needed)	200,000	360
Fuel samples	-	600
Airborne	5,000,000	2500
Sniffer in Great Belt Bridge	1,300,000	130

So far, 17 violations have been reported by the Danish EPA to the authorities in Denmark in order to take action and impose penalties. Recently, a fine of DKK 375,000 which equals to € 50,498 has been issued to a foreign shipping company for a ship sailing in northern Denmark with high levels of sulphur emissions. The violation was reported by the Danish EPA after an inspection that was initiated by an anonymous tip-off. Another smaller fine of DKK 30,000 which equals to approximately € 4,030 was imposed to another shipping company for a smaller violation of the law [4].

5.3 Penalties for non compliance in ECA zones

A problem brought forward by many stakeholders is the fines the owners are called to pay when they are caught for violating the regulations, especially in certain countries where a clear legislation regarding the punishment does not exist.Given the limited time the regulations have been in force and the absence of an international, common practice for the punishment of the violators, the enforcement of the regulations has been challenging. Port authorities are not in charge of issuing fines and cases have to be brought to court or to the responsible authorities to take action against them. This procedure not only delays the administration of justice but also encourages the continuation of this situation. The amount of the fines issued vary greatly all around the world and it depends on the gravity of the violation. The quality of the fuel burnt and its content in sulphur is the most important factor taken into account but not the only one. The repeated violations of the regulations and the size of the company and its resources are also taken into account by some authorities around the world before deciding the exact amount of fine. The volume of non compliant fuel burnt and the corresponding profit than can be made, should be a deciding factor for the fines but a specific method and procedure to calculate such profits has yet to be defined by the authorities. In Europe only, the variation of fines is substantial. Some countries are eager to enforce the regulation and have imposed high fines that correspond to the profits made from the violation under discussion. On the other hand some countries, for example some Baltic states, have only imposed fines considerably low compared to the profits shipowners make, allowing the companies to keep using the profitable practice of non compliance. Countries like Latvia, Lithuania and Germany have proved to be very reluctant with the prosecution of the offenders and the amounts of fines. The maximum penalty for non-compliance in Latvia in 2015 was € 2,900 , in Lithuania € 14,481 and in Germany up to € 22,000 [35]. On the contrary, the United Kingdom and Belgium are two of the European countries with the higher fines imposed so far. In the UK the maximum penalty imposed was £3 million and in Belgium €6 million. In the United States the decision about the fine is based on an assessment of the economic benefit for burning the non compliant fuel detected and the gravity of the violation [7]. This benefit can be estimated by the exceeding percentage of the sulphur content and the record of the violations occurred in ports all over the world. Last update on the U.S. penalty system in 2016 states fines of up to 25,000$ per day. More recent updates on these indicative amounts might give a more complete overview of the current situation. However, data about the imposed fines and the corresponding violation are treated as confidential and not shared publicly in most cases.

Table 5.5: Fines in Europe, Source: International Transport Forum [35]

Country	**Maximum fine**
Belgium	€ 6 million
United Kingdom	£ 3 million
United States	$ 25,000 per day
Denmark	€ 50,498
Germany	€ 22,000
Lithuania	€ 14,481
Latvia	€ 2,900
Sweden	SEK 10 million
Netherlands	€ 81,000 + economic gains

Chapter 6

Enforcement schemes

Enforcement of the regulations for the reduction of sulphur is exclusively dependent on the port state control and port inspection while the ship is at berth. These methods, though, cannot prove efficient in the high seas, away from the coast where the port state control has no jurisdiction and the existing technologies cannot provide us with any measurements. Some methods and technologies available in the ECA zones, that are already used in different parts of the world, are presented in this chapter. Further development in some existing methods is necessary, however important conclusions about the compliance in the ECA zones can be drawn.

6.1 Port inspection

IMO has approved certain policies for the enforcement of the sulphur regulations and they have already been used to control the compliance in the ECA zones. These policies are relying exclusively to the port state control and port inspections executed by the port state control officers. The methods approved as designated by the MARPOL convention, are:

- Bunker delivery notes
- Ship's log books
- Fuel samples

These methods have been proven useful for the inspection in ECA zones but very time and resource consuming. Port state control has only been able to inspect a 10% of ships entering a SECA port using these procedures [2]. The enforcement of the global sulphur cap is still relying on the same procedures which unfortunately cannot be effective in the high seas.

6.1.1 Bunker delivery notes

The bunker delivery note is a legal paper that proves what kind of fuel was last bunkered. The type, composition and properties of the fuel are reported in this document. It is provided by the bunker supplier to verify the quality of the fuel purchased and consists legal proof of the compliance of the ship. The bunker delivery note has to be kept on board for a minimum period of three years after the delivery date of the fuel and should be available at all times in case of an inspection, according to Annex VI, Regulation 18. It has to be kept together with the fuel sample, sealed and signed by the supplier's representative. The bunker delivery notes should all be kept on board and should be in order so that the inspection is facilitated.

These papers though should not be considered enough evidence of a ship's compliance because they can be easily falsified, as it has been done several times in the past. Many cases have been encountered where the sulphur content of the fuel has been found different compared to the sample taken from the tanks. The sulphur content might also not correspond to the one used because of the supplier's responsibility. It is possible that the bunker supplier provides fuel with a higher percentage of sulphur and due to insufficient control from the master or the officer in charge of the bunker operation, the incompliance is not detected. The sulphur in that case, exceeds slightly the limit set by the international standards but the responsibility lies within the ship owner, as the regulation clearly states that the quality of the fuel should be checked during the bunker operation.

6.1.2 Ship's log books

The log books include the following documents [11]:

- Oil Record Book
- Records of navigational activities
- Records of internal transfer of fuel
- Engine logbooks
- Tank sounding records
- Fuel oil change over records

The inspector has to check the log books to realize if the procedures followed on board match the ones required by the regulations. The Oil Record Book contains information about the handling of fuel and lubricant oil. The fuel used in the combustion engine has to be logged in the Oil Record Book and any change of fuel has to be reported. Prior the entry in an ECA zone the vessel has to change to a compliant fuel of maximum 0.1% m/m sulphur. A change to a different kind of fuel could take up to one hour in order to prepare the main engine and tanks and avoid causing damages, like thermal shock to injection components, clog of filters or pump failure due to the different viscosity of the high sulphur and low sulphur fuels (distillate fuels have lower viscosity than the residuals currently used for sailing in the high seas). Any residue of a high sulphur fuel could cause increased sulphur emissions above the limit and therefore sufficient time has to be provided for the non compliant fuel to be fully flushed from the service tanks to avoid contamination. The time of changeover, the volume of low sulphur fuels in each tank and the date, time, and position of the ship during the changeover, before entering or after exiting an ECA, have to be reported in the Oil Record Book. Plans and piping diagrams, the capacity plan and trim and stability booklet could be examined by the PSCO to provide a better perspective of the procedures undertaken on board.

The ship's log books are difficult to inspect and rarely do they lead to a certain conclusion. The main reason is that the regulation does not oblige the officer in charge to write in English and any language could be used. They usually are illegible because of the handwriting and most of the times have insufficient information about the procedures on board. Many logs are not recorded or many essential details are missing, resulting in increased difficulty of the PSCO to reach a conclusion. In addition, the log books are intentionally falsified to avoid creating suspicion and clear grounds for further inspection. Therefore, the uncertainty of the legal paperwork necessitates the acquisition of fuel samples in the majority of cases. PSCOs conduct more thorough inspections, as a general impression and a quick look does not allow in depth knowledge of the ship's state.

6.1.3 Fuel samples

If the port state control officer realizes clear grounds that a violation of the regulation has happened on board, then he has to take a fuel sample from the fuel carried on board. Clear grounds are considered to be evidence that the ship or the crew are violating international conventions regarding the safety and prevention of pollution from ships. Some examples of clear grounds are:

- Evidence that a ship's certificate is invalid
- PSCO's impression that the ship does not comply with regulations concerning the safety of the ship and the crew as well as prevention of pollution
- A report or complaint that the ship may have violated the regulation either in the port or during its trip

Indication that the ship is not complying consists clear grounds for a more detailed inspection in the port. All means that can provide with an indication of the ship's state regarding compliance could prove useful for targeting ships with a higher chance to be found non compliant. Random selection of the ships leads to a waste of resources and valuable time that could possibly lead to the sanction of substandard ships instead of compliant operators.

According to the IMO Guidelines for the PSC [20], the fuel samples might be taken directly from the fuel tanks and/or the fuel service system. Three representative samples have to be taken between the service tanks and the fuel inlet of the combustion machinery and one of them has to be kept sealed and properly labeled on board for at least 12 months after the inspection. The PSCO needs to estimate the spot the samples could be taken and the amount of samples needed. Multiple samples from various locations can be taken in case suspicion is raised that the ship is using different types of fuel stored in several tanks. The various tanks and pipes a ship is using to store and provide fuel in the main engine makes fuel sampling even more challenging for the PSCO. Several practices and tricks have been used on board to hide the non compliant fuel burnt in ECA zones. The use of ”magic pipes”, pipes that are not depicted in the designs of the ship and are used to provide non compliant fuel to the combustion engine, is only one of the practices that can be easily adopted in tankers, where a perfect chance is provided due to the chaotic piping system. Extreme care regarding the collection point and the safety of the sampling procedure has to be taken because of the high risk of fire and explosion if the necessary safety precautions are not taken.

Figure 6.1: Handheld XRF analyzers that use X-Ray for the detection of sulphur, Source: www.bruker.com

Once the fuel samples are taken, they have to be sent to specific labs on shore to be examined. The conclusion about the composition of the fuel is derived after a few days when the ship has already departed, as detaining the ship in the port without evidence and delaying its scheduled trip is not allowed. For the facilitation of the procedure and issuing of fines on the spot, portable devices able to analyze the fuel and determine its composition on the spot have been manufactured and are currently used in several ports, like the port of Rotterdam. In the context of the European project CompMon some handheld devices will be bought by the Swedish, Finnish and Dutch authorities for port inspections. These devices, however, have not been approved by the IMO as legal evidence of non compliance. Consequently, they cannot hold up in court or be used to issue fines. They consist a strong indication of non compliance and facilitate the identification of violators, but the sample needs to be sent and analyzed in a specialized lab on shore before imposing fines or suing the operator.

6.2 Airborne monitoring

Surveillance close to the coast can be performed by a few innovative systems that have been developed in the recent years. It has already been attempted to measure the emissions from ships away from the port by approaching the ship's plume. Helicopters, UAVs and special airplanes equipped with sensors are able to measure the levels of pollutants directly from the ship's plume without interfering to the ship's course and activities. They can use various forms of sensors like the so-called sniffers or optical measurement systems and potentially other advanced technologies.

