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Final Report of the Work Package 3 in the Sea Effects Black Carbon Project

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MERENKULKUALAN KOULUTUS- JA TUTKIMUSKESKUS
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Käyntiosoite / Visiting address:
ICT-talo, Joukahaisenkatu 3-5 B, 5.krs, Turku

Postiosoite / Postal address:
FI-20014 TURUN YLIOPISTO

Puh. / Tel. +358 (0)2 333 51
http://mkk.utu.fi

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ABSTRACT

Maritime transport is vital for global business but vulnerable in terms of competitiveness and environmental issues, especially in the Arctic regions. Global warming is proceeding twice as fast in the Polar Regions as in other parts of the world, resulting in a reduction of ice. Therefore, the Arctic sea route is more navigable, allowing an increasing number of ships in the route. Different diesel fuels and BC have a direct impact on climate change and the lowering of arctic ice coverage. In this study, we explore whether measuring black carbon (BC) opens up new business opportunities and designs for an integrated solution.

Fossil fuels are mainly used in sea transport, and emissions such as CO_2, SO_2, PM, NO_x and BC originate mostly from vessel combustion engines. BC is the most important factor in climate change after CO_2, and even though its share of international maritime transport is relatively small in terms of total BC emissions (estimations vary between 1 and 2%), the Arctic regions are sensitive to a climate forcer such as BC. If transport continues to increase as estimated, concerns about BC emissions will grow.

The International Maritime Organization (IMO) is the main body responsible for regulating international shipping emissions. The impact of BC in the Arctic regions was first addressed a few years ago by IMO. There is still only limited data available on BC emissions from ships and a limited amount of relative BC mass measurements before and after exhaust treatments. The majority of the previous BC research focused on diesel engines used in road transport.

There are different ways to mitigate BC emissions from ships. The techniques focus on fuel efficiency, slow steaming, exhaust treatments, fuel quality, alternative fuels and different exhaust treatments. The potential of creating business opportunities among these techniques is difficult to estimate before the corresponding regulations are implemented.

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1 INTRODUCTION

Control of the EU's existing and new emission regulations requires new integrated measuring solutions for various environments like vessels and ports. BC emissions are critical for the Arctic regions. Similarly, BC regulations that will require measuring and emissions information distribution (e.g. during voyages) are under development. There is evidence that the reduction in ambient SO_2 concentrations is the result of the new harbour directive. There is an additional need for onshore measurements. Similarly, measurements from a larger number of harbours and vessels are needed in order to verify this evidence.

Today the majority of ships are operated by diesel (100,000 diesel ships and around 250 LNG ships and some methanol and even electric ferries). However, changing from HFO to MDO does not solve challenges related to BC. Measuring environments in vessels during voyages is difficult, and they are changing continuously. Techniques for measuring BC are under development, and the results on their potential vary significantly, and therefore investment decisions are challenging, both economically and environmentally. The combination of the load rates in vessels and fuel types should be revealed in detail to achieve speed optimization with the lowest BC emissions. In this report, we focus on the business potential of an integrated solution that fulfils the needs of BC measurement. The goal is to create a robust and maintenance-free system that offers stakeholders the expected continuous information on BC emissions and data on other emissions.

BC is the second major contributor to climate change after carbon dioxide (CO_2) (Aplin 2015; Bond et al. 2013). The share of global BC emissions from international shipping is estimated to be up to 3% of global BC emissions (IMO 2015). Even though the share of shipping-induced BC emissions is currently small, the volume of maritime transport is continually increasing. At this very moment, there is no legislation on directly cutting BC emissions, but at IMO, BC is currently regulated indirectly by IMO´s MARPOL Annex VI, which sets limits for nitrogen oxides and the sulphur content of fuel (IMO 2015).

Total global CO_2 emissions in the year 2004 from the transport sector was 6.3 GT, which is 23% of the world's total CO_2 emissions. Road transportation is responsible for 74% of the total transportation CO_2 emissions (Ribeiro et al. 2007). According to the United Nations Framework Convention on Climate Change (UNFCC), global greenhouse emissions, including shipping, should be capped to prevent global temperatures from rising more than 2 °C. This is an enormous challenge for the shipping industry (Heitmann & Khalilian 2011). IMO has estimated that in the worst scenario, CO^2 emissions in shipping can be increased to 12–18% of total global emissions until the year 2050. Taking into account the projected increase in the volume of shipping, the emissions from global shipping operations will rise by 20–60% by 2050 (IMO 2014).

In the Polar Regions, 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 area into a seasonally navigable ocean (Humpert & Raspotnik 2012). According to the National Snow & Ice Data Center (NSIDC 2014), the continental ice in the Arctic Sea reached its likely minimum extent for the year 2014. That year was the sixth lowest extent in the satellite record, and this reinforces the long-term downward trend in the Arctic multiyear sea ice extent. The sea ice extent will now begin its seasonal increase through autumn and winter. Sea ice can be classified by stages in its development. Generally, it can inform the thickness and age of the ice. Usually it can be categorized as first-year or multiyear ice. When ice is new, technically its thickness is less than 10 centimetres. As the ice thickens, it enters the young ice stage and the thickness varies between 10 and 30 centimetres. First-year ice is thicker than 30 centimetres, but it has not survived a summer and it melts away. Multiyear ice has survived a summer melt season and is much thicker than younger ice, typically ranging from 2 to 4 metres thick (National Snow & Ice Data Center 2017).

Figure 1.1 presents the Arctic sea ice in September 2012 when it reached the smallest extent ever recorded in more than three decades of satellite measurements. The yellow line on the image shows the average minimum extent from the period covering 1979-2010 as measured by satellites (NASA 2012).

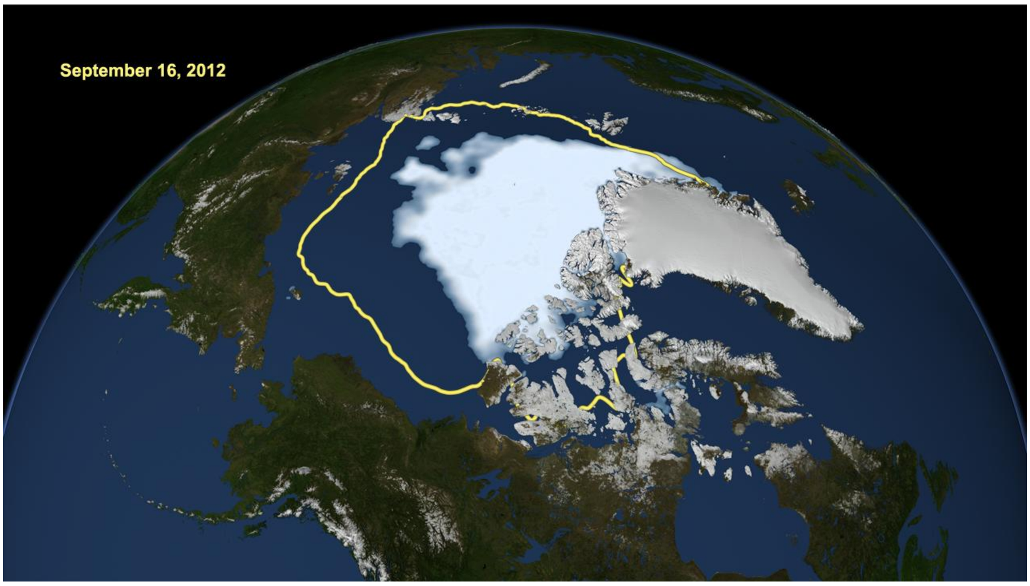


Figure 1.1. Arctic Sea Ice minimum 1979–2012 (NASA 2012).

Every year the ice in Arctic areas will be younger and thinner, and multiyear ice will melt more and more. The annual time duration of ice will be shortened, as can be seen in Figure 1. The retreat of the ice takes place during summer and autumn (Kupiainen & Vihanninjoki 2015). The expansion of ice-free areas in the Polar Regions increases the volume of maritime transport. These activities increase the environmental and safety risks in the Polar Regions. Less ice does not mean that shipping or operations in the Arctic areas would be easier, because the annual volume and type of ice in different areas varies a lot, and this affects the reliability of sea routes (Kupiainen & Vihanninjoki 2015). Significant obstacles might hamper the shipping routes, such as icing from sea spray, wind chill, remoteness as well as their implications for rescue and emergency operations. In the Arctic regions, these challenges hamper reliable weather forecasts, sea and ice charts, communication connections, and distances are long (Humpert & Raspotnik 2012).

1.1 Aims of the Research

The aim of this study is to create more detailed information on BC measurement and abatement methods and the business potential for the maritime sector. This study is part of the SEA-EFFECTS BC project, which aims at creating a more reliable and unequivocal basis for evaluating BC emissions in the shipping environment and at generating new options for online monitoring techniques. Definitions of sampling and sample treatment are essential for reliable measurements in the ship environment, particularly when using new fuels and emission control technologies. This approach will also support the generation of reliable ship emission factors. In-depth analyses of other emissions, in parallel with BC measurements, increase the understanding of the results obtained with different techniques, which is a prerequisite for further development. Business opportunities in the field of emission measurements are evaluated, including sensor and information technology.

2 BC AND ITS EFFECTS ON THE ENVIRONMENT AND REGULATION

2.1 Definitions

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

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 a 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*).*

2.2 The Impacts of BC Emissions on the Arctic Environment

BC emissions from different sources spread in the atmosphere and cause global warming. Warming is predicted to be fast, especially in the Polar Regions. BC particles are transmitted to the Polar Regions with atmospheric currents (Bond et al. 2013). For this reason, reduction of all human-induced BC emissions is crucial. The warming effect results because BC causes radioactive changes in clouds. As a result, clouds are darker and reduce their ability to reflect light back into the atmosphere, which in turn causes a greater warming effect. According to studies, BC has approximately a million times more heat-trapping power than CO_2. Despite its large effects, BC has a short atmospheric lifespan. BC remains in the atmosphere for only a few weeks (Aplin 2015; Bond et al. 2013).

In the Arctic areas, BC gets deposited on the surface of snow and ice, and it absorbs sunlight. As a result, sunlight does not reflect back into the atmosphere, and it starts to warm the air and the surface of the earth. BC snow forcing causes an imbalance. Globally, average climate warming is estimated to be +0.05 to +0.20 degrees Kelvin, especially in the spring and summer. There are still uncertainties about whether or not BC will melt glaciers (Bond et al. 2013). One can easily claim that all BC emissions are equal, regardless of their source. However, depending on the source, the qualities of these emissions are different. According to Azzara (2015), BC emissions that come from natural sources (e.g. from forest fires) contain more organic carbon and they create a cooling effect on the atmosphere, whereas emissions coming from ship diesel fuel emissions create the opposite effect. Therefore, BC emissions originating from shipping should be compared to other similar human-induced emission sources that are linked to atmospheric warming.

The negative effects of BC on climate are well-known. Uncertainty prevails on the role of human-induced BC emissions in global warming. The increase in human-induced BC content in the atmosphere can also cause unpredictable consequences. Bond et al. (2013) state that besides warming the climate in the polar and temperate regions, BC emissions in the atmosphere might have caused changes in the precipitation patterns of the Asian monsoon. According to current knowledge, the total impact of all emissions from BC-rich sources is slightly negative. This means that the uniform elimination of all emissions coming from BC-rich sources is required in order to stop global warming. Therefore, BC sources and emission mitigation measures should be carefully identified.

2.3 IMO Regulations on BC

IMO administrates the international conventions that set limits on shipping emissions globally. IMO took its first action toward addressing the impacts of BC on the Arctic a few years ago. The majority of BC emissions are transmitted to the Polar Regions from other parts of the globe. However, IMO has not yet set limits for BC emissions, either globally or regionally. Considering the significant impact of 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 sets limits for nitrogen oxides and the sulphur content of fuel. Particulate matter (PM), sulphur, and BC emissions have a negative impact on the environment and human health. BC is also indirectly regulated in the Emission Controlled Areas (ECA), where a 0.1% limit on sulphur emissions is already in force. The Baltic Sea is one of these areas. In the ECA areas, vessels need to use either low sulphur fuel or exhaust clean techniques such as scrubbers. In the future, IMO will drive further research on the impacts of BC, potentially bringing about future BC emission regulations (Aplin 2015). IMO has also commissioned studies on the impact of vessels' greenhouse gas emissions and the ship Energy Efficiency Design Index (EEDI), with the aim of continuous improvement in ship energy efficiency (IMO 2015).

The available data on BC mass emissions 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. The majority of previous BC research studies are focused on diesel engines used in road transportation. In vehicles used on land, 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, liquefied natural gas (LNG), scrubbers, low sulphur fuels (LSF), slow steaming and a fuel switch can reduce BC emissions from shipping by up to 70%. IMO will continue testing BC measurement methods and identifying mitigation technologies to reduce the shipping BC emissions in the Polar Regions.

2.4 BC Emissions from Ships and Emission Abatement Technologies

The share of global BC emissions from international shipping is estimated to be up to 3% of global BC emissions (IMO 2015). Even though the share of shipping-induced BC emissions is currently small, the volume of maritime transport is continually increasing. This means more emissions globally. The expected increase in maritime transport specifically in the Polar Regions results in the release of emissions directly into the local environment (IMO 2015; Bond et al. 2013). In the year 2000, international shipping produced 7–9% of BC emissions from diesel sources. When compared with 2010 emissions, the marine sector's contribution increased to 8–13%. Looking forward, global shipping is likely to maintain that share, while regional emissions in areas like the Arctic will increase (Aplin 2015; Azzara et al. 2015).

