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A cost-benefit analysis of the use of ammonia and hydrogen as marine fuels

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Introduction

- Reduction of greenhouse gas (GHG) emissions from shipping

- Contribution to global and regional targets for climate neutrality and decarbonization
- Paris Agreement and European Green Deal

- "IMO Initial Strategy for the Reduction of GHG emissions from Shipping"
  Replacement of fossil fuels by alternative fuels and energy sources

- A number of alternative fuels

- ***Hydrogen and ammonia*** seem to have the higher environmental benefits,
- but high capital investments for the installation of new engines and fuel systems, port infrastructure, and increased operational costs due to their high prices.

Scope

- This paper analyses the costs and benefits associated with the use of hydrogen and ammonia as marine fuels focusing on various production methods, comprising blue fuels – produced from fossil sources and using carbon and capture storage (CCS) - and green fuels – coming from renewable energy sources.

- A cost-benefit analysis of the use of hydrogen and ammonia as marine fuels in order to specify the cost differences between these fuels and the conventional ones and make policy recommendations on how this existing ‘cost gap’ could be somehow alleviated through market-based measures (MBMs) to stimulate further investments on these fuels.

- Additional identified challenges – including availability, safety and regulatory aspects - are also touched upon in this paper.

Green and Blue Hydrogen and Ammonia

- Both hydrogen and ammonia can be employed as marine fuels in different forms based on the energy sources used for their production.
- In case their production is based on fossil energy sources, they can be grey or blue; in case they are produced from renewable energy, they are called *green fuels.*
- *Blue fuels* – use carbon capture and storage (CCS) technology during the fuel production in order to reduce their carbon intensity, a reduction that reaches up to 90% compared to grey fuels.
- Blue hydrogen and ammonia cannot be considered as fossil-free fuels in contrast to green fuels that are produced from electricity coming from renewable energy sources such as solar, wind, hydro, tidal wave, and geothermal energy.

Green and Blue Hydrogen

- Green hydrogen is a sulfur free fuel with very low carbon intensity - GHG emissions reductions are even higher than 85% of conventional fuels.

- However, its low volumetric energy density requires high fuel storage volumes onboard and reduces the cargo space (Lemmon et al., 2010) and *makes weak its business case* for use in deep-sea shipping where the needed fuel storage volumes are very high.
- Additionally, hydrogen is easily ignitable over a wide range of fuel-air mixing ratios.
- Safe storage and handling of hydrogen onboard the vessels into major challenges.

- The demand for hydrogen as marine fuel is still emerging at the moment, with *no distribution or bunkering infrastructure for ships currently in place*.
- Upcoming port initiatives on the building of refueling points for hydrogen at major ports around the globe.

- The unique areas where ports are located also turn them into promising energy hubs for the production and storage of renewable energy that could also be used for the production of green fuels.

Green and Blue Ammonia

- Grey ammonia has a carbon footprint close to fossil fuels; green ammonia, though, can lead to almost zero CO_2 emissions while blue ammonia can also drastically reduce CO_2 emissions (Hansson et al., 2020).
- However, high toxicity of ammonia and safety considerations (Schönborn & Lee, 2022).
- Compared to hydrogen, ammonia is easier and less energy consuming to store requiring less severe temperature and pressure conditions for its transportation (Lemmon et al., 2010).
- Moreover, ammonia is already transferred as a cargo by sea with 120 ports across the globe already having in place facilities for handling ammonia.
- The bunkering infrastructure for ammonia is not yet in place in any port around the world;
- Limited availability of ammonia, and especially green ammonia. The production of green ammonia is currently emerging (77% of ammonia produced globally is grey).

Method/Data

- Cost-benefit analysis in order to specify the cost differences between these fuels and the conventional ones and make policy recommendations on how this existing 'cost gap' could be somehow alleviated.

- The cumulative cost for the lifespan of a ship is calculated considering both the capital expenditure (CAPEX) and the operational expenditure (OPEX) (Kim et al., 2020).

- The CAPEX includes the investment cost in €/kW for the propulsion systems, including engines and components (for four-stroke and two-stroke engines) (Korberg et al., 2021), while the fuel costs are included in the OPEX.

$$\text{Cumulative cost} = CAPEX + \sum_{n=1}^{n=25} \frac{OPEX*(1+i)^n}{(1+d)^n}$$

where n is the age of the ship from 1 to 25 years, d is the discount rate and r is the inflation rate.