Figure 6.2: Drones deployed for the emissions monitoring, Source: www.mpropulsion.com

Airborne monitoring offers the flexibility to check multiple ships away from the coast during a single flight, depending on the autonomy of the system. The ships are not warned of the upcoming inspection as they are targeted from the coast and no communication with the ship's crew is required. Unexpected inspections make spotting non compliant ships easier, as they have no time to react and change or falsify their emissions levels. This method has been successfully used by port state control in the ECA zones in many European countries like Denmark, Belgium and Netherlands, to target non compliant ships that are subsequently inspected when they reach port in order to collect the necessary proof of non compliance.

Although these technologies are on the rise, their capitalization for legal purposes is not possible yet. Data retrieved from remote sensing methods do not constitute evidence in case of prosecution of non-compliant vessels as long as European regulations do not include a relevant legal framework. Fines can only be issued after a detailed inspection in port involving check of the bunker delivery notes and logbooks, and fuel sampling. Therefore, sniffer results are only used as an indication of the non compliant ships as they consist a helpful tool for targeting ships and facilitating the inspection process in ports. The number of ships inspected in port can be cut down to minimum as the compliant ships will not undergo a sulphur inspection. These inspections require time and resources: trained port state control officers, fuel samples and labs authorized to analyze the samples and report the results, and a significant amount of time to be spent on the ship for the inspection, which is costly not only for the port state control but for the ship operators as well, because of the delay to their time schedule. However, an undergoing process by the authorities will hopefully legislate the use of airborne monitoring results as trustworthy proof of non compliance and allow their use for an immediate issuing of fines. This process is expected to take some years to complete because of the difficulty for legislation to be reviewed and changed.

Airborne monitoring can be conducted with UAVs, helicopters and airplanes. The range and the hours of flight differ from vehicle to vehicle. The UAVs used in Denmark for this kind of inspection ranges between very simple and cheap rotary drones to more costly and focused on more professional use. The commercial simple ones could cost from 10,000 DKK (approximately €1,350) to 50,000 DKK approximately (about €6,720), depending on the range and endurance. They are able to fly for 2 hours the most, depending on the payload, and cover an inspection area of 5 km. Professional drones, specifically designed for more demanding tasks could cost about €1.5 million and have an endurance of almost 6 hours, depending on the payload. These specifications provide the possibility to inspect a larger area, further from the port, or conduct more inspections within a more limited area.

Helicopters and airplanes are manned vehicles, driven by a pilot accompanied by a co-pilot responsible for the measurements. Helicopters and airplanes can fly away from the coast and conduct a significant number of inspections, as the fuel provides them with enough autonomy for a few hours. The range of the helicopters can be about 200 km from the coast, which ensures a wide range of potential ships to be inspected. The operation of UAVs is restricted from the frequent charge needed and the regulations that require visual contact with unmanned vehicles during their operation. That regulation limits their range in almost 25 km from the coast. An operator undertakes the task of flying the UAV over the ship's plume and position it in the right way that allows a measurement to be taken.

The sensors that have dominated this kind of operations by the port state control are the so called "sniffers". Such systems have been extensively used in Denmark and operated by a company named Explicit on behalf of the Danish EPA and the Danish Maritime Authority. Information regarding the operation of the airborne monitoring in Denmark was offered by Jon Knudsen, CEO of Explicit ApS., based in Kgs. Lyngby, in Denmark. The inspections were conducted in the context of two separate monitoring campaigns in the Danish waters. The first, more extended campaign lasted for almost one and a half year, it started in June 2015 and ended in the end of 2016. The campaign included airborne measurements using helicopters and UAVs as well as fixed stations' measurements obtained from a high quality sensor placed on the Great Belt Bridge, in Denmark. The entire campaign costed to the Danish government DKK 6.3 million which is € 846,279. The most costly method was the airborne monitoring with helicopters and UAVs compared to the monitoring from the Great Belt Bridge. The second campaign was conducted in the first semester of 2017 and involved a smaller number of inspections with sniffers as it was not considered vital to deploy so many measurements and the cost of the operation had to be reduced. The total cost of the second campaign was DKK 2 million which equals to € 268,660. Cost data about the campaigns was provided by Dorte Kubel on behalf of the Danish EPA. The results of the two different monitoring methods proved to be similar although they operated in different places and the sensors have a different accuracy and range. The fear of getting caught by sniffers that operate in these waters influenced highly the compliance rates as the vast majority of ships were found compliant.

The monitoring procedure is described, as explained by Jon Knudsen, the CEO of Explicit ApS. The first task to be completed is the targeting of the ships to be inspected. Suspicious or random ships have to be chosen for a measurement from the shore using a simple software. The software is called Project Sense and is the main database where the data is analyzed in the first place, measurement data is stored and the results are exported. The software provides the possibility to have an overview of the vessels in a close proximity from the shore and within the desired range using AIS data to locate the ships on the map. Details about the type of the ship, the cargo transported, the course and the speed of the ship can be obtained by the AIS system. The software is able to simulate the course of the ship and combined with meteorological data like wind direction and speed, it can predict the direction of the plume. This tool is very useful as it gives a good indication for the route the helicopter or the UAV should follow and their exact position compared to the ship during the measurement. The ships can be chosen either randomly or by using certain criteria, like history of compliance of the ship or the operator, unexpected route in order to avoid getting close to monitoring stations and a wide range of factors that can emerge in the future.

Airborne monitoring in Denmark, and in Europe in general, has been performed with helicopters and UAVs. These vessels need to be equipped with sniffer sensors as they have the ability to fly close to the plume and stay above the ship for the required amount of time. Sniffer sensors are preferred in this situation as they offer high quality and accuracy of measurement but at the same time the cost of acquisition and maintenance remains low. An inseparable part of the operation is the sniffer box that is mounted on the helicopter or UAV containing the sensors necessary for the ongoing measurement. The structure consists of electrochemical sensors for the detection of SO_2, NO_2 and NO and infrared sensors for CO2, integrated in a box made of metal, a small pipe and a vacuum pump for the inflow of air. The ambient air is pumped towards the sensors through the small tubes attached on the sniffer box.

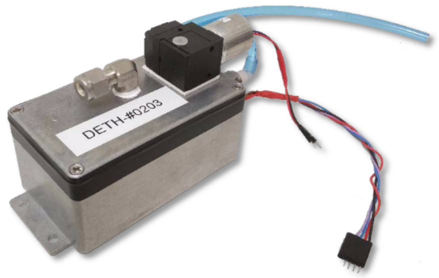

Figure 6.3: The sniffer box developed by Explicit, Source: www.explicit.dk

The box has a simple structure and is light-weighted so that it can be used on a small UAV and fly far from the coast. It can be integrated on a UAV or be adjusted as a dual system for better precision in a sniffer box and mounted on a helicopter depending on the sea area required to cover and the total inspection time. The hours of autonomy are limited by battery or fuel for the UAV and the helicopter respectively. The UAV can reach 25 km so that optical contact with the operator is kept during the flight. The helicopter can carry out multiple inspections within a 130 km to a maximum of 200 km radius from the coast depending on the autonomy provided by the fuel. These options are able to provide a very good sample of compliance rates within the SECA areas.

The flight over the ship's plume is simulated and the relative position and angle of the UAV or helicopter and the inspected vessel is predefined. The aircraft is not allowed to approach the ship from the stem but it can only fly behind the ship or next to it in an angle of maximum 90°. If the direction of the plume allows a reliable measurement,the aircraft will fly inside the plume, approximately 30 m to 50 m from the stack, and stay for a few seconds in the plume to provide the sensors with the time needed to measure the pollutants. Identifying the plume from a helicopter or from the coast when flying the

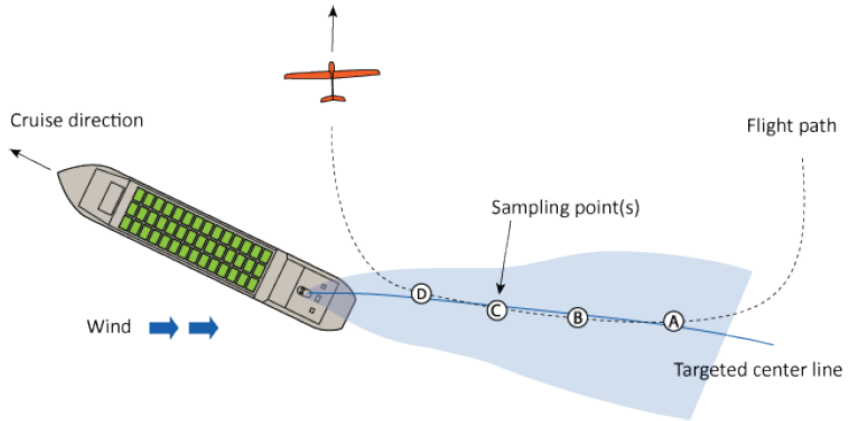

Figure 6.4: Flight path of the UAV or helicopter, Source: www.explicit.dk

UAV is impossible, as it disperses in the ambient air almost instantly after exiting the stack of the ship. It is required to have a system that can identify and locate the plume and the ideal position for a reliable and high quality measurement. This is achieved by using NO sensors which have a small response time and high sensitivity. The NO peaks help identify an emission event as it has been proven that high concentration of NO indicates the existence of exhaust gases and consequently the pollutants under discussion. Once an emission event is located, the SO_2, NO_2 and CO_2 levels can be measured with high accuracy by the other sensors integrated in the sniffer box. In order to minimize the error arising from the background pollution, a baseline has to be determined before every inspection by measuring the levels of pollutants away from the plume. Measuring the ambient air away from the exhaust gases provides an indication of the concentration of CO_2 in the area and creates a relative ground zero. The volume of every pollutant is measured but the concentration per kg of fuel can only be extracted after normalizing the measurements against the sum of CO_2 [6]. Because of the different response time of every sensor the peak width is differentiated in every gas and therefore the results are normalized so that the peaks of the pollutants' concentrations are compared [22]. The data is transmitted to a database in shore through satellite connection, where it is stored and analyzed to produce a report with the total emission levels. The sensors are properly calibrated to be equipped with a sensitivity that can detect a sulphur level of 0.13%. A value higher than 0.13% m/m sulphur will mark a ship as non-compliant for the 0.1% limit and an error of 0.01% to 0.03% is taken into account. Only the measurement results of the non-compliant ships are forwarded to the authorities, which will then take action on the matter. In Denmark the measurements were conducted by Explicit and the data were sent directly to the authorities.