According to different studies, there are several ways to mitigate BC emissions (Azzara et al. 2015; Cimac Working Group 2012 and IMO 2015). IMO categorizes 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

Previous studies, including the International Council on Clean Transport (ICCT) working paper, suggest that the use of diesel particulate filters, LNG, scrubbers and low-sulphur fuels (LSF) can reduce shipping BC emissions by up to 70% (Azzara et al. 2015). In the Sea-Effects BC project, a measurement campaign on a medium-speed engine was conducted in a laboratory setting. Another measurement campaign was then conducted on board a modern ship. The laboratory measurements showed that BC was higher for 0.5% sulphur than for 2.5% sulphur fuel at 25% engine load, but not at 75% load. Low BC was observed for the 0.1% sulphur and Bio30 fuels and particularly low BC and PAH for the Bio30 fuel. The measurements on board a modern ship showed that the new engine emission control technology (SCR + scrubber) and lower sulphur (~0.7% sulphur) fuels dramatically reduced the BC and PM concentrations of ship exhaust when compared to those of an old marine engine at 25% load. The engine load also had less influence on BC for this newly built ship when compared to the old marine engine (Aakko-Saksa et al. 2016; Timonen et al. 2017).

The CIMAC work group tested different BC emission abatement technologies, including diesel particulate filters, bag filters, electrostatic precipitators and scrubbers. The 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 is not a very suitable solution because a DPF system needs to be very large, and the ash components in particulate matter cannot burn away and ultimately it clogs the filter. There have been some tests conducted with ship engines and marine diesel engines on test-beds (CIMAC 2012; IMO 2015). Both bag filters and electrostatic precipitators have good particulate reduction, and both of them are commonly used in power plants. These systems work very well but are extremely bulky. Generally there has been limited experience with them in diesel engines and especially in large marine engines (Aakko-Saksa et al. 2016; 2017; CIMAC 2012).

Scrubbers are widely used in the maritime sector to reduce SOx emissions. Scrubbers can use both seawater and freshwater to remove pollutants. There are also dry exhaust scrubbers that remove SO_2 via chemical absorption to calcium hydroxide. With a seawater scrubber, the removal effectiveness of PM can be up to 75%, but it depends on particle size and seawater take-up ability. HFO fuels produce hygroscopic PM, which can be associated with BC. (IMO 2015). There is very limited data available on how scrubbers remove BC (Lack and Corbett 2012). In the onboard measurement campaign, a scrubber was installed on the ship. According to the results, the impact of the scrubber on BC was minor, but with the combination of a new ship, emission control systems, and low sulphur fuel, BC and PM concentrations were dramatically reduced when compared to an old engine with 25% load (Aakko-Saksa et al. 2016; 2017; Timonen et al. 2017).

3 CHALLENGES IN EMISSION DATA MANAGEMENT

3.1 Big Data

Big data is a large or complex data set that cannot be handled with traditional data processing. Big data also brings challenges such as analysis, capture, data validation, search, sharing, storage, transfer, visualization, querying, updating, and information privacy. Big data opportunities are particularly great in scientific research work. Timeline analysis, cluster analysis and regression testing, as well as pattern recognition, simulation, machine learning and artificial intelligence revolving around big data apps are much better than the traditional means of information technology. Big data allows very broad collection, storage and analysis of information and enables analyses of information and data that were previously impossible to execute (Vakkuri 2013).

Big data has become the raw material production and the new source of business, economic and social values (Tene & Polonetsky 2012). According to (Kennedy 2014), it is estimated that in 2014, big data business was approximately three trillion US dollars. The impact of an open data policy would boost the G20 countries' annual income by 700 by more than US dollars. The benefits would include reduced corruption, better workplace conditions, increased energy efficiency, and improved foreign trade (Kennedy 2014). Almost every country and government has its own strategies to promote digitalization, open data and big data, and the Internet of Things (IoT) in business operations. The Finnish government decided in 2016 to use this strategy (Finnish Government 2016).

3.2 Data Transfer from Sea to Shore

With big data, there are also challenges, especially on ships and in transferring data from the sea. Ship connectivity is the key factor when data is produced from ships. This result in a number of challenges. A well-known big data problem is 'swamping', which means the overwhelming amounts of raw data. In the future, ships having 1,000 sensors sampling at 1 Hz will produce 31.5 billion data points annually. And if each data point is 8 bytes, these sensors will produce approximately 250 GB of sensor data every year for the ship owner (Låg et al. 2015).

This type and amount of raw data needs an efficient use of storage and communication capacity as well as smart pre-processing and compression schemes. Different solutions are needed to meet these challenges. Data can be saved for intermediate and long-term storage. Should there be multiple data collectors or one centralized data collection facility on the vessel? Or is the data transferred in real time? Real-time data transfer at this moment is not rational, especially in the polar areas, because of the quality and price of the satellite connections. When a vessel is in port and connected to price-competitive and reliable connections, data transfer from a sensor becomes viable (Lovol & Kadel 2014).

There are also other problematic issues concerning data. Data quality is a challenge. Data must be reliable for different purposes and users. Sensors and measurement equipment must be standardized in some way to ensure the integrity and accuracy of the data. There are several possible contributory factors: sensor accuracy, compatibility of interfaces, the potential for communication outages causing loss of data and incomplete data sets, the requirement for the metadata needed to interpret and process the raw data correctly, and the possibility of accidental data insertion, updating, and deletion by analysts or unauthorized individuals (Låg et al. 2015).

Another issue is cyber security. The collected emission data is not too vulnerable or a threat to a ship, but the same systems have critical vessel functions, such as engine controls and navigation systems. These could become targets for cyber attacks from shore. According to Låg et al., the solution is in the settings and standardization. New standards and regulations can define functional and performance requirements to ensure the availability and reliability of new communication systems. System integration challenges can be tackled with well-defined network requirements and standardized interfaces. Big data challenges, such as data quality and cyber security, can be effectively mitigated by documenting and spreading best practices as standards.

4 SURVEY ON THE BUSINESS POTENTIAL OF BC MEASUREMENT

An online questionnaire study was conducted from August to December 2015. The questionnaire study was carried out using the Web-based system, 'Webropol' (http://w3.webropol.com/). The questionnaire was worldwide, and respondents were selected from different groups. The responding groups were universities or research centres, shipping companies, ports, associations, trade organizations and the like, marine industry companies, measurement technology companies, consulting companies and others. The aim was to reveal the interest and current knowledge of BC emissions from ships and also other emission measurement technology. The questionnaire was sent to 1415 recipients in 16 countries. The complete questionnaire is included in appendices 1 and 2.

4.1 Background Information of the Respondents

The questionnaire received answers from 12 different countries. We received only 67 answers. The questionnaire was resent five times to the respondents. According to the results, almost one-third of the respondents were from Finland and the second largest group was from the Nordic countries. A few answers came from North America and Japan (Figure 4.1).

As background information, the respondents were asked the type of their organization. The questionnaire was sent to different expert groups in order to ensure the extensiveness of the data. We received answers from everyone in the respondents' group. As shown in Figure 4.2, almost one-fourth (16) of the respondents were from the 'University or Research Centre' group. The next largest groups were 'Shipping Companies' and 'Group Others', which includes authorities, an energy company, an exhaust gas treatment company and a marine environment technology company. The fourth largest group was 'Ports'.

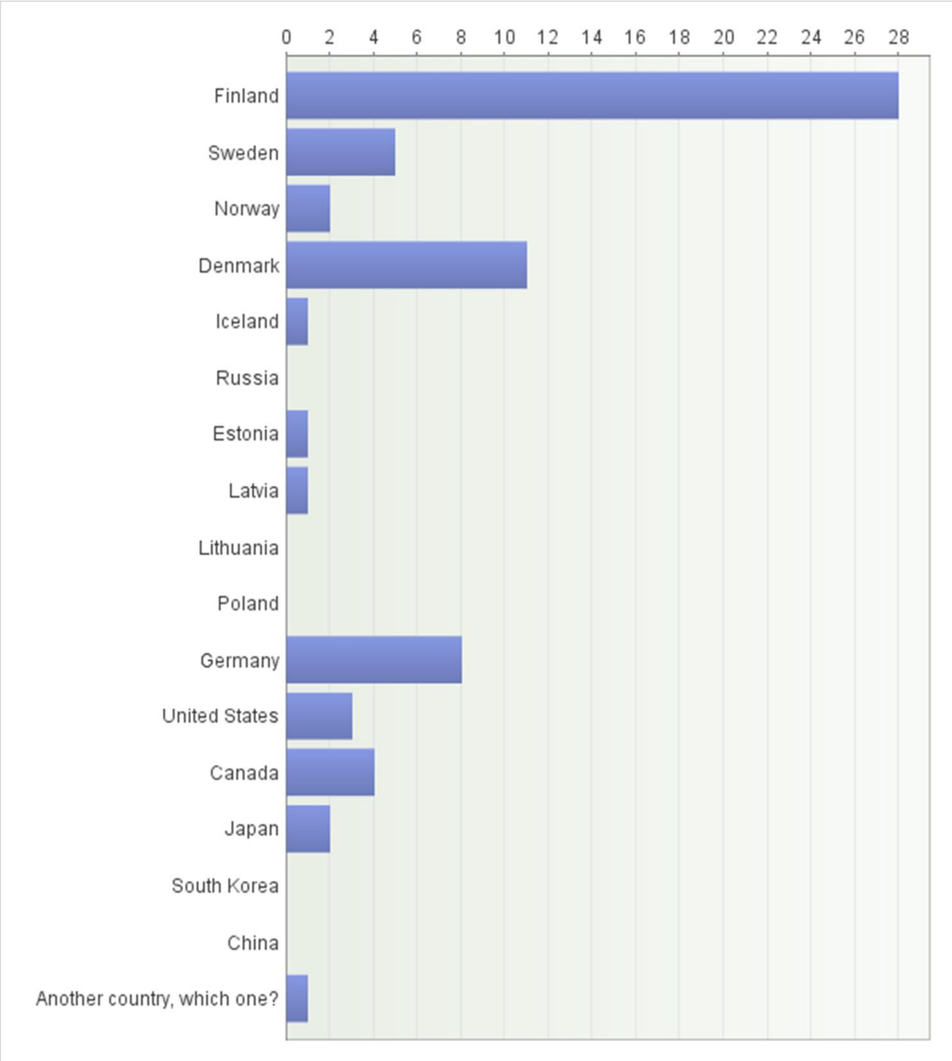


Figure 4.1. Location of head office.

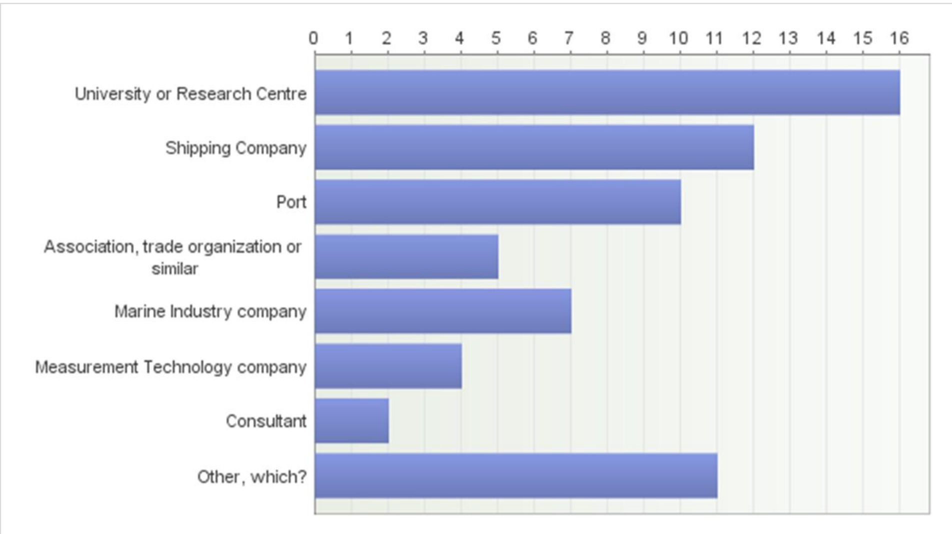


Figure 4.2. Types of respondent organizations.

We asked about the respondents' basic knowledge about BC (before this study): Half of the respondents had prior knowledge about BC emissions and half did not. We also asked about the general attitudes regarding emission control legislation and possible limitations (are they sufficient?). The results are presented in figures 4.3 and 4.4.

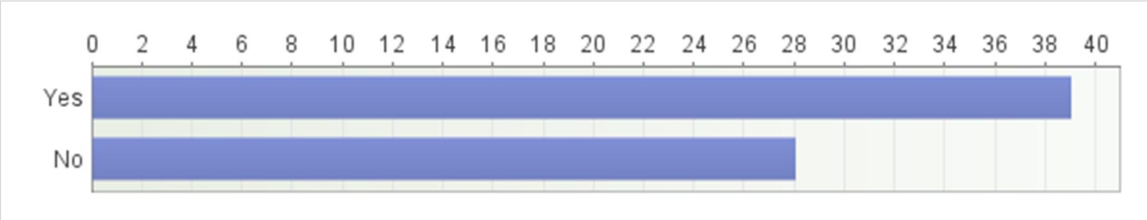


Figure 4.3. 'Before knowledge' regarding BC emissions.

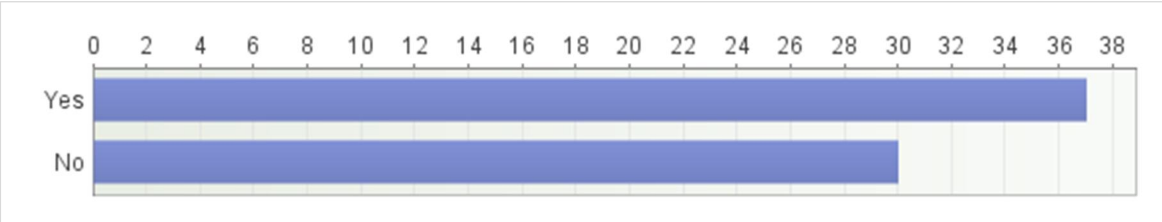


Figure 4.4. View on current legislation and emission controls.

