Black carbon and shipping – Environmental impacts and business potential

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Abstract

There are approximately 100 000 diesel ships, around 250 LNG ships and a smaller number of methanol or even electric ferries taking care of global transportation. This paper assesses environmental business opportunities and stakeholder opinions of black carbon (BC) measurement: The measuring solutions cover various hardware, software and satellite communication techniques and devices. These elements can be connected to real time data transfer. Measuring environments in vessels during the voyages are difficult and continuously changing. BC measuring techniques are under development, and still giving large variations in results – there is a great potential to make wrong decisions resulting wrong investments and impacts and finally massive economical and environmental failures for society. The combination of the load rates in vessels and fuel types should be revealed in detail to achieve e.g. speed optimization with lowest BC emission. Control of EU's existing and new emission regulations requires new integrated measuring solutions for various environments like vessels and ports. When vessels are operating the BC emissions should be measured and delivered to stakeholders even during the voyages. Different diesel fuels and BC affects seriously in the arctic regions and BC has direct impact to climate change and lowering of arctic ice coverage. EU air quality policy does not directly regulate BC, but the regulation is under discussion and development. There is evidence that the reduction in ambient SO2 concentrations is the result of the new harbor directive, and more onshore measurements. Such endeavors from a larger number of harbors and ships are needed for verifying the results.

Introduction

Control of EU's existing and new emission regulations requires new integrated measuring solutions for various environments like vessels and ports. Black carbon (BC) emissions are critical for Arctic regions. BC regulation development also needs proper measuring and delivering information of emissions, even during the voyages. Nowadays the majority of ships are operated by diesel (100 000 diesel ships, approximately 250 liquefied natural gas (LNG) ships, and a limited number of methanol and electric ferries). However, changing from heavy fuel oil (HFO) to marine diesel oil (MDO) does not solve problems and challenges associated with BC emissions. Measuring

environments in vessels during the voyages are difficult and changing continuously. BC measuring techniques are under development, and results about their potential variates significantly and therefore investing decisions are challenging both economically and environmentally (also Låg et al. 2015). The combination of the load rates in vessels and fuel types should be revealed in detail to achieve e.g. speed optimization with the lowest BC emission. In this paper we examine environment and business potential as an integrated solution, which fulfills the needs of BC measurement: The goal is to create a robust and maintenance free system, which offers the stakeholders expected continuous information of BC emissions and later data from other emissions.

BC is the second major contributor to climate change after carbon dioxide (CO2) (Aplin 2015; Bond et al. 2013). The share of global BC emission from international shipping is estimated to be up to 3% of global BC emissions (IMO 2015). Even though the share shipping induced BC emissions is currently small, the volume of maritime transport is continually increasing. At this very moment there is no regulation or legislation how to cut directly BC emissions but in the IMO currently BC is indirectly regulated by International Maritime Organization's (IMO) MARPOL Annex VI which set limits for nitrogen oxides and the sulphur content of fuel.

In the Polar region sea ice is melting rapidly, and it is estimated that in the next decade the effects of global warming may transform the Polar region from an inaccessible frozen desert into a seasonally navigable ocean (Humpert & Raspotnik 2012). According to National Snow & Ice Data Center (NSIDC 2017) the continental ice in the Arctic Sea ice reached its likely minimum extent for 2014. The year 2014 was the sixth lowest extent in the satellite record and reinforces the long-term downward trend in Arctic multiyear sea ice extent. Sea ice extent will now begin its seasonal increase through autumn and winter. Sea ice can be classified by stages of development of ice. Generally can inform thickness and age of ice. Usually it can be categorized as first-year or multiyear ice. When ice is new, technically thickness is less than 10 centimeters. As the ice thickens, it enters the young ice stage and the thickness varies between 10 to 30 centimeters. First-year ice is thicker than 30 centimeters, but has not survived a summer and it melt off. Multiyear ice is ice that has survived a summer melt season and is much thicker than younger ice, typically ranging from 2 to 4 meters thick (NSIDC 2017; NASA 2012).

Aims of the research

Black carbon (BC)

BC is an aerosol and component of particular matter (PM), which is the most efficient absorber of solar radiation. (Gogoi et al. 2015, Kholod & Evans 2015). BC emissions come from combustion process when fossil fuel or biomass is burned. Carbonaceous material is formed near flames during combustion process (Bond et al. 2013). Fossil fuels are commonly used in transport, industry and household sector and also a lot of BC emissions come from forest fires. BC is the second major contributor to climate change after carbon dioxide (Aplin 2015; Bond et al. 2013; Lack & Corbett 2012; Kupiainen & Vihanninjoki 2015).

