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FUTURE POWERING OPTIONS FOR CONTAINER VESSELS

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ABSTRACT

The drive for cleaner, more efficient and cost-effective powering options for container vessels is inevitable in the face of its rising demand and substantial greenhouse gas (GHG) emissions. In this paper, the main challenges of the container shipping industry are established, leading to identifying alternative powering options. A detailed and objective comparative analysis conducted establishes some important implications of these options for deep sea-going container vessels. From the analysis conducted it was found that despite its high bunker costs, low sulphur fuel oil such as marine diesel oil (MDO) could potentially be a transitional option for deep sea-going container vessels in the short term as it does not require any retrofit of vessels. With stricter emission limits looming, deep sea-going container vessels using LNG as a fuel will rapidly increase due to its high emission reduction potential, lower costs, availability, and reliability. A long term solution will require a departure from current practises in the maritime industry alongside a heavier reliance upon established and dependable technologies such as nuclear, solar and wind power.

Keywords: container vessel, powering, marine emission, marine fuel.

INTRODUCTION

In the late 19[th] century, the commercial shipping fleet transited from sail to full engine-powered vessels, and steam engines burning coal have dominated until the early 20[th] century [1]. Marine oil has then gradually displaced coal as the main fuel source for the commercial shipping fleet owing to the advent of diesel engines with higher efficiency, ease of handling and cleaner operations [1]. Today, approximately 77% of the fuel used in marine diesel engines is residual fuel, also referred to as heavy fuel oil (HFO) for its availability and affordability [2]. However, the HFO is of lower quality and its high sulfur content have resulted in significant emission of GHGs and harmful air pollutants such as carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x) and particulate matter [3]. In addition, the fluctuating but generally rising prices of marine fuels, which account for a large share of the operating cost of the commercial shipping fleet, have pushed the demand for more energy efficient powering options including alternative energy sources [4]. In this context, questions are being raised on whether the current powering options for the commercial shipping fleetare sustainable, especially when compounded with rising environmental considerations and economic concerns.

Container shipping, as one of the fastest growing sector [5] in the shipping industry, can hardly be free from the same questions. Since the first container vessel named 'Ideal-X' began operating in 1956, container shipping industry has been growing rapidly due to the multiple benefit of 'containerisation' which can be defined as the unitisation of general cargos by using standard container [6]. Currently, 52% of global seaborne trade in terms of value are carried through container shipping [7]. In addition, the container shipping industry is one of the primary contributors of carbon footprint in the shipping sector. Although the share of container vessels in world's maritime fleet is relatively small (12.7% in 2013 [7]), container vessels are one of the largest CO_2emitterin the industry. According to IMO, container shipping emitted approximately 232 million tonnes of CO_2, which equalled to 22% of the total shipping emission excluding military and fishing vessels [8].

The aim of this paper is therefore established to investigate alternative powering options for container vessels engaging in ocean-crossing trade. Within the container shipping sector, the two major segments are deep sea and short sea container shipping [9]. These two segments have significantly different characteristics in terms of transport route, vessel size, main engine type, sailing speed and etc. This paper will only focus on deep sea-going container vessels.

Container vessel

Container vessels are specially designed and equipped cargo vessels for carrying intermodal containers [10]. Like most of the other types of vessels, the main propulsion of a container vessel is fulfilled by diesel engines. Diesel engines are divided into slow speed two stroke engine, medium speed four stroke engine and high speed four stroke engine. Large container vessels with capacity above 2,800 Twenty-Footer Equivalent Unit (TEU)are normally powered by slow speed diesel engines of high rated power as their main propulsion due to their high cruising speeds. Trozzi and Vaccaro [11] reported that more than 90% of container vessels use slow speed diesel engines as their main engine. In terms of fuels, IFO380 and IFO180 are the most commonly used bunker fuels in container vessels [12]. The abbreviation IFO stands for intermediate fuel oil which is a type of residual fuel oil blended with distillates.

Container vessels sail at relatively higher speeds than other types of vessels e.g. bulkers and tankers. Large vessels for deep sea container shipping are the fastest merchant ships with a sailing speed of up to 24 – 26 knots, whilst small feeder class container vessels sail at 14 – 18

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knots [13]. The higher sailing speed affects fuel consumption and emissions.