The respondents wrote a number of comments on these issues. According to the comments, the current emission limits for NOx and BC are far from the level they could be. Too much power is given to IMO and their representatives to keep emission limits low. Much lower emissions could be achieved in a cost-efficient and feasible way. Special attention must be paid to emissions in the vicinity of people. Especially NOx, SOx and particle emissions should be reduced in coastal areas and harbours because of their effects on local air quality.

The respondents suggested that with different techniques and implementation standards and bans (or limitations), there is a potential to cut emissions effectively. For example, suggestions included requiring ships in ports to use shore-based power, regulating ship idling in terminals, and mandating fuel standards for ships seeking to dock in ports. The opportunities for regular vehicle emissions tests, retirement or retrofitting (e.g. additions) should be taken into account.

Some respondents suggest that banning the sale of certain fuels and/or requiring the use of cleaner fuels would be a good alternative to cut emissions. Respondents also brought up that emission caused by port operations (and shipping in general) are quite modest compared to other sources. It was also mentioned that there should be permits to operate industrial, power generating, and oil refining facilities and periodic permit renewals and/or modification of equipment. There should also be the use of filtering technology and high-temperature combustion (e.g. super-critical coal) for existing power generation plants and regulating annual emissions from power generation plants.

Other respondents thought that current legislation is enough at the moment when current the BC limitation status is still unknown and there is no agreed upon measurement method. The majority of the respondents thought that current legislation is good, and significant emission cuts are possible in the future. Regulations should be aligned with the technologies currently available. Future developments should also be considered in advance in order to keep shipping competitive in the future.

4.2 Universities and Research Centres

The questionnaire study was sent to 114 universities and research centres, and 16 of them answered the questionnaire. The first question was '*Have you done research on BC emissions?'* Out of sixteen universities and research centres, ten had done research before this study. Thirteen respondents were from Finland. When comparing the results to all respondents, the results are quite similar. Figure 4.5 indicates that more than two-thirds of the respondents from universities were aware of BC emissions. Additionally, 12 out of 16 have also discussed BC control and developments in reducing BC emissions (Figure 4.6).

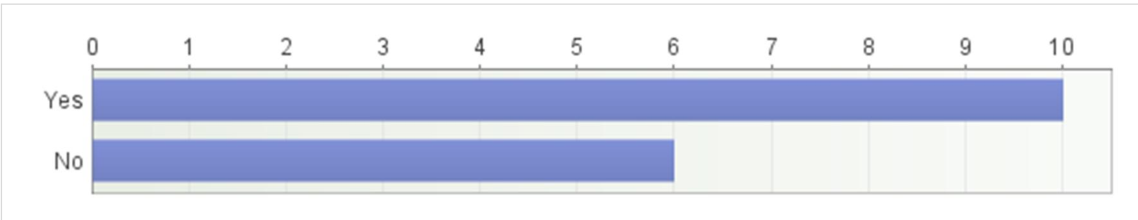


Figure 4.5. Have you done research on ship BC emissions?

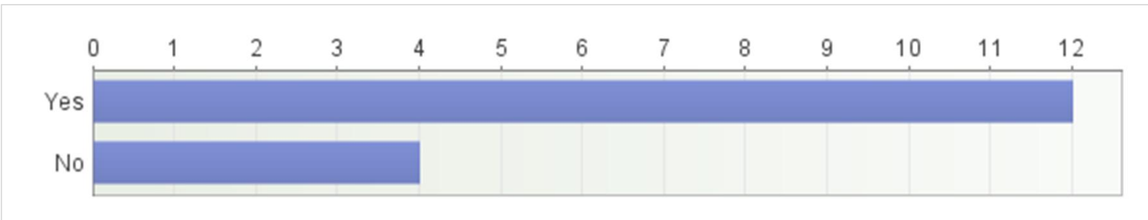


Figure 4.6. Have you been discussing the possible BC control and development needs for new BC technologies?

We were also interested in whether research institutions are planning or conducting collaboration with measurement companies. One-third of the respondents are developing or have plans to develop BC measurement technologies (Figure 4.7). This is an interesting result because IMO just implemented suitable methods to measure BC emissions. As illustrated in Figure 4.8, over half of the respondents are cooperating with private companies in this field.

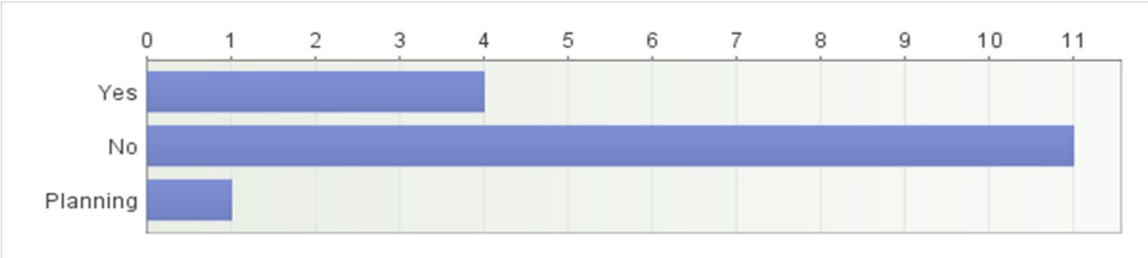


Figure 4.7. Have you developed new measurement technology for BC, or are you planning to do so?

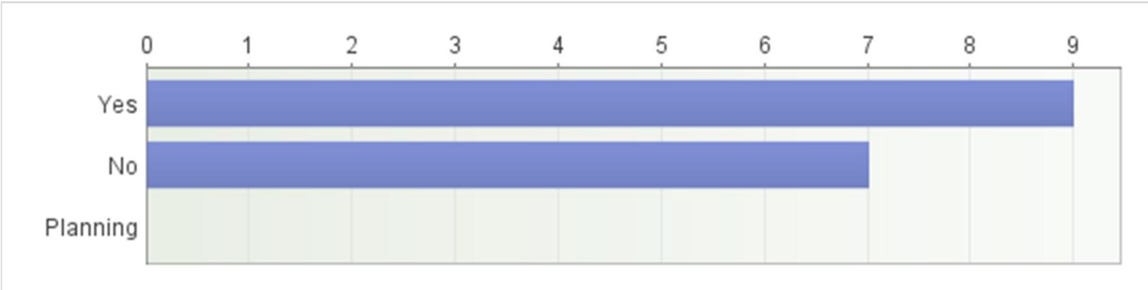


Figure 4.8. Are you doing collaboration with companies who offer measurement technology in order to develop products?

The last question (Figure 4.9) presents how universities and research centres estimate BC measurement development during the next five years. This question is significant for evaluating the business potential. The respondents answered that in the next five years, there will be new business opportunities, alternative fuels in use, more efficient engines and new innovations in the emission measurement business. Some respondents estimate that new innovations in the emission measurement business are only found in ECAs or areas of the Polar Code.

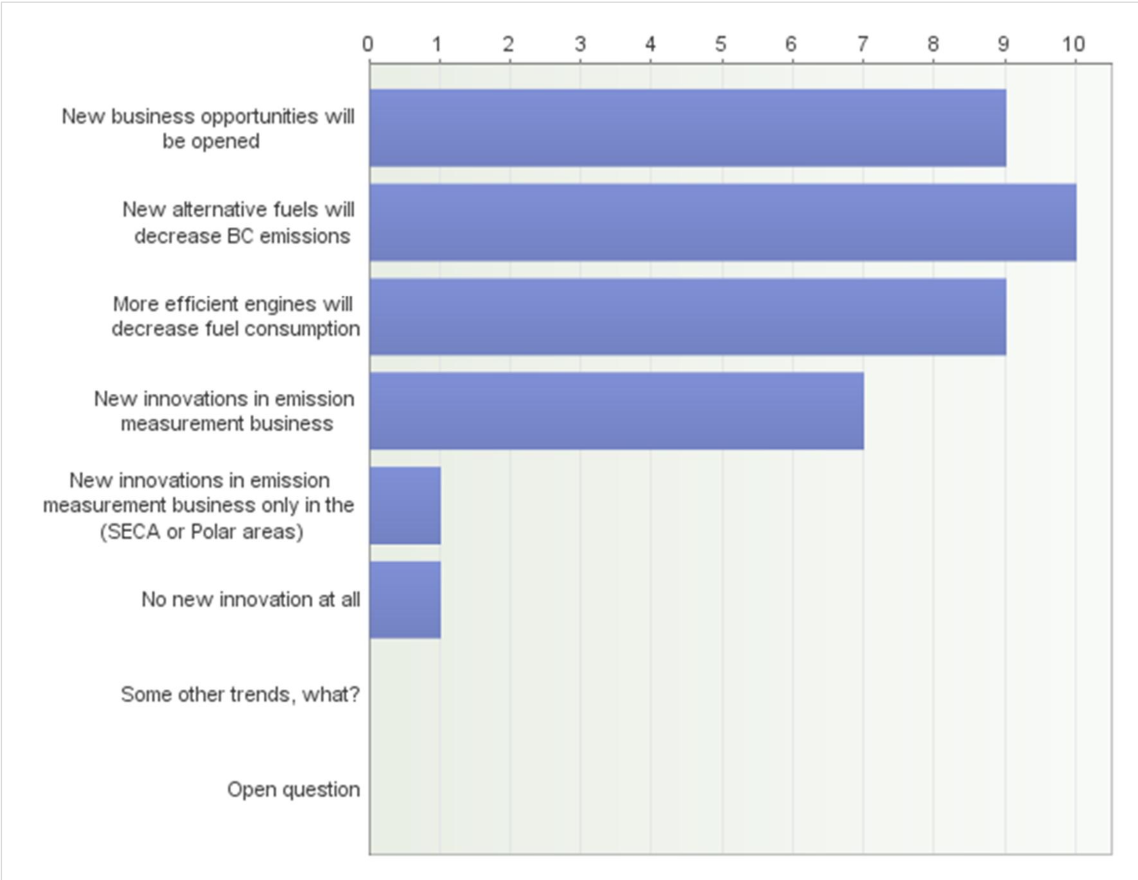


Figure 4.9. How do you see the market for BC control technology developing in the near future?

4.3 Shipping Companies

Shipping companies were asked about their awareness and future plans and if they see business potential in the measurement of BC. They are key players, as they have to invest in new technologies in order to decrease emissions. They also have to consider the measurement of emissions during ship operations. The first question concerns awareness about BC and their future investment plans concerning BC emissions and the future regulations. We sent the questionnaire to 295 companies, and we received 11 answers. Of those who answered (Figure 4.10), eight had prior knowledge about BC emission regulations. Figure 4.11 indicates that almost half of the respondents (5 out of 12) had not taken BC into consideration.

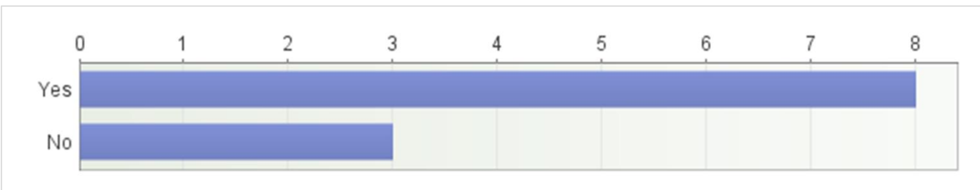


Figure 4.10. Are you aware of possible BC emission control regulations?

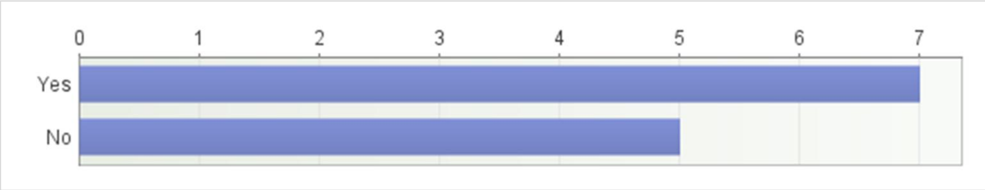


Figure 4.11. Have you taken into consideration possible BC emission controls when planning your operations or investments?

Figure 4.12 shows that companies that are aware of BC regulations have also established connections to measurement technology companies. They were also asked whether or not they have a need for BC emission reduction technologies. Similarly, Figure 4.13 indicates that five shipping companies require BC emission reduction technologies. However, the rest do not need them or they do not yet know their position on the matter. The lack of permanent regulations shows here. Shipping companies do not have enough information on how BC emission regulation will affect ship operations and where the regulation will come into force (also Figure 4.14).

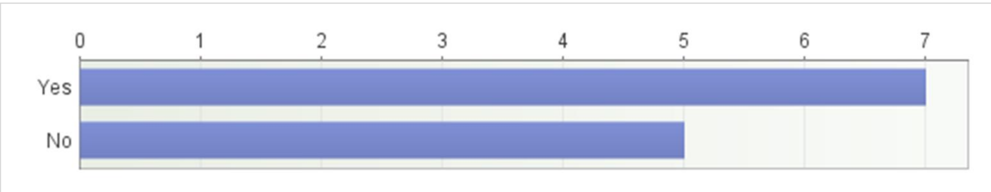


Figure 4.12. Have you been in contact with companies who offer emission measurement technology?