BC is distinguishable from other forms of carbon and carbon compounds contained in atmospheric aerosol because BC has a unique combination of physical properties:

- *"It strongly absorbs visible light with a mass absorption cross section of at least 5m2g-1 at a wavelength of 550 nm*
- *It is refractory; that is, it retains its basic form at very high temperatures, with vaporization temperature near 4000 K*

- *It is insoluble in water, in organic solvents including methanol and acetone, and in other components of atmospheric aerosol and*
- *It exists as an aggregate of small carbon spherules"* (Bond et al. 2013).

IMO regulation on BC

IMO administrates the international conventions that set limits to shipping emissions globally. The IMO took its first action toward addressing the impacts of BC on the Arctic few years ago. Majority of the BC emissions is transmitted to the Polar Regions from other parts of the globe. However, the IMO has not yet set limits for BC emissions either globally or regionally. Considering the significant impact of the BC emissions on global warming it is probable that such limitations will be set.

Currently BC is indirectly regulated by IMO´s MARPOL Annex VI which set limits for nitrogen oxides and the sulphur content of fuel. Particulate matter (PM), sulphur and BC emissions have a negative impact on the environment human health. BC is also indirectly regulated in the Emission Controlled Areas (ECA) where is 0,1% limit on sulphur emissions is already in force. Baltic Sea is one of the SECA areas. In the ECA areas vessels need to use either low sulphur fuel, or exhaust clean techniques such as scrubbers. In the future IMO drive further research into the impacts of BC, potentially bringing about future BC emission regulations. (Aplin 2015) The IMO has also commissioned studies on the impact of vessels' greenhouse gas emissions and ship Energy Efficiency Design Index (EEDI) with the aim of continuous improvement on ship energy efficiency (IMO 2015).

The available data on BC mass emission from ship engines is still limited. So far only a limited number of relative BC mass measurements have been conducted before and after exhaust treatment. Majority of previous BC research studies are focused on diesel engines used in road transportation. In vehicles used on land the fuel quality, fuel and exhaust gas treatment are already regulated, whereas in maritime transport this regulation does not yet exist. According to Azzara et al. (2015) the use of diesel particulate filters, LNG, scrubbers, low sulphur fuels (LSF), slow steaming and fuel switch can reduce the emissions of BC by up to 70% in shipping. The IMO will continue testing BC measurement methods and identifying mitigation technologies to reduce the shipping BC emissions in the Polar Regions.

According to different studies there are several ways to mitigate BC emission (Azzara et al. 2015; CIMAC 2012; IMO 2015). IMO categories BC abatement technologies as follows:

- Fuel efficiency – vessel design
- Fuel efficiency – monitoring options
- Fuel efficiency – engine options
- Slow steaming
- Fuel treatments
- Fuel quality (traditional fuels)
- Alternative fuels
- Exhaust treatment

The International Council on Clean Transport (ICCT) working paper suggests the use of diesel particulate filters, liquefied natural gas, scrubbers, and low sulphur fuels (LSF). These techniques can reduce shipping emissions of BC by up to 70% (Azzara et al. 2015). CIMAC Working Group proposed potential BC abatement methods, and assessed their strength and weaknesses. Their results show that if the diesel motor combustion

process is improved, there will be only marginal reduction of BC emissions. The use of LSF can reduce BC emissions, but in the test with large 4-stroke medium speed diesel engine the measured BC emissions were 50% higher with distillate fuel compared to HFO. The amount of BC correlates with the used engine load: the more power is needed, the more emissions are produced (CIMAC 2012).

The CIMAC work group also tested different BC emission abatement technologies, including diesel particulate filters, bag filters, electrostatic precipitators, and scrubbers. Diesel Particulate Filter (DPF) is suitable for small diesel engines such as trucks, which use ultra low sulphur diesel fuel. For large diesel engines, such as those used in vessels, this not very suitable solution, because DPF system needs to be very large also the ash components in particulate matter cannot burn away and ultimately it clogs the filter. There has been some test conducted with ships engines and marine diesel engines on test-beds. (IMO 2015) Both bag Filters and Electrostatic precipitators have good particulate reduction, and both of them are quite commonly used in power plants. These systems work very well but are extremely bulky. There is only a limited experience of them in diesel engines and especially in large marine engines (CIMAC 2012; UNCTAD 2011).