Method/Data

In order to estimate the benefits, the emission costs from the use of the different marine fuels were calculated by multiplying the life-cycle emissions from the use of each fuel with the fuel consumption of the vessel and the emission costs per tonne of emission using the formula below:

$$C_{m,m´,bn,gn,bn´,gn´,bh,gh} = E_{c,s,n,p} * C´_{c,s,n,p}$$

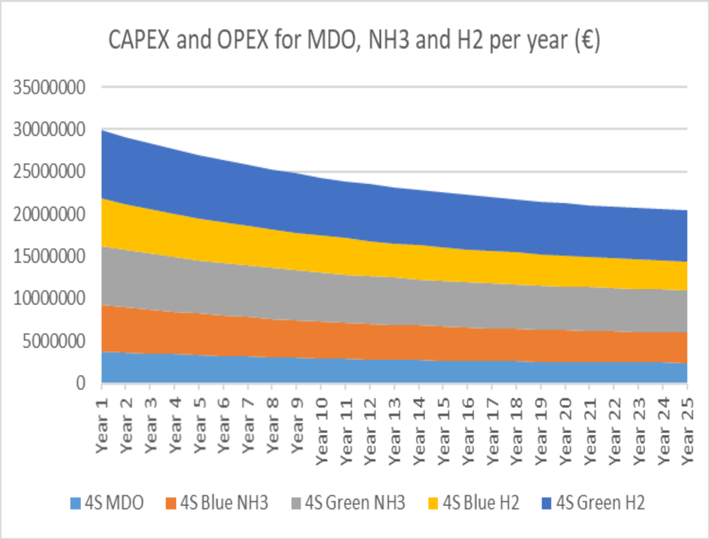
where $C_{m,m´,bn,gn,bn´,gn´,bh,gh}$ are the emission costs from the use of the MDO in 4stroke and 2stroke engines, blue and green NH_3 in 4stroke engines and 2stroke engines and blue and green H_2 in 4stroke engines.

$E_{c,s,n,p}$ are the life-cycle CO_2 eq., SO_x, NO_x, PM emissions per kWh from the use of the different fuels.

$C´_{c,s,n,p}$ are the emission costs per tonne of CO_2 eq., SO_x, NO_x, PM emissions (90€/tonne of CO_2eq., 6500€/tonne of SO_x, 4700€/tonne of NO_x and 2500€/tonne of $PM_{2,5}$) (Victoria Transport Policy Institute, 2020).

CAPEX and OPEX for the use of MDO, NH3 and H2 as marine fuels in 4stroke and 2stroke engines

The case of a tanker vessel with an engine of 6000 kW, a discount rate of 2% and an inflation rate of 10%.



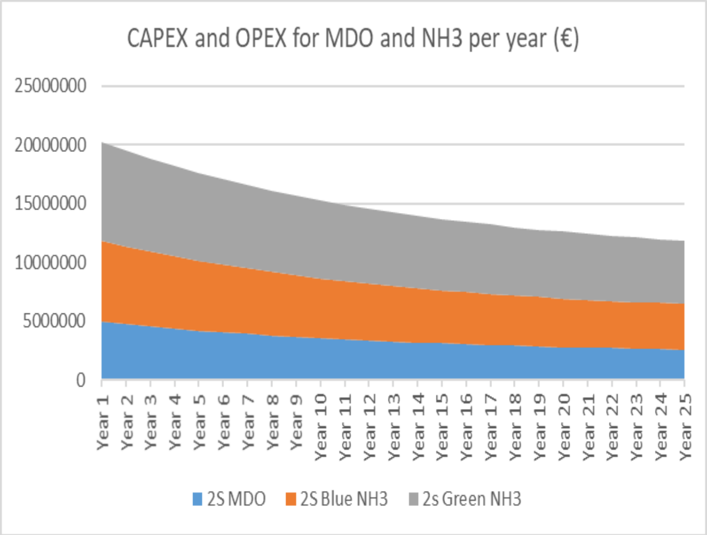
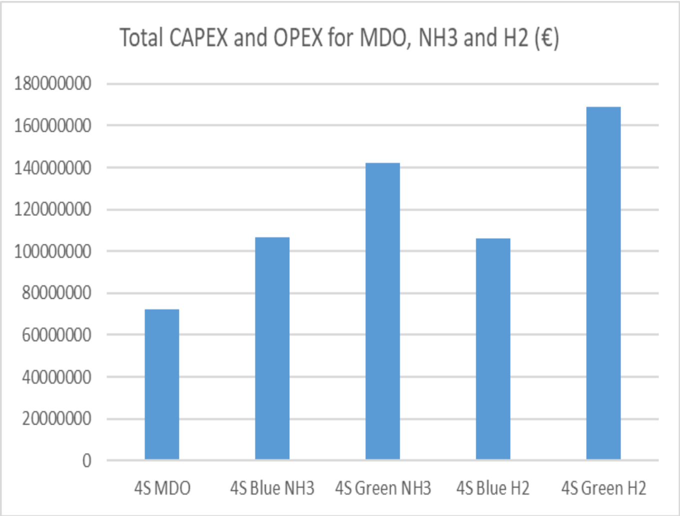