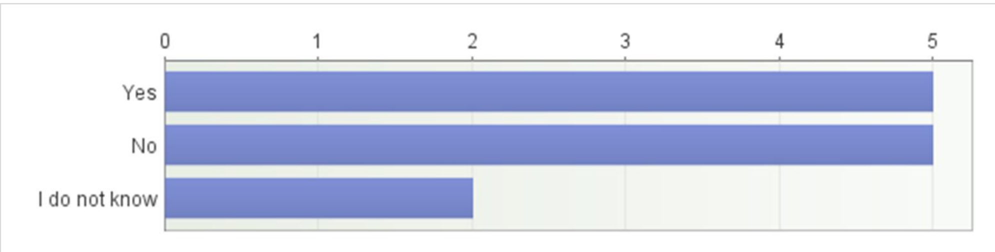


Figure 4.13. Do you have a need for BC emission reduction technology (clean engines, alternative fuels, and exhaust gas treatment equipment)?

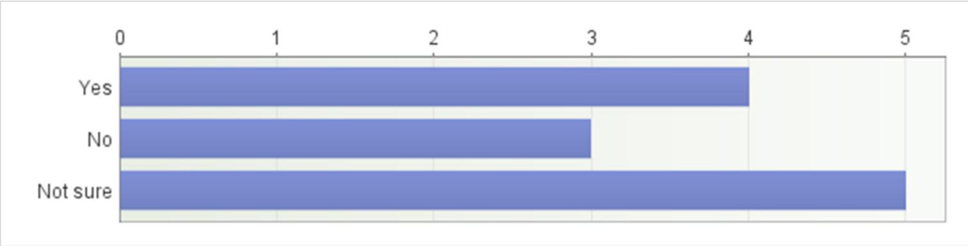


Figure 4.14. Do you have a need for BC emission technology (reduction or measurement)?

In general, the shipping business develops slowly, and the studied five-year time period is short for this business (Figure 4.15). According to the UNCTAD (2011) report on world vessel fleets, container ships are the youngest vessel type, with an average age of 10.7 years, bulk carriers average 15.3 years, oil tankers average 16.4 years, general cargo ships average 24.2 years, and other types average 25.1 years. The average age for all vessels is 22.5 years. For the question on how BC technologies will be developed in the future (the next 5 years), respondents answered that there will be new innovations in the emission measurement business and new business opportunities will emerge. Engines will also develop, and therefore fuel economy will increase and new alternative fuels will change the market. One shipping company answered: 'There are no new innovations, and there are other matters that must be tackled first before BC becomes a priority issue'.

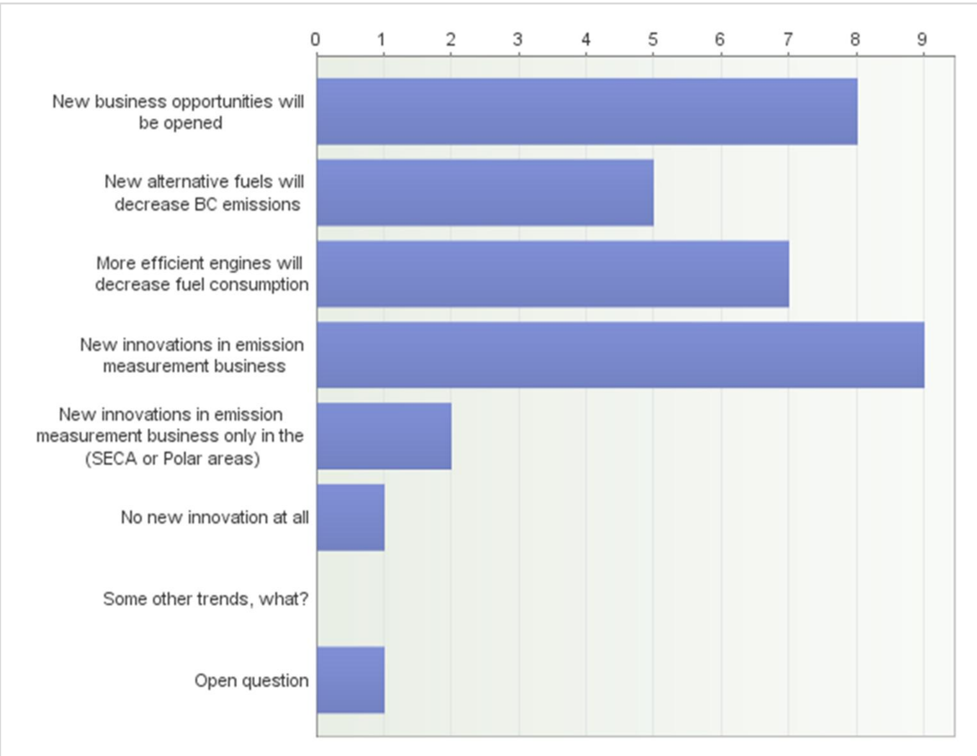


Figure 4.15. How do you see the market for BC control technology developing in the near future (the next 5 years)?

4.4 Ports

Ports have to follow relatively strict regulations, especially in the EU area. Ports may be considered as 'landlords', meaning that port companies own the land and the infrastructure, and other companies are their customers. Various regulations in the European Union have an impact on the functions and management of European ports. In EU legislation, there are more than twenty acts or directives that affect ports and port-related areas. And in the Finnish legislation, there are almost 90 different laws, acts, regulations and rules that affect the operation of Finnish ports and port construction (ESPO 2012). Permit requirements are based on national legislation and the IPPC directive. When environmental information is collected, the basic principles for all the collected data are comparability, balance between problematic questions and opportunities, continuity and clarity. It must be noted that it must be possible to compare the information so that the changes in the level of environmental protection can be established (Kujala 2010).

The questionnaire provided answers from ten ports. It was originally sent to 183 ports. In the first question—about awareness of BC—half of the respondents reported that they are aware of regulations concerning BC (Figure 4.16). However, only three ports had discussed the topic with their customers (Figure 4.17). Additionally, Figure 4.18 indicates the ports' knowledge about their customer preparedness concerning BC measurement. Only two ports had customers that were preparing or executing BC measurements.

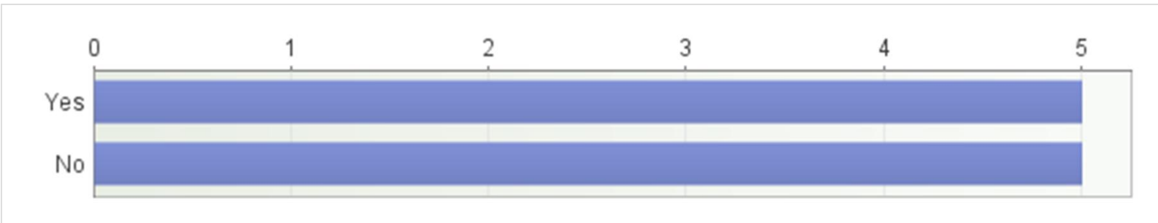


Figure 4.16. Are you aware of possible BC emission control regulations?

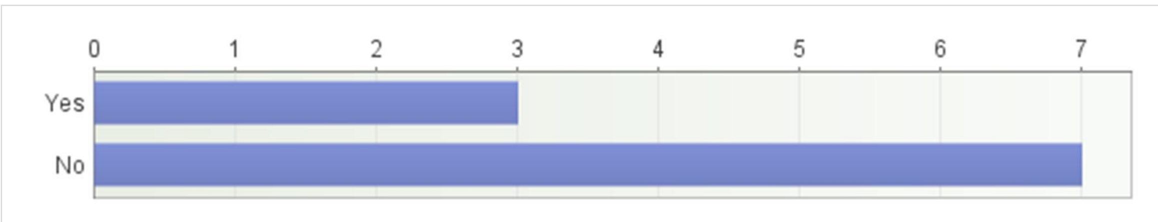


Figure 4.17. Have BC emissions come up in discussions with your customers, for example, shipping companies?

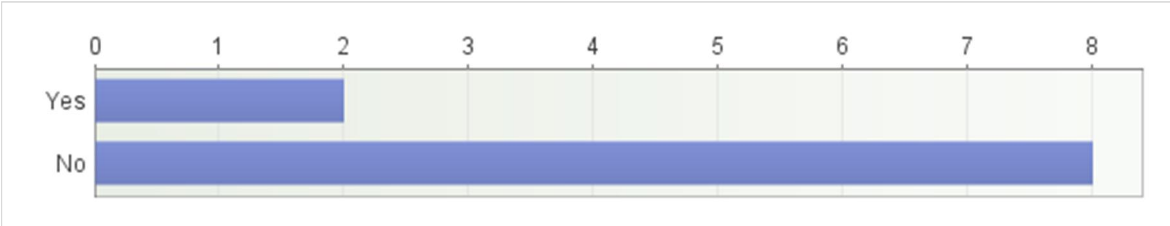


Figure 4.18. Are your customers preparing or executing measures related to BC emissions?

Figure 4.19 shows that future developments (which ports believe will be realised) will focus on alternative fuels and more efficient engines. They also were positive in their views on new innovations in the emission measurement business. This was particularly seen in ECA and in the polar area. One port answered 'Other trends' and further specified that shore energy in harbours will be developed.

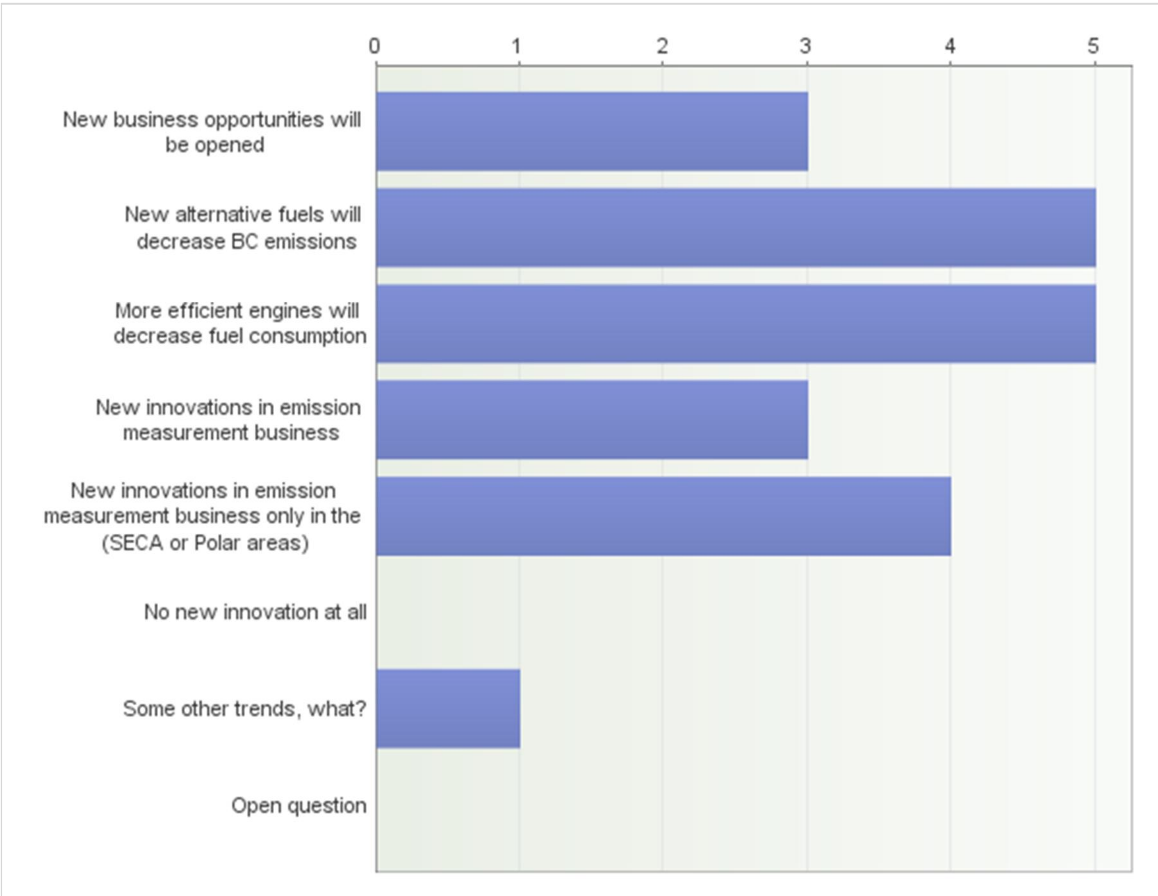


Figure 4.19. How do you see the market for BC control technology developing in the near future (the next 5 years)?

4.5 Associations, Trade Organization and Similar

This respondent group includes organizations such as ship owners and ship building associations, shipping industry associations and other lobbying organizations in the maritime sector. There were 29 respondents in 13 different countries. We received answers from only four respondents. All of these respondents were aware of possible BC control regulations before this inquiry study (Figure 4.20). They also have informed (or are planning to inform) their clients and stakeholders about future BC emission control and plausible regulations (Figures 4.21 and 4.22).

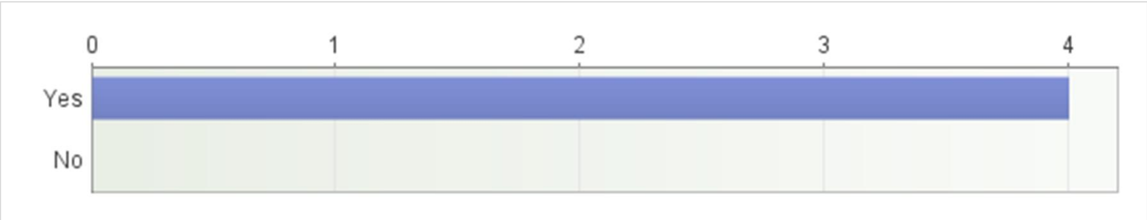


Figure 4.20. Are you aware of the possible BC emission control regulations?

