

# Greenhouse gas mitigation strategies : a ship operator' s perspective in the container shipping industry

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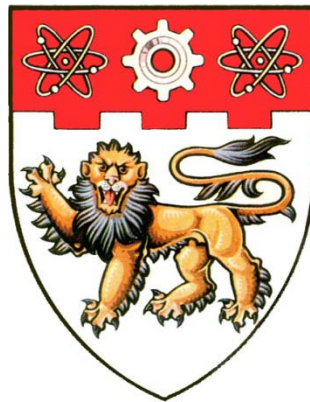
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**GREENHOUSE GAS MITIGATION STRATEGIES – A SHIP  
OPERATOR’S PERSPECTIVE IN THE CONTAINER SHIPPING  
INDUSTRY**

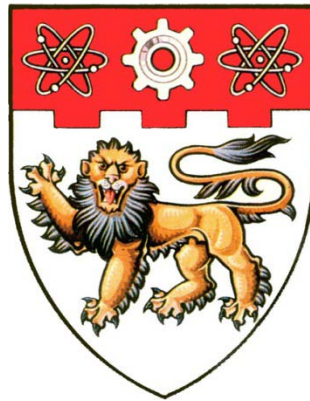


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**2012**

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INDUSTRY**



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in partial fulfillment of the requirements for the  
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2012

## SUMMARY

With the onset of the first ever greenhouse gas (GHG) regulation for ships by the International Maritime Organisation (IMO) in 2011, the container shipping industry requires the combined use of technical and operational emissions reduction measures to improve the environmental performance of its vessels. Studies show that most existing measures are cost effective with a range of emissions reduction potential. However, the level of implementation is not depicted and the potential of the measures may be over-estimated.

An evaluation of the GHG emissions reduction measures is thus conducted in this study through extensive literature reviews, survey of container shipping companies and interviews with industry professionals. Critical issues in the implementation are identified so that solutions can be provided to overcome the barriers. Lastly, recommendations for companies with regards to GHG issues are made.

The emissions reduction measures were evaluated based on 3 factors, namely *level of implementation*, *emissions reduction potential* and *cost effectiveness*. Cost effectiveness is defined as the monetary evaluation of the cost of implementing the measure relative to the cost savings that can be achieved through the usage of the measure. The strong link between cost effectiveness and level of implementation is highlighted in this study. It is shown that measures with higher perceived cost effectiveness generally have a higher level of implementation despite a lower perceived emissions reduction potential. Thus, improvement in the cost effectiveness of the measures is needed to increase the level of implementation. There is immense potential to reduce emissions from ships given the availability of measures with significant emissions reduction potential. However, the top barriers of implementation, namely *cost of measure* and *lack of information*, need to be addressed for a higher level of adoption.

The cost effective measures can be implemented on a greater scale in view of the benefits of bunker consumption savings. GHG emissions reduction is often a by-product of efforts to improve the energy efficiency of vessels. It is advisable for companies to consider savings from reduction in fuel consumption as a main factor in the adoption of measures. Companies should also monitor demand changes amid the environmental situation to identify business opportunities. With the careful packaging of the GHG strategy, the environmental issue can be valuable for business creation. Support for GHG regulations is also encouraged as regulations can drive the development of more efficient technologies. Companies have to realise that green is the way forward in the shipping industry and it is prudent to adopt a greener operation.

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## LIST OF ABBREVIATIONS

CATCH	Cost of Averting a Tonne of CO <sub>2</sub> heating
CCWG	Clean Cargo Working Group
CDP	Carbon Disclosure Project
CH <sub>4</sub>	Methane
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
EEDI	Energy efficiency design index
EEOI	Energy efficiency operational indicator
EU	European Union
GHG	Greenhouse gas
HFCs	Hydrofluorocarbons
HFO	Heavy fuel oil
HSSE	Health, safety, security and environment
IEE	International Energy Efficiency Certificate
IMO	International Maritime Organisation
LNG	Liquefied natural gas
MAC	Marginal abatement cost
MACC	Marginal abatement cost curve
MARPOL	The International Convention for the Prevention of Pollution from Ships
MBM	Market-based measures
MEPC	Marine Environment Protection Committee
MFO	Marine fuel oil
MPA	Maritime and Port Authority of Singapore
NMVOC	Non-methane volatile organic compounds
NO <sub>x</sub>	Nitrogen oxides
N <sub>2</sub> O	Nitrous oxide
ODS	Ozone depleting substances
PFCs	Perfluorocarbons
PM	Particulate matter
R&D	Research and development
SEEMP	Ship energy efficiency management plan
SF <sub>6</sub>	Sulphur hexafluoride
SO <sub>x</sub>	Sulphur oxides
TEU	Twenty-foot equivalent unit

VOC Volatile organic compound

WSC World Shipping Council

## GLOSSARY

### **Container liner shipping**

The trade which involves shipping containers on board vessels that sail according to fixed schedule. The vessels call at fixed ports along the service route. This distinguishes from tramp shipping which does not have a fixed schedule or published ports of call.

### **Cost effectiveness**

The monetary evaluation of the cost of implementing the measure relative to the cost savings that can be achieved through the usage of the measure over the investment timeframe. *Cost of measure* includes for example, equipment cost, opportunity cost, operating cost and staff training cost. *Cost savings* are mainly derived from the reduction in fuel usage.

### **Greenhouse gas (GHG)**

Gases that absorb and trap radiation within the atmosphere, causing a net retention of heat energy. According to the Kyoto Protocol, carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF<sub>6</sub>) are the six gases classified as GHG.

### **Heavy fuel oil (HFO)**

Oil that makes up the distillation residue and consists of large amount of impurities. It is used as the main engine driving fuel during a vessel's voyage for the generation of power, resulting in the release of harmful GHG emissions.

### **Marginal abatement cost (MAC)**

The cost per tonne of GHG emissions of the abatement project.

### **Marginal abatement cost curve (MACC)**

A graph demonstrating all the marginal abatement costs (MACs) of available abatement projects to facilitate decision making.

### **Marine Environment Protection Committee (MEPC)**

A committee of the International Maritime Organisation (IMO) that meets every 9 months to develop international conventions relating to marine environmental concerns.

## CHAPTER 1 INTRODUCTION

### *1.1 Background*

The international shipping industry is seen to be a significant contributor to overall global greenhouse gas (GHG) emissions (Eide et al., 2009). For shipping activities, GHG emissions mainly come from the burning of heavy fuel oil (HFO), the main marine transport fuel used by sea-going vessels. HFO accounts for approximately 80% of the marine transport fuel used due to its availability and affordability (Lee, 2010). However, the amount of impurities in HFO results in the release of harmful GHG such as carbon dioxide (CO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>) (Crist, 2009). With the increase of attention on environmental protection by international community, the industry faces mounting pressure to play its part in the reduction of GHG emissions. The International Maritime Organisation (IMO), in the second IMO GHG study 2009, proposed possible technical, operational and market-based measures that can be adopted by ship operators for control of GHG emissions from ships (Buhaug et al., 2009). However, the continuing lack of a proper regulation regime governing GHG emissions from ships has come under the attention of international organisations in recent years. The European Union (EU) declared that it will implement its own regulations if control is not executed by IMO (Eide et al., 2009). This led to IMO pushing for and finally introducing the first ever GHG regulation for ships in the Marine Environment Protection Committee (MEPC) 62<sup>nd</sup> Meeting in 2011 (IMO, 2011b).

With the onset of the new regulations, shipping companies are required to improve the efficiency of their new and existing vessels. It is important for shipping companies to understand the different requirements and work closely with trade associations and governmental agencies to determine the GHG emissions reduction measures that can achieve the required efficiencies. The voluntary initiatives that have already been put in place by shipping companies in recent years may lower the level of impact on the companies caused by new regulations (Zafral, 2012). However, there is still a need for shipping companies to manage the environmental concerns without affecting the economic performance of the company (Lun et al., 2010). Adopting cost effective measures to reduce emissions is thus extremely important. In addition, companies are increasingly competing on environmental performance and customers are also selecting service providers based on their environmental performance (Hart & Ahuja, 1996). It is a competitive advantage to be seen as an environmentally friendly company. Therefore, the benefit of a well-planned GHG mitigation strategy is enormous.

## ***1.2 Objective and Scope***

The objective of this study is to investigate the GHG mitigation strategies of container liner shipping industry amid the increased need for companies to be environmentally friendly. An evaluation of the implementation of various GHG emissions reduction measures is conducted. Critical issues in the implementation of measures are identified. This study also provides conclusions and recommendations about the position companies should take with regards to GHG issues. The scope of the project includes evaluating the perception of shipping companies towards current GHG emissions reduction measures and identifying critical issues through extensive literature reviews, surveys and interviews. For the present study, the research focuses on container liner vessels and excludes other types of commercial vessels such as tankers and bulk carriers.

## ***1.3 Methodology***

Annual reports of companies and information from public domain were reviewed extensively to identify current GHG emissions reduction measures that are adopted by shipping companies. Academic research papers and reports from agencies such as IMO, DNV and World Shipping Council (WSC) were examined to gather information on the potential and effectiveness of the measures and to identify critical issues. Primary research was conducted through a two-pronged approach of surveys and interviews. Survey questions were designed in accordance to the objective of this study and the questionnaires were posted to container liner shipping companies, both with and without offices in Singapore. A small number of survey responses were anticipated and therefore the surveys were used to capture ground information. The interviews with governmental agency, classification societies and selected shipping companies serve as the second pillar of the primary information collection in this study.

## ***1.4 Report Structure***

This report includes 5 chapters as shown in Figure 1.1. A list of abbreviations and a glossary are also included.

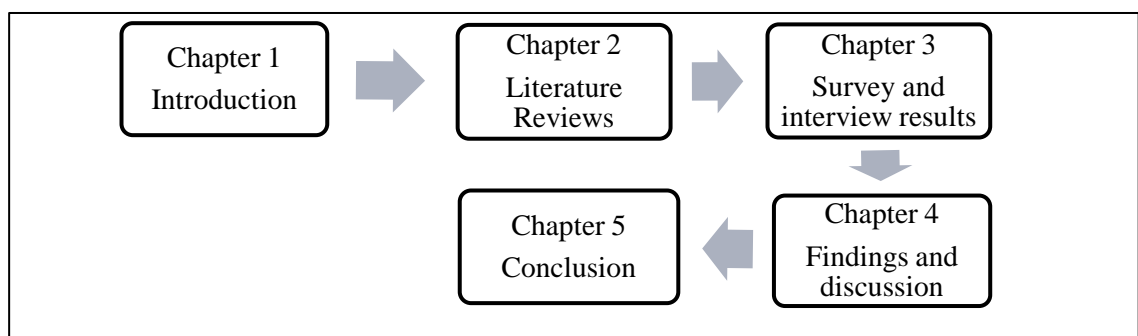


Figure 1.1 Report structure

## CHAPTER 2 LITERATURE REVIEWS

The information obtained through various literature reviews are organised in this chapter to understand the situation of GHG emissions from ships, the potential and effectiveness of current mitigation measures that are implemented by ship operators and critical issues in the implementation. Subsequently, an overview of this chapter is provided.

### 2.1 Shipping and emissions

International shipping emitted 890 million tonnes of air pollutants in 2007 (Buhaug et al., 2009). The major types of air pollutants from ships' emissions are listed in Appendix A. Figure 2.1 shows that out of the air emissions from all ship types in international shipping in 2007, 97.8% is CO<sub>2</sub>. CO<sub>2</sub> is seen to be the most significant GHG emissions from ships due to its quantity and global warming potential (Buhaug et al., 2009). Therefore, CO<sub>2</sub> is often used as synonymous to GHG.

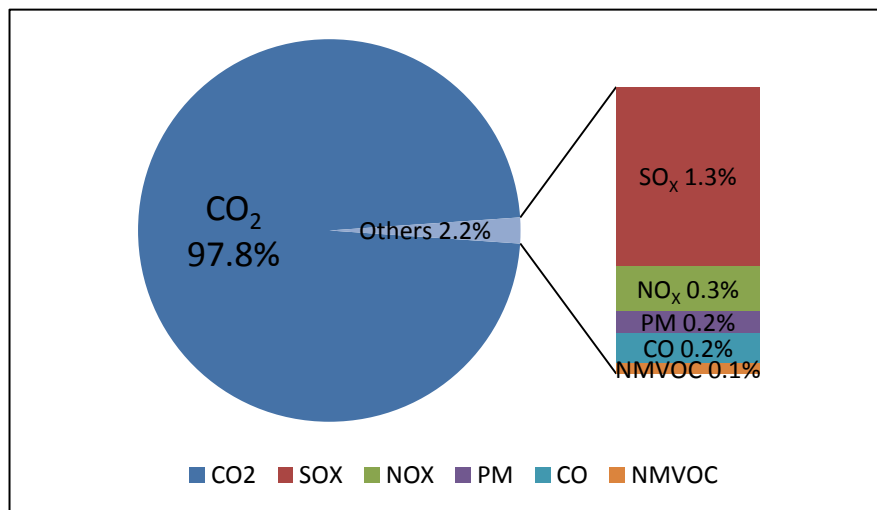


Figure 2.1 Composition of exhaust emissions from international shipping 2007 (Buhaug et al., 2009)

In terms of tonnage-kilometre, shipping is seen as the most carbon efficient way to transport goods over long distances (WSC, 2009). A container ship only releases 10 grams of CO<sub>2</sub> per tonne-kilometre as compared to 470 grams of CO<sub>2</sub> released by air freight (see Figure 2.2). This is the reason why shipping has remained largely an “invisible” industry until recent years, without much regulations regarding its CO<sub>2</sub> emissions in spite of its scale of operations. It is estimated that international shipping is responsible for approximately 2.7% of global CO<sub>2</sub> emissions (Buhaug et al., 2009). Although this amount may seem relatively low as compared to emissions from other activities (see Figure 2.3), there are calls for the shipping fleet to be responsible for the contribution to global GHG emissions.



