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Liquefied Natural Gas can be the alternative marine fuel with the new regulation on sulfur emissions to protect the environment

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Abstract

The economic growth has led to a rapid development of the international maritime trade. The air pollution has become the great concern with the increase of the global ships number and the high quantity of Sulfur oxides emitted. Difficulties are encountered Ship-owners and producers in complying with the new regulations to reduce Sulfur oxides emissions required by the International Maritime Organization. While research into alternative marine fuels that can overcome these difficulties is underway. In this study, different alternative fuels is compared based on several parameters such as; availability, cost, performance, economy and compliance with the new International Maritime Organization sulfur emissions regulation (0.5% max). This comparison revealed that Liquefied Natural Gas could be considered as the future fuel for replacing the heavy fuel (current fuel).

1. Introduction

World maritime transport consumes around 200 million tons per year of heavy fuel, which contains high sulfur content. Its combustion generates significant quantities of Sulfur Oxides (SOx), Nitrogen and fine particles [1, 2]. Sulfur oxides are known by their harmful impact on health and environment. A process of drafting international conventions aimed to combating marine pollution has started with Marbol convention. This convention envisages all kinds of pollution affecting the sea and the air. Through this convention, the International Maritime Organization (IMO) has enlarged its maritime monitoring program to Sulfur content and it has adopted regulations to lower the authorized ceiling of marine fuels Sulfur content for all ships. The maximum authorized rate has been set at 3.5% worldwide, except in controlled emission zones, it is called Controlled Maritime Area zones (ECA). In these zones, the maximum rate is set at 0.1%.

During the environment committee of the international maritime organization in October 2016, it decided to pass from 3.5% to 0.5% outside the ECA zone from January 1, 2020 [3]. The pollution health consequences of maritime transport even with the Sulfur content limited to 0.5%. Marine fuels are responsible each year for an average of 250000 premature deaths [4]. In heavy fuel oil, the most abundant particle is Sulfur, by current standards, it can contain up to 3.5%. It is 3500 times more than the limit tolerated in land gasoline. The result is that a single large ship can pollute as much as 50 million cars [5]. The use of Liquefied Natural Gas (LNG) significantly reduces emissions of CO_2, Sulfur oxides and Nitrogen. Compared to conventional fuel oil, the use of LNG will allow: (i) 99% reduction in Sulfur and fine particle emissions, (ii) 85% reduction in Nitrogen oxide emissions and (iii) reduction of CO_2 up to 25% [6].

Knowing that the cost of fuel is the main component of vessels operating costs and with the fear that prices will continue to increase in the future, the noncompliance of heavy fuel with the new Sulfur emission regulations added another difficulty. This is an important challenge for shipowners and producers of this type of fuel, which will be quickly adapted to this situation through direct investment (on the units or on ships) or suffer economic impacts. The revised measures should have significant positive effects on the atmosphere and on human health, especially for populations living in port cities and coastal populations. The economic model is used to calculate delivered costs of LNG for a supply chain comprising terminal costs, shipping costs, and annual onsite storage cost [7]. Xing et al., (2021) were carried out the technological review to determine the most promising alternative marine fuels given the simultaneous reduction in sulfur oxides, nitrogen oxides and carbon dioxide emissions as well as durability [8]. Bilgili, (2021) concluded that despite the success of low sulphur fuels during operation, the overall environmental effects are higher than other fuels [9]. The real option method is a more realistic, reliable and promising method for evaluating emission reduction projects, especially in the case of uncertainties and volatility in the material resources market [10]. Multi-criteria decision analysis[11], game theory [12]and bayesian simulations [13]are used to study maritime pollution..The control area policy reduce sulfur dioxides concentration in Shanghai [14] and China[15]

In this techno-economic study, the existing of alternative marine fuels that can be used in maritime is evaluated, such as Very Low Sulphur Fuel Oil (VLSFO) and LNG in order to know their profitability and opt for the best choice. A comparative study was carried out for three container ships of the same size from CMA-CGM Antoine de Saint Exupery Company, using engines of the same power, sailing using IFO380, VLSFO and LNG, respectively. These different bunker fuels have been compared according to several parameters such as: availability, cost, investments, safety, performance, economy and compliance with Sulfur emission regulations IMO 2020 (max 0.5%).