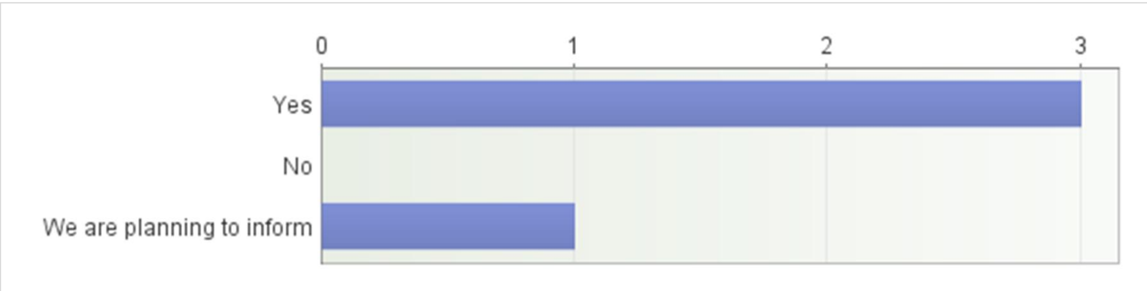


Figure 4.21. Have you informed your members about the possible BC emission control measures?

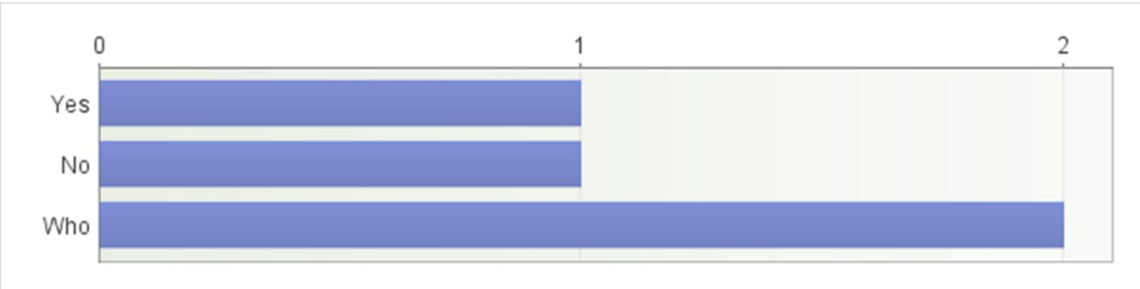


Figure 4.22. Has your organization been contacted in regard to BC, and who has contacted you?

Associations believe that in the next five years, there will be business opportunities, new alternative fuels, more efficient engines and innovation in the emission measurement business (Figure 4.23). The respondents also remarked that the definition and regulation of BC have a direct impact on the industry. This is particularly important for future development. An additional issue is how the market for BC reduction technologies will develop. It is believed that there will be a market for reduction technologies of BC in the near future, but it is unlikely that the reduction technologies would revolutionise the industry. This respondent group also reported that it is unlikely that the new BC regulation would enter into force in the next five years; it will take longer.

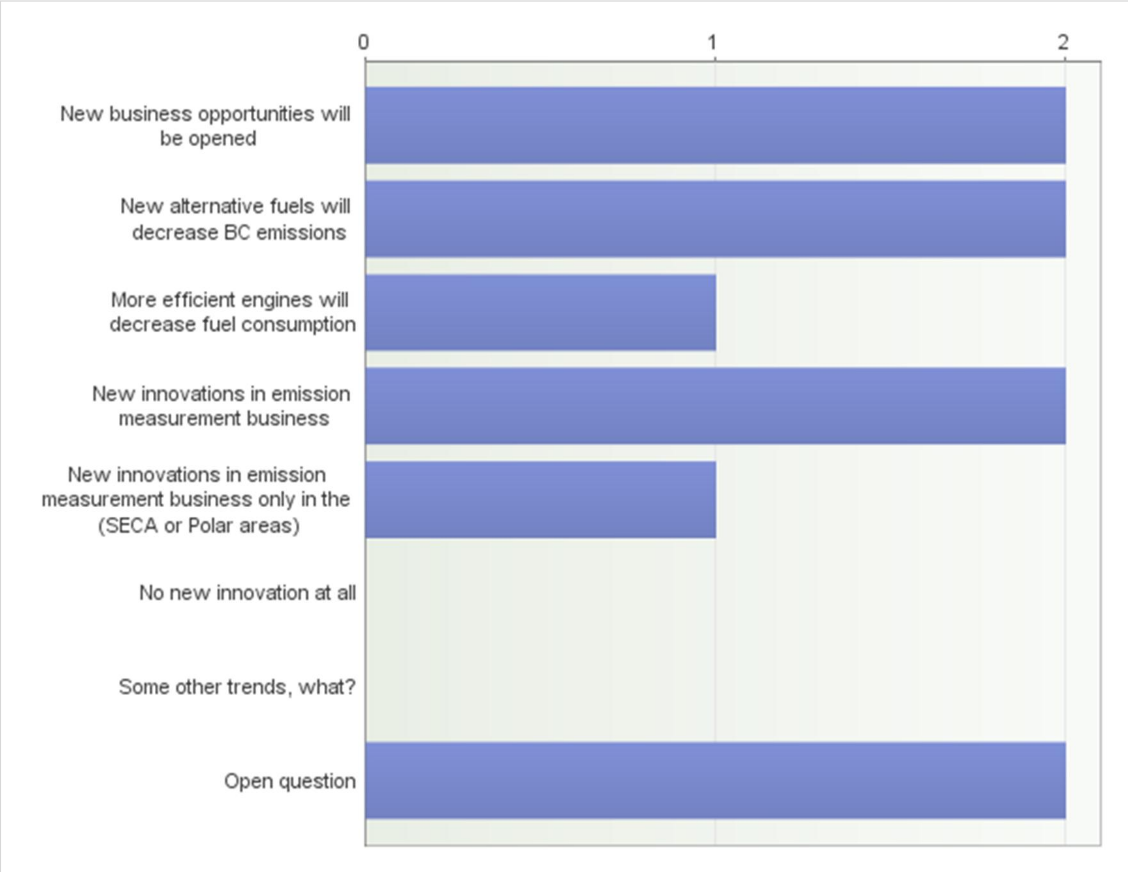


Figure 4.23. How do you see the market for BC control technology developing in the near future (the next 5 years)?

4.6 Marine Industry

We received seven answers from the marine industry. Because of their wide range of businesses, the respondents specified their market area. The respondents' operations included the marine industry in general, engineering and consulting, global marine operations, environmental controls, environmental technology for ships and polluting industries, and heat transfer and emission reduction. All of the respondents were aware of possible BC emission regulations (Figure 4.24). Additionally, figures 4.25 and 4.26 illustrate the respondents' business activities that are related to ship emissions and their interactions with their clients on BC issues.

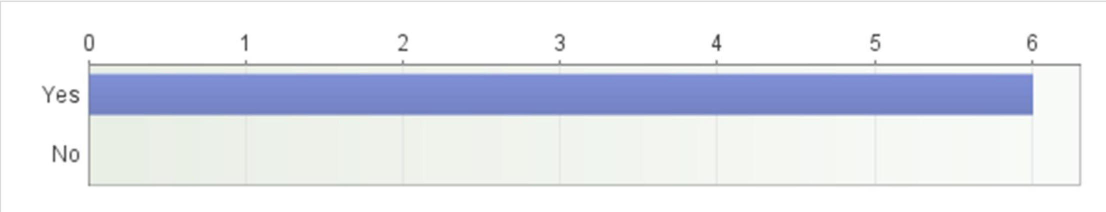


Figure 4.24. Are you aware of the possible BC emission control regulations?

Figure 4.25. Do your business activities include products or services related to ship emissions?

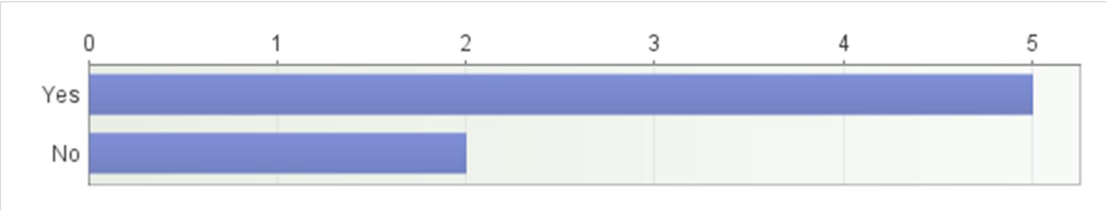


Figure 4.26. Has the BC issue come up in conversations with your clients?

In the marine industry, engine manufacturers have a very significant role when ships engines are designed, tested, maintained and installed on ships. For the question—'*have you developed technology for BC emission reduction or measurement, or are you planning to do so?*'—four out of seven are developing products, and one respondent is planning to do so. Those who are not active in this told that it is not a current issue and there is not enough information about emission control at this moment. In addition, capital investors will not support research that cannot prove a return on investment (ROI) for equipment developed at a feasible time. Investors also require that a regulation scheme is established for emissions. Emission reduction plans follow them. All of the marine industry respondents collaborate (or are planning to collaborate) with companies offering technologies related to BC emissions (Figure 4.27).

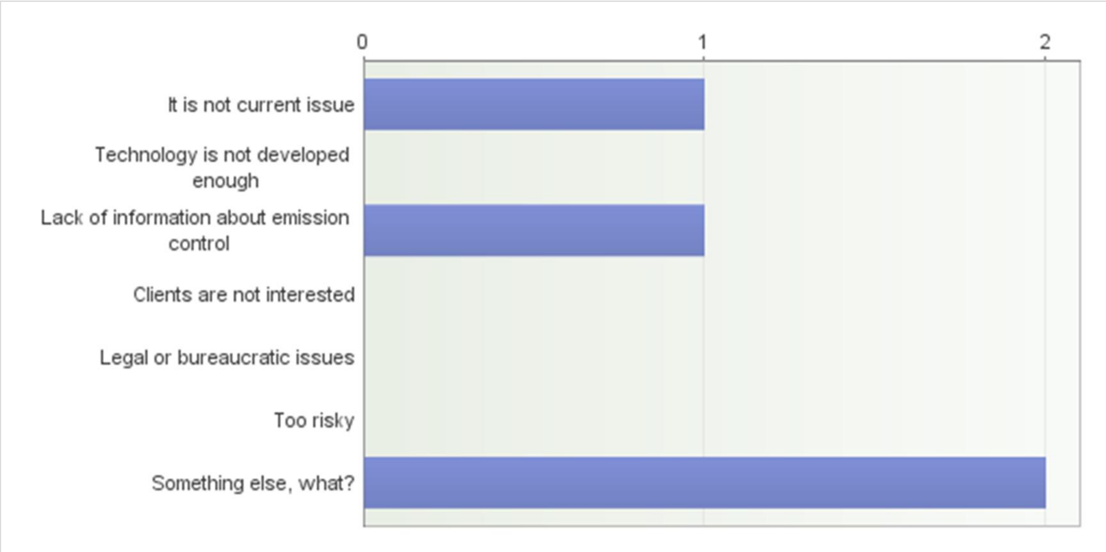


Figure 4.27. If you are not developing the new measurement technology for BC, what is the reason for that?

The whole marine industry is in a key position to consider how the market for BC control will develop in the near future (Figure 4.28). The respondents believe that there will be new business opportunities for new and innovative fuels and engines developed in order to decrease emissions. The respondents consider that the market for BC reduction technologies is not so bright in the short term (e.g., 5 years in the study), as it is too short a time for new innovations to mature, while a ten-year time frame was considered to be more optimistic. The respondents thought that the SECA requirements to reduce emissions are sufficient at this moment. Post-treatment devices that will be installed on ships, such as sulphur scrubbers, are one of the current options. Some respondents stated that there will not be a market for technologies that merely reduce BC emissions. It will not be possible to make a business plan with a positive result, and there is no knowledge about the ROI. On the other hand, the respondents considered that the market for other emission reduction technologies will be brighter in the next five years. Especially post-treatment technologies (e.g. scrubbers) will be growing, but also NO_x emission reduction technologies are waiting for market demand. Companies who invest in technologies and research also expect to make a profit from their products. If legislation for decreasing emissions is enforced, companies will be forced to implement and invest in these new technologies. But this will take more than five years.

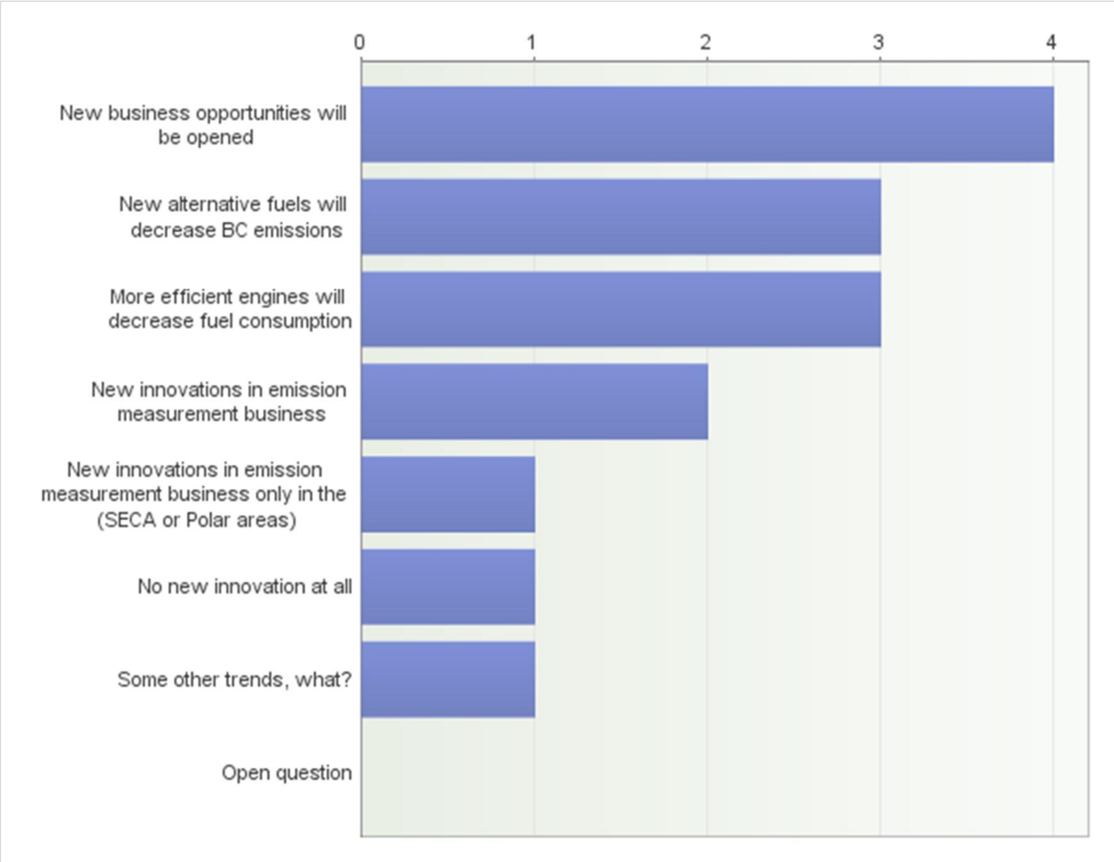


Figure 4.28. How do you see the market for BC control technology developing in the near future (the next 5 years)?