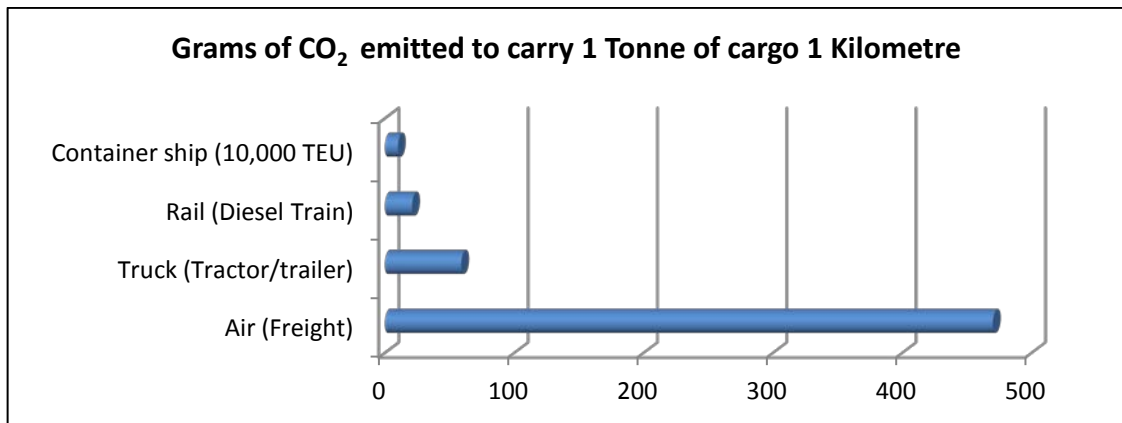


Figure 2.2 Comparison of CO<sub>2</sub> efficiency of different transportation modes (Maersk, 2010)

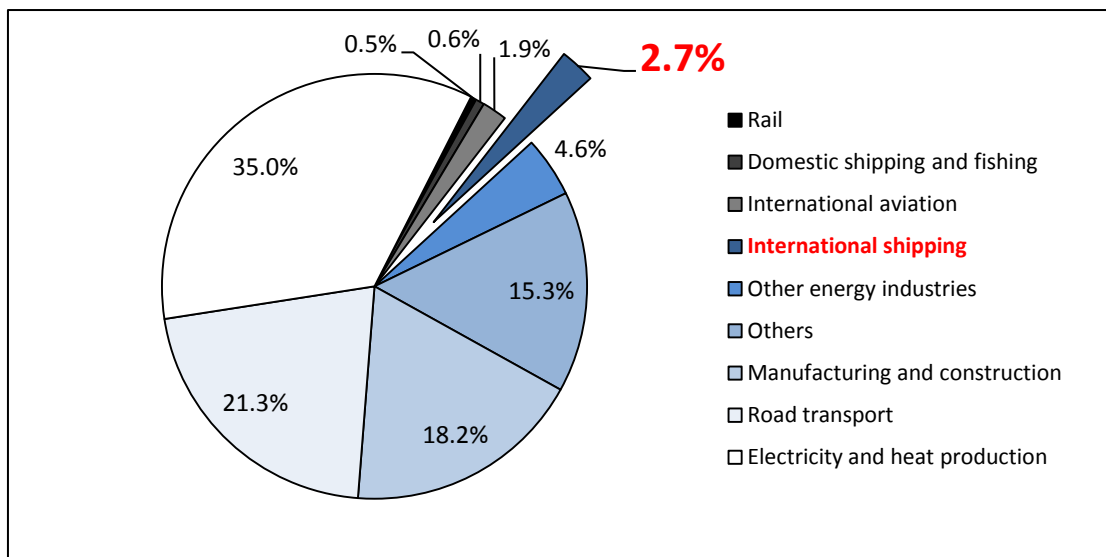


Figure 2.3 Emissions of CO<sub>2</sub> from international shipping compared with global total emissions in 2007 (Buhaug et al., 2009)

According to IMO, the emissions is expected to increase 200% to 300% in 2050 if a mid-range business-as-usual scenario is assumed with a tripling of world trade (Buhaug et al., 2009). There is a need to address emissions from ships and there are much potential for reduction. The shipping industry has not been inactive in efforts to reduce emissions in spite of the absence of regulations. Request from customers and cost savings have been driving the adoption of GHG reduction measures (Lai et al., 2011).

## 2.2 GHG reduction situation

The effort to reduce GHG emissions from vessels has been driven by a combination of mandatory regulatory requirements, pressure from customers and financial benefits.

### 2.2.1 Regulations

Regulatory progressions by IMO are prompting shipping companies to adopt green practices to improve their environmental performance (Cheng & Choy, 2007). IMO is the United Nations specialised agency responsible for developing and maintaining comprehensive regulatory frameworks for the improvement of maritime safety and security, and the control of pollution from ships (IMO, 2011a). As shipping is a transnational activity with mobile assets registered in many flag states, IMO is the most suitable forum to govern vessels' emissions with a uniform set of regulations that can be applied worldwide (Heitmann & Khalilian, 2011; WSC, 2009). The International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78 is the key international guidance under IMO which comprises regulations for prevention and control of pollution from ships. The 6 Annexes under MARPOL 73/78 and other pollution prevention conventions that are under the purview of IMO are shown in Appendix B. Out of the 6 Annexes, MARPOL Annex VI, which came into force in 2005, specifically deals with emissions from ships. The regulation sets limits on SO<sub>x</sub> and NO<sub>x</sub> emissions, particulate matter (PM) and ozone depleting substances (ODS) from ship exhausts.

In recent years, IMO is also working towards the adoption of a global regulatory regime to reduce GHG emissions from shipping operations (Longva et al., 2010). Appendix C summarises the development of IMO regulations on GHG emissions over the years. In 2011, the first ever mandatory GHG reduction regime was finally established at the MEPC 62<sup>nd</sup> meeting (IMO, 2011b). This new regulation makes mandatory the energy efficiency design index (EEDI) for new ships and the ship energy efficiency management plan (SEEMP) for all ships.

The regulation will enter into force in 2013 and developing countries will be able to waive compliance until 2019. Table 2.1 shows the emissions reduction targets that must be achieved in accordance to EEDI.

Table 2.1 Emissions reduction targets under EEDI requirements to regulate emissions from ships

Container ships	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Jan 2025 onwards
	>15 000 DWT	0%	10%	20%	30%
	10-15 000 DWT	n/a	0-10%	0-20%	0-30%

Source: (DNV, 2011a)

When EEDI is fully phased in, new ships will be 30% more efficient than they are today (IMO, 2011b). Container ships that are contracted for construction on or after 1 January 2013, or delivered on or after 1 July 2015, will be required to follow the EEDI requirements. The ships will have to be surveyed to be issued the International Energy Efficiency (IEE) certificate.

SEEMP, on the other hand, brings together best practices in vessel operations to improve the energy efficiency of ships and applies to both new and existing ships (IMO, 2011b). Such efficiency measures will significantly reduce fuel consumption and CO<sub>2</sub> emissions. SEEMP is part of the requirement for issuance of IEE certificate. In addition, the adoption of SEEMP will also be verified at surveys for the issuance of International Air Pollution Prevention Certificate.

With the regulations on EEDI and SEEMP in place, companies will be required to implement GHG emissions reduction measures. However, the choice of measures to adopt is left to ship operators (DNV, 2011b). They are allowed to select the most cost effective measures for their ships as long as the required energy efficiency is achieved. Therefore, it is important for ship operators to seek an evaluation of the various measures in order to find the most appropriate measures that can achieve the required efficiency at the lowest cost.

#### *2.2.2 Customer pressure*

Customers' expectation is an important factor that leads to the adoption of green shipping practices. Shipping firms are more likely to be green when customers have strong environmental request (Lai et al., 2011). Shippers such as IKEA conduct environmental audits of their carriers once every two years to ensure that their business partners are environmentally responsible (Solomon, 2011b). It is of great importance that companies appear to be green in order to increase their competitive advantage and in the process capture business opportunities. For APL, participation in the Clean Cargo Working Group (CCWG) is essential to establish collaboration with IKEA and other shippers (Solomon, 2011a). With the total environmental impact of the entire supply chain being an important measurement of performance, shipping companies will have to reduce their carbon footprint through the adoption of GHG emissions reduction measures.

#### *2.2.3 Cost savings*

To reduce GHG emissions from ships, a reduction in fuel consumption is essential. Emissions reduction is a common by-product of energy efficiency improvements on ships. The drive for improvement in energy efficiency is especially fuelled by the increase in bunker prices in recent years as shown in Figure 2.4. With fuel cost accounting for more than half of a container ship's

operating expense, it is seen as the most important factor affecting the profitability of shipping companies (WSC, 2009). There is a strong incentive to minimise energy use as bunker prices intensify. Therefore, the cost savings from a reduction in fuel usage also drive the adoption of GHG emissions reduction measures.



Figure 2.4 Bunker price hike (Clarksons, 2011)

## 2.3 GHG mitigation strategy

An important part of the GHG mitigation strategy of companies involves finding the right emissions control measures to employ. The evaluation of the measures done by several research studies are reviewed in this section, followed by an overview which summarises the evaluation criteria.

### 2.3.1 Emissions reduction measures

Emissions reduction can be achieved through three primary means: technical innovations, operational improvements, and market-based measures (MBM) (Psaraftis & Kontovas, 2010). Appendix D summarises the measures adopted by liner shipping companies through a review of available information on companies' websites and in annual reports.

#### 2.3.1.1 Technical innovations

Technical innovations include measures such as improvements to ship designs, power and propulsion systems and hull coatings (see Table 2.2). This approach mainly aims at reducing GHG emissions through improvement of the fuel efficiency of vessels. Substantial upfront investment cost may be required due to the need for retrofitting, but these measures usually have a significant potential for emissions reduction. Many technical measures can only be

applied to new ships due to the difficulties or high costs of retrofitting existing ships. The average life span of a container vessel is approximately 26 years (WSC, 2011). This would mean that most of the vessels operating in the market will not be of the most optimum design. Also, due to the lead time required to build a new vessel, implementation of technological innovations would only achieve substantial emissions reduction after a few years. Therefore, other measures that can reduce emissions in a shorter time frame have to be in place.

Table 2.2 Technical measures to reduce GHG emissions from ships

Technical Measures	How does it reduce GHG emissions?
Alternative fuels and power sources	Replacing the use of HFO with less carbon intensive fuel such as marine fuel oil (MFO) to reduce GHG emissions. Liquefied natural gas (LNG) is also an alternative fuel in development.
Cold-ironing	Using shore-based power when the vessel is berthed allows the vessel to shut down its auxiliary engines. This reduces fuel consumption and emissions in port.
Concept, speed and capability	Improving the specifications of the original design such as beam, draught, size and speed to increase energy efficiency of the vessel.
Hull and superstructure designs	Streamlining the hull and superstructure design and reducing the weight of the hull to minimise resistance and fuel consumption.
Hull coatings	Selecting the type of coating that can minimise resistance in water. The quality of application of the coating also contributes to the level of fuel efficiency.
Power and propulsion systems upgrades	Improving the efficiency of older engines through upgrading and adding enhancements such as vanes, fins, ducts and swirl devices to increase energy efficiency.
Waste heat recovery	Utilising the waste heat of the engines to drive turbines for electricity production. Thus, less fuel is needed for the production of electricity.

Source: (Buhaug et al., 2009; DNV, 2010b; Harrould-Kolieb & Savitz, 2010)

### 2.3.1.2 Operational improvements

Measures that involve operational improvements are the ones that can have an almost immediate effect on emissions reduction. Operational improvements relate to the way that the ship is maintained and operated, and include measures such as slow steaming, weather routing and optimisation of trim and ballast (see Table 2.3). Similar to technological innovations,

operational measures aim to reduce consumption of fuel by improving energy efficiency, which in turn decreases the amount of GHG emitted through exhaust. However, operational measures result in emissions reduction that can be realised across the existing fleet without huge investments and physical changes to the ship. They are near-term mitigation measures to reduce emissions through improvements to existing equipments and practices in current operations.

Table 2.3 Operational measures to reduce GHG emissions from ships

Operational Measures	How does it reduce GHG emissions?
Optimisation of trim and ballast	Operating at the correct trim and avoiding unnecessary ballast allow for a reduction of drag experienced by the vessel when sailing in water.
Propeller, hull and engine maintenance	Eliminating any inefficiency of propeller, hull and engine performance through periodic maintenance.
Speed reduction	Running the vessel at a slower speed to reduce fuel consumption.
Weather routing	Utilising information on weather and ocean current to better plan and execute voyages. Ship operators will be able to cut back on fuel usage and emissions.

Source: (Buhaug et al., 2009; Harrould-Kolieb & Savitz, 2010)

### 2.3.1.3 Market-based measures

Market-based measures (MBM) are being considered by IMO for application on a global scale. Emissions trading schemes and carbon levy schemes are examples of MBM, both of which will result in extra cost for the shipping companies if vessels' efficiency is not up to standard. These measures seek to drive the employment of more efficient technical and operational measures for emissions reduction. Many agencies are now studying the feasibility of MBM. It is probable that more interests and commitments will be generated in the near future, given the need for shipping industry to hasten the pace of GHG emissions reduction. However, the focus of this study would be on the reduction of emissions through technical and operational measures.

### 2.3.2 Emissions reduction potential and cost effectiveness

The wide range of GHG emissions reduction measures makes comparison between measures a challenge. A consistent methodology is necessary for evaluation of the measures.

### 2.3.2.1 Emissions reduction potential

One of the main factors used for evaluation is the CO<sub>2</sub> emissions reduction potential of the measures. The adoption of GHG emissions reduction measures arises from the need to protect the environment. Therefore, the ability of the measures to reduce emissions is a major consideration. Existing measures are found to have a range of emissions reduction potential as shown in Table 2.4. Studies show that technical measures generally have a higher emissions reduction potential than operational measures.

Table 2.4 CO<sub>2</sub> emissions reduction potential of measures

	Measures	Emissions reduction potential (%)
Technical	Alternative fuels	5 - 15
	Cold ironing	5 - 10
	Concept, speed and capability	2 - 50
	Hull and superstructure designs	5 - 20
	Hull coatings	5 - 10
	Power and propulsion system upgrades	5 - 15
	Waste heat recovery	8 - 10
Operational	Optimisation of trim and ballast	1 - 5
	Propeller, hull and engine maintenance	2 - 5
	Speed reduction	1 - 30
	Weather routing	0 - 4

Source: (DNV, 2010b; Faber et al., 2009; Harrould-Kolieb & Savitz, 2010)

### 2.3.2.2 Cost effectiveness

The various measures, however, have to be carefully evaluated not only for their environmental performance. A cost effective GHG emissions reduction policy is also important for a company's competitive advantage (Lun, 2011).

Cost effectiveness is defined as the monetary evaluation of the cost of implementing the measure relative to the cost savings that can be achieved through the usage of the measure over the investment timeframe. The cost of measure can include, for example, the cost of the equipments used to improve performance of the vessel and the opportunity cost incurred due to loss of earnings if retrofitting is not arranged with dry docking. The most significant cost savings comes from the reduction in fuel usage as the adoption of measures has a direct impact on the amount of bunker consumption. Appendix E shows a few examples of the relationship between implementation of the measures and direct bunker savings. Therefore, a measure is cost effective if the financial benefit from reduced fuel cost offsets the cost of investment.

The marginal abatement cost curve (MACC) is the most commonly used instrument to depict the cost effectiveness of the measures. It lists the abatement cost of avoiding 1 tonne of CO<sub>2</sub> emissions through the measure, in the order of lowest to the highest (DNV, 2010b). Figure 2.5 shows an example of a MACC for container vessels. The width of each bar represents the potential of the measure to reduce emissions and the height represents the abatement cost (DNV, 2010b). A measure, according to definition, is only profitable when its abatement cost is negative. Thus, Figure 2.5 suggests that LNG fuelled ships, reefer improvements, waste heat recovery and main engine retrofit are less profitable as indicated by their positive abatement cost.