Container vessels are generally classified by means of maximum TEU-sized container carrying capacity during a voyage. Generally, container vessels can be divided into 6 classes, as shown Table-1.

In general, deep sea-going container shipping deploy larger vessels with capacity above 5,000 TEUs, where vessels with capacity between 5,000 – 13,000 TEUs are mainly used for trans-Atlantic and trans-Pacific services whilst vessels above 13,000 TEUs are usually used for the Asia–Europe route [13].

Table-1. Container vessel classes and main application [13].

Class of container vessel	Container capacity	Main application
Small feeder	< 1000 TEU	Short sea container shipping
Feeder	1000 - 2800 TEU	Short sea container shipping Feeding large container vessel
Panamax	2800 - 5100 TEU	Mainly short sea container shipping Partly deep sea container shipping
Post-Panamax	5500 - 10000 TEU	Deep sea container shipping
New Panamax (Suezmax)	12000 - 14500 TEU	Deep sea container shipping
Ultra Large Container vessel (ULCV)	> 14500 TEU	Deep sea container shipping

The capacity of container vessels tends to grow as world sea trade expands and cargo traffic grows, because larger ships have the advantage of economies of scale [14]. Currently, container vessels capable of transporting 18,000 TEUs are already in operation and 20,000 TEUs vessels are currently under development [1].

METHODOLOGY

This study employed a detailed and objective comparative analysis, which establishes some important implications of these options for deep sea-going container vessels

First, the main challenges of the container shipping industry, which raise the demand for alternative powering options over next decades, are reviewed and established. Then, alternative powering options are introduced. These also include technical and operational energy saving strategies. From the list of potential options, some alternative fuels and measures suitable for deep sea-going container vessels are selected for analysis based upon the requirements of container vessels and a comparative analysis of the selected alternative powering options is conducted by considering environmental impact, economic viability, emission reduction potential, compliance with emission regulations, and cost effectiveness. Finally, a conclusion is drawn based upon the analysis conducted.

Major challenges in container shipping industry

Environmental considerations – When the amount of emissions from shipping is compared to other forms of transportation modes in specific terms i.e. amount of CO_2 emitted per tonne of cargo per kilometer, shipping is considered as one of the most carbon efficient way to transport goods over long distances [10]. As shown in Figure-1, a container vessel emits significantly less CO_2 than other types of vehicles partly due to the bigger payload carried per trip compared to rail, road and air freight [8].

However, the amount of GHG emissions of shipping is substantial and it is growing at unprecedented levels. The3rd IMO Greenhouse Gas Study reported in 2012 that the shipping industry emitted approximately 949 million tonnes of CO_2 and 972 million tonnes of CO_2e for GHGs combining CO_2, CH_4 and N_2O, which account for approximately 2.7% and 2.5% of global CO_2 and CO_2e emissions respectively [3].

It was also reported that if the global shipping industry were a country, it would be the sixth largest GHG emitting country in the world [16]. For sulfur oxide (SO_x) and nitrogen oxide (NO_x) emissions, it was reported that 16 largest ships in the world emit as much NO_x and SO_x as the world's 760 million cars [17]. Table-2shows total shipping CO_2 and CO_2e emissions compared to global total CO_2 and CO_2e emissions from 2007 to 2012.

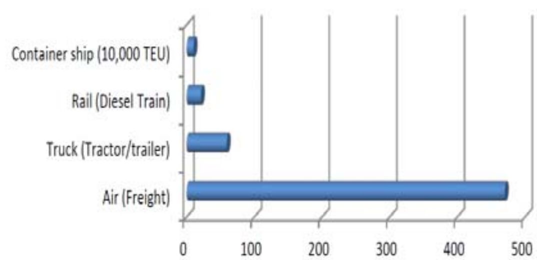

Figure-1. Comparison of CO_2 emissions of different modes of transportation [15]

Table-2. CO_2 and CO_2 emissions from shipping from 2007 to 2012 [3].

Year	Global CO_2	Shipping CO_2 (Million tonnes)	% of Global	Global CO_2e	Shipping CO_2e (Million tonnes)	% of Global
2007	31,409	1,100	3.5	34,881	1,121	3.2
2008	32,204	1,135	3.1	35,677	1,157	3.2
2009	32,047	978	3.1	35,519	998	2.8
2010	33,612	915	2.7	37,085	935	2.5
2011	34,723	1,022	2.9	38,196	1,045	2.7
2012	35,640	949	2.7	39,113	972	2.5
Average	33,273	1,016	3.1	36,745	1,038	2.4

More importantly, GHG emissions from the shipping industry are predicted to increase significantly

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over the next decades due to the anticipated economic growth and associated rise in transport demands [18].