The sniffing method is useful to apply close to the coast to assist the port state control's work and is cost effective compared to other existing methods, as the sensors used for the detection of pollutants are cheap and easy to produce and calibrate for this task. Measuring with a helicopter or a UAV provides the chance to return and repeat the measurement in case the quality is not satisfying. The small distance from the stack makes the measurement accurate enough even without very sensitive sensors. Although the sensors have a normal sensitivity, they are calibrated for higher accuracy in order to reach a threshold of detection of 0.13% which guarantees high performance with a small investment. FORCE Technology is the company responsible for the calibration and the relevant certificate in this project. The sensors have to be replaced after 100 hours of operation and they are provided to the company by lease because a large amount of sensors is used in order to achieve the required inspection hours. The low cost construction is based on cheap materials and thus becomes attractive as a possible solution for the enforcement of the regulations. It is a very reliable system because it is impossible to tamper with as there is no interaction with the crew of the ship. The lack of time to react and anticipate a control makes it impossible for non-compliant ships to escape from a possible penalty.

Optical systems have so far been used in combination with an airplane rather than helicopter or UAV, and are able to detect NO_2 and SO_2 but the detection of CO_2 is currently under development and is difficult to be done.

Consequently high accuracy is not achieved with the optical measurements and they are only used as an indication of gross non compliance. Optical systems require less time to complete a measurement and it can be done from a bigger distance from the ship once they target the plume.

Major European ports are already using the sniffing technology and the optical sensors in a pilot program for the law enforcement in ECAs. Denmark has both land based systems and air surveillance equipment. Sniffers adapted on the Great Belt Bridge and Øresund Bridge, a helicopter and a UAV equipped with sniffer systems, operating close to the Danish coast, are providing the Danish authorities with the law violation data. Sweden has invested in high quality sensors installed in the entrance of the port of Gothenburg since 2012, based on the technology developed by the Chalmers University of Technology. A Navajo Piper airplane was also certified for the conduction of controls and is based in Denmark on behalf of the Swedish authorities. The Netherlands are using a fixed platform system and a helicopter in the port of Rotterdam, one of the biggest ports in Europe. The Belgian coast guard is acting against polluters by engaging an aircraft with a SO_2 sniffer for a few hundred of flight hours in the part of the North Sea under Belgian jurisdiction.

6.2.1 Airborne monitoring in the high seas

Airborne monitoring is a very reliable yet difficult to realize method. The flexibility that aircrafts provide and the fact that they cannot be tampered with, is a perfect combination for the enforcement of the sulphur cap in the high seas. However, the weather conditions prevailing the oceans and the really long distances that have to be covered makes it almost impossible to inspect the ocean with the means available so far. Airplanes are an expensive option for an extensive use that will cover the whole merchant fleet and the UAVs used so far cannot reach the range and flight hours required. The popular and cheap rotary drones are impossible to use in the high seas. New UAVs with better specifications have been constructed the past few years and the rapid development in this field will make the flight over the ocean feasible.

Fixed wing drones can anticipate the needs of such a project as they have longer flight hours, much greater power capacity and payload. They can be equipped with either sniffer sensors or optical systems and inspect multiple ships per flight. These drones are already used for inspections in shore but would be possible to be used for inspections away from the coast. A fixed wing drone has specifications that would serve this purpose, however some research and development is required in order to achieve a more cost effective inspection plan. An appropriate drone of this class can fly approximately 20 hours without payload, which is satisfying, but any payload will substantially reduce the flight time. The maximum payload is 10 kg including the fuel and it can reach a cruise speed of 70 km/h. A payload of 5 kg is enough to reduce the flight time in half, that is 10 hours. The added payload reduces the fuel loaded on the UAV and therefore the flight time. The cost of such a drone can range from €1.5 million to €3 million including the necessary equipment.

Figure 6.5: Fixed wing drones can be used for sulphur inspection, Source: RMUS, Rocky Mountain Unmanned Systems

Compared to the simple, rotary drones that are already used for inspections in the ECA zones,the fixed wing drones are substantially more expensive and it is still doubtful whether we can rely on these drones to cross the oceans and inspect multiple vessels per flight. The cost of a rotary drone used for inspections is 150,000 USD, which is considerably less than the class of fixed wing ones that cost millions. Nevertheless, the drone technology is rapidly developing and new specifications are becoming available and less costly day by day.

Developments in drone industry have reached very high standards and although they are still in a research level there is more time ahead for further development and potential to use in 2020 for the enforcement in the high seas. Recently, Atlantik Solar published a paper about a new endurance world record reached with a solar powered drone. The flight of the solar drone lasted 81.5 hours and the distance traveled was 2338 km. The flight was fully autonomous for the 98% of the flight time and only a 2% was auto-pilot assisted. The payload of the solar drone was 6.8 kg and the total mass was measured to be less than 50 kg. The average power consumption was recorded to be 35-46 kW during the night and the power input through the cells was 260 kW, which provided enough power for the operation of the aircraft [28]. Developments in such drone technology can provide a bright solution for the enforcement even in the most unreachable parts of the ocean.

Figure 6.6: Atlantik Solar drone completed a 81-hour flight, Source: [28]

6.3 Fixed stations monitoring

Fixed platform systems include a very sensitive sensor adapted on a bridge or another fixed location like the entrance of a harbor, capable of detecting the level of pollutants by examining the plume when vessels sail under the bridge. The measurement in this kind of installations is usually conducted using a UV-fluorescence method. According to this method, SO_2 molecules' excitation by the UV light is used, and the fluorescence, which is a function of the SO_2 concentration, is measured. This method has been used in fixed stations installed in Hamburg port[22]. In this application the sensors were calibrated to have a response time of 120s and the percentage of SO_2 is determined by using a SO_2/CO_2 ratio to recognize the peaks of the sulphur and carbon dioxide and calculate the content for each set of peaks. The data is stored in an integrated data logger with time resolution of 1 min. However, data can also be sent to a central database using internet connection.

The sensors need to have excellent qualifications to overcome the problems that appear in the implementation of such a method. The ambient air and the pollution of the area is very important in determining the absolute value of the measurement and being able to distinguish compliant and non compliant vessels. Moreover, the wind direction affects the quality of the measurement, as it can lead the plume away from the sensor's position and make a measurement uncertain and inaccurate. The accuracy is also affected by the number of ships sailing close to the sensor and the plumes measured. A confusion could be created between the two ships and consequently the measurement will have to be discarded. The course of the ship and the distance from the sensor will affect the measurement in the same way by providing a faded measurement that has no value due to low quality. High sensitivity is therefore required in these cases in order to obtain a satisfying percentage of high quality measurements.

Sensors applied in fixed stations are of high quality and the cost can be accordingly high, but the main characteristic that influences the choice and installation of such systems is the accuracy of measurements that can be easily distorted and end up in a low quality measurement. Airborne monitoring systems can provide higher quality measurements but do not facilitate the enforcement operation and have a higher cost, as it can be noticed in Table 5.4.

Fixed stations could potentially be developed in the middle of the ocean, where they would have to be adjusted to the conditions of the high seas. A floating measurement station could become a useful tool that can measure emission from the passing ships. For that reason, such a station would have to be installed in one of the main shipping routes and increase the chances of being close enough to a merchant ship. However, this method has not been used before and multiple adaptations would have to be done in terms of the sensors used and the installation itself. The sensors and the structure they are integrated on need to be durable in the extreme weather conditions that dominate the ocean. Optical systems could be a solution for this kind of platforms as they have the possibility to measure in a radius of up to 5 km.

6.4 In situ emissions monitoring

In situ emissions monitoring can be conducted by applying specialized sensors on the stack of the ship and measuring the emissions directly from the plume of the ship. This method would ease the way for the authorities that would have a real-time overview of the compliance of every merchant vessel around the world. Data regarding the content of any pollutant emitted and measured on the spot could be sent to a database in shore, as it has already been imposed with scrubber installations and continuous emissions monitoring. A specialized device needs to be developed and integrate the sensors needed to measure the emissions. However, a number of restrictions have delayed and stopped the development of such a device.

One of the main restrictions regarding this project is the possibility of tampering with the device. A measurement device needs to be tamper-proof and deter the crew from changing the data input or pausing the data collection and transmission to the authorities. Non compliant ships will have the incentive and opportunity, once they are in the high seas or unreachable by the authorities, to tamper with the device and alter the outcome of the data analysis. Apart form tampering, the sensitivity of the sensors that need to be integrated in the ”measuring box” creates an important issue that needs further examination. SO_x, CO_2 and NO_x sensors are sensitive to high temperatures and could be destroyed if applied directly in the stack where the temperatures can be about 400°C. A protective structure for the sensors in the stack should be invented and applied in order to avoid potential loss of the sensors and the corresponding investment. The transmission of data is an issue that also needs to be resolved before implementation, as connection in the middle of the ocean is provided by satellite and potential communication of the box with the satellite connection provided by the ship entails the risk of tampering with the data. Encryption of the data would be a solution that can be applied in order to minimize investment costs for the autonomy of the device and the tamper-proof character of the device.

However, the technical problems described above are not the only ones preventing the application of this measure. The initial investment in this technology has to be done by the ship owners who will be obliged to equip their ships with the device. A special regulation that imposes the installation of this device, needs to be adopted by the IMO and oblige all merchants ships to be equipped with the technology and share the data of the measurements. It is unknown whether the authorities will choose to impose one additional law regarding sulphur enforcement but it is highly unlikely that another regulation will be used in order to enforce a regulation that will already cause a considerable change in the shipping industry and is accompanied by an unpredictable fuel cost.

6.5 Carriage ban

A feasible measure that could be immediately set in motion would be a carriage ban. This measure refers to controls and inspections in port of vessels that are not equipped with emission abatement methods and have chosen to comply with low sulphur fuel. The idea behind this method is that these ships have no reason to carry high sulphur fuel in their tanks and no excuse can justify the existence of a quantity of non compliant fuel or even traces of it. The only exception are tankers transporting this kind of fuel. In that case high sulphur fuel is considered cargo and it is stored in cargo tanks, separated from the fuel tanks that provide fuel to the combustion engine. However, the uncertainty about the composition and quality of the low sulphur fuel that will be introduced in the market in 2020 allows a certain amount of doubt since it might be possible to keep heavy fuel oil in tanks and blend it on board with ultra low sulphur fuel in order to achieve the demanded result. Blends are not yet examined in detail by the refining industry and the fuels that will be made available in 2020 have not been tested in the past in the maritime industry.

This check can be executed by the port state control when an ocean going vessel reaches port. The inspection does not require demanding or expensive technology and equipment and can be conducted by any PSCO. The enforcement of the carriage ban can be included in a routine port state control inspection that could cut down costs, man power and man hours. On the other hand, not only does it require a change in the legislation that will allow PSCOs to inspect the fuel tanks and charge the operators with a violation only for carrying this kind of fuel, but at the same time it can be a risk for the authorities as it can be tampered with from the operator and the crew. Ships could burn the total amount of non compliant fuel stored in their tanks while sailing in the high seas and before entering an ECA zone or a port. In case of inspection, the violation cannot be proved due to absence of fuel and consequently enough evidence to charge the culprits. The port state control will need additional information to target ships that are burning non compliant fuel in the high seas. This measure can be combined with other methods of inspection that could provide an indication of the non compliant ships and therefore improve the efficiency of the port inspections. Although it might not constitute a high end solution that will abolish any complimentary inspection method, it is a reasonable measure that will facilitate the enforcement in 2020, given that inspection methods are not developed and tested enough to provide experience for the upcoming sulphur cap. Substandard ships can still avoid getting caught by burning the non compliant fuel while sailing in high seas.