4.7 Measurement Technology Companies

Measurement technology companies have an important role because these companies develop equipment for the maritime industry and for BC measurement. Four measurement technology companies responded. Their main market areas are the shipping industry, ship and engine performance monitoring, automotive, and automotive particulate emissions. Clients of these responding companies are shipping companies, other marine industry companies and other industries such as scrubber manufacturers. Figure 4.29 shows that three out of four respondents are aware of BC emission control regulations. The respondent's business activities include products and services that are related to ship emissions, and three of their activities are connected to BC. One respondent is not yet developing technology for BC because there is still much to do with technologies focusing on NO_x and SO_x emissions.

Figure 4.29. Are you aware of the possible BC emission control regulations?

Despite the current busy situation with the other emissions measurement technologies, the respondents will invest in the next two to five years in BC equipment. But they do not think that BC emission technologies for the maritime industry will develop very quickly in the future because of the lack of regulations and the set IMO levels; it is too risky for large investments. Figure 4.30 shows the development in measurement companies' views of the markets for BC in the near future (the next five years). The measurement technology companies (like other respondent groups) also consider that there will be new business opportunities and that new alternative fuels will be developed to decrease fuel consumption. More efficient engines will decrease fuel consumption, and innovations in emission measurement business will be further developed. This respondent group was slightly more positive in their responses.

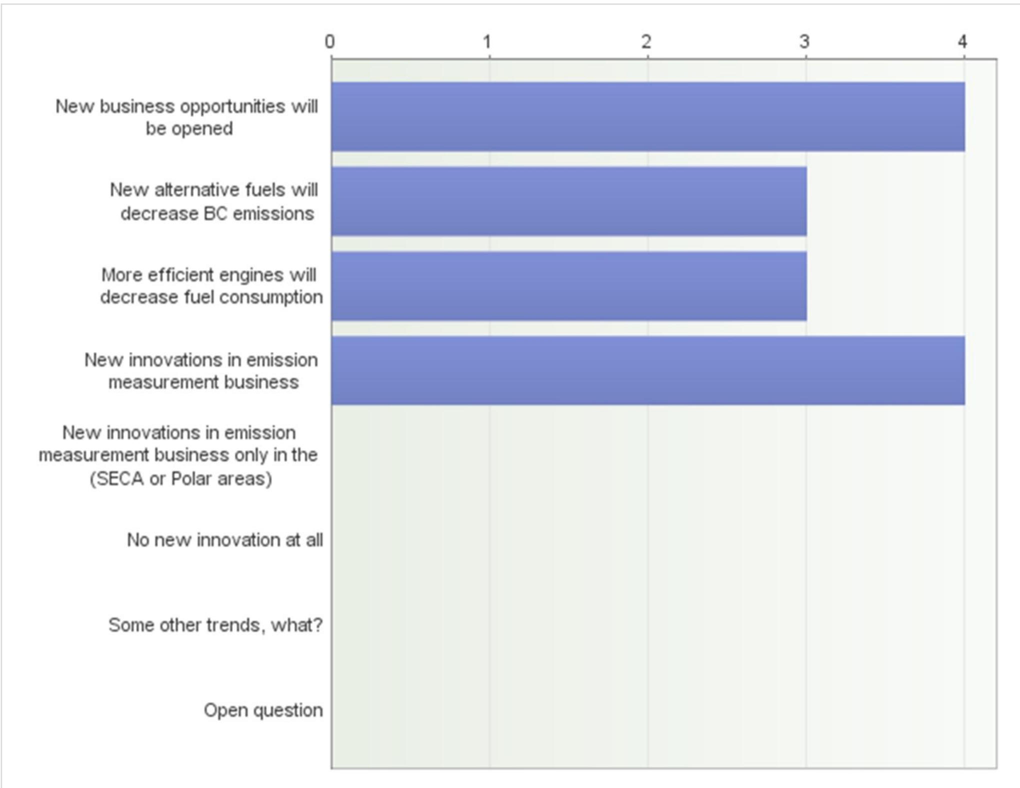


Figure 4.30. How do you see the market for BC control technology developing in the near future (the next 5 years)?

4.8 Consulting and Other Companies

There were only two respondents from the '*consulting companies'* group. Therefore, their answers are combined with the '*other companies'* group. Their main markets are focused on renewable energy, exhaust gas cleaning, emission control, LNG, the general maritime sector, and the port-related industries. The majority of respondents (11 of 14) already knew about possible BC emission control measures. Seven respondents have already developed a technology for BC reduction, and one respondent is planning to do so (Figure 4.31). Respondents who have developed this have had earlier conversations with their clients about BC (Figure 4.32).

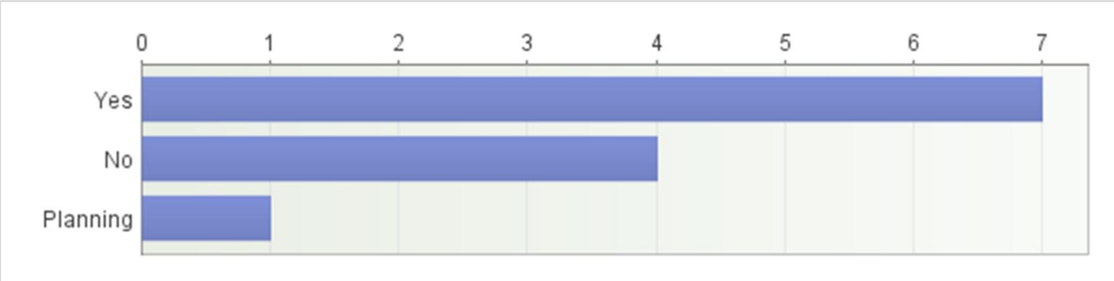


Figure 4.31. Have you developed technology for BC emission reduction or measurement, or are you planning to do so?

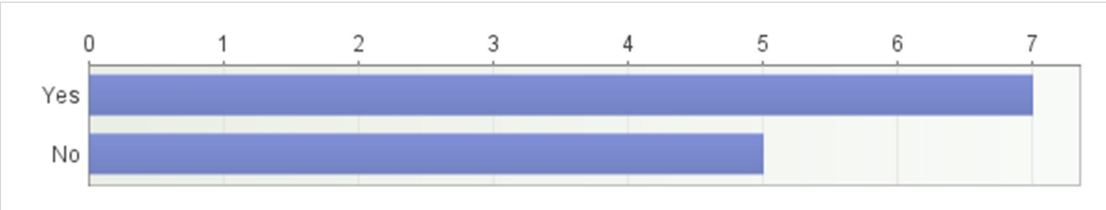


Figure 4.32. Has the BC issue come up in conversations with your clients?

The respondents were asked if they have other emission reduction technologies in conversations with their clients, and do they also have business activities with them. At this very moment, other emissions like CO_2, NO_x, SO2, PM, CH4 and VOCs are more relevant than BC. The reduction technologies that were observed by the respondents are now current and widely used. These technologies include Diesel Particulate Filter (PDF), Diesel Emission Control by Oxidation Catalyst (DOC), Particle Oxidation Catalyst (POC), Selective Catalytic Reduction (SCR), SO_x scrubbers, alternative fuels like LNG and propulsion systems, and ship hull technologies. Figures 4.33 and 4.34 present the current business activities with customers. Seven respondents have business activities, which include products or services connected to ship emissions and also to BC. Some of the products are indirectly related to BC, and some are focused directly on BC emissions (Figure 4.35). Generally this means that they develop services and products that can be used widely both in industry and on ships. However, we do not have exact details on what these products and services are.

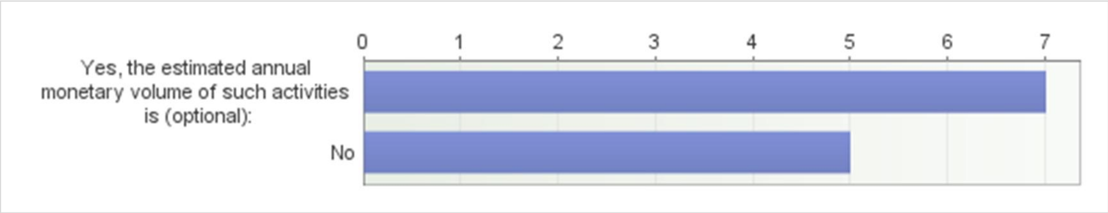


Figure 4.33. Do your business activities include products or services related to ship emissions?

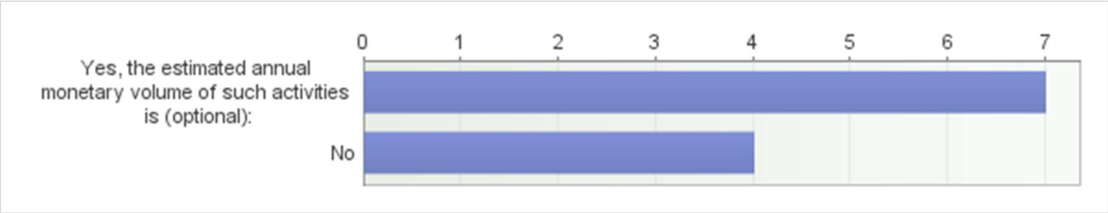


Figure 4.34. Do your business activities include products or services related to BC emissions?

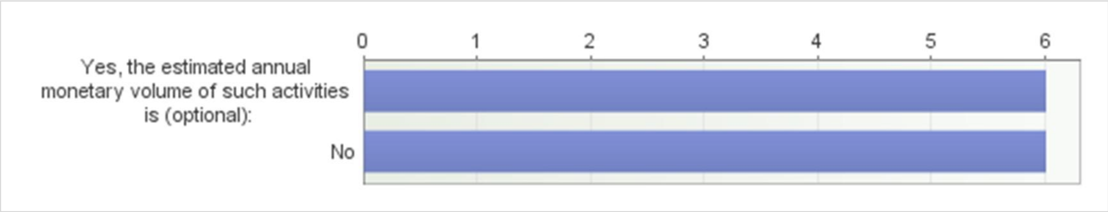


Figure 4.35. Do your business activities include products or services related to BC emissions from ships in particular?

Compared to the other answer groups for this question, there were more answers and comments in the open questions. The majority of the respondents see that there will be new opportunities in business, new alternative fuels, more efficient engines and new innovations in the emission measurement business in the near future (Figure 4.36). This group also considered that in the next five years there will be other trends. LNG in marine use will be more common than it is now, as will exhaust gas-cleaning systems on ships. Some respondents evaluated that the Fuel Water Emulsion technologies will increase in the near future. There were also detailed answers that there should be tighter limits (in addition to NOx emissions) and that the first focus should be on ECA.

The respondents thought that along with this implementation, increasing the use of low sulphur fuels (or best available gas cleaning techniques) is the best current solution for reducing emissions. On the other hand, when IMO regulations or EU-level directives come into force, it creates business for all maritime-related sectors. A good example is the EU strategy for LNG, as the ports that belong to the Trans-European Transport (Ten-T) Network must have the LNG bunkering option in a certain time frame. This creates positive activity for the whole marine industry, especially for shipbuilding.