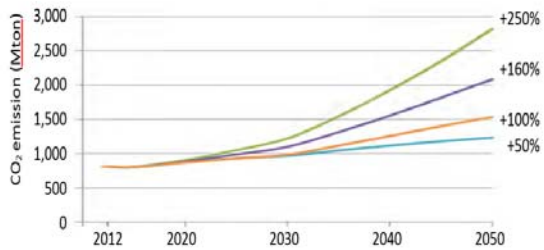

Figure-2. BAU projections of CO_2 emissions from total shipping [3].

According to the third IMO Greenhouse Gas Study [3], all four business as usual (BAU) scenarios predicted an increase in CO_2 emission by 50% to 250% in the period up to 2050 depending upon their assumptions on fossil fuel consumption, future economic growth, fuel mix, and efficiency improvement, as shown Figure-2.

International and Regional Regulations – Environmental concerns previously mentioned have led international bodies such as International Maritime Organisation (IMO) to adopt regulations to reduce polluting chemicals and GHG emissions discharged from vessels. The regulations designed by the IMO are outlined in "International Convention on the Prevention of Pollution from Ships Annex VI", known as MARPOL Annex VI [18]. MARPOL Annex VI consists of two standards for emissions. The first is a global standard applied to all vessels arriving at or departing from countries which are party to the MARPOL treaty [19]. The second is regional standard applied to designated emission control areas (ECAs), which are subject to more stringent restrictions on sulfur content in marine fuels and NO_x emission [19].

First of all, for the sulfur content in marine fuels, as shown in Figure-3a, the global limit will be reduced to 0.5% by 2020 and the limits in ECAs has been lowered to 0.1% since 2015 [20]. The sulfur ECAs (SECA) currently established are the Baltic Sea area, the North Sea area, the North American area and the US Caribbean Sea area [20].

Next, for the NO_x, the emissions are regulated depending upon the engine speed, as shown in Figure-3b. Tier I standard applies to marine engines produced after 2000.However, engines produced after 2011 faced Tier II standard requiring approximately 20% reduction in NO_x emissions compared to Tier I standard [20]. Furthermore, in NO_x Emission Control Areas (NECAs), Tier III standard will apply from 2016, representing a decrease of approximately 80% in NO_x emissions compared to Tier I standard and so far, the North American area and the US Caribbean Sea area are established as the NECAs [20].

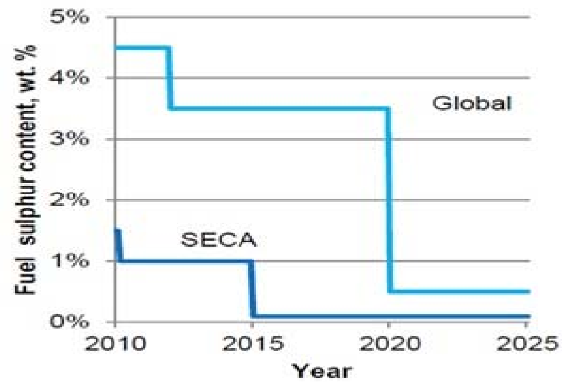

Figure-3a. MARPOL Annex VI fuel sulfur content limits[21].

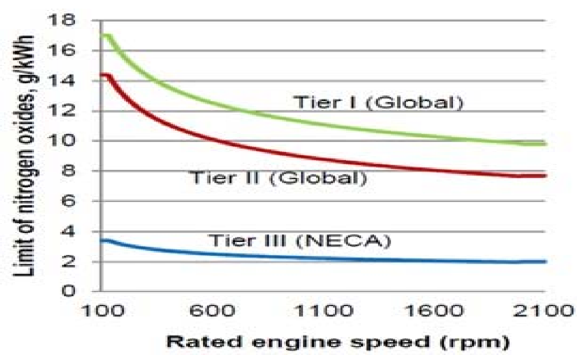

Figure-3b. MARPOL Annex VI NO_X emission limits[21].

