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Assessment of cost as a function of abatement options in maritime emission control areas

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ABSTRACT

This paper assesses cost as a function of abatement options in maritime emission control areas (ECA). The first regulation of air pollutions from ships which came into effect in the late 1990s was not strict and could easily be met. However the present requirement (2015) for reduction of Sulfur content for all vessels, in combination with the required reduction of nitrogen and carbon emissions for new-built vessels, is an economic and technical challenge for the shipping industry. Additional complexity is added by the fact that the strictest nitrogen regulations are applicable only for new-built vessels from 2016 onwards which shall enter US or Canadian waters. This study indicates that there is no single answer to what is the best abatement option, but rather that the best option will be a function of engine size, annual fuel consumption in the ECA and the foreseen future fuel prices. However a low oil price, favors the options with the lowest capex, i.e. Marine Gas Oil (MGO) or Light Fuel Oil (LFO), while a high oil price makes the solutions which requires higher capex (investments) more attractive.

Introduction

With stricter emission rules and more public focus on maritime transport, reducing emissions in a cost efficient way has become a necessity for shipping lines. Historically, shipping emissions were not perceived as a problem since vessels operated at sea far from humans. In the 1970s several studies confirmed the hypothesis that air pollutants could travel several thousands of kilometer before deposition and damage occurred. In the late 1980s, the International maritime organization (IMO) started its work on prevention of air pollution from ships, and in 1997 the air pollution Annex (VI) was added to the International Convention for the Prevention of Pollution from Ships (MARPOL Convention). The Annex (VI) sets rules for nitrogen oxides (NOx) and Sulfur oxides (SOx) emissions in the exhaust gas. Developments in regulating maritime carbon dioxide (CO_2) emissions started in the same year (1997).

According to the Third IMO (2014) Greenhouse gas study, Sulfur and Nitrogen oxide emissions from maritime transport in 2012, accounted for 10–15% of global anthropogenic SOx and NOx emissions compared to around 3% of global CO_2 emissions (Smith et al., 2014). In response to the impact of these emissions, IMO is tightening the emission limits for NOx, SOx and CO_2 (Lindstad and Sandaas, 2014). First, IMO has defined the coast around North America and the North Sea and the Baltic as Emission Control Areas (ECA) with stricter SOx rules beginning in 2015, i.e. the Sulfur emissions has to be less than 0.1%

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of the emissions content by weight. Globally the Sulfur rule becomes stricter from 2020, i.e. 0.5% compared to the present cap of 3.5%; Second, IMO requires that new-built vessels from 2016 onwards which operates fully or parts of their time in the North American ECA shall reduce their NOx emissions by 75%, i.e. less than 3.4 g (IMO tier III) compared to less than 14 g globally (IMO tier II); Third, the EEDI uses a formula to evaluate the CO_2 emitted by a vessel per unit of transport based on a fully loaded vessel as a function of vessel type and size. The EEDI thresholds have been agreed upon for major vessel types and it is expected that the EEDI thresholds stepwise will become up to 30–35% stricter within the next 20 years (Lindstad et al., 2014).

Ships emissions, their impact and solutions to reduce their emissions have been part of major studies such as: the *Second IMO GHG study 2009* (Buhaug et al., 2009); the *Technical support for European action to reducing GHG emissions from International Transport* (Faber et al., 2009); and the *Quantify project* which assessed the climate impact of global and European transport systems (Eyring et al., 2007, 2007a, 2009). Hennie et al. (2012) addresses the complexity of reducing NOx and that some of the technical options for reducing NOx emissions increases fuel consumption and hence CO_2 emissions. Brynjolf et al. (2014) has studied the environmental impact as a function of technical abatement option and available fuels, and their results indicates that gas based fuels has better environmental performance than diesel based abatement options. Jiang et al. (2014) has compared sulfur scrubbers versus Marine Gas Oil (MGO) and their results indicate that scrubber technology is efficient in reducing Sulfur and particle emissions, and that scrubber's gives best profitability at high price spread between Heavy Fuel Oil (HFO) and MGO. Acciaro (2014) has used real option analysis for financial assessment of retrofitting existing vessels to run on Liquid Natural Gas (LNG) instead of HFO or MGO. The findings indicates that increased use of LNG as a marine fuel depend on reduction in retrofitting cost and the price ratio between LNG and the traditional fuels (HFO, MGO).

Taking the perspective of the ship-owner, there is a need for more focus on cost assessments as a function of annual fuel consumption in the ECA's. This is also relevant for the policy makers since the Ship Owners, their Associations and the sea based Intermodal providers all communicates the message that the stricter rules will make short sea shipping less competitive versus road only solutions.

Methods

We need assessment of costs and fuel consumption, see Lindstad et al. (2011, 2014) limiting our attention to the vessels and their use, not including port side consequences. The annual fuel consumption can be divided into three (3) parts: fuel consumption for sailing outside an ECA, for sailing inside ECA and during port stays. The power required for sailing (1) can be split into four parts: the propulsion power required for calm water conditions (P_s), the power for countering added resistance by waves (P_w) and wind (P_a), and the auxiliary power (P_{aux}) for equipment and hotel load. The required engine power with respect to required propulsion power is a function of the propulsion efficiency η, which typically is around 65–75% at calm water conditions and designs speed and which drops in rough seas and at low speeds (Lindstad et al., 2013).

$$P_i = \frac{P_s + P_w + P_a}{\eta} + P_{aux} \tag{1}$$

This setup is established practice (Lewis, 1988; Lloyd, 1988; Lindstad et al., 2013, 2014).

During a voyage, the sea conditions will vary and this is handled by dividing each voyage into sailing sections, with a distance D_i for each sea condition influencing the vessels speed v_i and the required power P_i. In general this amounts to

$$\sum_{i=1}^{n} \frac{D_i}{v_i} \cdot P_i, \tag{2}$$

where the quotient denotes the time spent on each leg. The annual fuel consumption consists of the fuel consumption in the ECA and non-ECA sailing. Adding the port stay we get

$$F^O = K_f^O \cdot \left(\sum_{\substack{i=1 \\ i \notin ECA}}^{n} \frac{D_i}{v_i} \cdot P_i \right), F^{ECA} = K_f^{ECA} \cdot \left(\sum_{\substack{i=1 \\ i \in ECA}}^{n} \frac{D_i}{v_i} \cdot P_i + T_{lwd} \cdot P_{aux} \right) \tag{3}$$

where F^O denotes the fuel consumption outside an ECA, while F^{ECA} denotes the consumption for sailing inside ECA and for staying in port. These are the two terms for each voyage. The formula (3) assumes a linear relation between fuel consumption and produced power.

The annual cost including voyage fuel costs and abatement costs is given by (4)

$$C_a = C^{ECA} \cdot F^{ECA} + C^O \cdot F^O + C_v^{capex} \tag{4}$$

Hence, the annual costs increase as a function of abatement technology and fuel is given by (5)

$$\Delta C_a = C^{ECA} \cdot F^{ECA} + C^O \cdot F^O + C_v^{capex} - C^{HFO} \cdot F^{HFO} \tag{5}$$