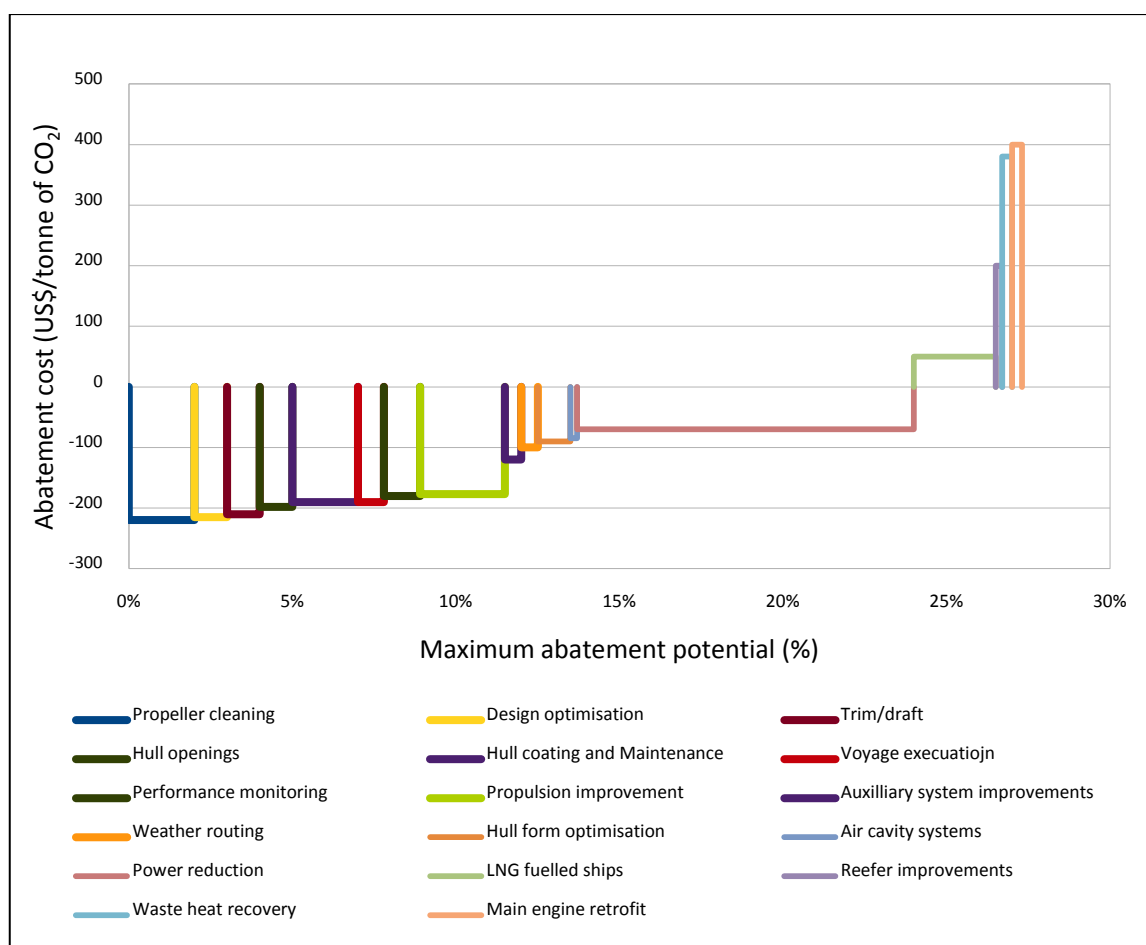


Figure 2.5 MACC for container vessels of all sizes (Sames, 2011)

Instead of the MACC, a combined assessment of emissions reduction potential and cost effectiveness can be achieved by the *CATCH* (Cost of Averting a Tonne of CO<sub>2</sub>-eq Heating) equation suggested by Eide et al. (2009) as shown by Equation (2.1).



$$CATCH = \frac{\Delta C - \Delta B}{\Delta E} \quad (2.1)$$

Where:

$\Delta C$  is the cost of implementing a measure

$\Delta B$  is the benefit other than emissions reduction

$\Delta E$  is the expected reduction of CO<sub>2</sub> emissions

The study suggests that the CATCH value should be around US\$50 per tonne CO<sub>2</sub> averted for the measure to be adopted (Eide et al., 2009). This figure is thus recommended for use as a decision criterion for investments. For the 8000 TEU container case ship used in the CATCH study as shown in Figure 2.6, it is demonstrated that most emissions reduction measures, except fuel cell and solar panels, can be recommended for implementation due to their cost effectiveness (Eide et al., 2009).

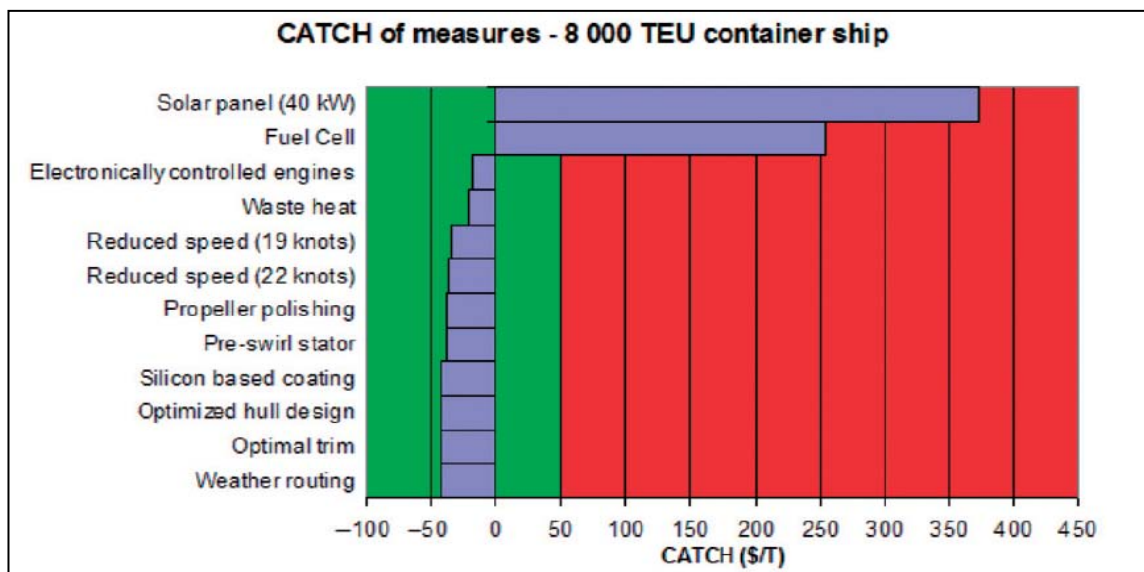


Figure 2.6 CATCH calculations for selected emissions reduction measures (Eide et al., 2009)

Various studies have devised varying MACC based on a range of case ships and abatement measures (Buhaug et al., 2009; Faber et al., 2009). Appendix F consolidates the rankings of measures from the studies. The different bunker prices and interest rates used in the studies make the comparison between studies complex (Faber et al., 2009). A higher interest rate for example, leads to a rise of the measures' annuities and thus to an aggravation of the cost effectiveness (Buhaug et al., 2009).

Although the MACC developed by the different agencies are varying, the assessments suggest that there are many cost effective measures with immense potential to reduce fuel consumption. These savings will be accentuated as fuel prices are expected to increase over the long term. However, it is important to note that current MACC are mostly based on the entire fleet. In actual fact, the performance of the measures can vary among the segments. There are measures that do not have high cost effectiveness on average but are especially efficient for particular ship segments (DNV, 2010a). Therefore, ship operators must take caution when using the existing MACC to make implementation decisions on a particular ship segment.

### *2.3.3 Critical issues of implementation*

A range of barriers hinder the implementation of measures by ship operators. The critical issues are identified in this section mainly with reference to Kollamthodi et al. (2008) and through interviews conducted at the initial stage of this study.

#### *2.3.3.1 Lack of information*

Despite the developments in emissions reduction technologies, there is often a lack of evidence that benefit exceed cost of implementing the measures (Lun, 2011). The emission reduction potential and cost of the measures are hard to verify. Ship operators often doubt the reliability of model testing as the artificial conditions of speed, draft and water depth may cause an over-estimation of the emissions reduction potential (Lockley & Jarabo-Martin, 2011). The lack of reliable information on cost savings cause ship operators to only undertake measures with a proven track record.

#### *2.3.3.2 Cost of measure*

Many of the measures require expensive retrofit. To make a vessel cold-iron capable, approximately US\$1 to 2 million has to be spent on each vessel. In addition, apart from the direct cost of retrofitting the vessel, there are also indirect costs that can be incurred due to the time lost during retrofitting. Some retrofitting measures such as propeller upgrades and hull coatings require a vessel to dry dock. Opportunity cost will have to be incurred due to loss of earnings if retrofitting is not arranged with dry docking. Ship operators are concerned that the investment cannot be fully recouped and are especially wary of measures that have uncertain and long payback. The smaller operators also face a lack of access to capital.

#### *2.3.3.3 Hidden cost*

All measures entail decision-making and staff training costs, which can be considered as additional or unknown cost. Hidden cost for fleet management measures such as slow steaming is most significant. Ship operators that implement slow steaming may lose competitiveness in terms of transit time. For example, cargo originating from Thailand and bound for the US West Coast takes 29 days after implementation of slow steaming instead of 20 to 22 days in the past. Ship operators will face difficulty in securing business from shippers who value fast transit time. Another type of hidden cost may be concerning new technologies which can incur “first of a kind” costs related to the learning process of operating a new technology.

#### *2.3.3.4 Owner-user problem*

A large number of ships are operated by the ship charterer who is not the owner. Ship owner often only pays for the initial investment while the charterer pays for the operating cost which consists mainly of fuel expenditure (Eide et al., 2011). The contract between the charterer and owner will usually result in fuel savings being gained by the charterer, while the payment for ships with better technologies are made by the owner (DNV, 2010a). Such arrangement is likely to cause significant owner-user problem (Kollamthodi et al., 2008).

#### *2.3.3.5 Technological and infrastructure constraints*

Not all published reduction measures are suitable for all types of vessels. For example, alternative energy such as towing kite, wind energy and solar cell are considered not so suitable for application on container vessels (Faber et al., 2009). In addition, not all measures can be applied to existing vessels as shown in Table 2.5. Emissions reduction measures such as air lubrication are hard to implement once the vessels are out of the yard. The adoption of emergent measures is especially hindered by infrastructure constraints. For example, despite the potential of LNG as an alternative fuel for ships, the challenges posed by storage on board vessels and availability of bunkering facilities in ports hamper the adoption of the measure. The implementation of cold-ironing is also limited by port infrastructure as the reliability of electricity provision at the port is a major concern for ship operators.

#### *2.3.3.6 Materiality*

A number of measures entail energy efficiency improvements below 5%. Such measures may be ignored by ship operators due to their limited impact.

Table 2.5 Applicability of measures (R = Retrofit, N = New built and O = operational)

Container vessels	Propeller/rudder upgrade	Propeller boss cap fins	Propeller performance monitoring	Propeller brushing	Transverse thruster opening	Hull performance monitoring	Hull coating	Hull brushing	Air lubrication	Common rail upgrade	Waste heat recovery	Weather routing	Speed optimisation
8,000+ TEU	R	R	O	O	R	O	O	O	N	R	R	O	O
5 - 7,999 TEU	R	R	O	O	R	O	O	O	N	R	R	O	O
3 - 4,999 TEU	R	R	O	O	R	O	O	O	N	R	R	O	O
2 - 2,999 TEU	R	R	O	O	R	O	O	O	N	R	R	O	O
1 - 1,999 TEU	R	R	O	O	R	O	O	O		R		O	O
0 - 999 TEU	R	R	O	O	R	O	O	O		R		O	O

Source: (Faber et al., 2009)

## 2.4 Overview

The evaluation of the GHG emissions reduction measures can be summed up by Figure 2.7. The measures are evaluated by agencies mainly using two factors: emissions reduction potential and cost effectiveness. For a shipping company, the best measure would be one that is the most cost effective while achieving a high level of emissions reduction as indicated by the star in Figure 2.7.

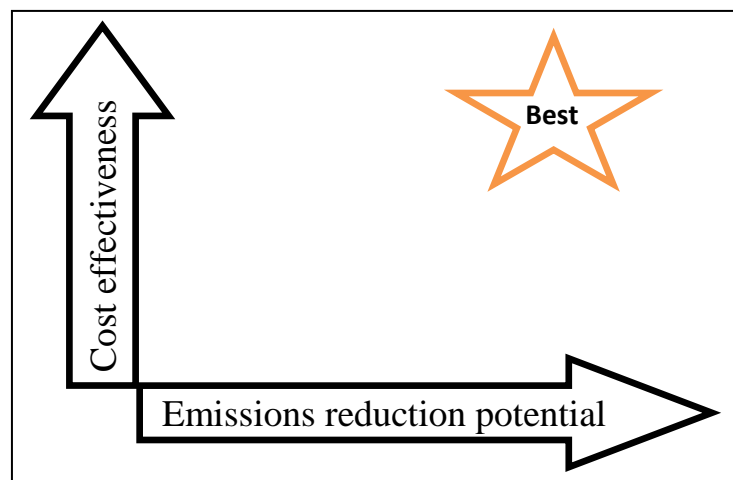


Figure 2.7 Evaluation criteria of GHG emission reduction measures

The abatement cost curves and emissions reduction potential measurements from many studies show most existing measures to be cost effective with a range of emissions reduction potential. However, these studies do not depict the level of adoption of the measures and the abatement potential may be over-estimated. There is a need to understand the evaluation of GHG emissions reduction measures from the ship operators' perspective. Therefore, this study will identify the extent to which existing measures are being implemented and the reasons for doing so.

The factors that impede the adoption of measures will also be evaluated. The 6 critical factors that have been identified are listed in Table 2.6. The level of barriers will be examined so that possible solutions can be provided to overcome the barriers.

Table 2.6 Critical factors of adoption of emissions reduction measures

a) Lack of information about measures
b) Cost of measure
c) Hidden cost
d) Owner-user problem
e) Technological and infrastructure constraints
f) Materiality

## CHAPTER 3 SURVEY AND INTERVIEW RESULTS

This chapter consists of 4 parts. The first part on methodology highlights the survey and interview procedures. The survey and interview results obtained are presented in part two and three, respectively. An overview of the chapter is provided in the last part.