In addition to these regulations, the IMO adopted another mandatory measure, the energy efficiency design index (EEDI), in order to reduce GHG emissions from vessels in 2011 [4]. The EEDI is intended to set a minimum requirement for energy efficiency of new large vessels, therefore all newly built vessels must satisfy the EEDI baseline requirements, which will gradually be lowered with time [4]. For example, the required baseline of very large crude oil carriers (VLCC) will be reduced by 25% in 2018 and by 35% in 2023 [22]. In order to comply with regulations whilst keeping the operation costs as low as possible, the best measures to effect cost effectiveness and emission reduction should be identified and adopted on vessels. Hence, these new limits set by the IMO have a significant impact upon the criteria for the assessment of future powering options for container shipping.

Bunker Fuel Prices – Historically, bunker prices of marine fuels have fluctuated significantly at prevailing market conditions. However, when viewed in a longer time frame, bunker prices of marine fuel have shown an increasing mean trend [24], as shown in Figure-4. For shipping as a whole, the price of current oil-based fuel and its usage are likely to rise due to limited supply of oil and gas, rising world demand for energy and public and regulatory pressure on environmental emissions.

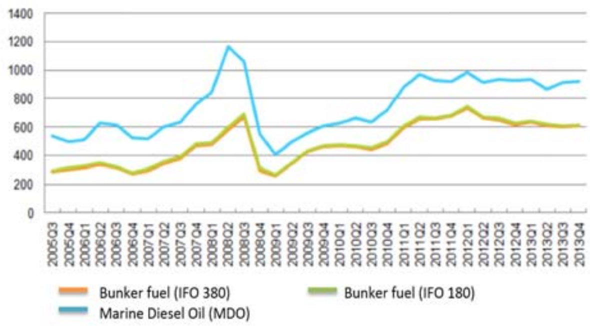

Figure-4. Marine bunker fuel spot prices USD per tonne (average unit value, FOB Singapore) [24].

Consider that fuel cost accounts for 50 – 60% of total operational expenditure of container vessels [4], bunker fuel prices are one of the critical factors affecting ship operating economics and the profitability of the container shipping industry. Hence, market forces already provide sufficient motivation for the container shipping industry to identify future alternative powering options in order to minimise energy use and associated GHG emissions.

Future powering options

Alternative Fuels– It is undeniable that improving energy efficiency through operational measures can be one of the effective solutions to address the major challenges in the container shipping industry. However, operational measure cannot be a fundamental solution as major challenges in these challenges resulted from the fact that container vessels are using oil-based fuel for their propulsion. Therefore, using alternative fuels is the fundamental solution which could potentially address the major challenges in the container shipping industry for decades to come.

Low Sulfur Fuel Oil– First of all, using low sulfur fuel oil appears to be the easiest option for container shipping industry. The currently used bunker fuel oil can be classified as distillates and fuel oil [12]. Distillates usually contain a low level of impurities which including sulfur and carbon residues. It is usually divided into marine gas oil (MGO) and marine diesel oil (MDO) [12]. Both of these are light and the key difference is that MDO is a little heavier than MGO and may contain little residual fuel oil. MGO and MDO are both considered as fuels producing low sulfur emission. Since the average sulfur content in heavy fuel oil (HFO) is 3 to 4.5% which obviously cannot comply with the emission limits required under ECA, many vessels begin to use low sulfur fuel oil with only 1.5% sulfur content [25]. As a result, economic issues aside, using low sulfur fuel oil appears to be the easiest alternative fuels to comply with environmental regulations. However, Low sulphur fuel oil costs more than high sulphur fuel oil such as HFO which will adversely affect operational expenditure [12].

Liquefied Natural Gas (LNG) – Applying LNG as a marine fuel has a history of approximately fifty years especially in LNG carriers [26]. However, recently using LNG as marine fuel has gained more attention from other segments of the fleet including deep sea-going container vessels mainly due to its clear environmental benefits and relatively low price [27]. Burning LNG as a fuel will reduce the emission of CO_2 compared to HFO [4]. In addition, lesser volume of nitrogen in the combustion process can significantly reduce NO_x and no SO_x emissions are produced because there is no sulfur content in LNG [4,21]. The other benefit is that the price of LNG has been consistently lower than oil prices by a significant margin [25], especially when the world oil price is volatile [4].