Chapter 7

Marine fuels in 2020

7.1 Marine fuel demand in 2020

The global demand of marine fuels can be predicted by using projections based on the supply and demand of the previous years for the different fuels. A substantial error has to be considered before using this data, as market analysis for the next three years cannot be accurate due to fluctuations stemming from political decisions and socioeconomic changes in the society. When projecting the demand and supply of the marine fuels, it is very important to take into account the new fuels that will be introduced in the fuel market in 2020 in order to meet the new requirements, as well as the uptake of scrubbers and LNG until that date that will have an impact on the demand of compliant fuels. The supply that will be determined by the refiners will affect highly the price of the fuels available in the market. All these factors considered, two individual studies have been conducted and submitted to IMO for the fuel availability in 2020, one by CE Delft and one by EnSys/Navigistics. Although they have different conclusions, the general fuel market trend remains the same.

The three scenarios developed in the study conducted by CE Delft show a global demand of marine fuels as presented in the table below (Table 7.1) [9].

Marine fuel demand is evaluated to increase by 8% between 2012 and

Table 7.1: Global fuel demand, Source:Assessment of fuel oil availability 2016 by CE Delft[9]

Sulphur content(%m/m)	**<0.10%**	**0.10%-0.50%**	**>0.50%**
	million tonnes per year		
Low case	33	198	38
Base case	39	233	36
High case	48	290	14

2020. This increase will be driven by changes in transport demand, fleet composition and operational efficiency. The market share of every kind of fuel will change according to the scrubber uptake and the LNG powered ships that will be operating in 2020. The demand of HFO is expected to decrease from 228 million tonnes in 2012 to 36 million tonnes in 2020 in the base case because the ships equipped with scrubbers occupy only a small share of the merchant fleet. A new type of fuel with 0.5% sulphur content or less will absorb most of the demand and is estimated to reach 233 million tonnes in the base case. The low sulphur fuel used in the ECA zones with 0.1% m/m or less is mainly Marine Gas Oil (MGO), Marine Diesel Oil (MDO) or Ultra Low Sulphur Fuel Oil (ULSFO). The demand for these fuels is projected to be 39 million tonnes per year in 2020, while demand only for MGO in 2012 was recorded to be 64 million tonnes per year.

The results of this fuel availability assessment were doubted by the study submitted by EnSys/Navigistics, as it was thought that is has conservative calculations about the demand[12]. In the second study submitted by BIMCO and IPIECA to the IMO, a total volume of 342 million tonnes of marine fuels per year is predicted to be needed in 2020. Out of 342 million tonnes, 195 million tonnes are expected to be marine distillates with sulphur content of 0.5% or less, and 48 million tonnes HFO. The marine distillates will replace an amount of 205 million tonnes per year HFO that is used now in the high seas and the demand for HFO corresponds to the ships equipped with scrubbers. The HFO demand according to this study will drop about 44%, from 253 to 48 million tonnes per year in the base case, which is 12 million tonnes more than the prediction of the study by CE Delft.

The conclusions of the two studies are different, as the difference in projected demand and supply for the marine fuels leads to different results for the fuel availability in 2020. However, they both draw a similar picture about the demand of marine fuels in 2020. A drop is predicted in the demand of HFO and a significant increase for the marine distillates with 0.5% m/m sulphur or less, like MGO, MDO, ULSFO and blends that are expected to be available in 2020.

7.2 Marine fuel price predictions

Fuel prices are dependent on many different factors related to political, social, economical and other incidents that highly affect the fuel prices. Fluctuations in fuel prices are therefore risky to predict and any degree of accuracy cannot be guaranteed. Prices for marine fuels for the period July 2015 to April 2016 are depicted in the graph 7.1, where the fuel prices are provided by Bunkerworld[29].

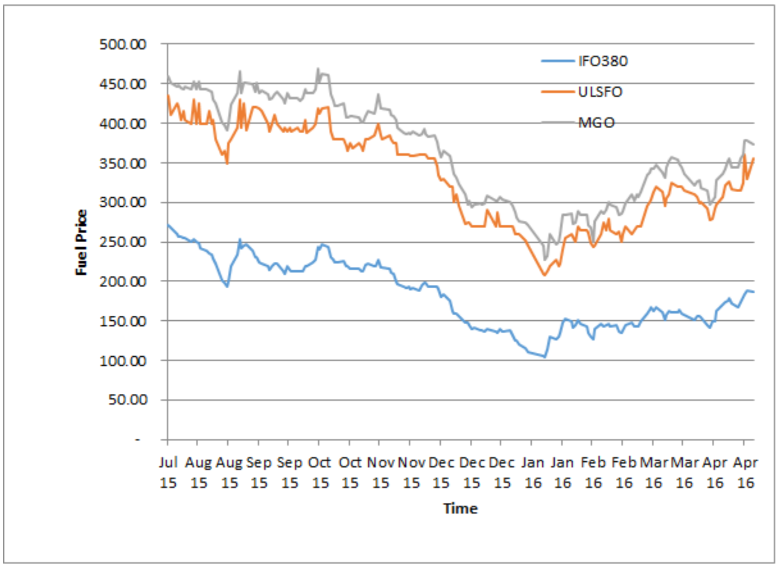

Figure 7.1: Fuel prices July 2015-April 2016, Data adapted from Bunkerworld

A drop in fuel prices started in mid-2014 and reached a minimum in the end of 2015 and beginning of 2016. In Figure 7.1 it can be observed that prices are rising again from 2016 and on, as shown in Figure 7.2, to reach approximately $ 340 USD per metric tonne in June 2017 for IFO380, $ 590 USD per metric tonne for MGO and $ 480 USD per metric tonne for MDO. According to Platts data [24] a very conservative estimation gives a $ 30/mt premium of 0.5% m/m over 3.5% m/m fuel. An overview of the latest prices of MGO and IFO380 is available at the graph 7.2.

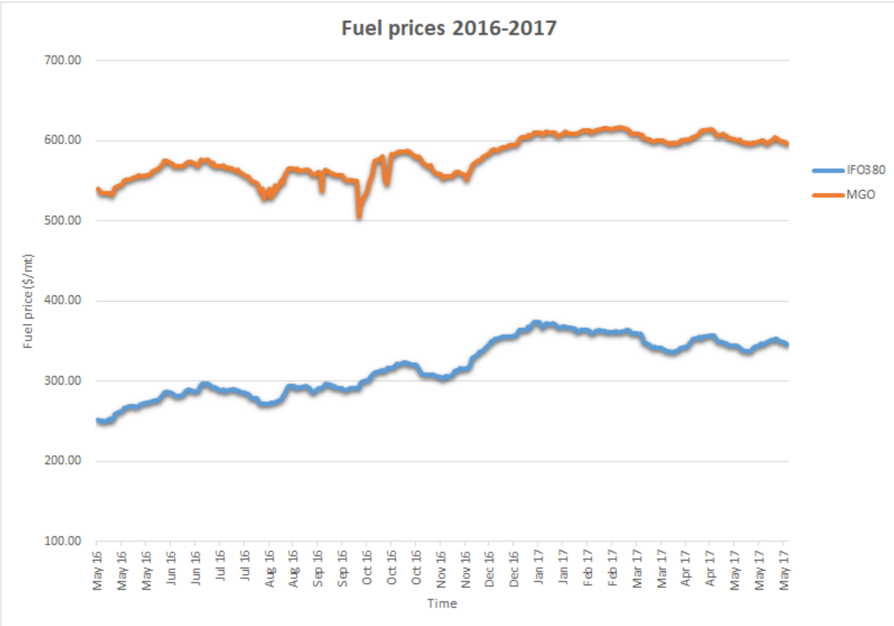

Figure 7.2: Fuel prices May 2016-May 2017, Data adapted from Bunkerworld

The last five years in the ECA zones, ULSFO that has a maximum sulphur content of 0.1% has taken market share over MGO due to its lower price, an average discount of $20/mt or more, the higher viscosity and lower volatility compared to the MGO. It can be used with lower risk for the engine and boiler, as it has to be heated like HFO and a thermal shock can be avoided.

The low sulphur fuels with 0.5% m/m sulphur that are expected to enter the market in 2020, are hard to estimate in terms of cost. Their price is not defined yet although some rough estimations give a general picture of the price trends. According to IBIA [15], the <0.5% fuel is expected to range from \$550 to \$620, depending on the demand and the uptake of scrubbers and LNG. MGO price is also expected to rise in 2020 due to the higher demand and is estimated to be around \$630. The price of the HFO will depend not only on the uptake of scrubbers and the demand, which is expected to fall substantially, but also on the supply from the refinery industry. Discussions about unavailability of HFO after 2020 are often encountered. Unavailability will result in a smaller drop of the fuel price. The uncertainty on this matter has led to price predictions with a wide range for the HFO price: from \$200 to \$350. In any case, the price differential of the 0.5% sulphur fuel oil and MGO or ULSFO is expected to be much smaller than the one with HFO due to the higher quality of the new fuel compared to HFO.

Chapter 8

Case studies

Case studies have been conducted in order to estimate the cost of complying for ocean going vessels that are also sailing in ECA zones. The cost of compliance is calculated using the price difference of HFO and LSFO in 2020. The objective of this section is to use the calculated compliance cost when the sulphur cap will be put in force in order to estimate the amount of fines that should be imposed in the ships that get caught violating the regulations. In that way, the enforcement strategy can be optimized and incentives for compliance are provided. The amounts of fines are currently decided by the police, and the profits are often not taken into account, resulting in poor enforcement that allows shipowners to continue burning non compliant fuel and making profits, unlike some of their competitors. In order to achieve a level playing field and a high level of compliance which will reduce emissions and improve pollution levels, it is necessary to force operators to pay a fine that exceeds their profits. A MATLAB code was developed in order to complete all the relevant calculations and several case studies have been conducted for individual ships in different routes and with different cargoes or engine specifications.

8.1 Cost estimation methodology

Due to the uncertainty in the predictions of the marine fuel prices, three scenarios have been examined, a low case, a base case and a high case scenario. The low case reflects a situation where the fuel prices are barely affected by the global sulphur cap. MGO will exhibit a price increase due to the expected increase in demand that will happen overnight and HFO price will not be affected significantly but will follow a descending course. The prices used in the low case are $550/mt for MGO and $360/mt for HFO. The base case follows the predictions for 2020, given that the market will respond to the changes within the expected limits and according to historical data. The prices for this case are taken as $300/mt for HFO and $600/mt for MGO. The high case reflects a situation where the HFO price will plummet due to the very low demand and MGO will have a corresponding increase. The prices considered in the high case for the case studies are $250/mt for HFO and $640/mt for MGO.