### 3.1 Methodology

A 5-page questionnaire (refer to Appendix G) consisting of 3 parts was constructed to investigate the implementation of the GHG emissions reduction measures and to identify critical issues in the implementation. The survey was designed to start with an introduction to the research project. The request for a personnel experienced in the environmental aspect of the company's operations to complete the questionnaire was emphasised in the introduction. This was followed with 3 parts on organisation information (1 question), GHG emissions reduction measures (6 questions) and feedbacks (2 questions), respectively. A glossary was included to provide clarification of the technical and operational measures addressed in the survey. Prior to distribution of the questionnaire, a pilot test was conducted to detect and iron out possible problems. The valuable feedbacks were incorporated into the survey questionnaire and copies of the revised questionnaire were posted to the top 100 container liner shipping companies (refer to Appendix H) ranked according to the total cargo carrying capacity of vessels owned or operated. Information of container shipping companies was obtained from the CI-online (Liner Intelligence) database available in NTU Library. Figure 3.1 shows the survey distribution process. For companies with offices in Singapore, hard copies of the survey questionnaire were distributed via postal services. Soft copies were sent through email to companies without a Singapore office. An online survey link was also included as an alternative participation method.

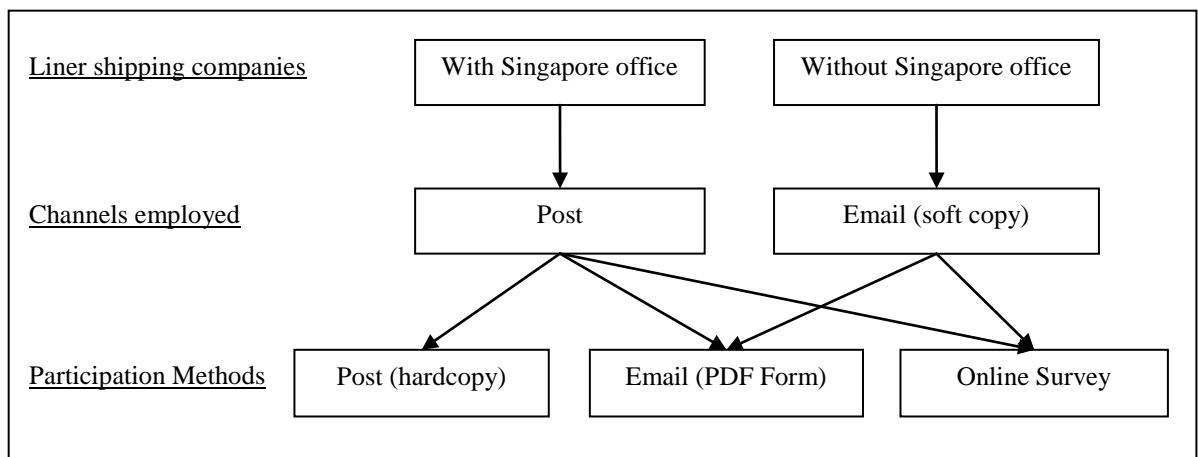


Figure 3.1 Channels of participation for survey

As shown in Table 3.1, a total of 95 sets of survey questionnaire were despatched, of which 21 were sent by post and 74 were sent through email to companies with and without a Singapore office, respectively. It was found that 5 companies in the listing of top 100 liner shipping companies do not have published contact information that are valid and therefore could not be reached.

Table 3.1 Survey inventory

	Survey sent		Responses received	
Method	Post	Email	Post (hardcopy)	Online Survey
Number sent and received	21	74	9	5
Total number	95		14	
Percentage of participation	14.7%			

A total of 14 replies were received including 9 copies of hardcopy postal responses and 5 online survey responses. The response rate is 14.7%. The lower level of response rate may be attributed to the nature of liner shipping industry. The top 20 liner shipping companies account for almost 90% of the total capacity in the market in terms of TEUs, with the rest of the companies accounting for much smaller operations (Alphaliner, 2011). Smaller companies may pay lesser attention to environmental issues due to the lower overall impact of their operations on the environment. The nature of the shipping industry also means that increasing the sample size beyond the top 100 liner shipping companies will not increase the response rate significantly as these companies have very small operations. Despite the low response rate in terms of number of replies received, the response of larger companies operating the majority of the total fleet can be taken to be largely representative of the situation in the market. Their responses are significant in representing strategies that are undertaken by the industry to handle the GHG environmental challenges.

To obtain more insight into issues that cannot be readily acquired through surveys, a total of 11 interviews were conducted. Four liner shipping companies, two shipping agencies, one governmental agency, one classification society and one marine equipment manufacturer (see Appendix I) participated in the interviews. Second interviews with another representative from APL and MPA were also conducted. Interview questions (refer to Appendix J) were drafted and emailed to the respondents prior to the interviews. Permissions were sought from the respondents to record voice memos of the interviews. The voice memos of the interviews were transcribed and a copy of the interview summary was sent to each respondent to verify the accuracy of the recorded information.

### 3.2 Survey results

This section analyses the survey results and discusses mainly on 4 areas: emissions reduction potential, cost effectiveness, level of implementation and the critical issues of implementation of emissions reduction measures.

#### 3.2.1 Company profile of survey respondents

The number of container ships owned or operated by the companies was collected in part 1 of the survey questionnaire. The number of ships owned or operated by the liner shipping company is taken as an indicator of the size of the company in this study. It is assumed that companies with more than 50 vessels fall under the category of medium-large operators while companies with 50 or fewer vessels are considered as small operators. The responses in Figure 3.2 show that 10 (71.4%) out of the 14 replies fall under the medium-large category while 4 companies (28.6%) are under the small category. The size of the company indicates the financial strength and expertise available in the company. Implementation of emissions reduction measures often requires substantial investment and monitoring. Larger companies are able to dedicate more resources to implement new technologies. Therefore, analysis of the survey results is done by considering the number of ships owned or operated by the company.

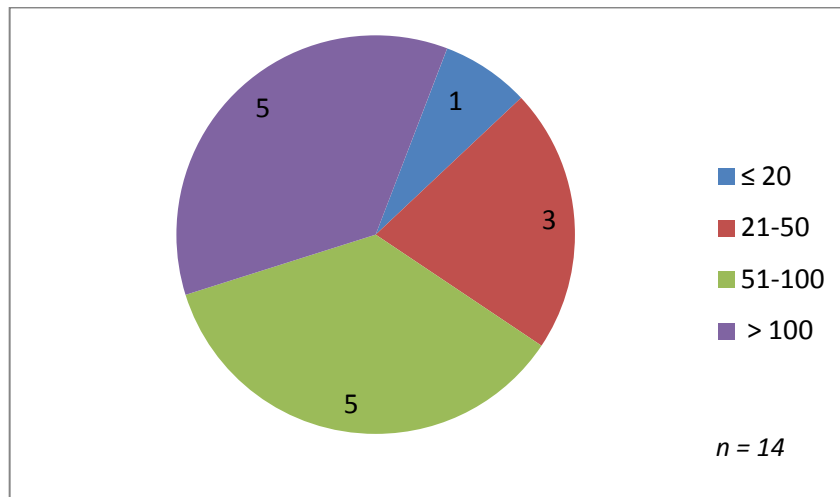


Figure 3.2 Number of container ships owned or operated by survey respondents

#### 3.2.2 Emissions reduction potential and level of implementation

The result for question 2 of the survey questionnaire which addresses the emissions reduction potential and level of implementation of the measures is shown in Table 3.2. To assist the data analysis process, the response choices in the survey are given numerical values from 0 to 3, with 0 being no potential or no implementation and 3 being high potential or high implementation.



Table 3.2 Mean ratings of perceived emissions reduction potential and level of implementation

	Measures	Perceived emissions reduction potential* (n=14)	Level of implementation** (n=14)	Gap
Technical	Alternative fuels	2.36	0.86	1.50
	Cold ironing	1.93	1.29	0.64
	Concept, speed and capability	2.36	1.93	0.43
	Hull and superstructure design	2.07	1.93	0.14
	Hull coatings	2.00	2.00	0.00
	Power and propulsion system upgrades	2.07	1.71	0.36
	Waste heat recovery	2.00	0.79	1.21
	<b>Mean</b>	<b>2.11</b>	<b>1.50</b>	<b>0.61</b>
	<b>Standard deviation</b>	<b>0.18</b>	<b>0.52</b>	<b>0.34</b>
Operational	Optimisation of trim and ballast	1.86	2.36	-0.50
	Propeller, hull and engine maintenance	1.79	2.71	-0.92
	Speed reduction	2.14	2.50	-0.36
	Weather routing	1.71	2.43	-0.72
	<b>Mean</b>	<b>1.88</b>	<b>2.50</b>	<b>-0.62</b>
	<b>Standard deviation</b>	<b>0.19</b>	<b>0.15</b>	<b>-0.04</b>
<b>Overall mean</b>		<b>2.03</b>	<b>1.86</b>	<b>0.16</b>
<b>Overall standard deviation</b>		<b>0.21</b>	<b>0.68</b>	<b>0.47</b>

\* 0 - no potential; 1 - low potential; 2 - medium potential; 3 - high potential

\*\* 0 - no implementation; 1 - low implementation; 2 - medium implementation; 3 - high implementation

The measures are perceived to have low-medium to medium-high level of emissions reduction potential, with *alternative fuels* having the highest mean perceived potential of 2.36 (medium-high) and *weather routing* having the lowest mean perceived potential of 1.71 (low-medium). The level of implementation of the measures has a greater difference in ratings, with *propeller, hull and engine maintenance* having the highest mean rating of 2.71 (medium-high) and *waste heat recovery* having the lowest mean rating of 0.79 (none-low). The overall standard deviation for level of implementation is 0.68 as compared to 0.21 for perceived potential. This shows that the measures are recognised to have a comparatively consistent medium-high potential but the level of implementation is more variable. There is immense potential for greater utilisation of current measures given the relatively high perceived potential (overall mean rating of 2.03). This is especially so for *alternative fuels* and *waste heat recovery* as these measures have the greatest gaps (1.50 and 1.21 respectively) between level of implementation and perceived potential. More effort will need to be focused on making the measures more attractive to ship operators to improve their level of implementation. An understanding of the factors that operators consider in the implementation is thus necessary.

However, this method mainly applies for technical measures which are observed to have higher perceived potential than the level of implementation as shown by the positive gaps in Table 3.2. Interestingly, operational measures show a reverse trend. They have a higher level of

implementation than their perceived potential. In such a case, more R&D will need to be conducted to improve the emissions reduction potential of the measures.

Survey results also show that the level of implementation does not exactly follow the perceived potential. If emissions reduction potential is the main decision criterion for implementation, it is expected that measures with greater potential will have a higher level of implementation. Instead, as illustrated in Figure 3.3, the general trend is that measures with lower perceived potential have a higher level of implementation.

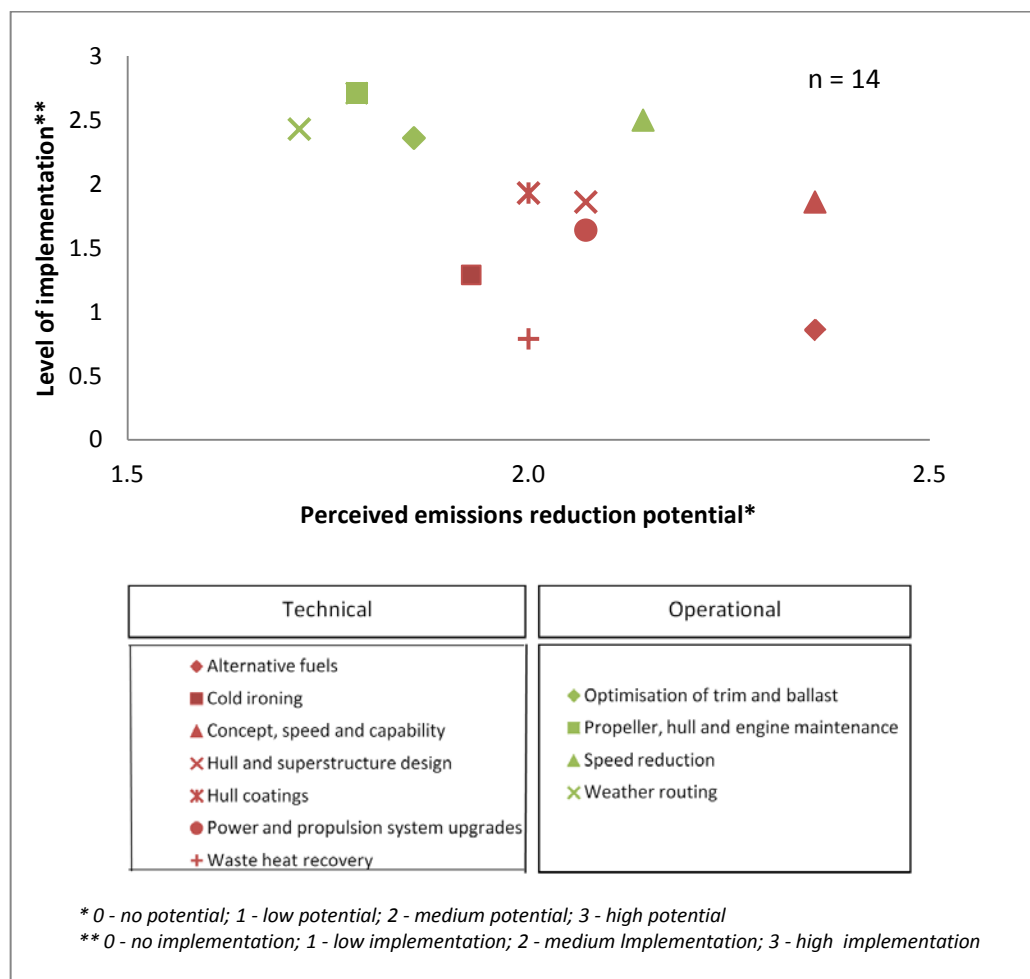


Figure 3.3 Perceived reduction potential and level of implementation

Operational measures such as *weather routing*, *propeller, hull and engine maintenance* and *optimisation of trim and ballast* have a higher level of implementation than technical measures in spite of their lower perceived potential. This indicates that the emissions reduction potential is not the only determining factor of the overall implementation of the measures. Companies consider other factors which result in the difference between level of implementation and reduction potential and also a greater implementation of operational measures.

### 3.2.3 Cost effectiveness and level of implementation

Question 3 of the survey questionnaire examines the relationship between cost effectiveness and level of implementation of the measures. The results are shown in Table 3.3.