Biofuels– Biofuels are being tested as alternative fuels mainly in the segment of freight and passenger vessels [28]. Biofuels have the potential to contribute to a substantial reduction in overall GHG emissions. In addition, biofuels are flexible as they can be mixed with conventional fuels to power conventional internal combustion engines [1].

Nuclear Power–The US Navy used nuclear power for their submarine as a powering option since 1955. Since then approximately 700 nuclear reactors have been utilised for ship powering. Currently there are approximately 200 reactors in operations in aircraft carriers or submarines [4]. There were only four nuclear powered merchant vessels built and in operation. The latest one is a Russian flagged NS Sevmorput as an icebreaking container vessel with the capacity of 1,324 TEUs for the purpose of research and testing [29]. However, safety issue has always been a concern with nuclear power. Acceptance by the general public and approval for port visits have hampered NS Servmorput's progress.

Renewable Energy Sources– In 2008, the world's first solar powered cargo vessel MV Auriga Leader was constructed, proving that solar energy can be a feasible energy source for ship propulsion [4]. In addition, techniques that could take advantage of wind energy on ship propulsion such as kites, wing sail and wind turbine has been explored in recent years [4]. The major advantage of renewable energy sources e.g. solar and wind is that they are zero emission and zero air pollutants. However, the barriers prohibiting the usage of wind and solar energy as powering options for container vessels are mainly due to its intermittency and huge equipment cost [30].

Comparison criteria

To compare alternative powering options, several criteria for analyzing alternative fuels and energy sources are established and comparative analysis is conducted using these criteria. Two analysis criteria, emission reduction potential and economic costs, were established based upon current challenges of the container shipping industry i.e. environmental consideration and increasing bunker price. The other criteria i.e. impact on cargo capacity, safety and reliability were established based upon the characteristics of deep seagoing container vessels.

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ARPN Journal of Engineering and Applied Sciences

Emission reduction potential– Since one of the main challenges facing current powering option is high level of CO_2 emission, the alternative powering option should have ability to reduce CO_2 emission as much as possible. Furthermore, considering the fact that container vessels are major CO_2 emitters amongst all vessel types, the potential for CO_2 emission reduction should be an important criterion especially when assessing the feasibility of potential alternative powering options for container vessels.

All of the current crude oil based fuels for container vessels have air pollution problems mainly involving NO_x, SO_x and PM. There will be more international regulations restricting the emission of NO_x, SO_x and PM, such as stringent emission limits in designated emission control areas (ECAs). Hence, the reduction potential air pollutants should be also considered an important criterion.

Economics and Costs– The bunker price is directly related to cost and benefit. When the price of HFO increases to a certain level, other alternative options may become competitive with their low prices. Currently, it has been estimated that fuel cost contributes approximately 60% of the total operational cost of container shipping [4]. As container vessels' sailing speed is relatively higher than other types of merchant vessels, they consume more fuel [13]. In reality, a recent survey also showed that developing strategies to promote fuel efficiency is a top priority for the container shipping industry [31]. Application of a new powering option usually requires retrofitting an existing vessel or building new vessels. When deciding alternative powering options, the cost of shipbuilding or retrofitting plays a significant role. In addition, the application of a certain alternative fuel in a vessel requires significant changes in infrastructural support e.g. fuel storage and bunker.

Cargo Carrying Capacity – In deep sea-going container vessels, cargo carrying capacity is an underlying factor, as it directly affects revenue. Therefore, alternative options should also be assessed using this criterion. For example, some fuel requires larger tanks to store due to its low energy density and reduced refuel frequency. This may result in the loss of cargo carrying capacity. On the contrary, there may also be an alternative fuel requiring smaller fuel tanks than that of conventional marine fuels.

Safety Considerations– The safety of the vessel is an important criterion in powering options assessment. Safety consideration covers not only ship operation but also the working environment for crews and port and the local community. An alternative powering option should be proved safe before it can finally be used. In addition, reliability is also assessed ensuring the alternative fuel and energy sources can propel the vessel without any intermittency

Comparative analysis

Emission reduction potential– Comparing CO_2 emission reduction potential, HFO produces high levels of GHGs emission. MGO can reduce the SO_x emission significantly compared to HFO but emits almost same amount of CO_2 and NO_x. Since the principal constituent of LNG is methane (CH_4), LNG can reduce the CO_2 emission by 25% in combustion engines [8]. However, Burning LNG as a marine fuel will increase the emission of methane (CH_4) which has even higher global warming potential (GWP) than CO_2. As a result, the net GHGs emission reduction potential of burning LNG as a marine fuel will be reduced to approximately 15% in the whole life cycle assessment perspective [8]. In addition, burning LNG as a fuel for marine propulsion can significantly reduce NO_x emission by 85 – 90% and totally remove SO_x emissions because there is no sulfur content in LNG [4,21].