2. Material and Methods

Based on informations gathered from several sources, this study is carried out in order to determine the profitability of fuel marine used in each ship LNG, Intermediate fuel oil (IFO380) with a maximum viscosity of 380 centistokes (Sulfur <3.5%), Marine Gas oil (MGO), Very Low Sulphur Fuel Oil (Sulfur <0.5%) and Ultra Low Sulphur Fuel Oil (ULSFO) (Sulfur <0.1%). Three giant container ships of the company CMA-CGM are taken as example:

1. Ship 1: Engine sailing using VLSFO.
2. Ship 2: Engine sailing using IFO380 equipped with a Scrubber.
3. Ship 3: Engine sailing using LNG.

These ships have similar capacities and performance. They make journeys between Northern Europe and Asia starting from the port of Le Havre in France and arrive in Tianjin Xingang in China, during a period of 84 days with 16 stopovers, as indicated by the ride shown in Figure 1 [16]. The shipowner sails 336 days (four rotations of 84 days) during the year and devotes a month to the annual maintenance of these vessels and the rest of these crews.

2.1 Calculation of annual ships consumption of bunker fuel

For calculation purposes, these vessels were selected and provided us all information needed to carry out this study;

1. The average consumption of fuel [Cons Fuel (l/ EVP km)], 1 liter of fuel consumed by each container transported for 100 kilometers [16].
2. The number of containers (n EVP) = 21000 EVP [16].
3. The volume of LNG consumed during the year (VLNG)= 18000 m^3 [17].
4. The number of rotation (n) = 4.
5. The mechanical power developed by the ship's engine (Pmech) = 80000 Horses [16].
6. The total distance traveled during a year (D) was calculated as follows:

$$D = n \times DR \quad (1)$$ **Eqn. 1**

The distance traveled for the rotation (DR) was estimated by Google-maps. The distance found is equal 50000 km from Le Havre (France) to Tianjin Xingang (China) for back and forth, as indicated by the ride (see **Figure 1**).

Figure 1. The journey of the CMA-CGM Antoine de St Expery container ship [16].

Knowing the average fuel consumption [Cons Fuel (l/ EVP km)], the mass of fuel consumed by the ship during the year is deduced using the following equation:

$$m\ Fuel = Cons\ \ Fuel(t / EVP) \times D \times nEVP$$ **Eqn. 2**

The average LNG consumption for a rotation (Cons LNG (r)) is deduced by the equation:

$$V\,LNG = n \times Cons\ LNG(r)$$ **Eqn. 3**

Knowing the annual fuel consumption for each vessel; their costs relative to their selling prices is calculated as follows:

$$Fuel\ cost = Fuel\ price \times Fuel\ consumption \qquad \textbf{Eqn. 4}$$

The recovery period or the profitability duration is the time necessary for the initial stake to be recovered. It can be calculated using the following equation:

$$Recovery\ \ period = \frac{Cost\ of\ investment}{Gain\ from\ \ investment} \qquad \textbf{Eqn. 5}$$

Knowing the annual fuel consumption for each vessel; the costs relative to their selling prices is calculated as follows:

$$Annual\ Fuel\ cost = Fuel\ price \times Annual\ Fuel\ consumption \qquad \textbf{Eqn. 6}$$

The fuel savings of IFO380 and LNG are calculated basing on the relation of annual cost of VLSFO as follows:

Ship 2:

Grain from investment equal Grain carb (IFO380).

$$Gain\ carb(IFO380) = Cost(VLSFO) - Cost(IFO380) - Cost\ ScrubberMaint \qquad \textbf{Eqn. 7}$$

where;

Cost (IFO380) is the annual cost of IFO380;

Cost Scrubber Maint is the annual maintenance cost of Scrubber =15 080 $.

Cost VLSFO is the annual cost of VLSFO;

Cost investment (Scrubber) =10 000 000 $.