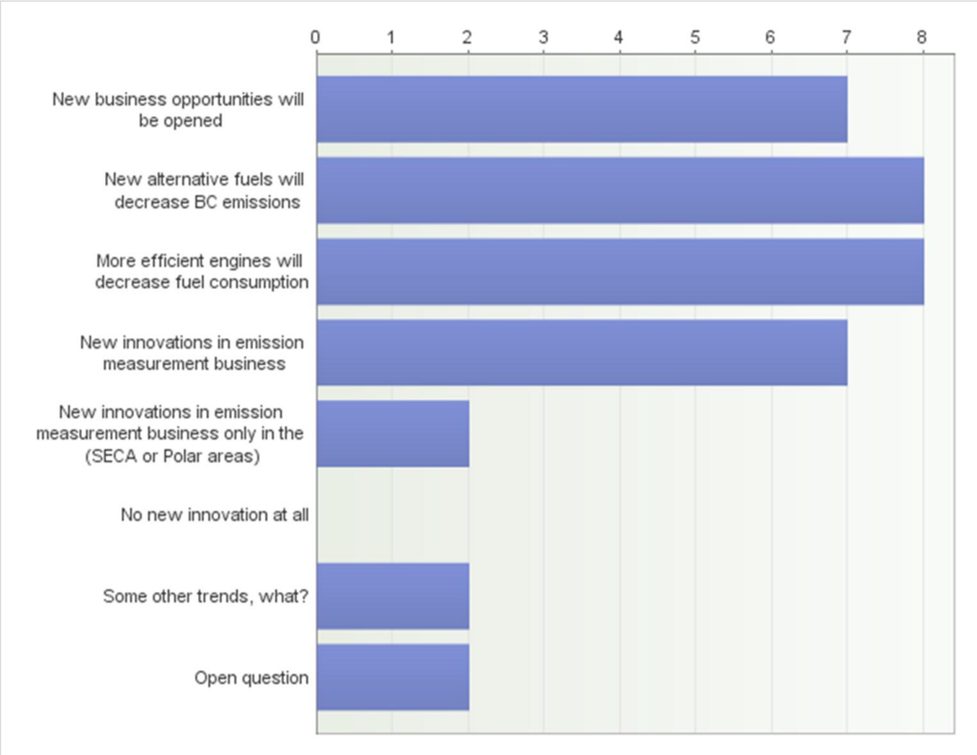
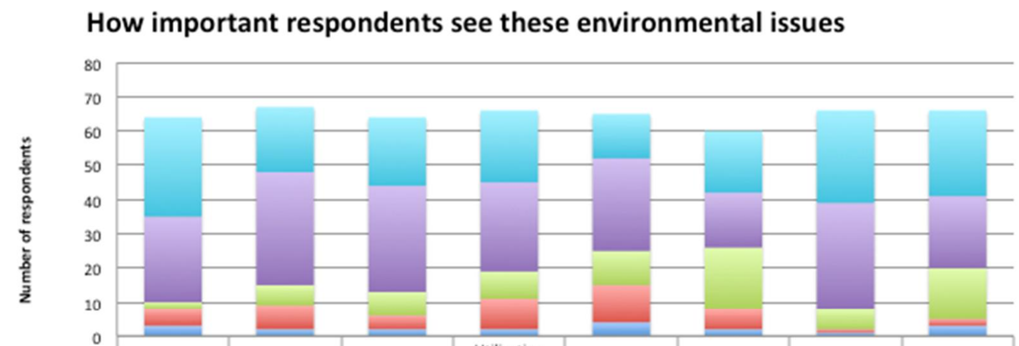


Figure 4.36. How do you see the market for BC control technology developing in the near future (the next 5 years)?

4.9 General Environmental Issues in Maritime Operations

The last set of questions in the survey focused on how the respondents see maritime environmental issues and how these issues have an effect. Even though this part was addressed to all, some did not answer it, and the number of respondents was 67 (Figure 4.37). In the first question, the respondents were asked how they see the measurement and monitoring of emissions? The majority (83%) answered 'important' or 'very important'. Ten respondents (17%) did not see it as important or they did not have an opinion. In the second question, the respondents see equipment (e.g. sulphur scrubber) in exhaust gas cleaning operations as important or very important (78%), and 22% see exhaust cleaning techniques as being not so relevant. Greenhouse gases were significant, as 80% of the respondents see it is as important or very important, and only 20% thought it was irrelevant (not important or no opinion).

The respondents' opinions about investments in alternative fuels, such as LNG and low carbon fuels, yielded the result that investment in low carbon fuels is slightly more important (77%) than LNG (71%). This result must be considered as surprising. Especially in Europe, LNG has been in a strong position, and EU strategies also support LNG as an alternative fuel for ships. Another interesting opinion is about the reduction in fuels costs: only 57% of the respondents saw it as important or very important. This means that 43% of the respondents did not. It should be noted that there were differences among respondent groups—fuel costs are most important for shipping companies. Almost all of the respondents see investments in energy efficiency as being important, and only 10% did not have an opinion or answered 'important'. In the last question—'how respondents see optimization of logistics'—70% consider it to be important, whereas 22% have no opinion or do not think it is relevant to their operations.



	Measurement and monitoring of emissions	Exhaust gas cleaning equipment such as scrubbers	Greenhouse gases such as CO2 and other gases	Utilisation and / or investment into alternatives fuel such as LNG	Investments into low carbon biofuels	Reduction of fuel costs	Investments into energy efficiency	Optimisation of logistics
Very important	29	19	20	21	13	18	27	25
Important	25	33	31	26	27	16	31	21
Do not have an opinion	2	6	7	8	10	18	6	15
Less important	5	7	4	9	11	6	1	2
Not important	3	2	2	2	4	2	1	3

Figure 4.37. Respondent views concerning environmental issues.

Generally all respondents are environmentally friendly and see environmental issues as important in their everyday operations. The respondents' views vary a little bit, and some consider other things as more important than others. Different answer groups have different emphases on environmental issues and different interests in the broad maritime sector.

At the end of the questionnaire was a feedback section, where the respondents were able to write comments about the questionnaire and leave clarifications. In general, comments and clarifications focused on what should be done in the future with BC emissions. The respondents see that climate change is the most significant problem of the 21st century, and they think that global shipping should be forced to reduce GHG emissions. BC emissions also need to reduced, but opinions on the emission control area varied on whether the reduction of BC should only be in the polar areas or be global. The respondents thought that unified standards in measurement methods, certification at the test-bed on board, and legislation (globally) should be obligatory if BC emissions are to be reduced.

Some respondents wrote that currently the focus is strongly on 'how to measure' BC. Instead, the focus should be on BC-reducing equipment and techniques. One respondent stated that it is impossible to ever make a reliable measurement of BC on board a ship, i.e. with accuracy below 50%, because the conditions on board are not proper (i.e. long straight pipelines or distributed flow and space), and there are never standard conditions (i.e. temperature and humidity), so the results have been compensated for all these various conditions, which makes a measurement very inaccurate and repeatability very low.

One respondent replied that BC emissions could be lower than in the current situation if existing engines would be better maintained. In addition, with a new engine or equipment, it has to be ensured that the new technology will perform well after years of service. The question is whether or not there should be future legislation for engine maintenance and requirements. Thus, is there a need to regulate maintenance, not only from the safety point of view like SOLAS, but also from the point of view of emissions and the environment?

5 EXPERT VIEWS ABOUT BC MEASUREMENT TECHNIQUES

Interviews for experts were conducted in order to acquire more data and visions about BC measurement's business potential in the future. The interview request was sent to experts from different fields expertise. The experts were divided into three different groups: (1) research institutes, (2) measurement technology companies, and (3) engine manufacturing companies.

5.1 Opinions Concerning Abatement Techniques

The first section focused on expert opinions concerning IMO's definition of BC abatement techniques. What opinions are there about different techniques, and what is the best abatement technique for reducing BC (and why)? IMO has defined the following techniques:

1) Fuel efficiency – vessel design (excludes engine, fuel options)
2) Fuel efficiency – monitoring options
3) Fuel efficiency – engine options
4) Slow steaming
5) Fuel treatments:
   - Colloidal catalysts
   - Water in Fuel Emulsion (WiFE)
6) Fuel quality (traditional fuels)
7) Heavy Fuel Oil – distillate
8) Alternative fuels:
   - Biodiesel
   - LNG
   - Methanol – Dimethyl Ether (DME)
   - Nuclear
9) Exhaust treatment:
   - Electrostatic precipitators (ESP)
   - Diesel particulate filter (PDF)
   - Diesel oxidation catalysts (DOCs)
   - Selective catalytic reduction (SCR)
   - Exhaust gas recirculation (EGR)
   - Exhaust gas scrubber (EGS)

All those interviewed thought that there is no single solution that would decrease BC emissions. The Measurement Technology Company argues that the best of these IMO abatement methods for reducing BC is the Exhaust Gas Scrubber (EGS). According to the research institute, the slow steaming method can cause more problems, depending on the ship type and especially the ship's engine type. In old engines, there might not be problems in high engine loads, but in slow loads, fuel does not burn as efficiently as it should. With the new engine types, including the common rail fuel injection system, fuel burning is more efficient and BC emissions might have decreased. This was studied in September 2016 as part of the Sea Effects measurement campaign. Research should focus on different methods to find the best solutions to cut BC emissions.

An engine manufacturer saw the importance in fuel efficiency. Burning can be improved by raising the pressure. That leads to more effective burning and the optimal condition for burning. If the NOx emission is smaller, there will also be more unburned material; therefore the balance is important. NOx is also limited nowadays and emission is formed in the engine. IMO has certified emission boundaries for test-beds. They are in a controlled environment and are meant to make repeatability possible. And that makes it possible to classify engines. Slow streaming, driving slower or switching off engines saves fuel and also reduces emissions, depending on a different set of factors like fuel, the burning process and the engine.

5.2 Implementation of BC Limitations

The respondents widely consider that the time frame for implementing BC limits will be at least 5–10 years. The earliest time for the limitations is considered to be in 2020. During 2017, IMO's measurements are being elaborated. Furthermore, the methods should be standardized in order to achieve threshold values. It also needs to be jointly decided which regions will be included in the limitations. The question is mainly whether the area will be the Arctic region or some larger area. The methods for BC abatement development in the next 10–20 years are very difficult to estimate. However, it seems unlikely that new reduction methods will be developed. Current abatement methods can and will be developed to be more accurate. Existing methods include sulphur scrubbers. They were seen as becoming more efficient and reliable. In factories, there are electrostatic precipitators that are very efficient, but this method is not suitable for ships because of the equipment size. Respondents from a research institute thought that currently the best solution is perhaps to change the ship fuel to low sulphur fuel.

5.3 Monitoring BC Emissions in the Arctic

How can ship emissions be monitored in the Arctic areas? Officials can conduct spot checks of ship emissions in the Arctic areas. There must be both a stick and a carrot so that regulations and limitations are followed. There are different opinions among the respondents on who should control the emission monitoring in the Arctic areas. For example, should countries monitor their own regions and emissions? IMO does not have rights to monitor sea areas. Ship emission monitoring will be a very difficult task. Remote emission measurement systems are very difficult to execute, and they are also expensive. In the Arctic areas, weather and ice conditions vary a lot, which creates challenges for the measurement equipment. With satellites, it is impossible to monitor BC emissions, and with the help of aerosols, some information on BC can be acquired, but it is still challenging. One solution would be to control fuels. Another solution is issuing ship permits for Arctic area operations.

Similar issues were raised with sulphur emission regulation. The further the ships are from the coastline, the more difficult the measurement and controlling are. When ships are outside national economic zones, no one has a mandate to conduct inspections. In the port areas, the emission controlling and inspections are much easier. From the perspective of jurisdiction, there have not been any preliminary legal cases where the data from emission measurement equipment would have been strong enough evidence for a ship inspection.

BC measurement systems should be the same as for NOx emissions. The measurement systems are standardized and certified. In every engine test-bed, the measurement campaign is documented, and engines are adjusted so that the emission level is under the set limits. That means that measurements are conducted in laboratory conditions and there is evidence for the results. An inspector checks the results and documentation as well as the cleaning technology. Ship monitoring could be done with an exhaust fumes darkness meter, which would give a signal when the emissions exceed the set limit. For example, in Alaska, visual exhaust fumes measurement is commonly used. IMO has not yet decided what limits to set and how they would differ between new and old ships. Internationally, emission control could be possible, but the existing control is not an IMO responsibility, and individual countries are responsible for controlling their territorial waters.

5.4 Suitability of Different BC Measurement Methods

Interviewees were asked for their views on IMO's recommended measure methods and which of them is the most accurate for BC emissions. Those methods are as follows:

- Photo Acoustic Spectroscopy (PAS)
- Multi-Angle Absorption Photometry (MAAP)
- Laser Induced Incandescent (LII)
- Filter Smoke Number (FSN)

There was some variation in the responses as to which IMO-recommended technique would be suitable for BC. In the view of a measurement company, a combination might be the best solution. According to a research institute, MAAP is a dilution method, and measuring ships' FSN would be operationally the most suitable and functional. In addition, the PAS method might work as well. Other methods should be developed for suitable use on ships, but there has been no need to develop them in that direction.

An engine manufacturing company supported using FSN because other methods are more focused on research methods. Those other methods have been used in environmental measurements, not in emission measurements. FSN has been used for several decades in engine measurement campaigns. It is simple, inexpensive and does not require acidic know-how. It is still undecided if the measuring would be conducted on ships or in test circumstances. FSN measures all emissions, not just BC, whereas MAAP is suited for BC but not for ship use.

IMO has supported FSN as the standard method. A measurement technology company thought it might weaken the market for measurement equipment and sensors, while an engine manufacturer does not see that as a possibility because it is suitable for monitoring and determining threshold values. Research institutes and universities are using other methods for research. FSN technology is the only standardized method, and it can create threshold values. A research institute told that if ship emission control is the desired result, it might strengthen the FSN method, but in research there are different methods in use. It is believed that in the future, measuring equipment will be pluralised and further developed.

Those interviewed thought that it is hard to estimate whether background emission measurement is suitable for the Arctic areas. According to a measurement technology company, the best alternative would be if there is real-time measurement equipment on every ship. An engine manufacturing company found it challenging, since a test-bed is needed for measuring reliable results. Background measures do not give readable information about the real emissions due to the large number of variables.

In research it is possible to use different methods in data collection. In some countries, public authorities are using the distant measuring method, which is not actually reliable or a particularly good method. The Danes are monitoring ship emissions from the air. For example, when a ship arrives in a port, it is possible to check if there are any anomalies with an airplane or a helicopter. Distance monitoring is more of an indicative method. However, the research institute argued that there is a large measuring network (4) in Finland and three of the networks are also measuring BC. It is possible to measure locally, but not the entire Arctic region. Canadians had found out that measuring is very challenging and very expensive. Canada has two stations in the Arctic regions, and according to the Canadians, BC emissions are difficult to measure where the distances are long. A station should be about 100 metres away from the origin of the emission (ship's exhaust gas pipe). That would be difficult to realise in the Arctic region. Stations should also be occupied to be able to take care of maintenance. They also saw that the most reasonable measurement method is to be on a nearby ship or on board the ship. If there is no regulation requiring measured data to be in real time, measuring it on board using satellites saves costs and time.