Nuclear and renewable energy are considered the cleanest energy sources because no emissions are produced. Similarly, nuclear and renewable energy do not emit SO_x and NO_x. Table-3 shows the estimated emission factors of the alternative fuels discussed in this research.

Table-3. Emission factor of different fuels [8, 21].

	HFO (reference)	Low sulfur fuel oil (MDO)	LNG	Nuclear power	Renewable energy
CO_2	78g/MJ	74g/MJ	57g/MJ	0g/MJ	0g/MJ
SO_2	0.5g/MJ	0.05g/MJ	0g/MJ	0g/MJ	0g/MJ
NOx	1.6g/MJ	1.5g/MJ	0.17g/MJ	0g/MJ	0g/MJ

Economics and Costs – Comparing cost of bunker, the relative low price of LNG especially in the US and Europe has boosted its attractiveness as an alternative marine fuel. Historically, the prices of natural gas in the US and UK have been lower than low sulfur fuel oil and almost the same as HFO. Furthermore, the availability of LNG has also been growing rapidly because the reserves of both conventional and unconventional gas have been increasing due to dramatic development of new extraction technology and shale gas revolution [4]. Banawan *et al.* reported that due to less frequency of maintenance activity, the maintenance cost of LNG-fueled vessels can be reduced by 40% compared to that of the conventional vessels under the same circumstances [32].

Nevertheless, a LNG-fueled vessel requires significant capital investment when compared to conventional vessels. Even though the initial capital cost may vary depending upon ship design, engine type, fuel tank sizing etc., overall 20 – 25% additional cost will be incurred to build a new LNG-fueled vessels compared to building a conventional vessel [33].In addition, the current lack of established bunkering infrastructure and distribution networks for delivering LNG to the ship requires significant capital and operational expenditure. Whilst the economic analysis on the alternative powering options may vary significantly depending upon these factors and assumptions, Figure-5 shows an insight for total economic supply cost of LNG as a marine fuel. As shown in the figure, LNG is the most cost effective option

ARPN Journal of Engineering and Applied Sciences

when considering LNG price itself. However, if considering other costs such as additional investment capital for building port facilities to support LNG bunkering and new shipbuilding costs, it is not always the best option compared to HFO because the LNG prices are largely regional. Nevertheless, Figure-7 shows that LNG is still more attractive compared to MDO.

On the other hand, the costs of building a nuclear vessel may be several folds of a conventional vessel. However, the cost of uranium is low compared to LNG and nuclear power has lower sensitivity to market price changes, because one refuel can last for a long time. In addition, the designed speed for nuclear powered vessels could reach 35 knots [4], whilst the designed speed for a conventional post-Panamax sized container vessel is 25 knots [13]. Therefore, nuclear powered vessels has mileage advantage compared to conventional vessels.

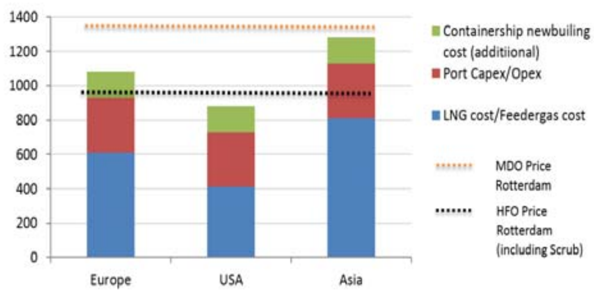

Figure-5. Comparison of total LNG supply cost and alternative fuels [4].