Table 3.3 Mean ratings of perceived cost effectiveness and level of implementation

	Measures	Perceived cost effectiveness* (n=14)	Level of implementation** (n=14)	Gap
Technical	Alternative fuels	0.93	0.86	0.07
	Cold ironing	1.00	1.29	-0.29
	Concept, speed and capability	1.14	1.93	-0.79
	Hull and superstructure design	1.64	1.93	-0.29
	Hull coatings	2.29	2.00	0.29
	Power and propulsion system upgrades	1.71	1.71	0.00
	Waste heat recovery	0.64	0.79	-0.15
	<b>Mean</b>	1.34	1.50	-0.16
	<b>Standard deviation</b>	0.57	0.52	0.05
Operational	Optimisation of trim and ballast	2.14	2.36	-0.22
	Propeller, hull and engine maintenance	1.93	2.71	-0.78
	Speed reduction	2.00	2.50	-0.5
	Weather routing	2.29	2.43	-0.14
	<b>Mean</b>	2.09	2.50	-0.41
	<b>Standard deviation</b>	0.16	0.15	0.01
<b>Overall mean</b>		1.61	1.86	-0.25
<b>Overall standard deviation</b>		0.59	0.68	-0.09

\* 0 - no effectiveness; 1 - low effectiveness; 2 - medium effectiveness; 3 - high effectiveness

\*\* 0 - no implementation; 1 - low implementation; 2 - medium implementation; 3 - high implementation

*Hull coatings* and *weather routing* have the highest perceived cost effectiveness of 2.29 (medium-high) while *waste heat recovery* is perceived to be the least cost effective with a rating of 0.67 (none-low). The ratings for perceived cost effectiveness vary widely, especially across technical measures. The standard deviation for technical measures is 0.57 while that of operational measures is lower at 0.16. It is also shown that operational measures have a higher level of perceived cost effectiveness than technical measures. The mean rating for operational measures is 2.09, higher than the 1.34 for technical measures. Therefore, operational measures are generally more mature with a more consistent level of higher cost effectiveness as compared to technical measures.

The relationship between perceived cost effectiveness and level of implementation is more obvious than that between perceived emissions reduction potential and level of implementation. As illustrated in Figure 3.4, the general trend is that the higher the perceived cost effectiveness, the higher the level of implementation. Operational measures have a higher level of

implementation than technical measures and this is consistent with the perceived cost effectiveness of the measures. Thus, it is suggested that improving the cost effectiveness of the measures is likely to bring about a higher level of implementation.

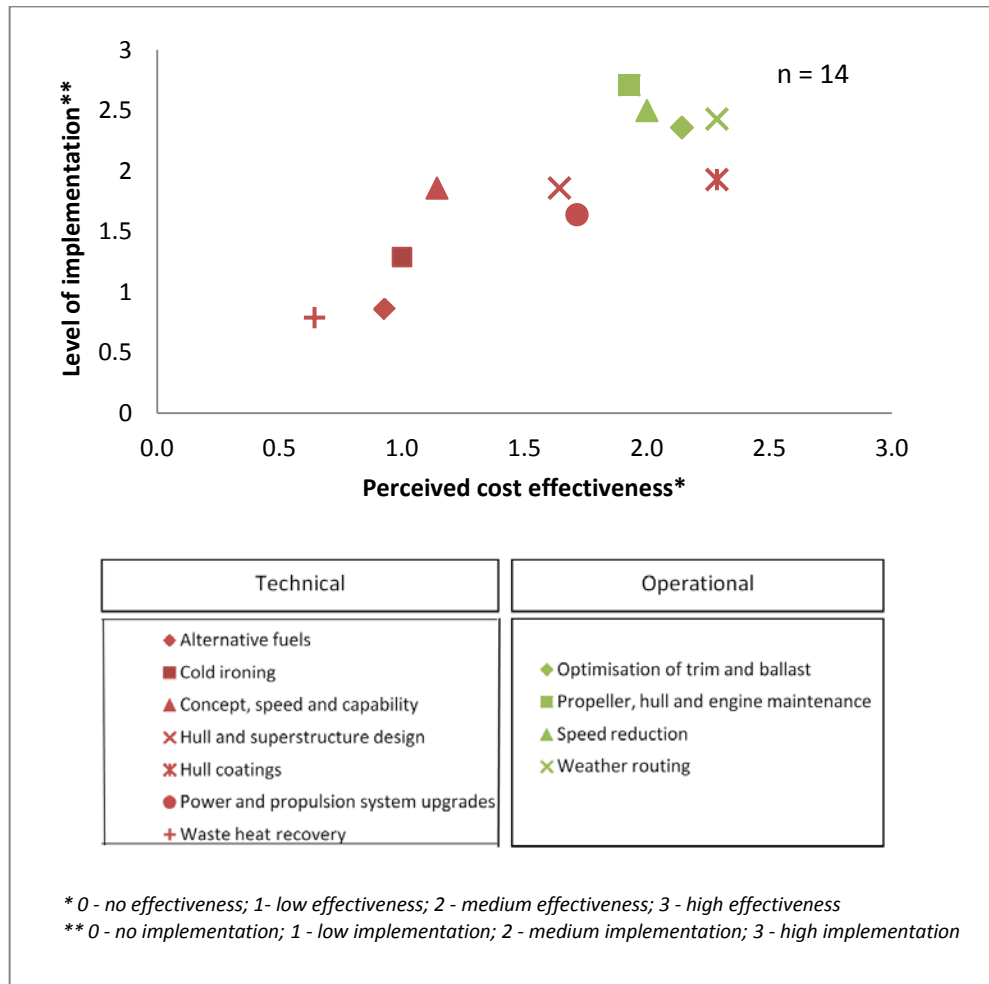


Figure 3.4 Perceived cost effectiveness and level of implementation

### 3.2.4 Emissions reduction potential and cost effectiveness

Figure 3.5 compares the survey results for perceived cost effectiveness and perceived emissions reduction potential. In general, companies are more reserved in implementing measures that have a low cost effectiveness. This holds true even when the measure has high emissions reduction potential. The most notable examples are *waste heat recovery* and *alternative fuel*. They have the lowest level of implementation and perceived cost effectiveness, but not the lowest perceived emissions reduction potential. Alternative fuel is even perceived to have one of the highest emissions reduction potential among the measures. This finding, together with the higher level of implementation of measures such as *weather routing* in spite of the lower perceived potential, highlights the importance of cost effectiveness in decision making.

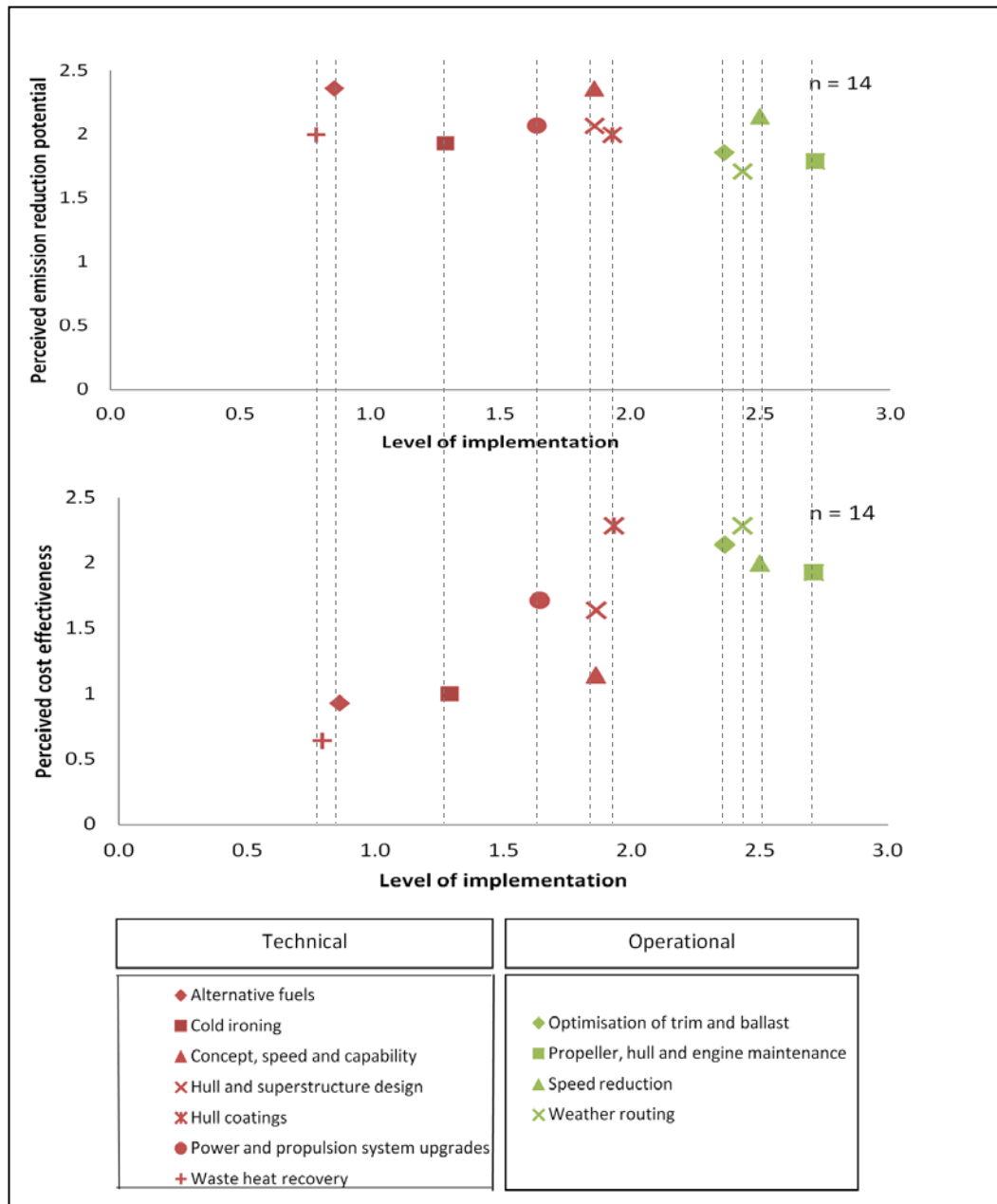


Figure 3.5 Comparison of perceived emissions reduction potential and cost effectiveness

### 3.2.5 Critical issues of implementation

The critical issues of implementation are examined in question 6 of the survey questionnaire in order to highlight the most significant barriers. The results are shown in Table 3.4.

The *cost of measure* is seen to be the largest barrier to implementation with a mean score of 2.79. Additional barriers that were specified by respondents as free response in the survey include “uncertain payback period”, “difficulty of achieving return on investment”, “loss of income” and “too many competing cost effective measures”. This shows that the cost aspect of implementation to be of great concern for companies.

Table 3.4 Extent of barriers to implementation of measures

Factors	Mean ratings for level of hindrance* (n=14)	Standard deviation
Cost of measure	2.79	0.43
Materiality	2.57	0.51
Lack of information about measures	2.36	0.50
Hidden cost	2.29	0.73
Technological and infrastructure constraint	2.14	0.66
Owner – user problem	1.64	0.50

\* 1 - limited hindrance; 2 - some hindrance; 3 - substantial hindrance

The importance of cost in shaping the adoption and evaluation of measures is also shown by the responses for question 5 of the survey questionnaire. As shown in Table 3.5, the *cost of measure* and *cost savings* have higher comparative importance than *emissions reduction potential* in the evaluation of the measures. This may explain the lack of positive correlation between the level of implementation and the perceived emissions reduction potential as the level of implementation is likely to follow more closely with the cost effectiveness. A reduction of the cost barrier is likely to result in a higher level of implementation and a more positive correlation between emissions reduction potential and level of implementation.

Table 3.5 Importance of factors in evaluation of measures

Factors	Level of importance* (n=14)	Comparative importance** (n=14)	Standard deviation of comparative importance	Rank
Cost of measure	2.57	2.64	0.50	1
Cost savings	2.50	2.07	0.62	2
Emissions reduction potential	2.43	1.29	0.73	3

\* 1 - low importance; 2 - medium importance; 3 - high importance

\*\* 1 being the most important, 2 being second most important and so on

### 3.3 Interview results

This section discusses the results from interviews with industry professionals. The interviews serve as the second pillar of this study and complement the survey of liner shipping companies.

#### 3.3.1 Emissions reduction potential, cost effectiveness and level of implementation

The survey results show that the level of implementation does not exactly follow the perceived emissions reduction potential. This trend is exemplified with the level of implementation of operational measures being generally higher than technical measures despite their lower perceived potential.

Mr. Khorshed (2011) from APL explained this by describing the operational measures as the low-hanging fruits. They are already implemented in the day-to-day operations and can be applied across the existing fleet with relatively low cost and risk. On the other hand, more investments may be necessary for implementing technical measures. To better understand this trend, the reasons for the difference in perceived potential and level of implementation of three technical measures with the greatest differences (as shown in Table 3.2) were examined. Interview respondents pointed out the following barriers of implementation (see Table 3.6).

Table 3.6 Barriers of implementation

Measures	Barriers
Alternative fuel	Currently, alternative fuels are mainly used to address SO <sub>2</sub> rather than GHG. The two potential alternative fuel, LNG and bio-fuel, face technological and infrastructure constraints.
Cold ironing	Cold ironing requires high investment and not all ports are suitable for cold ironing. Appropriate infrastructure has to be available.
Waste heat recovery	The loss of freight earning opportunity from the space needed to install the machinery required for the system is a concern. The high cost of implementation is also a deterrent.

Despite having high emissions reduction potential, the various barriers impede the implementation by ship operators. The barriers can be summed up as *technology and infrastructure constraints* and *high cost*. Mr. Lim (2011) from MPA highlighted that such barriers are not only limited to technical measures. The adoption of operational measures also faces such barriers but the barriers are significantly lower. Therefore, companies are more steered towards adopting operational measures. Mr. Solomon (2011b) from APL felt that the barriers, especially the cost barrier, will have to erode for companies, even those with smaller operations, to adopt the wide range of measures. The general sentiment is that an improvement in cost effectiveness will result in a greater increase in implementation as compared to the same level of improvement in emissions reduction potential (Solomon, 2011b).

### 3.3.2 Critical issues of implementation

Survey reveals that the cost aspect of implementation is of great concern for companies. Similarly, interview respondents highlighted the significant amount of investment required for some measures. An offset rudder and cold-ironing system cost about US\$1 million each to install (Khorshed, 2011). Mr. Ellehave (2012) from Maersk pointed out that the US\$10 million

investment required for the waste heat recovery system and the uncertainty of return on investment in the range of 5 to 10 years deter the implementation of the measure. There is also a concern that the measures may quickly become obsolete as new and better technologies emerge at a more affordable cost (Nixon, 2012). The decision to install such cost intensive measures will be dependent upon the level of risk and commitment that the company is willing to take for environmental issues.

The *lack of information* is also seen as a significant barrier. Industry representatives interviewed agreed that there is a need for more accurate information regarding abatement costs and opportunities of these measures. There are many energy saving technologies with claims of significant savings but they are usually tested under specific conditions which ships do not have the chance to meet. Respondents felt that the availability of reliable information will enhance their confidence to implement the measures.

Despite being ranked highly in the survey, interview respondents generally felt that *materiality* is not considered a critical barrier as measures with low materiality are usually more cost effective. Measures with lower materiality can be implemented on a wider scale due to its cost effectiveness. The only concern is the possibility that the measure can result in negative emissions reduction potential. For example, the propeller boss cap fin did not work for APL vessels and actually caused an increase in fuel consumption (Khorshed, 2011). Therefore, sufficient research on the applicability for the particular ship and constant monitoring need to be conducted to ensure its feasibility.

Respondents expressed the views that the barriers to implementation inevitably result in higher financial burden. A reduction of these barriers will make the measures more cost effective and will result in a higher level of implementation.