Scrubbers are widely used in maritime sector to reduce SOx emissions. Scrubbers can use both seawater and freshwater to remove pollutants. There are also dry exhaust scrubbers which remove SO2 via chemical absorption to calcium hydroxide. With seawater scrubber the removal effectiveness of PM can be up to 75% but it depends on particle size and seawater take ability. HFO fuels produce hygroscopic PM that can associate with BC and this increase removal BC from the current level that is around 20–30%. In the case of Low Sulphur fuels the removed BC caries between 20–55% (IMO 2015; Lack & Corbett 2012).

Worldwide questionnaire about BC measurement and business potential

An electronic questionnaire study was conducted during August to December of 2015. The questionnaire study was carried out in using the web survey system "Webropol" (http://w3.webropol.com/). The questionnaire was worldwide and respondents were selected from different stakeholder groups, including academia and research centers, various industry fields and consultancy. The aim was to reveal interests and current knowledge of BC emissions from ships and also other emissions measurements technology. With the questionnaire study and literal review results to make market analysis in order to help the decision making in the near future. The questionnaire was sent to 1415 recipients and to 16 different countries.

The questionnaire received answers from 12 different countries. However, the total number of respondents is only 67. Overall, the questionnaire was sent five times to respondents. The low response rate indicates the difficulty of obtaining survey data from companies, particularly operating on traditional fields of industries (such as maritime sector). According to results almost one third of the respondents were from Finland and second largest group was from Nordic countries. Answers were also received from North-America and Japan. We received answers from all respondents groups. Almost one fourth (16) of respondents were from the academia. Second largest groups were shipping companies and "group others", including public authorities, an energy company, an exhaust gas treatment company and a marine environment technology company. Third largest group included ports.

The starting question dealt with the respondent's pre-knowledge about BC (before this study). The results were divided, and 42.5% of the respondents knew about BC

emissions before hand, and the rest (57.5%) did not. Respondents thought that current legislation is enough at the moment when current BC limitation status is still unknown and there no agreed measurement method approved. Majority of respondent's thought that current legislation is adequate and a significant amount of work can be done to cut emissions in the future. Regulations should be aligned with technology available now and technology expected to be available in the future and should always keep in mind to keep shipping competitive.

Number of respondents varied from 60 to 67 for each survey question. In the first question was asked how respondents see measurement and monitoring of emissions? Major (83%) see that it is important or very important. Ten respondents (17%) did not see it important or does not have opinion. In the second question the respondents considered equipment like sulphur scrubbers in exhaust gas cleaning operations important or very important (78%) and 22% saw that exhaust cleaning techniques are not so relevant in their operations. When asking about greenhouse gases 80% of respondents see it is important or very important and 20% irrelevant or does not have a opinion.

When asking respondents opinion about investments into alternative fuels such as LNG and low carbon fuels respondents see investments to low carbon fuels more important (77%) than LNG (71%), which is quite surprising. Especially in Europe LNG have been strong position and also EU strategies support LNG as a alternative fuel for ships. Another interesting opinion was when asking about reduction of fuels costs? 57% of respondents see it important or very important and 43% does not. In this result have to take into account there were different kind of answer groups and fuel costs are the most important to shipping companies. Almost all respondents see that investments into energy efficiency are important and 10% of respondents did not have an opinion or it is not important. In the last question how respondents see optimization of logistics? 70% see it important but 22% do not have an opinion about that or it is not relevant in their operations.

The main question of this paper is that how the respondents see maritime environmental issues and BC in them? Generally all respondents are very environmentally friendly and see environmental issues important in their every day operations (Figure 1). Respondents view varied to some extent. Reason is that different answer groups have different emphasis for environmental issues and interest in wide maritime sector.