Impact on Cargo Carrying Capacity– The selection of alternative fuel may affect the vessel's cargo carrying capacity. Due to the smaller energy density, LNG-fueled vessels require 2 – 4 times more space for LNG storage tanks [34]. A research estimated that a medium-sized container vessel between 4,600 – 8,500 TEUs will incur the biggest losses in cargo carrying capacity of approximately 3% of the total available TEU slots [35]. It is obvious that the loss of cargo carrying capacity will directly affect revenue potentials of deep sea-going container vessels in a negative way. Using renewable energy sources such as wind and solar power may result in substantial cargo capacity loss, due to the space requirement for installing additional equipment such as solar panel and wind turbines. Switching to MDO may not impact upon cargo capacity whilst using nuclear power can increase a vessel's cargo carrying capacity compared to conventional vessels due to its smaller bunker size. In addition, when small modular reactor (SMR) is installed for vessels powered by nuclear, this advantage will be strengthened.

Safety Considerations– Comparing safety aspects, MDO have proven its safe operation for a long time. LNG as a shipping fuel also has excellent safety records. However, there are still some safety issues yet to be addressed. LNG is a combustible fuel so there may fire risks. In addition, LNG has very low storage temperature which means that frostbite accident may occur when handling the fuel. However, for nuclear power, safety issues related to radiation leakage are always a major concern. In addition, a unique safety worry concerning nuclear power is its radioactive waste. If nuclear power is considered as a potential future powering option then its radioactive waste will require more appropriate handling methods.

Operational and technical measures

Besides using alternative fuels, operational and technical measures which can significantly reduce emissions and fuel consumption are also considered. The International Chamber of Shipping argued that more than 15% of CO_2 produced per tonne of cargo transported can be reduced by 2020 through operational and technological measures [36].

Slow Steaming and Engine De-rating– Slow steaming is defined as operating a vessel at a speed below the design speed [24]. It has been considered as one of the most attractive operational measures, because immediate benefits can be reaped by savings in fuel cost. This can be easily implemented without any modification to the vessel. Fuel consumption and sailing speed of a ship are generally related by a cubic function, whilst the amount of emissions discharged by a ship is proportional to the fuel consumption [37].

In reality, it was estimated that a 10% reduction in sailing speed can result in approximately 19% reduction in fuel consumption and emissions per unit of time [38]. Taking one step further, IMO suggested that if sailing speed is reduced by 10% across the world's fleet, total GHG emissions of the entire fleet could be reduced by 7.9% below business as usual (BAU) scenario by 2020 [8].If the operational speed of a vessel is generally lower than its designed speed, main engine de-rating can be an attractive option for reducing fuel consumption and associated GHG emissions for a container vessel. Engine de-rating refers to the procedure of changing the rating (power and speed) of an engine [10]. Therefore, engine de-rating can offer the benefit of slow steaming by optimising the engine layout to the actual operational speed in slow steaming situation and the fuel-saving potential is estimated at 10 – 12% based upon the new optimisation speed [38].

Weather Routing– Voyage and heading optimisation is important as the shortest distance over water does not necessarily give the lowest fuel consumption or shortest voyage time. In adverse weather, maintaining sailing speed may consume more fuel due to added resistance resulted from adverse wind and waves [4]. Therefore, the basic idea of weather routing is concerned with route optimisation using data such as weather forecast, ocean current, wave, wind direction and speed to reduce the fuel consumption and therefore emissions [39]. The IMO estimated that weather routing can achieve 2 – 4% reduction in fuel consumption and associated GHG emissions [39].

DISCUSSIONS AND CONCLUSIONS

Through the comparative analysis, it was found that there is no perfect alternative powering option. Therefore, future deep sea-going container vessels will likely be powered by a variety of fuels and energy sources. Firstly, despite of its higher bunker cost, MDO can be the transitional option for deep sea-going container vessels in the short term as it complies with regulation on SO_x emission. However, its higher bunker cost and CO_2 emission prohibits this low sulphur fuel oil from becoming the key solution for the container shipping industry. Secondly, with stricter emission limits coming into force, the use of LNG as a marine fuel will rapidly increase due to its low emission, low price, higher availability and reliability. If the required support infrastructures can be established, LNG could be the fuel of choice for decades to come. Thirdly, whilst LNG is available in vast quantities, it is still a fossil fuel and so emits CO_2. Therefore, achieving full independence from fossil fuels in the longer term will be inevitable. Lastly, although it appears impossible to overcome both the environmental and fuel cost challenges, technical and operational options such as slow steaming are effective strategies to be employed to reduce emissions.

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