### **3.4 Overview**

Survey and interview results on the evaluation of GHG emissions reduction measures and identification of critical issues of implementation were presented in this chapter.

The emissions reduction potential, cost effectiveness and level of implementation of the measures were evaluated. The research shows that operational measures have a higher level of implementation than technical measures despite their lower perceived potential. This can be attributed to the higher perceived cost effectiveness of operational measures. The relationship between the 3 factors will be analysed in Chapter 4.



Survey results also show that measures available in the market to reduce GHG emissions are seen to have a rather consistent medium-high emissions reduction potential but the level of implementation is not that uniform. There is immense potential for greater utilisation of current measures given the high potential. However, the top barriers to implementation namely *cost of measures* and *lack of information*, need to be addressed for a higher level of implementation. Strategies that can be put in place to overcome the barriers will be addressed in the next chapter.

## CHAPTER 4 FINDINGS AND DISCUSSION

This chapter will draw findings from surveys and interviews to better evaluate the emissions reduction measures. Suggestions to overcome the critical barriers of implementation will be made. Recommendations will also be made to shipping companies based on the situation in the industry.

### 4.1 Choosing the right measures

From findings in survey and interviews, a relationship between the 3 factors, namely emissions reduction potential, cost effectiveness and level of implementation, can be established (see Figure 4.1). In general, measures with higher emissions reduction potential do not have a high level of implementation. This is mainly influenced by the cost effectiveness of the measures. There are two components to cost effectiveness, namely cost of measure and cost savings. In general, an improvement in emissions reduction potential would bring about further reduction of fuel consumption and hence, an increase in cost savings. This should lead to higher cost effectiveness. However, measures with high emissions reduction potential such as waste heat recovery require expensive investments. The increase in cost of the measures outweighs cost savings that are derived from an improvement in emissions reduction potential. Therefore, cost effectiveness of the measures is lower when emissions reduction potential improves. A lower cost effectiveness of the measure will lead to lower level of implementation due to the importance of cost factor in the decision making of companies. The barriers to implementation also affect the scale of implementation as it can have an implication on cost effectiveness. Therefore, the main factor that should be addressed would be the cost effectiveness of the measures.

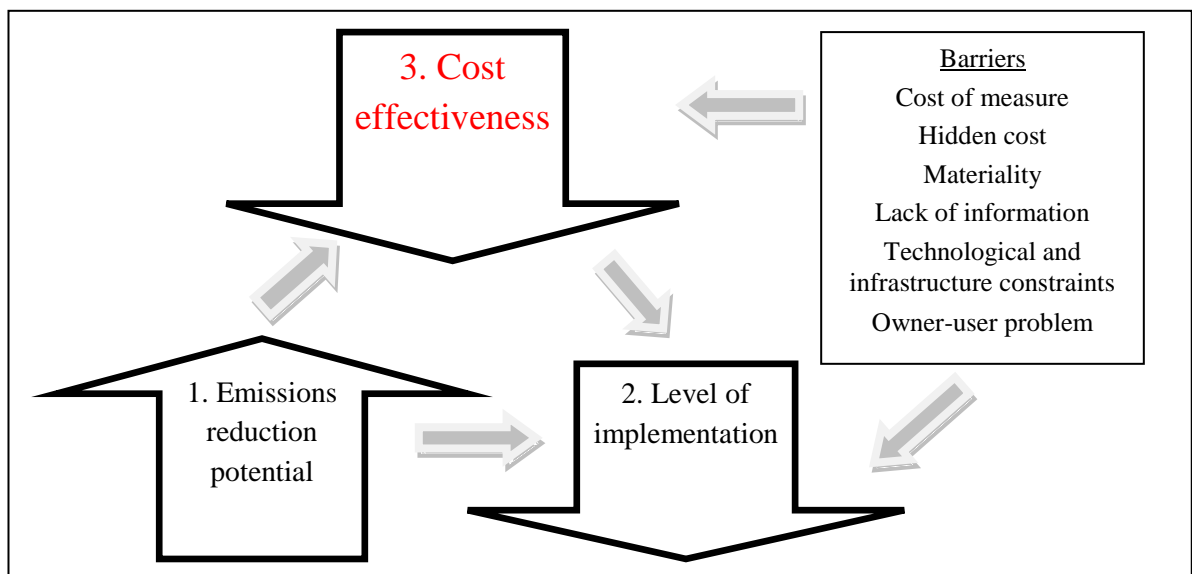


Figure 4.1 Relationship of emission reduction potential, cost effectiveness and level of implementation

With the importance of cost effectiveness in mind, the recommended stages of implementation of measures are summarised in Figure 4.2. Companies can first implement measures that are cost effective and have a high emissions reduction potential, followed by the consideration of cost effective measures with lower potential. Eventually, when such measures are exhausted, companies can implement the less cost effective measures.

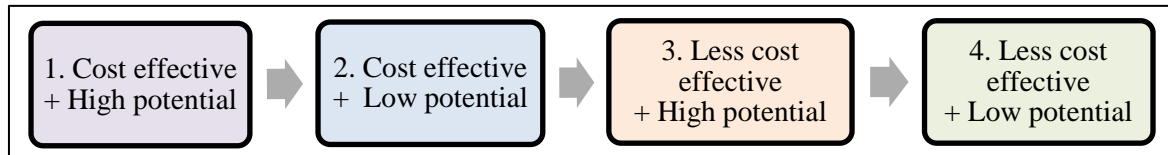


Figure 4.2 Recommended stages of implementation

This framework is exemplified through the categorisation of measures using the survey results on perceived cost effectiveness and emissions reduction potential (see Figure 4.3). The figure is divided into 4 quadrants to represent different levels of cost effectiveness and emissions reduction potential.

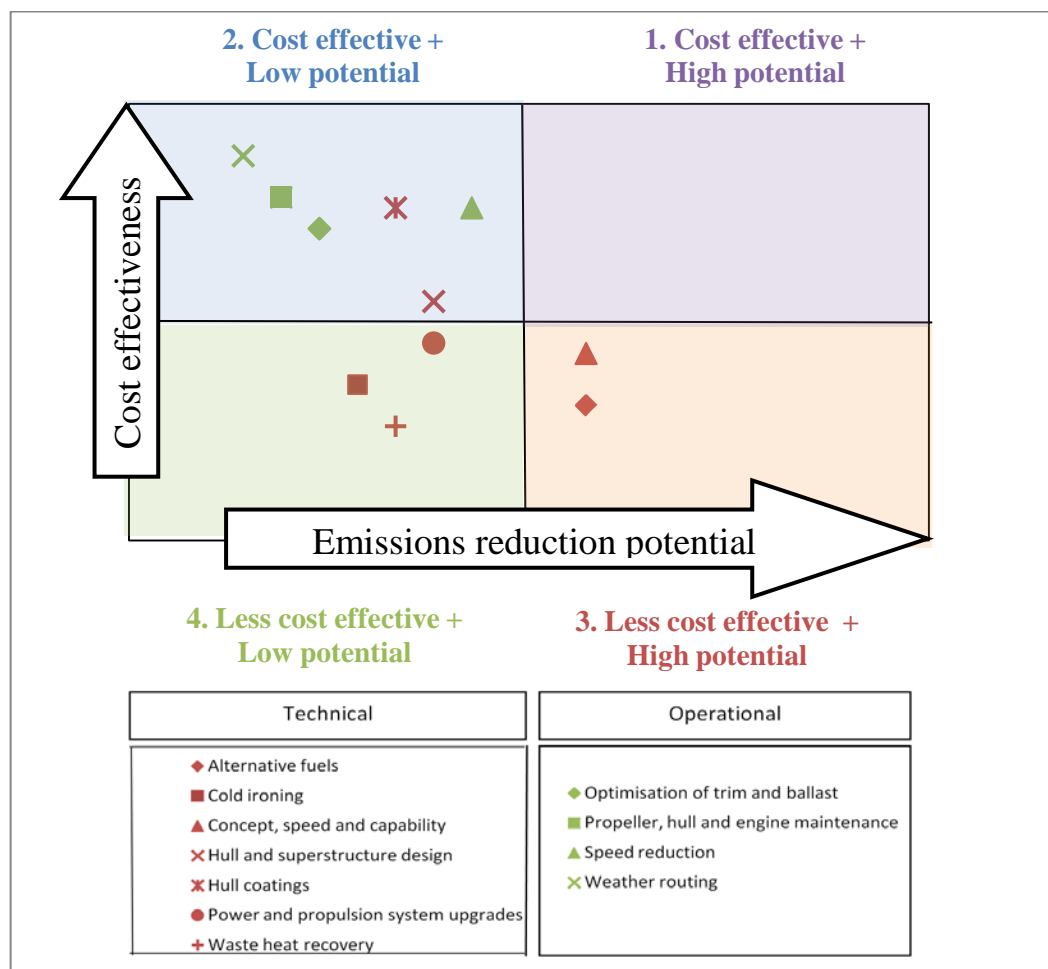


Figure 4.3 Illustration of proposed framework through categorisation of measures

The measures that are the most ideal are depicted in the top-right quadrant of Figure 4.3 with high cost effectiveness and high emissions reduction potential. However, such measures are non-existent as a trade-off relationship exists between reduction potential and cost effectiveness.

Ship operators should then adopt measures that have high cost effectiveness but lower potential. *Weather routing, speed reduction, hull coatings and optimisation of trim and ballast* are some examples of measures in this category. These measures should be implemented by shipping companies without the need for much risk analysis. Indeed, as shown by survey results, these measures are most highly implemented by companies.

The next stage will involve implementing the measures that are less cost effective but have high potential. Measures that are in this category include *alternative fuels* and *concept, speed and capability*. Such measures constitute high risk and high chance of failure and thus require more detailed risk analysis.

Lastly, measures with low cost effectiveness and low potential should in theory not be implemented by shipping companies. However, they may be needed to comply with regulations. An example would be *cold-ironing*. The State of California has enacted that all ships calling at its ports should be cold-iron capable by 2014. Therefore, it is mandatory to adopt this measure for ships trading at these ports. Choosing the right measures will involve taking regulatory requirements into consideration.

The proposed stages of implementation are particularly applicable in this economic condition. As mentioned by Mr. Jones (2012) from Island Shipbrokers, companies do not have the cash at this difficult period to invest in the less cost effective measures. It is acknowledged that the situation can be different when market condition improves and companies may be more willing to pump in cash for uncertain measures that have the potential of high emissions reduction (Jones, 2012). Therefore, it is possible that the companies will implement the less cost effective but high potential measures as a first option if the financial status of the company is permissible. An important point to note is that the cost effectiveness and emissions reduction potential of the measures do not remain stagnant. The ideal situation would be an improvement in cost effectiveness and reduction potential through a combination of R&D and financial incentives.

#### **4.2 Overcoming critical barriers**

Survey and interview responses show that *cost of measure* and *lack of information* are the top critical issues of implementation of measures. Some enabling factors that can reduce the hindrance of these key barriers will be highlighted in this section.

#### *4.2.1 Cost of measure*

For most measures, the cost is a major concern in the implementation. The abatement cost curves in the market show that most measures are actually profitable in the long run. However, the amount of initial investment is a massive sum for most companies to handle.

Interview responses indicated that this cost barrier is likely to erode naturally. With fuel prices increasing, Mr. Khorshed (2011) from APL suggested that the measures will get increasingly cost effective due to the savings in fuel consumption. Also, with the increasing uptake of the more cost effective measures, there may be a bottleneck where companies will have to look at those measures that may not be that cost effective in order to achieve the improvement in vessels' efficiency. Mr. Jones (2012) from Island Shipbrokers also expressed his opinion that the market condition has amplified the importance of the cost factor in decision making. This cost barrier will decrease when market condition improves.

Nevertheless, respondents agreed that monetary incentives to improve the cost effectiveness of the measures will aid in a more rapid erosion of this barrier (Heah, 2012; Nixon, 2012). Mr. Lim (2011) from MPA suggested that companies can seek for grants from governmental agencies. The green technology programme by MPA which provides grants of up to 50% is an example of such monetary incentive. With external monetary support, companies will be more willing to implement the measures with high reduction potential as cost barrier is significantly reduced.

#### *4.2.2 Lack of information*

The lack of accurate information regarding abatement costs of the measures is a significant barrier as pointed out in surveys and interviews. To solve this problem, it is advisable for companies to use their own effort to verify the information (Ellehave, 2012). The Maersk Maritime Technology initiative, which includes a dedicated in-house research department, provides the company with comprehensive information of measures. Maersk also actively collaborates with various agencies and other companies to develop and trial test new solutions. A more active participation by companies can overcome the barrier caused by the inadequacy of information provided by external agents.

It is also suggested that there can be development of risk sharing contracts between technology suppliers and owners for claims made for technologies. Through this way, companies will have better incentives to adopt the uncertain technologies. Monetary incentives by agencies may also prove to be useful for shipping companies to experiment the measures.

Better consolidation of information is also practical in addressing ship operators' concern. The fathom guide to ship efficiency is an example of a valuable guide compiling emissions

reduction technologies available in the market (Lockley & Jarabo-Martin, 2011). Ship operators are more receptive of measures that have gone through large scale demonstration project to verify the efficiency of the measures. The guide provides a consolidation of data from demonstration projects that have been conducted and will assist in the decision making process.

### ***4.3 Moving ahead***

This section will highlight key points that are helpful to companies when dealing with the GHG environmental challenges.

#### ***4.3.1 Businessmen remain as businessmen***

The two key principles of running a business, which are saving cost and increasing revenue, can be adhered to when addressing environmental issues.

Survey and interviews show that cost is the key component affecting ship operators' decision. Profit will remain as the bottom-line for ship operators, especially during this period of difficult economic condition. It will be prudent for companies to deal with environmental challenges by treating the measures as ways to improve the energy efficiency of the vessels (Khorshed, 2011; Zafral, 2012). The key now is to focus on measures that can bring about immediate fuel consumption savings amid the high bunker prices (Nixon, 2012).

Ship operators can also ride on the environmental issues to do more business. Maersk, for example, has developed a method for transporting live lobsters in special containers (Ellehave, 2012). Similarly, APL has also undergone several successful shipments of live frogs and fishes (Khorshed, 2011). These shipments are normally transported by air, and transporting them by sea reduces their carbon footprint. The environmental issue allows shipping companies to market themselves as being more environmentally friendly and to take on market share from other modes of transportation. Mr. Nixon (2012) from NYK also highlighted the shipment of energy efficient products as an emerging market that can be tapped upon. For example, NYK has been shipping solar panels from China to USA and Europe. The shipment of the green equipments is a valuable business opportunity to leverage on for the next ten to fifteen years.

#### ***4.3.2 Importance of marketing***

All efforts, no matter how small are counted towards the perception of being a green shipping company. Shipping companies should focus on marketing and publicising their green efforts since their operations are often not in direct sight of consumers (Lim, 2011). Many of the measures are already used in the day-to-day operations to improve operational efficiency.