The price of the low sulphur fuel oil with sulphur content 0.50% or less can only be estimated as it is not yet available. Therefore, in the case studies we use for the LSFO: $530/mt for the low case, $570/mt for the base case and $610/mt for the high case, according to data from the IBIA [15].

Table 8.1: Projected fuel prices used in case studies

	Low case	**Base case**	**High case**
$ per tonne			
HFO	360	300	250
MGO	550	600	640
LSFO (<0.5%)	530	570	610

The fuel consumption of the ship in various engine loads is necessary for the evaluation of the volume of fuel consumed and the cost of fuel. Real fuel consumption was not possible to be found for every vessel examined, therefore a nominal fuel consumption for all engine loads is used. Engine loads and the corresponding nominal fuel consumption can be obtained from the data provided by engine manufacturers, but real fuel consumption has to be provided by the shipping company owning the vessel.

The engine load of the main engine for various speed values is not available in the data gathered because it would have to be provided by the shipping company, so it is calculated using the propeller law or cubic law [40]. The engine load is dependent on the engine speed, the weather conditions and the loading condition of the ship. Using the sailing speed we can estimate the engine load with Equation 8.1:

$$\frac{EL_1}{EL_2} = (\frac{V_1}{V_2})^3 \tag{8.1}$$

The exponent n=3 is a good estimation for bulk carriers and tankers that sail in usual operational speeds. However, faster ships, like container ships or cruise ships that usually sail in higher average speeds in order to deliver goods on time or reach their destination according to schedule, need higher exponents for more accurate results. According to Zis et al. [40], values from n=3.2 or n=3.5 can be used for medium-sized vessels, tankers and feeder container ships, and higher exponents up to n=4.5 for fast container ships and in extreme weather conditions. In these case studies, cargo load and weather conditions are not taken into account due to lack of relevant data. The propeller law is applied with data about the average speed of the vessel from port to port. A drawback of the cubic law is the result returned in very low speeds [30]. It cannot be applied in very low or zero speed. In zero speed it returns zero consumption, whereas a ship keeps consuming some amount of fuel even while at berth. It would be preferable not to use a very low engine load and obtain more realistic results about the fuel consumption.

The engine load calculated in this study is set to have a minimum of 10% for engine safety and maintenance reasons, but also for cost minimization. According to a technical report published by the marine diesel engine manufacturer MAN Diesel & Turbo [36], although newer engines are designed in a way that specific fuel oil consumption is low even in very low engine loads, damage due to wear can be provoked to the engine in a continuous low load operation. Low loads in the region of 10% require increased operation time of auxiliary blowers(A/B) which might lead to an increased number of break-downs of the A/B. In order to avoid break-downs, more frequent maintenance is necessary and consequently higher engine cost. MAN B&W recommends to carry a spare blower on board if the vessel is scheduled to operate in low loads for a longer period of time than the usual. In low engine loads it has been observed that increased cylinder pressures and low cylinder liner wall temperatures can provoke extreme wear in the main engine due to the phenomenon of cold corrosion [13]. In the case studies in the context of this thesis, a lowest limit of 10% is set, in order to avoid extreme wear and increased maintenance costs.

The engine load in the case studies determines the specific fuel oil consumption (SFOC), which is used to calculate accurately the fuel consumption of the vessel. SFOC values are obtained by the engine manufacturer's websites and the SFOC curves and tables they provide for every type of engine. In cases where the specifications of the engine installed are not available by the manufacturer, a relation between the installed power and the SFOC deviation from the minimum SFOC that is met at 80% of MCR, is used to assess the SFOC values. The equation used to calculate the SFOC deviation from the minimum SFOC value and therefore the values for all engine loads, was developed by Hans Otto Kristensen for two-stroke engines [23]:

$$SFOCdeviation(\%) = 0.0028 * MCR^2 - 0.41 * MCR + 15 \tag{8.2}$$

where MCR is used as a percentage. The equation is inserted in the program whenever accurate fuel consumption data is not available. Fuel consumption of every vessel can be then estimated with the equation 8.3.

$$FC_i = 10^{-3} * SFOC_i * EL_i * EP * t_i \tag{8.3}$$

where i is a specific engine loading condition, FC is the fuel consumption in tonnes, SFOC is given in g/kWh, EL is the engine load in the i situation, EP expresses the installed engine power and t is the sailing time for the i condition [40].

Speed is adjusted according to the engine load and follows the limits set by the manufacturer, aiming in the good preservation and maintenance of the main engine. The minimum speed depends on the minimum load which, for the purpose of this study, is set to 10% and the maximum speed corresponds to 100% engine load. The speed inside and outside ECA is optimized with the objective of minimizing the cost of fuel, given that fuel with 0.1% m/m sulphur is more expensive than 0.5% m/m. Consequently, we expect to have higher speeds outside ECA zones and lower speeds in ECAs. This practice is often followed by many shipping operators that are trying to save "expensive" fuel when sailing in ECAs. However, in some cases like container ships and other liner shipping routes, it is essential to stick to the predefined schedule and very low speeds are not always possible to reach. Apart from the engine load, the schedule given from the company is also used as a constraint to set the lower and upper bound of the speed values.

Schedules of the container ships are obtained by the websites of the operators where some data is provided, including departure and arrival time and the ports called. Due to the lack of data regarding the exact transit time, the speed limits set inside and outside ECAs determine the waiting time and transit time from port to port. The values are not obtained by the shipping companies, therefore they might differ from real transit times, but provide us with a good estimation that allows to calculate the engine load and SFOC. Distances between ports and distances traveled within ECA zones are acquired by MarineTraffic.

Engine specifications in combination with the vessel's schedule and speed provide us with the cost of the fuel per trip in Eq.8.4, and the yearly cost if multiplied by the trips a vessel is conducting per year in Eq.8.6. The cost is calculated separately for both ECA and non-ECA zones assuming that compliant fuel is used in every case, i.e. 0.1% m/m sulphur inside and 0.5% outside ECA zones. The total fuel cost results from the sum of the two independent costs, as shown in Eq.8.5. The cost in case the ship is not compliant in the high seas is calculated assuming that the fuel burnt is HFO with percentage higher than 0.5% m/m sulphur.

$$Cost_k = FC_{i,k} * FP_{j,k} \tag{8.4}$$

$$Cost_{TOTAL} = Cost_{ECA} + Cost_{NON-ECA} \tag{8.5}$$

$$Cost_{YEAR} = Cost * No \tag{8.6}$$

where FP_j is the fuel price for the case scenario j and k characterizes the ECA or non-ECA sailing cost. In Equation 8.6, the yearly cost is estimated by multiplying the cost per trip with the number of trips per year. Three cases are examined for the given vessels: a low case, a base case and a high case. In every case, different fuel prices are assigned, as explained above.

8.2 Calculation of fines

The main purpose of this task is the calculation and suggestion of a minimum amount of fine that should be imposed if a ship gets caught for non complying. The fine should be such, that shipowners would have no reasonable incentive to violate the regulation and bunker non compliant fuel. The profits made by non compliance should be eliminated and a penalty has to be high enough to deter any similar behavior in the future. It has been observed that the fines imposed in some regions are not even covering the profits made by the shipowners per trip. The suggested fine is determined by the profits calculated and is suggested to be equal to at least twice the savings per trip. That would provide enough deterrent for the shipowner not to risk being caught non-compliant. If the fine is lower or equals the profits, the shipowner will be willing to take the risk to burn cheaper fuel and pay the fine if the ship gets caught.

8.3 Case study 1: Magleby Maersk

Magleby Maersk is a container ship owned by the Danish shipping company Maersk and belongs to the Triple E Class that was introduced by Maersk and comprises of container ships of more than 18,000 TEU. Magleby was built in 2014 by Daewoo Shipbuilding and it sails since under the Danish flag and registered at the American Bureau of Shipping (ABS). It has an overall length of 399.2 m, breadth 59 m and maximum draft 16 m. The Gross Tonnage (GT) is 194,849 t and the nominal TEU are 18,270 as reported by Maersk. The ship is equipped with two MAN B&W engines with a power output of 29,680 kW each and in total they can produce 59,360 kW. An overview of the general particulars is available in Table 8.2. Maersk has deployed it in route AE10, from Asia to Europe and the opposite. It has many port calls in European waters inside the European ECA, but also in Asia where, although Asian waters have not been recognized as ECA, the national regulations decided by the Chinese government are gradually restricting the sulphur emissions.

Table 8.2: General particulars of Magleby Maersk

MAGLEBY MAERSK	
Class	Triple E
Date of build	10-02-14
TEU	18,270
GT (t)	194,849
LOA (m)	399.2
B (m)	59
Tmax (m)	16
Engine	2x 8S80ME-C Mk9.2 by MAN B&W
Total output (kW)	59,360
Max. speed (knots)	22

According to the schedules made available in the Maersk Line website, the ship follows a route from Gdansk to certain ports in northern Europe inside Baltic and North Sea and it proceeds to the Suez Canal with direction to Asia and its next stop in Tanjung Pelepas. After several calls in ports like Shanghai in China and Busan in South Korea, where it will probably load cargo, Magleby is headed back to Europe and Rotterdam through Suez Canal. The whole trip lasts approximately 81 days and almost 9 of them are spent in ECA zones and more specifically in the European ECA. In graph 8.1, the time spent sailing in ECA zones is represented by blue color and it is projected against the total time for one trip which is represented by green color. This graph provides an overview of the zone where the ship is sailing most of the time and the fuel it should burn in each case.

