Assessment of the lost cargo capacities of a container vessel when transitioning to alternative fuels

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المستخلص:
تمثل الوقود البديلة حلاً قابلاً للتطبيق لتقليل الانبعاثات الكربونية في صناعة الشحن البحري. هناك العديد من الخيارات المتاحة، حيث أن بعض التقنيات ناضجة وجاهزة للاستخدام، في حين أن تقنيات أخرى ما تزال قيد التطوير. ومع ذلك، من المؤكد أن الوقود البديل والتقنيات الأحدث يمكن أن تحل محل الوقود التقليدي. التحول إلى الوقود البديل يأتي بتكلفة، حيث تتمثل بالنسبة للسفن التجارية في فقدان مساحة الحمولة بسبب كثافة الطاقة العالية للوقود البديل مقارنة بالوقود الأحفوري. تحسب الدراسة الحالية تكلفة فقدان الحمولة عندما تستخدم سفينة حاويات بسعة ٨٠٠٠ وحدة مكافئة للحاويات (TEU) الميثانول والأمونيا كوقود. وقد لوحظ أن المساحة الإضافية المطلوبة للميثانول تبلغ ١٦٧٤ مترًا مكعبًا، بينما للأمونيا تبلغ ٢٢٧٧ مترًا مكعبًا. إن فقدان مساحة الحمولة له تأثير كبير على القدرة على الكسب للسفينة طوال عمرها التشغيلي. بغض النظر عن ما إذا كان المالكون سيختارون نهج التوقف الواحد أو التوقفين، يجب على المالكون تحديد تكرار التزوّد بالوقود بناءً على مسار السفينة وإجراء مراجعة شاملة لسعة خزانات الوقود.

Abstract:
Alternative fuels represent a viable solution to the decarbonization of the maritime industry. There are several options available with some technologies mature and ready to use. Other technologies are still under development; however, it is a certainty that alternative fuels and newer technologies could substitute conventional fuels. Changing to alternative fuels comes with a price. For cargo vessels, it is the loss of cargo space, due to the higher energy density of alternative fuels compared to fossil fuels. The present study calculates the cost of lost cargo when an 8000 TEU container vessel is burning methanol and ammonia. It is noted that additional cargo space required for methanol is 1674 m^3, while for ammonia is 2277 m^3. The cargo lost space has a significant impact on the earning potential of the vessel throughout its lifetime. Regardless of whether the owners choose a one-stop or two-stop approach, the owners must determine the frequency of bunkering based on the vessel's route and conduct a thorough review of the fuel tank capacity.

1- Introduction

Maritime transportation is responsible for 3% of the total GHG emissions worldwide. To reduce the impact on the environment, the International Maritime Organization has established a set of regulations and policies intended to reduce harmful pollutants. IMO's ambition is to reach net-zero GHG emissions from international shipping by 2050. There are both operational and technical solutions available and ready to use. Operational measures can reduce emissions in the short term; however, long-term solutions are new technologies and alternative fuels. New technologies include wind and solar systems, nuclear power, fuel cells, and carbon capture and storage technology. One of the most viable measures is to replace fossil fuels with alternative fuels, such as LNG, methanol, ammonia, biofuels, and hydrogen. In 2023, 98% of the ships in operation were burning conventional fuels and 26% of the ships on order will be powered by alternative fuels. Depending on the type of fuel and the energy density, the fuel tank space is larger and requires more space for alternative fuels than for conventional fuels. This transition comes with a cost. Even if the emissions are significantly reduced, the cargo space will also be affected. The space concerned depends very much on whether the vessel is retrofit or new build. In case of a new build, the vessel's design will consider all the aspects, so that the cargo space loss will be affected as little as possible. In the case of a container vessel, it depends on the type of alternative fuel, as well as the size of the vessel, the route, the bunkering facilities, or the alternative fuel infrastructure.

2- Literature review

MMMCZCS, (2022) and the partners conducted a report regarding the environmental and techno-economic analysis when converting a 15000 TEU container vessel to alternative fuels. When vessels operate on conventional fuel, a typically 6000 m^3 fuel oil is required. However, changing to alternative fuels, the most probable option is to shorten the range to reduce the tank sizes, therefore reducing the cargo space loss. The same study shows that for a 15000 TEU vessel, the lost cargo space for methanol is on average 500 TEU and an average of 700-800 TEU for ammonia fuel. Their study concluded that lost cargo space can be reduced by placing fuel tanks under the accommodation. It is also important to mention that cargo lost space is different between a new build and a retrofit. When changing to hydrogen, container vessels must either make more refueling stops or eliminate space dedicated to cargo, as hydrogen needs four times more fuel tank space than conventional fuels (Deloitte, 2023). DNV, (2023) has done extensive work on alternative fuels for container vessels, and regardless of the type of fuel, the cargo space is reduced. Various options such as increasing the frequency of the bunkering ports, different arrangements of fuel tanks, in-depth analysis of CAPEX and OPEX, and the vessel's operational profile should be taken into account when designing a vessel powered by alternative fuel. The use of hydrogen fuel can result in a lost cargo space up to 13% for a short sea vessel (Law et al., 2022). The same authors stated that cargo space loss depends on the type of cargo, therefore fuels with volumetric density engage less with cargo storage. The loss of the cargo capacity of the vessel can restrict financial opportunities for the vessel owner and charterer (Lagemann et al., 2023).