Ship 3:

Grain from investment equal Grain carb (LNG), it is calculated as follows:

$$Gain\ carb(LNG) = Cost(VLSFO) - Cost(LNG) \qquad \textbf{Eqn. 8}$$

Where;

Cost LNG is the annual cost of LNG:

Cost VLSFO is the annual cost of VLSFO.

3. Results and discussion

The international selling prices used in this study of bunker fuels at the port of Rotterdam from 01 July 2019 to 01 June 2020 are shown in **Table 1** [18]. The delivery of LNG increases the cost of 25%. From **Table 1**; it is clear that, the LNG is very cheap compared to other fuels, its price ranges from 2.0075 to 3.2675 ($/mmBtu), with an average value equals 2.6023 ($/mmBtu). The price of VLSFO oscillates between 216 and 564 $/TM, with an average value equals 438.3$/TM. For the IFO380**,** the price varies from 141 to 397 $/TM, with an average value equals 272.90 $/TM. The ULSFO price varies from 207.5 to 567.5 $/TM, with an average value equals 451.4$/TM**.** The price of MGO changed from 228.5 to 606 $/TM with an average value equals 477.10 $/TM.

From table 2, the annual cost from July 2019 to June 2020 of LNG, IFO380 and VLSFO used for these ships shows that, the cost of ship used LNG is the cheapest compared to ships used other fuels. It ranges from 3 349 865.58 to 5 452 396.40 ($), with mean value equals 4 342 379.71 ($). The cost of ship used IFO380 with Scrubbers varies from 6 288 893.00 to 17 557 472.00 ($), with mean value equals 12 228 452.5 ($). The cost of ship used VLSFO oscillates from 8 871 664.50 to 24 109 756.50 ($), with mean value equals 18 069 169.25 ($).

Table 1. The price of marine fuels ($/TM) and LNG ($/mmBtu) used in this study [18].

	Jul-2019	Aug-2019	Sep-2019	Oct-2019	Nov-2019	Dec-2019	Jan-2020	Feb-2020	Mar-2020	Apr-2020	May-2020	Jun-2020
VLSFO	550	564	491,5	529,5	500	498	586	460	394	217.5	216	253
IFO380	397	382	282	344	276	241.5	289	284.5	283.5	148	141	206
ULSFO	567.5	549.5	500	543	530.5	536	581.5	459	417	254.5	207.5	270.5
LNG	2.8575	2.6762	2.8825	2.815	3.2675	2.9375	2.7037	2,3125	2.1812	2.0075	2.3612	2.225
MGO	584	579.5	543	576	557	558	606	476	442	280	228.5	295

Table 2. Annual cost of ships used LNG, IFO380 and VLSFO) ($).

	Ship used LNG	Ship used IFO380 with Scrubbers	Ship used VLSFO
Jul-2019	4 768 239.55	17 557 472.00	22 676 902.50
Aug-2019	4 465 792.16	16 930 811.00	23 182 006.50
Sep-2019	4 809 956.43	12 739 694.00	20 249 035.50
Oct-2019	4 697 320.85	15 359 528.00	21 824 230.50
Nov-2019	5 452 396.40	12 521 546.00	20 647 801.50
Dec-2019	4 901 733.57	11 103 584.00	20 582 154.00
Jan-2020	4 511 680.73	13 157 468.00	24 109 756.50
Feb-2020	3 858 811.53	12 704 708.00	18 931 377.00
Mar-2020	3 639 797.91	12 593 576.00	16 268 169.00
Apr-2020	3 349 865.58	6 683 000.00	9 034 551.00
May-2020	3 940 159.45	6 288 893.00	8 871 664.50
Jun-2020	3 712 802.45	9 101 150.00	10 452 382.50

The comparison of the annual fuel consumption of each ship shows that, the vessel sailing used VLSFO has the highest bill. The second is the vessel sailing of ship used IFO380 equipped with Scrubber and the last is the vessel sailing of LNG (see **Table 3**). Knowing the difference price between VLSFO and IFO380, which is between 47 and 297 $/MT, in the case of ship equipped with a Scrubber, the investment will be amortized between 1 and 8 years, it is related to the fuel cost of each month. Knowing that these ships have the same size and equipped with mechanical engines of the same power, it is assumed that, their maintenance costs are the same. For vessel 2, the sailing on fuel equipped with Scrubber; an additional annual maintenance cost is dedicated to the maintenance of the latter ship must be covered by 15080 $ (see **Table 3**).