5.5 Collecting BC Emissions Data

When asked if shipping companies would invest in future BC measurement technologies on board, one measurement company answered Yes, because several customers wants turnkey solutions. This means that all equipment, system, data collecting and servicing of the measurement equipment is included in a deal. This service could provide a competitive advantage for companies who offer these measurement services. The measurement company also agreed that real-time emission measurement will be mandatory for ships in the future. The company also believes that background emission measurement is not enough in the Arctic areas.

An engine manufacturer pointed out that researchers and other controllers need connections and equipment such as helicopters. Those who are creating engines have an interest in the development and measuring being repeatable. Communication systems are small things that are needed to be able to take care of the control. There is a need for certified equipment that continuously measures, controls and sends the data. For example, Trafi is in need of this type of information. It should be noted that ship crews are not trained in using measuring equipment. Systems should be calibrated and maintained, and this requires specific know-how and training. There are different needs in measuring: Those obligated by the law, standardized methods, and researcher measurements. For real-time emission measurement (to become mandatory on ships), it is estimated that even 20 years may be too short a time limit. The shipping companies are strongly resisting it. To put it bluntly, 'devices should not cost anything', 'require no maintenance', and 'should still produce reliable measuring output'.

In 2017, the EU started collecting data on ship fuel consumption. There is an option to use bunkering data on what fuel and how much has been bunkered. Another option is real-time measuring sensors on ships. The reporting obligation is only for CO_2, but there is an option that in the future, NOx, particles, etc., should also be measured. It is an option in directive, but not necessarily an implementation. CO_2 is measured in the first place. New ships can create information about consumption and possibly also about emissions. Small gas sensors in the future could be a solution within 20 years.

When asked about the rational possibility to use satellite capacity for transferring emission measurement data from the open sea or by much cheaper (4G or 3G) transfer communication systems in ports, a research institute mentioned that a Finnish company, Kyynel, has a radio-wave-based system in which every ship acts as a server. It is also possible to send information about emissions when a ship is arriving at a port. A satellite connection to a ship is an investment worth tens of thousands of euros and will hardly be realised if it is not set as an obligatory tool.

5.6 Storing of BC Measurement Data

A measurement company noted that authorities had told them that data storage containing emission data should be controlled and operated by a data centre (officials). Data should also be openly accessible because this might boost companies to greener visibility and could also motivate them to invest in new technologies. All stakeholders should have access to the data so that they would be able to use the data for research and possible applications. A research institute argued that because of the way sulphur is controlled, Trafi (the public authority) would have the supervision in the case of Finland. IMO would be involved in reporting. If there are sanctions, the public authority would issue them. Shipping companies are very careful not to provide their competitor with any benefits. Every bilateral agreement between different stakeholders is practically closed. From the viewpoint of research institutes it would be very useful because now these issues have to be modelled. Measured results would make model verification and post-comparisons possible.

Data bank privacy received very few answers, perhaps because of the expected long time span. A research institute thought that privacy could be done in a similar way as in sulphur measures. Open access was seen by the research institute as an ideal case, but the first step should done by a public authority. It is the same issue as in Portnet and AIS, in which the information field on cargo is 'other cargo'. According to one measurement company, the falsification of measurements would be a real concern. In industrial espionage, it depends on what the data is used for. For example, in emission trading, the falsification of measurement data could be possible.

5.7 Real-Time Measurement of BC Emissions

A measurement company believes that in the future, onboard real-time and BC emission measurement is important, and ship monitoring in the Arctic areas should be overseen with spot tests conducted by authorities. The research institute pointed out that EPA in the U.S. is demanding real-time and continuous measuring for NOx for ships under the U.S. flag. IMO's legislation does not favour continuous measurement, but rather the test cycle methods. In continuous measuring, a single value does not tell anything. For example, on a ship, one has to load engines with different outputs (100–75–50–25) and all of them should have a measured value. Threshold values created in the past 20 years have been developed in test-beds that enable loading the engine rapidly. Measurements on ships are made under a continuous change in air moisture.

Setting limits for ship emissions and monitoring them while they operate in the Arctic region was seen as 'important' by one research institute. Ships should be allowed to enter the Arctic regions only if the emissions from the fuels used fall below the set limits, and there should be a supervisory ship that would oversee which vessels have the right to access the region. When ships are operated in the Arctic areas, the supervision of used fuel must be done in the same way as in the SECA region.

5.8 BC Measurement Business Potential

The business potential is currently seen as 'quite limited', since there are no obligatory measurement duties. It depends on how the emission measurement system in the future is built. There is room for development in the measurement and sensor sector for serving the needs of researchers and authorities. This development for decreasing emissions would also serve ship owners when they would have a better input-output ratio for ships (low BC emissions). BC measuring should be reliable and inexpensive. There might be business opportunities for alarm systems such as FSN if there are abnormal exhaust pipe emissions. These alarms would enhance fuel saving. These are important especially in port regions. A cheap and simple meter would be a good solution, enabling a fast reaction also at engine test-beds for the engine manufacturer. According to one research institute, there might be a lot of business potential, for example, if an inexpensive sensor would be developed. This could create a whole new business branch for the industry. Communication components provide a potential growth business. This is dependent on how and what technique is used in the emission data transfer. The business potential for the emission metrics themselves (measurement results, data, and emission loads) is doubtful because ship owners are likely to be unwilling to give this type of information to external parties.

6 DISCUSSION

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

Different stakeholders are finding BC emissions and its measurement an interesting subject, and especially universities and research institutions are well aware of the effect of BC on the Polar Region. However, a majority of stakeholders had not heard about BC emissions before, a result that might be caused by the limited response rate. The questionnaire study as well as interviews support the idea that the time is not suitable to cut down on BC emissions. There are still unsolved challenges with the sulphur directive, and NOx limitations will take place in the year 2022. As long as IMO remains undecided about when and what threshold values will be pursued, there will be no interest in investing in this issue.

According to the respondents, they have the same opinion that there is no 'single solution' on a abatement technique that would decrease BC emissions. With slow steaming, the need for total engine output decreases, and some engines can be stopped or the overall engine load decreased. Even though the g/kWh emission of the engine can increase at lower load, the time-based total emissions (g/hours) of the vessel could be decreased by utilizing slow steaming or other energy reduction technologies.

Finally, satellite connections work relatively well in the Arctic regions, but because of the cost, the connection is seen as more important to use for weather information or e-mail than for real-time measurement information transmission. The collected data is seen as more reasonable to transfer in ports (and holistic waste management; see Svaetichin & Inkinen 2017). There are plenty of future research challenges. They include (a) what kind of data exists, (b) who uses it and (c) who owns it? In addition, data management and security should be focused on. In future measuring, standardized and inexpensive sensor technologies combined with an easy-to-use principle on board are essential.

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APPENDIX 1

General structure of the stakeholder survey

SHIP BLACK CARBON EMISSIONS MEASUREMENT

1. Where is your head office located?

2. What is the type of your organization?

3. Did you know or had you heard about black carbon emissions before this study?

4. What is your view on current legislation and emission control? Is there too much or too little legislation or too few limitations?

5. Open field for specifications

6. Have you done research on ship black carbon emissions?

7. Have you been discussing the possible black carbon control and development needs for new black carbon technology?

8. Have you developed new measurement technology for black carbon, or are you planning to do so?

9. Are you collaborating with companies who offer measurement technology in order to develop products?

10. How do you see the market for black carbon control technology developing in the near future (the next 5 years)?

12. Open field for detailed answers

13. Are you aware of the possible black carbon emission control regulations?

14. Have you taken into consideration possible black carbon emission control when planning your operations or investments?

15. Have you been in contact with companies who offer emission measurement technology?

16. Do you have a need for black carbon emission reduction technology (clean engines, alternative fuels, exhaust gas treatment equipment, etc.)?

17. Do you have a need for black carbon emission technology (reduction or measurement)?

18. Open field for detailed answers

APPENDIX 2

SEA-EFFECTS BC phase on the questionnaire

Dear Recipient,

You are invited to participate in a survey on a market analysis of emission measuring technology. The survey is part of the research project, SEA-EFFECTS BC, being conducted by the Maritime Research Centre at the University of Turku, Finland.

The aim of this inquiry is to collect more detailed information on black carbon measurement and abatement methods and the business potential in the maritime sector. This questionnaire is part of the SEA-EFFECTS BC project, which aims at creating a more reliable and unequivocal basis for black carbon (BC) emission evaluation in the shipping environment and at generating new options for online monitoring techniques. Definitions of sampling and sample treatment are essential for reliable measurements in a ship environment, particularly when using new fuels and emission control technologies. This approach will also support the generation of reliable ship emission factors. In-depth analyses of other emissions, in parallel with BC measurements, increase the understanding of results obtained by different techniques, which is a prerequisite for further development. Business opportunities in the field of emission measurements are evaluated, particularly regarding sensor and information technology.

If you have any questions or concerns, please contact:

Olli-Pekka Brunila
Project manager
Brahea Centre at the University of Turku/Centre for Maritime Studies
olli-pekka.brunila@utu.fi
+358 40 4855710

General questions:

What is your organization?
• University or research centre
• Shipping company
• Port
• Association, trade organization or similar
• Marine industry company
• Measurement technology company
• Consultant
• Other, which ___________________

IMO'S ABATEMENT METHODS

1. IMO has defined the following BC abatement techniques. What is your opinion of these techniques, and which is the best abatement technique for reducing BC, and why? You can choose several alternatives.

- Fuel efficiency – vessel design (excludes engine, fuel options)
- Fuel efficiency – monitoring options
- Fuel efficiency – engine options
- Slow steaming
- Fuel treatments:
  - Colloidal catalysts
  - Water in Fuel Emulsion (WiFE)
- Fuel quality (traditional fuels)
- Heavy fuel oil – distillate
- Alternative fuels
  - Biodiesel
  - LNG
  - Methanol – dimethyl ether (DME)
  - Nuclear
- Exhaust treatment
  - Electrostatic precipitators (ESP)
  - Diesel particulate filter (PDF)
  - Diesel oxidation catalysts (DOCs)
  - Selective catalytic reduction (SCR)
  - Exhaust gas recirculation (EGR)
  - Exhaust gas scrubber (EGS)

2. When do you see that limitations on BC emissions will be implemented?

3. How will BC abatement methods be developed in the future (the next 10-20 years)?

4. Do you believe that ship emissions can be monitored in the Arctic areas, and is it possible bring sanctions if abatement techniques are not used?

5. Which official or organization should control emissions in the Arctic areas?

IMO'S RECOMMENDED MEASUREMET METHODS

6. Which of the following recommended measurement methods by IMO is the most accurate and suitable for BC emissions?

- Photo Acoustic Spectroscopy (PAS)
- Multi-Angle Absorption Photometry (MAAP)
- Laser Induced Incandescence (LII)
- Filter Smoke Number (FSN)

7. IMO has supported the Filter Smoke Number (FSN) method. If this method is chosen as the standard method, do you believe that markets for measurement equipment and sensors will weaken in the future and will focus on this FSN technique?

8. Is background emission measurement possible in the Arctic areas, particularly in winter?

9. Is real-time measurement from the exhaust pipe the most reasonable measurement method?

COLLECTING BC EMISSION DATA

10. Do you think that in the future shipping companies will invest euros to BC measurement technologies on board?

11. Will real-time emission measurement be mandatory for ships in the future?

12. Do you think it is rational to use satellite capacity for transferring emission measurement data from the open sea or by the much cheaper (4G or 3G) transfer communication systems in ports?

13. Is background emission measurement technology sufficient in the Arctic areas for emission data to be collected closer to the ship routes?

STORING BC MEASUREMENT DATA

14. Who should operate the information system or data storage where emission data is collected?

- Authorities
- Shipping company
- IMO
- Companies / Cloud services (Microsoft, Google)
- Some other
- Open field

15. In which form should the data bank be?

- A system where access is limited to certain groups
- Open data
- Cloud service operated by a commercial company
- Something else, what?

16. Who will grant access to data?

- Officials
- Shipping company
- All
- Universities and research centres
- Companies
- Some other, who?

DATA PRIVACY

17. What information security threats would affect emission measurement data?

- Scams
- Effects on privacy
- Industrial espionage
- Viruses
- Falsification of measuring data
- Some other factor?

REAL-TIME MEASUREMENT OF BC EMISSIONS

18. How important do you see real-time emission and BC measurement on board in the future?

- Very important
- Important
- Not so important
- Irrelevant
- Open field for comments

19. How should ship emission monitoring be executed in the Arctic areas?

BC MEASUREMENT BUSINESS POTENTIAL

20. What factors create business potential for emission measurement?
    - Selling emission measurement data
    - Special measurement and custom measurements
    - Laws requiring mandatory measurement campaigns for ports and other companies.
    - What else?

COSTS OF DECREASING BC EMISSIONS

IMO has estimated the BC reduction costs in new and retrofit ships for different ship types (Aframax, Container, Bulk Carrier, Gas, Passenger, OSV/AHTS and Tug). For a retrofit ship, the operating time is 10 years, and for a new ship it is 30 years. For example, it is used in an Aframax tanker with a 14.4 MW engine When calculating cost-effectiveness (USD/gBC) using MDO as fuel, it can be stated that slow steaming and LNG are the cost-effective techniques and the fresh water sulphur scrubber is the most expensive.

22. According to an IMO report, slow steaming and LNG as fuel are the cost-effective methods. In a previous inquiry, the scrubber was a popular technique to reduce emissions. What is your opinion about abatement techniques and costs? Open question.

Brahea Centre at the University of Turku
CENTRE FOR MARITIME STUDIES

FI–20014 TURUN YLIOPISTO

http://mkk.utu.fi

Turun yliopisto
University of Turku