Companies can carefully market these as environmental initiatives. In addition, with the trend of various regulations made mandatory, companies can move ahead of the regulations. A first-mover strategy can help to build up a company's reputation. Mr. Khorshed (2011) from APL highlighted their effort to be the first shipping line to cold-iron at the Port of Oakland as an example of a well thought out marketing effort while addressing environmental concerns. Table 4.1 shows some of the environmental efforts that are seen as good marketing opportunities.

Table 4.1 Marketing opportunities while addressing environmental concerns

Voluntary use of indicators to evaluate and publicly report on environmental progress
Participation in major environmental initiatives such as CCWG and CDP
Issuance of regular environmental reports highlighting the companies' environmental policy
Availability of information regarding emissions control through websites, brochures and publications
Provision of carbon calculator

#### 4.3.3 Regulations

Interview respondents generally felt that the industry is well positioned to meet the challenges of the new GHG regulations (Nixon, 2012; Zafra, 2012). Efforts to improve the energy efficiency of the vessels are already evident since the 2005 boom in bunker prices. The drive for efficiency has also accelerated with the economic downturn in 2008. Shipping companies indicated that most of their vessels are already more efficient than the requirement of the new regulations (Ellehave, 2012; Khorshed, 2011). The significant difference that the regulations will bring is the need for planning and documentation. Companies will also need to implement performance monitoring systems to record efficiency data that would be necessary under impending regulations (Khorshed, 2011).

The regulation is actually quite minimal currently as mentioned by Mr. Lim (2011) from MPA. The main aim of the regulation is to raise awareness and to accelerate the process of adoption of emissions reduction measures. However, it is possible that regulations will get increasingly stringent (Lim, 2011). The regulatory compliance pressures will continue to build up especially with MBM being hotly debated. It would be prudent for companies to adopt the emissions reduction measures incrementally to meet future challenges. The best way to counter regulations is not to meet regulations but to beat the regulations. Shipping companies can refer to IMO and other professional consultants for guidance on the new regulations (Heah, 2012; Zafra, 2012).

Most importantly, companies should push for an effective international standard as variation in regulations regionally may prove to be an additional cost for companies. Active communication with governmental agencies will create a win-win situation (Lim, 2011).

Although the regulations may lead to an increase in pressure and cost, this is not necessarily harmful as significant efforts in R&D will be taken by industry players, such as shipbuilders, classification societies and equipment providers to bring about greater cost effectiveness and emissions reduction potential of existing and new measures (Heah, 2012). The regulations will also lead to the establishment of more private professional consultation firms which can provide advice on environmental issues. Companies will be able to gain from a wider selection of promising measures and services. Support for the regulations is thus beneficial.

#### *4.3.4 Future*

With the tightening of regulations governing emissions from ships, it is expected that there will be development of more energy efficient technologies in the future. In many other sectors, more stringent pollution regulations bring about advancement of pollution control technologies. This is likely to be the case for the shipping industry as more resources are pumped into the development of technologies.

In the longer term, it is believed that the shipping industry should be able to further reduce emissions from vessels as technologies develop. Interview respondents highlighted the potential of biodiesel and LNG in reducing emissions (Khorshed, 2011; Nixon, 2012). However, the rate of implementation will depend on the improvement in infrastructure. In the shorter term, ship operators can optimise the fuel consumption of existing ships through a combination of energy audits and performance benchmarking. These efforts will help in the identification of areas of inefficiency that can be improved, which will eventually yield an optimisation of fuel usage and a reduction of emissions from ships.

This is a tough time for the container shipping industry. Market condition is poor and more stringent environmental regulations are imminent, resulting in more cost for companies at a point when they do not have the extra cash. With the increasing cost of fuel, the wise move would be to consider measures that can fulfil the regulations while saving on bunker cost. It is advisable for companies to focus on the reduction of fuel consumption as the main strategy. Companies should not neglect the environmental aspect of operations. The ability of companies to meet the environmental challenges will determine their competitive advantage.



#### 4.4 Summary of research findings

- The commonly adopted emissions reduction measures can be categorised into technical and operational measures. The measures are evaluated based on 3 factors, namely level of implementation, emissions reduction potential and cost effectiveness in this study.
- Level of implementation of operational measures is generally higher than technical measures. The top 3 emissions reduction measures implemented by companies are operational measures, namely *speed reduction*, *propeller*, *hull and engine maintenance* and *optimisation of trim and ballast*. Operational measures are low-hanging fruits that are adopted in the day-to-day operations without expensive retrofit to improve operational efficiency. The adoption of such measures shows the importance of cost effectiveness in decision making. R&D to improve the emissions reduction potential of these measures will be beneficial.
- The measures available in the market are perceived to have a consistent medium-high emissions reduction potential but the level of implementation is quite variable. There is immense potential to reduce emissions given the availability of measures with significant reduction potential. Efforts to improve the cost effectiveness of the measures are needed to improve their level of implementation. The assessment of current measures shows that future measures will have to be cost effective in order for companies to consider implementing them.
- The most important critical issues of implementation are *cost of measure* and *lack of information*. Interview responses indicate that the cost barrier is likely to erode naturally with the increase in fuel prices. However, monetary incentives will accelerate the process. Companies are advised to use their own effort to verify information provided by external sources to solve the problem of lack of information. Risk sharing contracts and financial assistance may also be useful.
- Development has been focused on new technologies such as wind power with higher emissions reduction potential. However, this study shows that current measures are already perceived to have significant environmental feasibility. The critical barrier of implementation is actually cost effectiveness. Therefore, attention should be on making these measures more affordable instead of developing new measures that have greater

emissions reduction potential. An improvement in cost effectiveness can result in a greater increase in implementation as compared to the same level of improvement in emissions reduction potential.

- With the importance of cost effectiveness in mind, the proposed stages of implementation of emissions reduction measures is to first focus on cost effective measures then on the measures with high emissions reduction potential that have lower cost effectiveness.
- GHG emissions reduction is a by-product of effort to improve the energy efficiency of the vessel in order to save bunker consumption. This is especially fuelled by the increase in bunker prices in recent years. Companies can treat the measures as ways to improve the fuel efficiency of the vessel. Companies should implement the measures on a higher level in view of the cost savings from a reduction in fuel usage.
- Ship operators can ride on the environmental issues to do more business. Companies can market themselves as being more environmentally friendly and take on market share from other modes of transportation. The shipment of the green equipments is also a valuable business opportunity to leverage on for the next ten to fifteen years.
- Marketing is an important component of the GHG mitigation strategy. Shipping companies should focus on marketing and publicising their green efforts. One good marketing tactic is to move ahead of the regulations. A first-mover strategy can help to build up a company's reputation. The best way to counter regulations is not to meet them but to anticipate them.
- There will be an advent of more emissions control technologies as air pollution from ships become increasingly regulated. Regulations can drive R&D to bring about greater cost effectiveness and emissions reduction potential of existing and new measures. Regulations may get increasingly stringent. It would be prudent for companies to adopt the emissions reduction measures incrementally.

## CHAPTER 5 CONCLUSION

In this chapter, conclusion will be drawn from research findings. Recommendations for future research will also be made.

### 5.1 Conclusion

Evaluating and selecting measures using appropriate decision criteria is an imperative component of a good GHG strategy. The importance of *cost effectiveness* in decision making from a ship operator's perspective is highlighted in this study. This prompts the adoption of measures that are most cost effective first before measures with high emissions reduction potential. It is advisable for companies to consider savings from reduction in fuel consumption as a main factor in selecting measures, especially with the increasing cost of fuel. Companies should also monitor demand changes amid the environmental situation to identify business opportunities. With the careful packaging of the GHG strategy, the environmental issue can be valuable for business creation. It is also vital to examine the development of new regulations and work closely with consultants to determine the best measures for achieving the required efficiency.

There is immense potential to reduce emissions given the availability of measures with significant reduction potential. However, the top barriers of implementation, namely *cost of measures* and *lack of information*, need to be addressed for a higher level of adoption. It is probable that there will be development of more energy efficient technologies at a faster pace in the future as regulations tighten. Ship operators can expect to gain from a wider selection of promising measures and services as more resources are gathered for the improvement of energy efficiency. Support for the regulations is thus encouraged. It is prudent for shipping companies to adopt a more environmentally friendly operation as green is the way forward in the shipping industry.

### 5.2 Recommendations for future research

This research focused on examining critical issues for implementation of emissions reduction measures as a whole. Further research can look at the critical barriers for specific measures. This will allow for more detailed study in the future on identifying enabler schemes to remove or overcome the barriers.

The technical and operational measures that were chosen for this study are the existing measures in the market that have published data on emissions reduction potential. There are

sub-categories of measures such as route planning and scheduling that were not addressed in this study. Upcoming technologies such as wind energy were also not included in this study. Further research can assess the economic, social and environmental impacts of these measures. This project is also mainly focused on the technical and operational measures of emissions reduction. A follow-up project on market-based measures will allow for a more comprehensive study of the overall strategies that can be adopted by ship operators.

Lastly, this study largely represents the views of larger companies as the majority of survey and interview respondents are medium-large companies. Future research needs to pay greater attention to the smaller companies as they are less likely to respond to survey questionnaires. These companies can be contacted before the survey questionnaires are sent. A larger sample of smaller companies would better represent the strategies of these companies. The survey questionnaire will also need to capture the names of the companies so that a second copy of the questionnaire can be sent to companies that did not respond.

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## APPENDIX A Emissions from ships

Emissions	Source	Amount from ships and the possible harmful effects	GHG?
CO <sub>2</sub>	Ships Exhaust	Annual CO <sub>2</sub> emissions from ships are estimated to be more than 1000 million tonnes, approximately 3.3% of total CO <sub>2</sub> emissions from all activities. It is the most significant emission responsible for global warming.	Yes
NO <sub>x</sub>		Annual NO <sub>x</sub> emissions from ships are estimated at 5 million tons, approximately 7% of total global emissions. It threatens human lives in local areas and forms acid rain.	Yes
SO <sub>x</sub>		Annual SO <sub>x</sub> emissions from ships are estimated to be around 5 million tons, about 4% of total global SO <sub>x</sub> emissions. High level of SO <sub>x</sub> concentration can create localised environmental problems.	No
Particulate Matter (PM)		Emissions are estimated to be 1.5 million tonnes per year. Inhalation of PM can cause respiratory problems and other harmful effects on health.	Yes
Volatile Organic Compounds (VOC)		Emissions are about 0.7 million tonnes from international shipping. Exposure to large quantities of harmful VOC can pose risk to health.	Yes
CFC	Refrigeration	Emissions from ships are estimated at 3000 to 6000 tons, which is about 1% to 3% of global emissions. CFC results in the depletion of ozone.	Yes

Source: (Connaughton, 2009)

## APPENDIX B MARPOL and other IMO pollution regulations

MARPOL ANNEX	Deals with	Year of Adoption	Entry into force
I	Oil	1973/1978	1983
II	Noxious liquid substances in bulk		1983
III	Harmful substances in packaged form		1992
IV	Sewage		2003
V	Garbage		1988
VI	Emissions	1997	2005

Conventions	Year of adoption	Entry into force
International Convention on the Control of Harmful Anti-fouling Systems on Ships	2001	2008
International Convention for the Control and Management of Ships' Ballast Water and Sediments	2004	Not yet in force
International Convention for the Safe and Environmentally Sound Recycling of Ship	2009	Not yet in force

Source: (IMO, 2011c)

## APPENDIX C Development of IMO regulations on GHG emissions

	Date	Development
MEPC 53	July 2005	Interim Guidelines for Voluntary Ship CO <sub>2</sub> Emissions Indexing for Use in Trials was approved. The CO <sub>2</sub> Indexing Scheme considers matters related to construction and operation of the ship, and market based incentives.
MEPC 55	October 2006	It was noted that the shipping industry needs to take action on GHG emissions. A work plan was developed for the reduction of CO <sub>2</sub> emissions from ships. Work on technical, operational and market-based measures for reduction of GHG emissions from ships was set for completion in 2009. There was also further development of the CO <sub>2</sub> Emissions Indexing Scheme.
MEPC 56	July 2007	The consensus to update the 2000 IMO GHG Study was reached. The work was scheduled for completion by MEPC 59 in 2009.
MEPC 58	October 2008	Progress was made in identifying technical and operational measures to address GHG emissions. The energy efficiency design index (EEDI) for new ships and the energy efficiency operational index (EEOI) were developed.
MEPC 59	July 2009	It was agreed that interim guidelines for EEDI, EEOI and Ship Energy Efficiency Management Plan (SEEMP) will be circulated.
MEPC 60	March 2010	Significant progress on technical and operational measures was made. Further finalisation of EEDI details such as target dates and reduction rate were required.
MEPC 61	September 2010	There was consideration to make EEDI and SEEMP mandatory under MARPOL Annex VI. The study on technical and operational measures to reduce emissions from ships proved to be already comprehensive. The discussion was focused more on the progress of market-based measures for reducing GHG emissions.

MEPC 62	July 2011	The EEDI and SEEMP were made mandatory. EEDI requires new ships that are built in or after 2013 to improve their efficiency by 10% as compared to today's new ships. This requirement will rise to 20% in 2020 and 30% for ships built after 2024. The mandatory measures will enter into force on 1 January 2013 and developing countries will be able to waive compliance until 2019. SEEMP applies to both new and existing ships and requires companies to draw up plans for efficient operation of the vessels.
Future work		Work on energy efficiency measures for ships will be continued. The details for EEDI framework will need to be enhanced. Attention should be on detailing the specific requirements for different ship types and sizes. Further evaluation of the use of market-based measures for GHG emission reduction will also be carried out.

Source: (MEPC, 2005, 2006a, 2006b, 2007, 2008a, 2008b, 2009a, 2009b, 2010b)

## APPENDIX D Measures adopted by liner shipping companies

Measures	APL	Evergreen	Hamburg Süd	Hapag-Lloyd	Hanjin Shipping	Maersk	MOL	MSC	NYK
Cavitated emulsified fuel	✓								✓
Cold-ironing	✓	✓						✓	✓
Constant water injection	✓								
Hull coatings	✓	✓		✓	✓		✓		
Propeller boss cap fins/Thrust fins	✓			✓			✓		
Propulsion system upgrade and maintenance	✓	✓	✓	✓		✓		✓	✓
Slow steaming	✓	✓	✓	✓		✓	✓		
Trim optimisation	✓	✓	✓	✓			✓		
Electronic controlled fuel injection engine		✓		✓	✓			✓	✓
Hull design optimisation		✓		✓				✓	
Turning off unnecessary electric power in lighting and pumps		✓							
Weather routing		✓	✓	✓	✓		✓		✓
Optimisation of engine performance through constant monitoring			✓						
Usage of two stroke engines with direct injection			✓						
Reduction of container weight				✓					
Rudder efficiency monitoring				✓					
Voyage planning				✓	✓	✓	✓		
Fuel additives					✓		✓		✓
Main engine low load tuning					✓				
Ship performance monitoring system						✓		✓	
Waste heat recovery							✓		✓
Hybrid energy models								✓	
Pre swirl stator								✓	
Air lubrication system									✓

(APL, 2012; Evergreen, 2012; Hamburg-süd, 2011; Hanjin, 2012; Hapag-Lloyd, 2012; Maersk, 2011; MOL, 2012; MSC, 2011; NYK, 2012)

## APPENDIX E Implementation of measures and direct bunker savings

### *Slow steaming*

Slow steaming results from a reduction in operating speed of vessel. In general, bunker consumption  $B$  can be approximated by Equation (1) (Stopford, 2008):

$$B = \left(\frac{v}{v^*}\right)^a B^* \quad \text{—————} \quad (1)$$

Where

$a \approx 3$  (cube rule)

$B^*$  = design bunker consumption

$B$  = actual bunker consumption

$v^*$  = design speed

$v$  = sailing speed

Treating  $B^*$  and  $v^*$  as constant, we arrive at Equation (2):

$$B \propto v^3 \quad \text{—————} \quad (2)$$

Therefore, reducing speed can reduce the rate of bunker consumption significantly.