The cost of investments is estimated at 10000000 $, it includes the cost of Scrubber. For vessel 3, the investment cost is estimated at 38000000 $, it includes the cost of conversion from diesel vessel to LNG, which represents 20% of the vessel price.

In the case of LNG, the investment represents 20% of the vessel price, which is very important but the fuel cost savings is also high, it is around 55-80% per year depending on the price of VLSFO. This study has revealed that liquefied natural gas can be considered as the future bunker fuel replacement for the heavy fuel (current fuel). Since it offers significant advantages compared to the latter terms of fuel cost. The investments will be amortized between 2 to 7.7 years depending on the price of VLSFO and (**Table 4**), it has been shown to have environmental advantages.

Table 3. Results of the annual consumption for each case.

Ships Designation		Ship 1	Ship 2	Ship 3
Annual consumption	**ULSFO**	2 223		
	VLSFO	38 937		
	IFO380		41 160	
	LNG			72 000
Scrubber consumption	**MGO**		2 058	
Total annual consumption		41 160 (TM)	43 218 (TM)	72 000 m^3
Annual maintenance cost of Scrubber ($)			15 080	
Cost of investment ($)			10 000 000	38 000 000
The payback period (years)			0.9-7.5	1.9 -7.7

Table 4. Sensitivity of the recovery period according to the price of LNG and IFO380

	Jul-2019	Aug-2019	Sep-2019	Oct-2019	Nov-2019	Dec-2019	Jan-2020	Feb-2020	Mar-2020	Apr-2020	May-2020	Jun-2020
Recovery Period For LNG	2.1	2.0	2.5	2.2	2.5	2.4	1.9	2.5	3.0	6.7	7.7	5.6
Recovery Period For IFO380	2.0	1.6	1.3	1.6	1.2	1.1	0.9	1.6	2.7	4.3	3.9	7.5

LNG is the cheapest compared to other fuels, with its adoption as an alternative fuel; it will be continue with the deployment of bunkering infrastructure in ports around the world. At the same time, making LNG attractive for shipping segments will lower the sulfur surcharge (LSS20), which currently stands at 120$/TEU for this company. It increases profits and therefore amortizes these investments in a shorter period than the current one. It is a clean energy option that offers a way to reduce emissions in order to comply with current and future environmental regulations. It is perhaps an important factor that can encourage the growth of natural gas use as marine fuel. The attractiveness of LNG from an environmental standpoint is well-established decreasing corrosion problems with the decrease of Sulfur content from 3.5 to 0.5. The utilization of LNG in the marine diesel engines are evaluated comprehensively from three aspects of environmental protection, energy structure and economic benefits [19, 20]. The economic benefit of LNG is showed by [21, 22].

Conclusion

The present work highlight the difficulties encountered by shipowners and producers in complying with the new regulations on sulfur emissions required by IMO 2020, while research into alternative marine fuels that can overcome these difficulties is underway. This study has revealed that liquefied natural gas could be considered as the future bunker fuel replacement for the heavy fuel (current fuel). Liquefied natural gas is a clean energy option that offers a way to reduce emissions in order to meet current and future environmental regulations, and it is possibly a significant factor likely to encourage the growth of natural gas as marine fuel.

The use of natural gas will result in environmental benefits, including emission reductions of 25% of carbon dioxide (CO_2) emissions, 90% of nitrogen oxides (NOx) emissions, 100% emission of sulfur dioxide (SO_2) and fine particles 22 [23]. The emergence of LNG as an alternative marine bunkering fuel will depend on the availability of port and logistics infrastructure for LNG refueling.

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