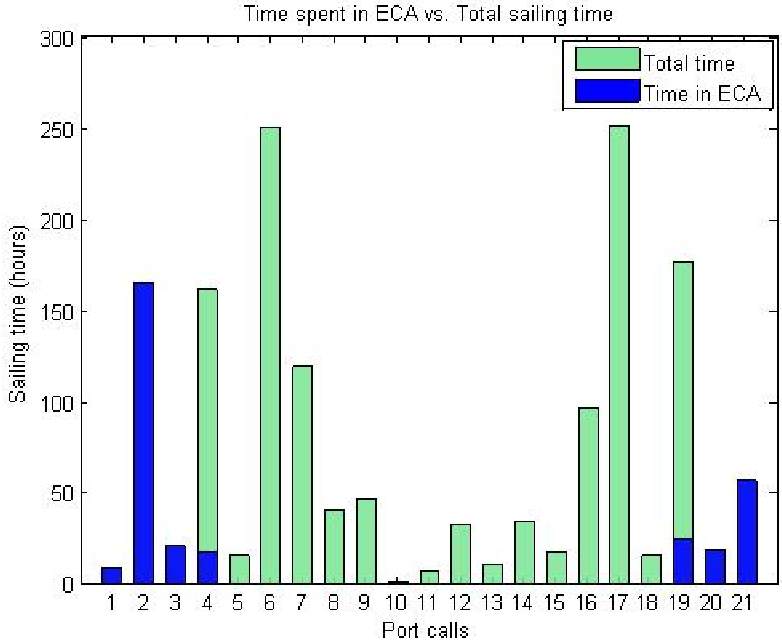

Figure 8.1: Time spent in ECA against total sailing time

The fuel consumption during its trip is calculated using the engine data provided by the manufacturer and is presented in the graph 8.2. The bars of the graph show the fuel consumption in the ECA zones from port to port in blue color and the total fuel consumption from port to port in magenta. Therefore we can realize that the volume of fuel spent in the ECA zones is depicted in blue and the rest that is colored in magenta is the fuel spent in the high seas. For the specific route and ship a major part of the total fuel consumption is spent in the high seas or outside ECA zones as it is travelling to Asia, where no ECA zones have been designated so far or planned to apply form 2020 and on. The sums of the fuel consumption per trip are presented in Table 8.3.

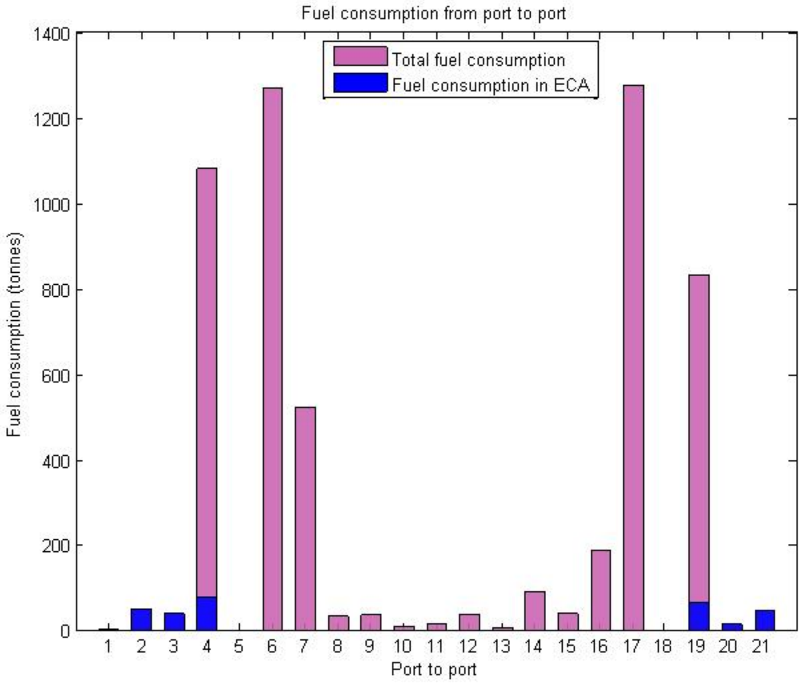

Figure 8.2: Fuel consumption from port to port

Table 8.3: Fuel consumption per trip

Fuel consumption (tonnes)	
ECA zones	307.13
High seas	5298.14
Total	5605.27

The emissions if Magleby Maersk complies with the regulation and bunkers LSFO with sulphur <0.5% m/m are presented in Table 8.4 where a comparison with the emissions if the ship was burning HFO with sulphur content 2.7% is available. The 2.7% value is used because many of the residual oils available in the market have a sulphur content of 2.7%.

Table 8.4: Sulphur emissions per trip for Magleby Maersk

	LSFO (<0.5%)	**HFO (2.7%)**
Sulphur emissions (tonnes)	0.56	3.02

The SFOC values were retrieved by MAN B&W and the project guides published online and were used to produce the SFOC curve in order to have an overview of the ship's specific fuel consumption, presented in Figure 8.3.

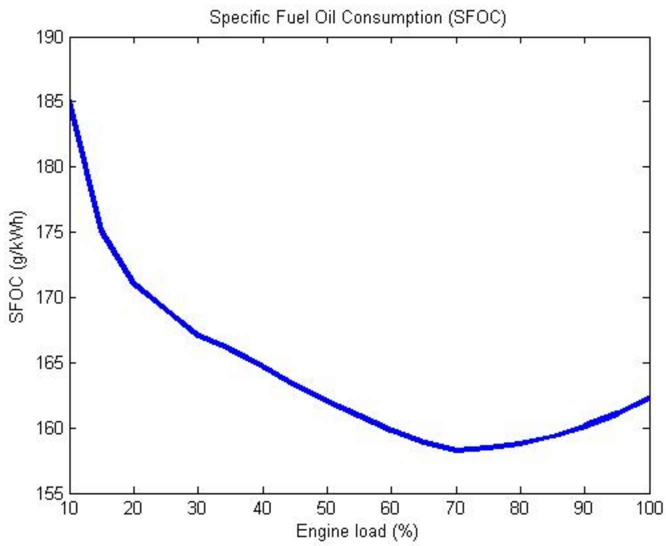

Figure 8.3: SFOC Curve of Magleby Maersk

Using the engine load and SFOC values with the time spent inside and outside ECA, the fuel consumption was calculated and consequently the fuel cost for the three case scenarios. Service speed is assumed to be at 80% engine load and according to the speed from port to port that is obtained by the speed optimization section, the corresponding engine load and SFOC is assigned to every speed. The fuel cost graphs show the fuel cost for the ECA zone presented against the total cost of the ship. The costs are distributed between the port calls, with port 1 being Gdansk and heading to Asia and port 21 being the last port call when returning from Asia in Gdansk again.

The fuel costs are calculated for all three case scenarios and the base case scenario is presented in the graphs 8.4-8.5 for LSFO and HFO respectively.

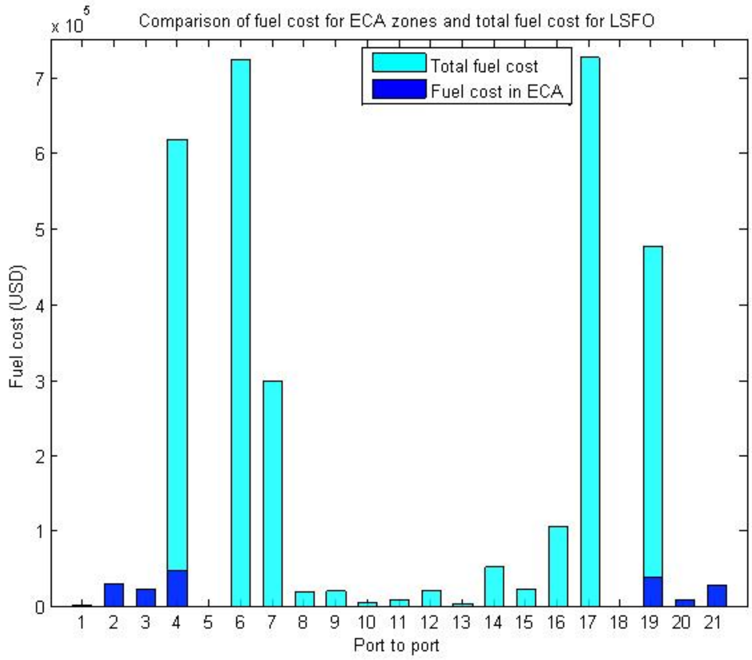

Figure 8.4: Fuel costs for running in LSFO

The fuel costs for every scenario are presented in the Table 8.5 where we get an overview of the costs for a single trip of a ship of that size. The ship spends only 13% of its time inside ECA zones and therefore the fuel cost inside an ECA is as high as the one in the high seas. The difference in the total cost before and after 2020 is considerably high as the bunker consumption in the high seas is the prevailing value compared to the ECA consumption. In order for Magleby to be compliant, the fuel cost in 2020 will be approximately 74% more because it spends most of the time in the high seas.

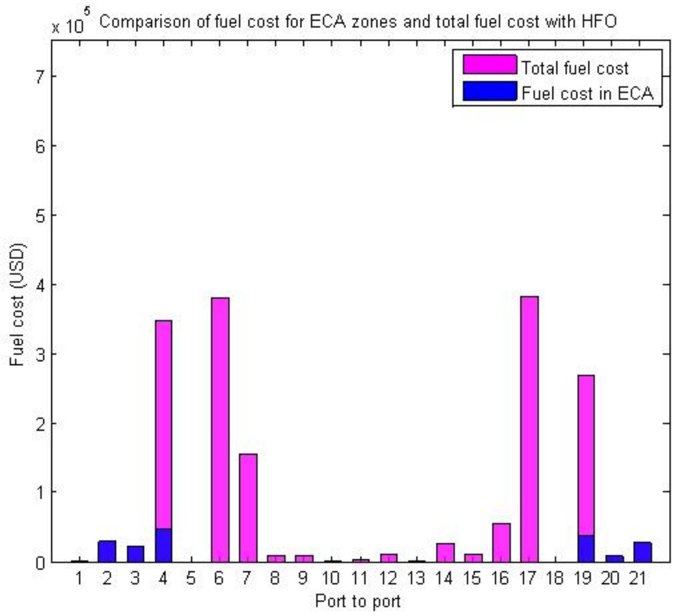

Figure 8.5: Fuel costs for running in HFO

Table 8.5: Fuel costs and savings for LSFO and HFO per trip

	Burning LSFO<0.5%	**Burning HFO**	**Savings per trip**
in millions USD			
Low case	2.976937	2.076253	0.900684
Base case	3.204219	1.773720	1.430498
High case	3.428430	1.521099	1.907331

The additional cost per trip for Magleby Maersk for burning LSFO in the high seas instead of HFO is presented in Table 8.6 in percentage. The table presents the extra cost the shipowner has to pay compared to HFO. In the low case it will cost 43% more. in the base case 80% more and in the high case 125% more. The cost is very high due to the increased time the vessel spends in the high seas and the operation time which reaches 81 days.

Table 8.6: Additional cost for burning LSFO instead of HFO for Magleby Maersk

	Additional cost for burning LSFO
Low case	43%
Base case	80%
High case	125%

It can be observed that for a ship of this type and similar size the fines need to be considerably higher than they have been so far. If such a ship is caught not complying in 2020, the fine imposed would be affected by the gravity of the violation, that is the sulphur content of the fuel that was burnt, but a general estimation of a fine equal to double the profits is presented in Table 8.7.

Table 8.7: Fines suggested for burning HFO in three scenarios

	Low case	Base case	High case
in millions USD			
Fine for burning HFO	1.801368	2.860997	3.814662

8.4 Case study 2: Maersk Iowa

Maersk Iowa is a container ship belonging to the Danish Shipping company Maersk Line and was built by Hyundai Heavy Industries Ltd. Co in South Korea in 2006. It carries a US flag and is registered in Lloyd's Register. The ship has a capacity of 4,650 TEU and its gross tonnage (GT) is 50,686 t. It is equipped with two main engines which are manufactured by Wartsila and have a total power output of 45,764 kW that provide the vessel with a maximum speed of 23.3 knots. The main particulars are shown in the Table 8.8.