3- Case study

The present article analyzes the lost cargo space of a container vessel when changing to alternative fuels.

For the purpose of this study, Vessel has the following characteristics:

LOA	334 m
DWT	101906 t

GRT	90745 m^3
TEU	8238
YEAR BUILT	2004
ENGINE POWER	68640 kW

For the one-year route studied, the vessel must apply operational efficiency measures defined in SEEMP III to follow the regulations and be more attractive to the charterers.

The operational measures are short-term solutions, but these options will not be applicable in the long term. Therefore, cost analysis of alternative fuels, methanol, and ammonia, will be illustrated.

CAPEX for conventional fuel, ammonia, and methanol are presented in Table 1. CAPEX values include construction costs, which depend on the engine cost with all the systems and arrangements.

Table 1. CAPEX values for power and tank (Fam et al., 2022)

Type of fuel	**CAPEX Power Value** (Euro/kW)	**CAPEX Tank Value** (Euro/kWh)
Diesel/MDO/MGO	385	0.08
Methanol	400	0.14
Ammonia	503	0.17

OPEX for a year for different types of fuels, is presented in Table 2. OPEX values mean the operational costs of the vessel – voyage costs, repair, and maintenance, insurance, stores, spares, crewing, and miscellaneous expenses.

Table 2. OPEX in 2030 for alternative fuels "adapted from (Statista, 2023)"

Type of fuel	**OPEX in 2030 (million Euro)**
HFO	15
Methanol	35
Ammonia	40

The required storage capacity of methanol and ammonia fuels compared to MGO, are shown in Table 3.

Table 3. Storage capacity of methanol and ammonia fuels compared to MGO "adapted from (Reusser & Perez, 2021)"

Fuel type	**Specific Energy (MJ/kg)**	**Storage onboard**	**Required storage capacity (m^3)**
MGO	42.7	Liquid at ambient temperature	1000
Methanol	23	Liquid at ambient temperature	2272
Ammonia	17	21°C under 8.8 bar; -33°C atm pressure	3121

The cost of lost cargo due to extra space required for the installation of fuel tanks (Fam et al., 2022) is:
For Methanol: It is assumed that for the vessel studied the cargo space lost for a fuel tank is 1 674 m3, compared with a conventional fuel tank.

For Ammonia: Ammonia has 1.36 less volumetric energy density than Methanol, thus the cargo space lost for Ammonia will be multiplied by 1.36 Methanol.
Therefore:
Additional cargo space for Methanol = 1 674 m^3
Additional cargo space for Ammonia = 2 277 m^3

$$Cost\ of\ lost\ cargo = Average\ price\ TEU \times \frac{Additional\ cargo\ space\ for\ fuel\ typy}{Volume\ TEU}$$

Considering the following:
Volume/TEU = 38.5 m^3
Average price/TEU = 1 280 Euro
Additional cargo space for Methanol = 1 674 m^3
Additional cargo space for Ammonia = 2 277 m^3

Table 4. Cost of lost cargo "adapted from (Fam et al., 2022)"

Type of fuel	Cost of lost cargo (Euro)
Methanol	55 655
Ammonia	75 703

4- Conclusions
Both CAPEX and OPEX increase significantly when changing to alternative fuels. In addition, there is the cost of lost cargo for the fuel tanks, which are considerably larger for alternative fuels than for fossil fuels. The owners must decide the bunkering frequency based on the vessel's route and perform a detailed analysis of the size of the fuel tanks whether deciding on a one-stop or two-stop strategy. Another aspect that should be taken into account is the optimal location for alternative fuel tanks. For large container vessels, it is proven that placing the fuel tanks under the accommodation can have the smallest impact on the cargo lost space. Besides the alternative fuels, vessels can choose different new technologies that can reduce emissions (wind, solar, carbon capture and storage), however, all of them have an impact on the cargo capacity of the vessel. For example, wind technologies are more appropriate for vessels that don't carry cargo on deck, such as bulk carriers or ro-ro vessels. For container vessels, alternative technologies are limited and the change to alternative fuels is proven to be the best decision.
The cargo lost space has a significant impact on the earning potential of the vessel throughout its lifetime.

When retrofitting or choosing an alternative fuel, the owners have to evaluate all strategies based on the following:

- Frequency of bunkering
- Financial assessment, financial losses due to reduced cargo capacity vs potential cost savings
- Port rotation and bunkering infrastructure to allow the possibility of bunkering more than twice per voyage
- Vessel design and tank arrangements
- Evaluation of tanks' capacity
- Intendent lifetime of the vessel
- Long-term fuel availability
- Environmental regulations and policies

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