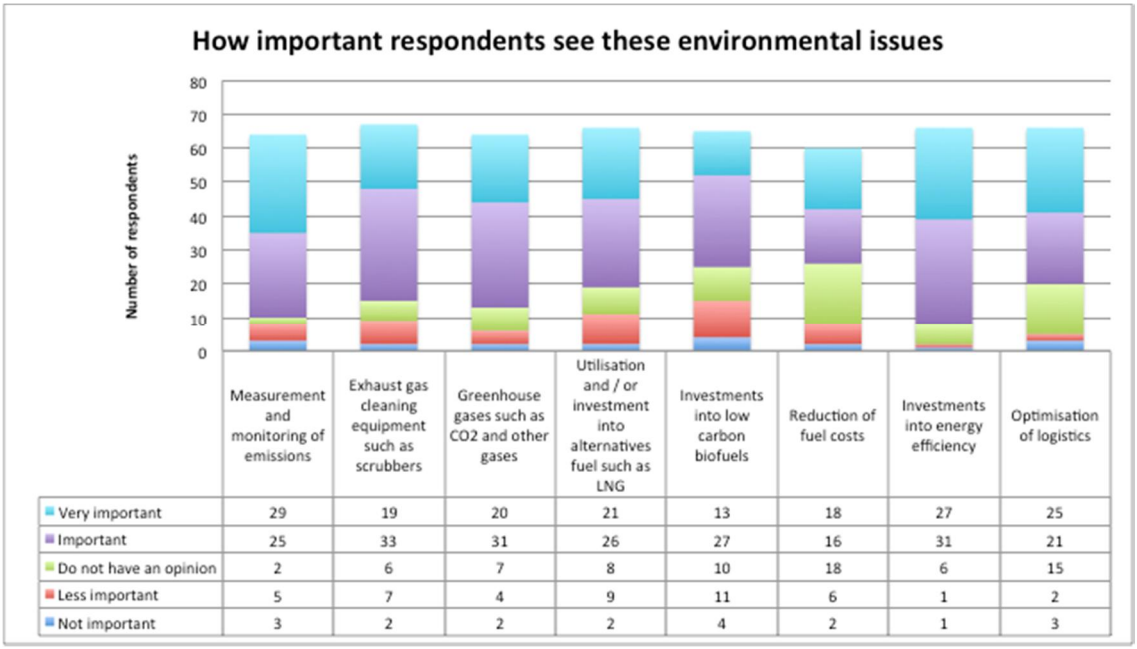

Figure 1. Respondents view in environmental issues.

In the end of questionnaire there was a feedback section, where respondents could write comments about questionnaire and leave clarifications. They focused on what should be done in the future with BC emissions. Respondents consider that climate change is the crucial problem of 21st century and global shipping should be forced to reduce greenhouse gas (GHG) emissions. Also BC emissions must be reduced according to respondents, but there were different opinion about the emission control area. Should reduction of BC be in the Polar areas or globally? Unified standards in measurement methods, certification at the test bed on board and legislation globally is required if emissions and BC are to be reduced.

Some respondents comments that currently the focus is on how to measure BC, and they considered that instead the focus should be in BC reducing equipments and techniques. A respondent stated that it is impossible to ever make a reliable measurement of BC on-board in a ship, i.e. with accuracy below 50%. The reason is that there are not proper conditions on-board (i.e. long straight pipelines/distributed flow and space) and there are never standard conditions either (i.e. temperature or humidity). Therefore, the results have been compensated for all these various conditions which cause an inaccurate measurement and low repeatability. A consideration was made that BC emissions could be much lower level than now if existing engines would be better maintained. Also with new engine or equipment development it has to be ensured that this new technology performs well also after years in service. Maybe there would be in future legislation engine maintenance requirements, not only from a safety point of view like SOLAS but also from an emissions point of view.

Discussion

Both literature and interviews are supporting same results. The business potential is too early to see, since there is no demand for measurement devices before forcing legislation and standards are decided. This is seen to take at least 10 to 20 years. Additionally, as Kiiski (2017) points out in his recent doctoral work, there are only a very limited potential found in commercial cargo shipping in the Arctic regions in the current conditions.

Different stakeholders are finding BC emission and it's measuring an interesting subject and especially universities and research institutions are well aware of BC effect to the Polar Regions. However, a majority of stakeholders had not heard about BC emissions before, a result that might be caused by a limited respond rate. Questionnaire study as well as interviews support the idea that it the time is not suitable to cut down BC emissions. There are still unsolved challenges with the Sulphur directive and NOx limitations currently considered. As long as it is still open in IMO what is pursued and when, the threshold values are undecided there is no interests in investing this issue.

According to respondents they have same opinion that there is no "single solution" on abatement technique that it would decrease BC emissions. In slow steaming the need for total engine output decreases and some engines can be stopped or overall engine load decreased. Even though the g/kWh emission of the engine can increase at lower load, the time based total emission (g/hours) of the vessel could be decreased by utilizing slow steaming or other energy reduction technologies. Finally, satellite connections are working relatively well in the Arctic regions, but because of the cost the connection is seen more important to use e.g. for weather information or e-mail than real-time measurement information transmitting. Collected data is seen more reasonable to transfer in ports (also holistic waste management, see Svaetichin & Inkinen 2017). There are plenty of future research challenges. They include, for example, a) what kind of data there is; b) who uses it; and c) who owns it? In addition, data management and security should be focused on. In the future measuring the standardized and inexpensive sensor technologies are essential combined with an easy-to-use principle on board.

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