Table 8.8: General particulars of Maersk Iowa

MAERSK IOWA	
Class	Lloyd's Register
Date of build	10-01-2006
TEU	4,650
GT (t)	50,686
LOA (m)	292.08
B (m)	32.35
Tmax (m)	13.5
Engine	2xWartsila 8RT-flex96C
Total output (kW)	45,764
Max. speed (kn)	23.3

The vessel is deployed in the route TA1 from Europe to the US and reaches 7 different ports. The trip lasts 36 days and the schedule is presented in Table 8.9. The sailing route and schedule is obtained by Maersk Line website where the timetable is published.

Table 8.9: Schedule of Maersk Iowa

Port calls	**Date of departure**
Antwerp	19-06-17
Rotterdam	20-06-17
Bermerhaven	22-06-17
Norfolk	01-07-17
North Charleston	03-07-17
Miami	05-07-17
Rotterdam	09-07-17
Norfolk	14-07-17
Antwerp	-

By analyzing the schedule we can get the graph of the time spent inside and outside ECA zones (Figure 8.6). The vessel operates in the Baltic Sea and North Sea ECA and in the North American ECA and the distances are obtained by Marinetraffic.com. The time spent in ECA zones is presented in graph 8.6 and corresponds to blue color bars and the total time for one trip is also presented in the same graph with green color. This graph provides an overview of the zones where the ship is sailing most of the time and the fuel it should burn in each case.

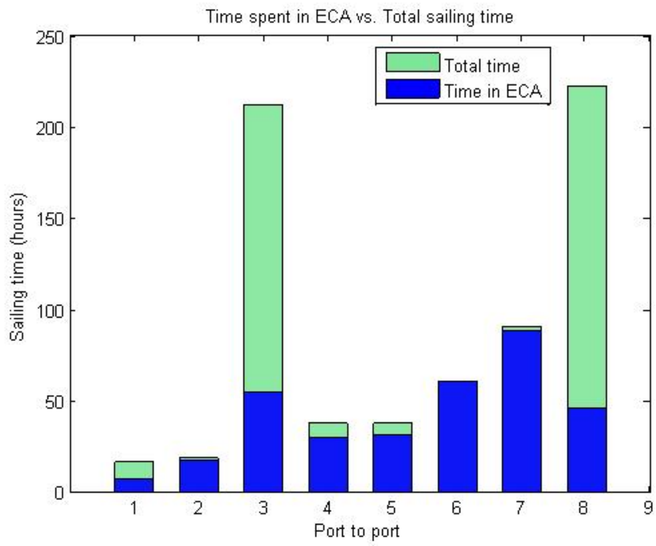

Figure 8.6: Time spent in ECA against total sailing time

The fuel consumption during its trip is calculated using the engine data and is presented in the graph 8.7. The engine data are obtained by the manufacturer's website and the project guide of the engine published. The bars of the graph show the fuel consumption in the ECA zones from port to port in blue color and the total fuel consumption from port to port in magenta. Therefore we can realize that the volume of fuel spent in the ECA zones is depicted in blue and the rest that is colored in magenta is the fuel spent in the high seas. For the specific route and ship an important part of the total fuel consumption is spent in ECA zones due to the amount of time sailing in ECAs. The sums of the fuel consumption per trip are presented in Table 8.10.

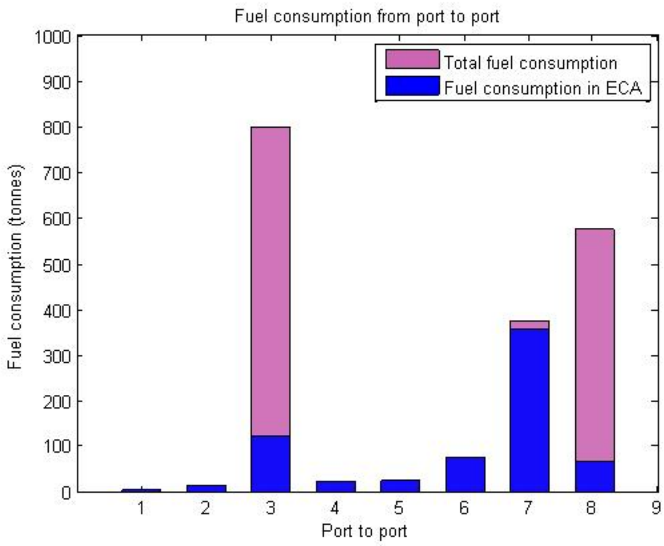

Figure 8.7: Fuel consumption from port to port

Table 8.10: Fuel consumption per trip

Fuel consumption (tonnes)	
ECA zones	702.11
High seas	1197.54
Total	1899.65

The sulphur emissions during one trip can be easily calculated for every kind of fuel and are indicatively presented in Table 8.11 for LSFO and HFO assuming a sulphur content of 2.7% which is a high content in fuel and the violation would be listed as severe violation of the sulphur regulation. The 2.7% value is used because most of the residual oil available in the market contains 2.7% sulphur. The engine load and SFOC values are dependent on

Table 8.11: Sulphur emissions for Maersk Iowa per trip

	LSFO (<0.5%)	**HFO (2.7%)**
Sulphur emissions (tonnes)	0.19	1.025

the speed of the vessel which was optimized for sailing inside and outside ECAs. After the optimization, a value of the engine load is assigned to every speed value and a corresponding SFOC value is calculated using Equation 8.2. The service speed is assumed to be obtained at 80% of the engine load and the minimum SFOC is provided by the manufacturer as 171 g/kWh. The following figures (8.8 and 8.9) depict the fuel costs for sailing inside ECA zones versus the total cost between port calls.

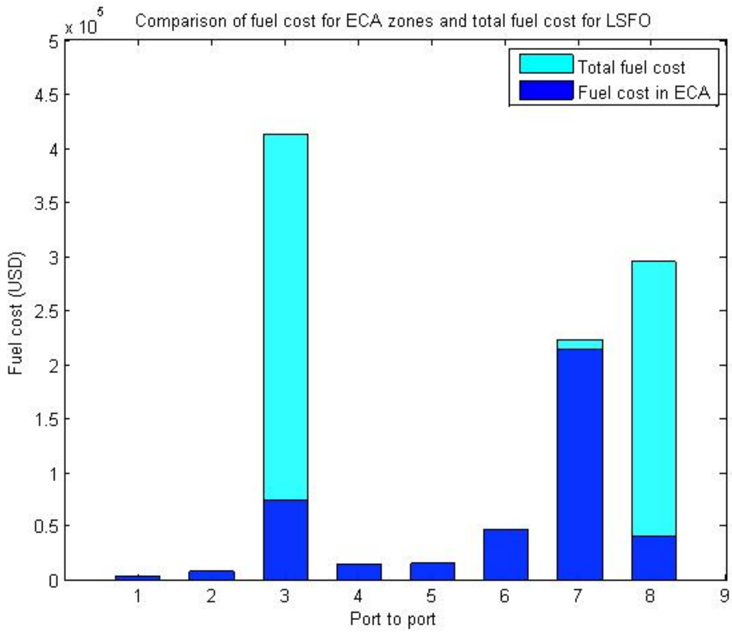

Figure 8.8: Fuel costs for running in LSFO

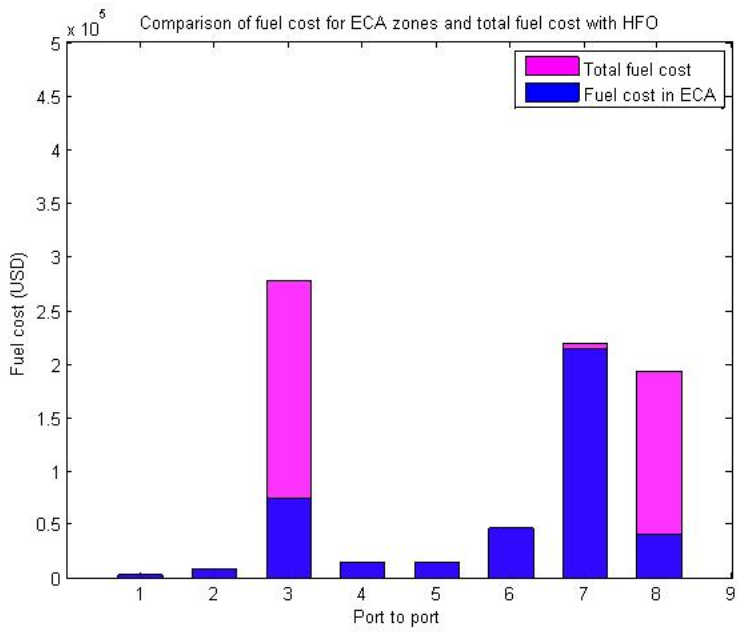

Figure 8.9: Fuel costs for running in HFO

The fuel costs calculated for the three scenarios using the engine data are presented in Table 8.12.

Table 8.12: Fuel costs and savings for LSFO and HFO per trip

	Burning LSFO <0.5%	**Burning HFO**	**Savings per trip**
in thousands USD			
Low case	925.053	817.274	107.778
Base case	1,020.035	780.526	239.508
High case	1,131.947	748.733	383.213

The additional cost for burning low sulphur fuel instead of residual fuel in 2020 using the projected prices in 2020 for the estimation in all three scenarios is presented in percentage in Table 8.13. In the low case the shipowner will have to pay 13% more for LSFO compared to if he bunkered HFO, in the base case 30% more and in the high case 51% more for fuel.

Table 8.13: Additional cost for LSFO instead of HFO for Maersk Iowa

	Additional cost for burning LSFO
Low case	13%
Base case	30%
High case	51%

It should be mentioned that the size of the ship and the route followed play an important role to the amount of fuel cost per trip. Maersk Iowa has much lower fuel costs compared to Magleby Maersk as it would be expected, not only due to the size of the ship which is considerably smaller, but also due to the route followed. Maersk Iowa spends 48% of its sailing time inside ECA zones and the fuel cost is higher due to the more expensive fuel that needs to be consumed in ECAs. The cost difference in 2020 will not be proportionally as high as in the case of Magleby due to the route followed. Sailing with LSFO in spite of HFO will cost approximately 30% more for one trip.

The fines suggested in the case of Iowa Maersk are double the savings as calculated above and are presented in Table 8.14.