### *Hull maintenance*

The purpose of hull maintenance is to remove hull debris that increases the wetted surface area of the vessel, leading to more resistance experienced by the vessel in water. The relationship of wetted surface area with bunker consumption is found in Equation (3):

$$B = f s v^n \quad \text{—————} \quad (3)$$

Where

$B$  = actual bunker consumption

$v$  = sailing speed

$f$  = Friction constant

$n$  = constant

$s$  = wetted surface area

When the wetted surface area  $s$  increases, bunker consumption  $B$  increases. Therefore, reduction of fuel consumption can result from hull maintenance.

### ***Trim optimisation***

Trim optimisation ensures that the vessel is operating at a draft that minimises its resistance in water. The relationship of draft and bunker consumption is shown in Equation 4. Bunker consumption is a function of speed and draft of the vessel.

$$\boxed{B = f(v, d)} \quad \text{—————} \quad (4)$$

Where

$B$  = actual bunker consumption

$f$  = Friction constant

$v$  = sailing speed

$d$  = draft of the vessel

**APPENDIX F          Marginal abatement cost curves**

	<b>DNV</b>	<b>IMO</b>	<b>Germanischer Lloyd</b>	<b>CATCH</b>
Bunker price (US\$/T)	300 for HFO, 500 for MDO	500	743	243
Interest rate	Not available	4%	5%	5%
Vessel types	All vessel types	All vessel types	Container vessel of all sizes	8000 TEU container ship
Rankings <sup>1</sup>				
1	Voyage execution	Retrofit hull measures	Propeller maintenance	Weather Routing
2	Propeller upgrades	Voyage and operational options	Design optimisation	Optimal trim
3	Optimal trim	Air lubrication	Optimal trim	Optimised hull design
4	Propeller maintenance	Propeller upgrades	Hull openings	Hull coating
5	Weather routing	Hull coating and maintenance	Hull coatings and maintenance	Propeller system upgrade
6	Air lubrication	Propeller maintenance	Performance monitoring	Propeller maintenance
7	Hull maintenance	Auxiliary systems	Propeller upgrades	Slow steaming
8	Main engine retrofit	Slow steaming	Auxiliary systems	Waste heat recovery
9	Slow steaming	Main engine improvements	Weather routing	Main engine retrofit measures
10	Waste heat recovery		Hull form optimisation	Fuel Cell
11	Cold ironing		Air lubrication	Solar Panel
12	Solar panel		Slow steaming	
13	Wind generator		LNG fuelled ships	
14			Reefer improvements	
15			Waste heat recovery	
16			Main engine retrofit	

Source: (DNV, 2010b; Eide et al., 2009; MEPC, 2010a; Sames, 2011)

<sup>1</sup> The measures are ranked with 1 being the most cost effective measure, 2 being the second most cost effective measure and so on. The shaded portions indicate measures without cost effectiveness.



## APPENDIX G      Survey questionnaire

### Survey of Greenhouse Gas Emissions Reduction by Container Shipping Companies

I am Lin Shimin from Nanyang Technological University, School of Civil and Environmental Engineering, Maritime Studies programme. I would like to seek your kind help in completing the survey form attached.

The objectives of this survey are to investigate the implementation of the GHG emissions reduction measures and to identify critical issues in the implementation of the measures.

The survey consists of 3 parts which would take you about **10-15 minutes** to answer all the questions.

*Part 1: Information about Organisation*

*Part 2: Greenhouse Gas Emissions Reduction*

*Part 3: Feedback*

**All information will be kept confidential** and only aggregated results will be released.

Please fill this survey form by **a personnel experienced in the environmental aspect of the company's operations** and **use the postage-paid envelope** attached with the survey questionnaire to mail back the completed survey form.

Alternatively, **an online version of the survey** can be accessed through the following web link:  
<http://survey.ntu.edu.sg/efm/se.ashx?s=705E3ED46CEA6147>

Please feel free to contact me if there is any enquiry regarding the project. I can be contacted as follow:

Investigator: Ms. Lin Shimin  
Phone: +65 9628 9740  
Email: [lins0037@e.ntu.edu.sg](mailto:lins0037@e.ntu.edu.sg)

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Phone: +65 6790 5250  
Email: [cydwong@ntu.edu.sg](mailto:cydwong@ntu.edu.sg)

*Thank you for your time and effort.*

## Part 1 Information about organisation

1) Please select the number of **container ships** owned or operated by the company.

☐ ≤ 20

☐ 51-100

☐ 21-50

☐ >100

## Part 2 Greenhouse Gas Emissions Reduction

2) Please rate the **emissions reduction potential** and the **level of implementation** of the following emissions reduction measures according to the situation of your company.

Measures (Please refer to glossary for details)		Emissions reduction potential				Level of implementation			
		None	Low	Medium	High	None	Low	Medium	High
Technical	Alternative fuels								
	Cold ironing								
	Concept, speed and capability (e.g. Ship size, design speed)								
	Hull and superstructure design								
	Hull coatings								
	Power and propulsion system upgrades								
	Waste heat recovery								
Operational	Optimisation of trim and ballast								
	Propeller, hull and engine maintenance								
	Speed reduction								
	Weather routing								

3) Please rate the **cost effectiveness** (monetary valuation of material, resources, time, effort, risk and opportunity forgone) of the following emissions reduction measures.

Measures (Please refer to glossary for details)		Cost effectiveness			
		None	Low	Medium	High
Technical	Alternative fuels				
	Cold ironing				
	Concept, speed and capability (e.g. Ship size, design speed)				
	Hull and superstructure design				
	Hull coatings				
	Power and propulsion system upgrades				
	Waste heat recovery				
Operational	Optimisation of trim and ballast				
	Propeller, hull and engine maintenance				
	Speed reduction				
	Weather routing				

- 4) What are the **top 3 measures** that are most commonly adopted by the company to reduce emissions of ships?

Top 1	Top 2	Top 3
<p><b>A.</b> Alternative fuel</p> <p><b>B.</b> Cold ironing</p> <p><b>C.</b> Concept, speed and capability (e.g. Ship size, design speed)</p> <p><b>D.</b> Hull and superstructure design</p> <p><b>E.</b> Hull coatings</p> <p><b>F.</b> Power and propulsion system</p> <p><b>G.</b> Waste heat recovery</p>	<p><b>H.</b> Optimisation of trim and ballast</p> <p><b>I.</b> Propeller, hull and engine maintenance</p> <p><b>J.</b> Speed reduction</p> <p><b>K.</b> Weather routing</p> <p><b>L.</b> Others</p> <p>_____</p> <p>_____</p> <p>_____</p>	

- 5) Please rate the **level of importance** and the **comparative importance** of following factors in the evaluation of emissions reduction measures.

Factors	Level of importance (Please tick)			Comparative importance (Rank among the factors, with 1 being the most important, 2 being the second most important and so on)	
	Low	Medium	High	(e.g.)	
Cost of implementing measure				3	
Emissions reduction potential				1	
Cost savings (e.g. from reduction in bunker consumption)				2	
Others, please specify: _____					

- 6) Please rate the extent to which the following barriers may hinder the implementation of GHG emissions reduction measures?

Barriers	Limited hindrance	Some hindrance	Substantial hindrance
Lack of information about measures			
Cost of measures			
Hidden cost (e.g. staff training for sophisticated measures)			
Owner - User problem (e.g. If the ship is operated by an agent different from the owner, owner have to pay the upfront capital investment while user get to enjoy the benefit of improvement in energy efficiency)			
Technological and infrastructure constraints			
Materiality (e.g. Measures with limited energy efficiency improvements)			
Others, please specify: _____			

- 7) In your opinion, what are the critical issues in adopting GHG emissions reduction measures?

\_\_\_\_\_

\_\_\_\_\_

### **Part 3                      Feedbacks**

- 8) Would you be interested to have an interview session?

- ☐ Yes
- ☐ No

If yes, please leave your contact information here:

Name: \_\_\_\_\_

Email: \_\_\_\_\_

Company: \_\_\_\_\_

- 9) Would you be interested in having a copy of the summary findings of this research project (available in June 2012)?

- ☐ Yes
- ☐ No

If yes, please leave your email address here: \_\_\_\_\_

--- End of survey. Thank you for your time. ---

## Glossary

	Measures	Description
Technical	Alternative fuels and power sources	Replacing the use of heavy fuel oil (HFO) with less carbon intensive fuel.
	Cold ironing	Using shore-based power when the vessel is berthed.
	Concept, speed and capability	Improvements to specifications of the original design such as beam, draught, size and speed.
	Hull and superstructure designs	Improvements in streamline designs and reduction of the weight of the hull.
	Hull coatings	Improving the type of coating that is used and the quality of application of the coating to reduce resistance.
	Power and propulsion systems upgrades	Improving the efficiency of older engines through upgrading. Adding enhancements such as vanes, fins, ducts and swirl devices to increase energy efficiency.
	Waste heat recovery	Utilising the waste heat of the engines to drive turbines for electricity production.
Operational	Optimisation of trim and ballast	Finding and operating at the correct trim. Avoiding unnecessary ballast.
	Propeller, hull and engine maintenance	Avoidance of inefficiency of propeller, hull and engine performance through maintenance.
	Speed optimisation	Running the vessels at a slower speed to reduce fuel consumption.
	Weather routing	Utilising information on weather and ocean current to better plan and execute voyages.

## APPENDIX H Top 100 liner shipping companies (as of 21 October 2011)

Rank	Operators	Rank	Operators	Rank	Operators
1	APM-Maersk	19	UASC	37	Emirates Shipping Line
2	MSC	20	PIL	38	Seaboard Marine
3	CMA CGM Group	21	MISC Berhad	39	S.C. India
4	Evergreen Line	22	Wan Hai Lines	40	Schöller Group
5	APL	23	HDS Lines	41	Samudera
6	Hapag-Lloyd	24	RCL	42	Swire Shipping
7	COSCO Container Lines	25	Sea Consortium	43	Sinotrans
8	CSCL	26	Grimaldi (Napoli)	44	Nile Dutch Shg
9	Hanjin Shipping	27	TS Lines	45	Linea Messina
10	NYK	28	KMTC	46	Sinokor
11	CSAV Group	29	CCNI	47	Turkon Line
12	K Line	30	STX Pan Ocean	48	Crowley Liner Services
13	OOCL	31	SITC	49	Grand China Logistics
14	MOL	32	Horizon Lines	50	Temas Line
15	Yang Ming Line	33	Arkas Line / EMES	51	MACS
16	Hamburg Süd Group	34	UniFeeder	52	Meratus
17	Zim	35	Maruba + CLAN	53	Dole Ocean Liner
18	Hyundai M.M.	36	Matson	54	Heung-A Shipping

Rank	Operators	Rank	Operators	Rank	Operators
55	Westwood	73	Samship	91	Johan Shg
56	Nam Sung	74	NSCSA	92	Formosa Plastics
57	Simatech	75	Universal Africa Line	93	Melfi C.L.
58	Delphis NV / Team Lines	76	Tarros	94	Peel Ports (BG Freight)
59	United Feeder Services	77	Great White Fleet	95	Qatar National Line
60	Tanto Intim Line	78	Bien Dong Shg (Vinashin)	96	Dannebrog / Nordana
61	FESCO	79	SeaFreight	97	Shanghai Hai Hua (Hasco)
62	Containerships OY	80	Shanghai Jin Jiang	98	IMTC
63	OEL / Shreyas	81	Tropical Shg	99	UAFL
64	Borchard Lines	82	OPDR	100	Marguisa
65	Log-In Logistica	83	Eimskip		
66	HubLine Bhd	84	DAL		
67	Vinalines	85	Kambara Kisen		
68	Marfret	86	Conti Lines		
69	Mariana Express Lines	87	Caribbean Feeder Services		
70	Boluda Lines	88	Independent Container Line		
71	Valfajre Eight Shg Co	89	Yanghai Shipping Co (YSC)		
72	Irish Continental Group	90	Chun Kyung (CK Line)		

Source: (Alphaliner, 2011)

## **APPENDIX I                      Interview respondents**

Mr. George Solomon, Director (Security and Environment), APL

Mr. Alam Khorshed, Director of Engineering Research & Energy Management, APL

Mr. Mark Lim, Deputy Director (Shipping), MPA

Ms. Desiree Chen, Assistant Manager (Registry and Manning), MPA

Mr. Bo Ellehave, General Manager (Sustainability), Maersk

Mr. Christopher A Jones, Director (Sales and Purchase), Island Shipbrokers

Ms. Katharine Koh, Director of Research, Island Shipbrokers

Mr. Jeremy Nixon, Chief Operating Officer, NYK

Mr. Lau Joo Yong, Vice Country Manager, Singapore, Hanjin Shipping

Mr. Torsten Mundt, Head of Group Environmental Services (Research), Germanischer Lloyd

Mr. Outi Korhonen, Manager, Environmental Portfolio Management (Ship Power), Wärtsilä

Mr. Mark Heah, General Manager, Jardine Shipping Services

Mr. Zafra Alam, Assistant Director, MPA



## APPENDIX J                      Interview guidelines

1. What is the general sentiment of the company towards reduction of GHG emissions from ships?
2. What is the decision making process prior to the adoption of new technologies or operational practices for environmental improvement?
3. According to survey results, the top 3 emissions reduction measures being implemented are operational measures, namely *speed reduction*, *vessel maintenance*, *optimisation of trim and ballast*. Why are these measures more attractive as compared to other measures? Will this trend continue?
4. What are the barriers or critical issues that may hinder the implementation of GHG emissions reduction measure?
5. From the survey, the top 3 critical issues of implementation are *cost of measure*, *materiality* and *lack of information*. What measures can be put in place to overcome these barriers?
6. How might the enforcement of EEDI and SEEMP affect the operation of shipping companies? What are some of the problems or difficulties to comply with the regulations?
7. What is the position that companies should take with regards to GHG issues?
8. What strategies can be put in place to meet future environmental challenge while taking care of business profitability?