Table 8.14: Fines suggested for burning HFO in three scenarios

	Low case	**Base case**	**High case**
in thousand USD			
Fine for burning HFO	215.557	479.017	766.427

The fines recommended are based on a double-the-savings estimation but could be adjusted according to the situation and the violation. The fines of every case study constitute a suggestion for the penalty policy and various methods can be devised to estimate the fines imposed for the sulphur regulation. The compliance history of the ship and the shipping company is suggested to be taken into account, as well as the willingness of the shipowner to pay an administrative fine on the spot or proceed to court. A case taken to court would add in time and resources and it could even lead to a shipowner being discharged of the obligation to pay a fine. Administrative fines should be available in all countries and port state control should be authorized to issue them on the spot.

Chapter 9

Penalties

9.1 Fines

The authorities responsible for the fines in every state should be able to adjust the fines in every situation. The main parameters that should affect the amount of a fine, either administrative or issued by the court, are the gravity of the violation, i.e. what was the sulphur content of the fuel used, and the profits that the operator made by burning non compliant fuel. A methodology to estimate the profits of non compliance has been explained above and used to present the suggested fines in specific cases. This methodology can be used for various types of ships and sizes and provides the opportunity to adjust the calculations to the fuel used and therefore take into account the gravity of the violation. The fluctuation of the fuel prices is also an issue that can be easily resolved as it can be implemented for a variety of prices. The prices used in the case studies are projection estimations and the fact that these prices are dependent on many factors and can suddenly change can be resolved.

It is recommended that the fines should be at least twice the savings a ship has per trip, in order to make non compliance unprofitable for the shipping companies. The compliance history of the shipping company should play a crucial role in the decision of the fine imposed. Ships found consistently non compliant, should be punished with higher fines in order to deter future non compliance. The frequency of inspections and the chance of a ship getting caught in the port is a variable that should be examined before deciding the amount of the fine, but because of the lack of data regarding the inspections and the confidentiality of the whole procedure, it was not possible to assess this variable.

9.2 Detention

An alternative but very effective measure to impose as a penalty for non compliant ships is detention in the port. Currently, detention of a ship is possible when violations of laws and regulations are found on board during the inspection of the port state control officer. These violations usually regard the structural safety of the ship and the safety and health of the crew. Non-compliance with air pollution prevention regulations has not been punished with detention so far.

Detention of a ship in the port can be directly translated to cost implications. A delay of a ship in the schedule may result to loss of cargo, as a very sensitive cargo needs to be quickly transported. In addition, when a ship is kept in port, the operative costs have to be covered, despite the fact that it is not operating at the time. The crew need to be paid as if it was working on the ship and all actions on the ship are charged normally to the charterer or shipowner. A delay in the port could result in severe costs that will burden the ship operator immediately and cannot be dealt later in a courtroom. Lodging an appeal for the fine imposed is not going to save any of the costs that the shipowner will be charged with.

Detention is an effective measure that will create a satisfying incentive for the ship operators to comply with the sulphur regulations. Violations regarding airborne emissions and air pollution have not been punished with detention before and the current policy does not promote detention of a ship in port as a measure to tackle this problem. However, it could be proposed and considered by the authorities and IMO, in case of severe violations. The adoption of this measure should be reviewed in combination with the legal regime of each country that chooses to impose it. Introduction of a new law in the national legislation may be required in order to impose detention for this reason and extensive legal research is necessary before adoption. The duration of the detention of the ship could be decided by the current authority and port state control according to the gravity of the violation and the willingness of the shipowner to pay a fine on the spot.

9.3 Incentives

Imposition of fines is necessary to ensure that shipowners comply with the regulations, but positive reinforcement sometimes might prove more helpful and effective. Shipping companies will become more condescending and willing to carry the burden of the additional cost of the compliant fuel, if rewards to compliant ships are awarded by ports or port states. Facilitation in ports, lower port fees and taxes and more incentives can be considered to be offered to ships who are found systematically compliant and violations of the regulations are not registered.

Controls in ports or in the high seas can distinguish complying ships, and by extension, shipping companies and reward them with advantages in ports. Although all ships ought to be compliant, additional motivation could raise the compliance rates and coerce the shipowners' collaboration. The incentives provided to companies with compliant ships should be decided by the port administration and port state control of the specific country. This is a policy in which ports can invest voluntarily in order to increase compliance and depends on the approach of every coastal state.

Chapter 10

Conclusions

This chapter summarizes and categorizes the results for the penalty policy and presents an overview of the enforcement schemes that are or could be applied to the inspections for the global sulphur cap.

The implementation in 2020 needs to be accompanied by strict enforcement which will ensure high compliance levels. Many methods have been developed and measures have been proposed and the most prominent ones are summarized in this chapter.

10.1 Enforcement schemes

10.1.1 Carriage ban

A carriage ban implies that non compliant fuel will be carried in the fuel tanks by the ships in the high seas. This measure can only apply to the ships that will choose to comply by burning low sulphur fuel and not to ships that are complying with emission abatement methods or LNG fueled engines. It will be prohibited for these ships to bunker and burn heavy fuel oil and port state control will have to inspect the bunkering operations or check the fuel in the fuel tanks to make sure that non compliant fuel is absent from the tanks. Heavy fuel oil transported as cargo in tankers is exempted from this rule, but tankers are still not allowed to burn heavy fuel oil. The most important disadvantage of this measure is that not all ships can be controlled while bunkering fuel and therefore they can burn all the non compliant fuel in the high seas where they will not be inspected. However, it is a very easy measure to implement and enforce and it can provide increased pressure to the shipowners.

10.1.2 Airborne monitoring

Airborne monitoring has been discussed as a method for monitoring every kind of emissions with different sensors and methodologies that provide the possibility to use for various applications. Airborne monitoring provides a wide range of measuring units and means like, airplanes, helicopters and UAV. Every system offers different specifications and can be used in different instances resulting in different costs of operations.

UAV is the most popular solution that is dominating this field. UAVs provide a low acquisition and operation cost compared to the helicopters or airplanes and therefore the cost of each measurement. UAVs provide flexibility due to the absence of pilots on the aircraft and their speed is satisfying enough to complete measurements above the plume of the ship or even higher in case optical systems are integrated. The restrictions that apply for the UAVs close to the coast limit their functionality and raise the cost, but UAVs have managed to stay competitive. Research and development in this field has provided a wide range of solutions that can be effective in the high seas. Fixed wing drones, solar drones and micro fuel cells that provide higher autonomy and longer flight duration are some of the possibilities that could be examined before 2020. Further development is needed towards this direction but the fast progress offers promising potential for the future enforcement methods.

Specially equipped aircrafts like helicopters and airplanes are deployed for measurements further from the coast where the UAVs are not allowed to operate. Helicopters usually operate with sniffers that require to stay above the plume for a few seconds, but airplanes are equipped with optical measuring systems that can operate in higher speeds and from a longer distance from the vessel. The cost for operating airplanes and helicopters is increased compared to the UAV, not only due to the manning of the aircraft but also due to the fuel, operation and maintenance costs of such an aircraft. Airplanes used for these missions are special airplanes with characteristics that facilitate the measurements, as they have the ability to fly closer to the sea level and not to develop very high speed that will not provide the sensors the required time to complete a high quality measurement.

10.1.3 In situ emissions monitoring

Although many restrictions apply to this technical solution, an application of such a measurement would be a complete solution to the enforcement not only of the global sulphur cap, but at the same time of future regulations concerning the emissions from ocean going vessels, including CO_2, NO_2 and particulate matter (PM). The sensitivity of the sensors and their protection from the dangerously high temperatures of the plume, the tamper-proof character required to deliver real data to the authorities and the unwillingness and resistance of the shipowners to buy a device and invest more out of their resources are the main problems that hinder the implementation of this measure.

Indicative costs for the predominant inspection options so far are presented in Table 10.1.

Table 10.1: Cost per measurement for various methods applied in Denmark

Surveillance method	**Cost per inspection/ measurement (€)**
Port inspection	48
Fuel samples	80
Airborne	336
Fixed station monitoring	17.5

10.2 Penalty policy

A method for the calculation of penalties, for ships sailing both in ECA zones and in the high seas, according to the fuel cost savings and the gravity of the violation using the type of non compliant fuel burnt as a variable, is presented in chapter 8. The suggested fines that emerged from the case studies examined in this thesis are presented in this chapter extensively and the main conclusions from the implementation are provided below.

A tool to calculate the fuel consumption and fuel savings according to the fuel burnt by each vessel was developed. This tool is using the engine power and the Specific Fuel Oil Consumption (SFOC) curve and values to estimate the fuel consumption of the specific vessel under investigation from port to port. The distances traveled and transit times needed are inserted in order to decide the optimal speed to sail inside or outside ECA zones. The speed of the vessel could alternatively be inserted if known. Speed is used to determine the engine load in which the ship operates in different occasions and the corresponding SFOC value that will allow us to calculate the fuel consumption of the main engine. Fuel consumption is then used to estimate the cost of the fuel by inserting current or projected fuel prices in 2020. The type of fuel determines the price of the fuel and the sulphur emissions which are also calculated in order to provide an overview of the environmental impact of a non compliant vessel.

The fines are calculated using an approach of double the savings per trip. This approach constitutes a suggestion in order to prevent shipowners from burning non compliant fuel in the future and risking getting caught, but many different suggestions can be inserted and implemented using this tool. The fuel costs and savings were calculated for three case scenarios which correspond to three different fuel price estimations for 2020. The results for the fuel costs cannot be compared to the fines that have been imposed from 2015 and on because they do not correspond to routes inside the ECA zones, where the regulation has been implemented and enforced so far. It can be observed that the fuel savings vary a lot according to the ship type and size, the route and the time sailed inside an ECA. Special attention should be payed to the fines that will be imposed in 2020 to non compliant ships, as the profits exceed by far the ones that have already been encountered inside the ECA zones. Savings of approximately $1.4 million per trip could be common in 2020, depending on the route and the fuel prices at the time. The fuel savings of Magleby Maersk as calculated in Chapter 8 are presented below to give an overview of the scale of the problem that needs to be anticipated in 2020 (Table 10.2).

Table 10.2: Fuel costs and savings for LSFO and HFO per trip

	Burning LSFO<0.5%	**Burning HFO**	**Savings per trip**
in millions USD			
Low case	2.976937	2.076253	0.900684
Base case	3.204219	1.773720	1.430498
High case	3.428430	1.521099	1.907331

The fines are calculated in each case using the same methodology and the fines proposed for Magleby Maersk are presented below as an example for the amounts suggested (Table 10.3).

Table 10.3: Fines suggested for Magleby Maersk for burning HFO in three scenarios

	Low case	**Base case**	**High case**
in millions USD			
Fine for burning HFO	1.801368	2.860997	3.814662

The requirements of input for the tool are minimal as a good estimation is provided by using nominal values of the engine specifications and the routes as they are published by the shipping companies. Consequently, the cost savings calculated are based in estimations and not in values provided by the companies and can be used by the authorities in order to save time and resources to acquire accurate information of the fuel consumption.

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