Figure 1: CAPEX and OPEX for different fuels per year (€)

CAPEX and OPEX for the use of MDO, NH3 and H2 as marine fuels in 4stroke and 2stroke engines



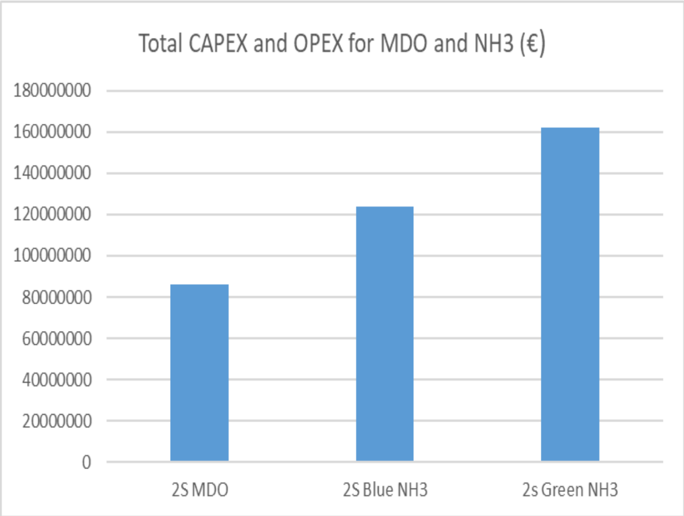


Figure 2: CAPEX and OPEX for different fuels for the whole lifespan of the vessel (€)

Emission costs and CAPEX/OPEX from the use of different marine fuels

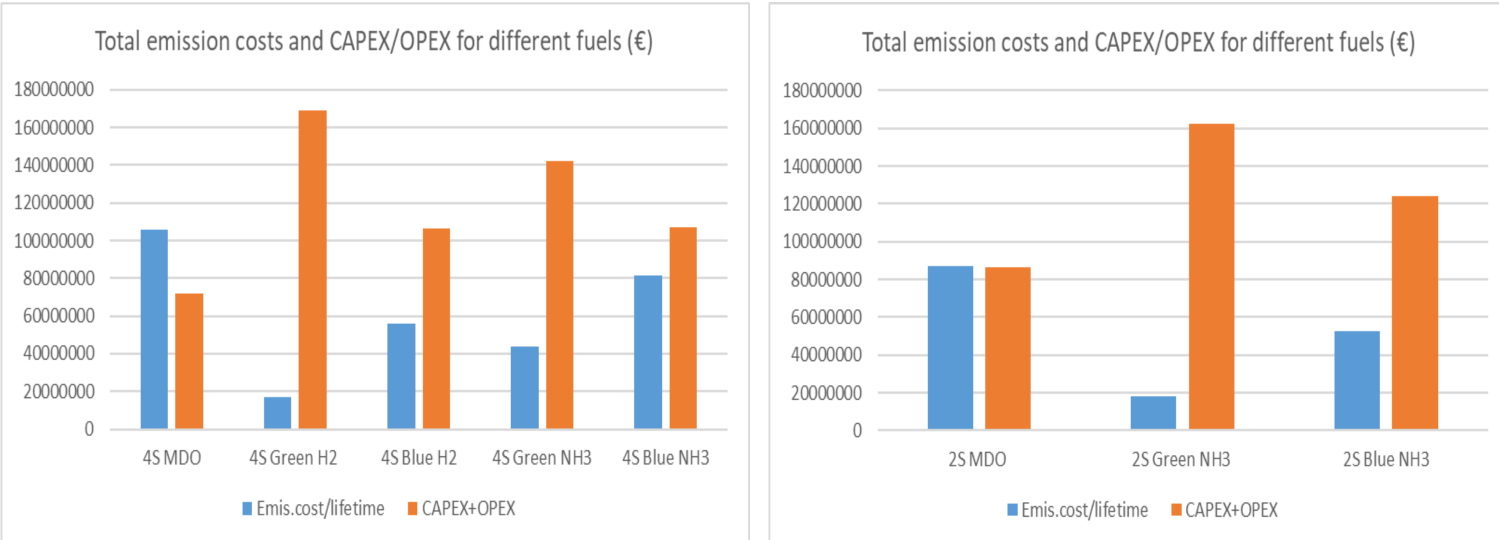


Figure 3: Total emission costs and CAPEX/OPEX for different fuels (€)

Emission costs and benefits from the use of different marine fuels

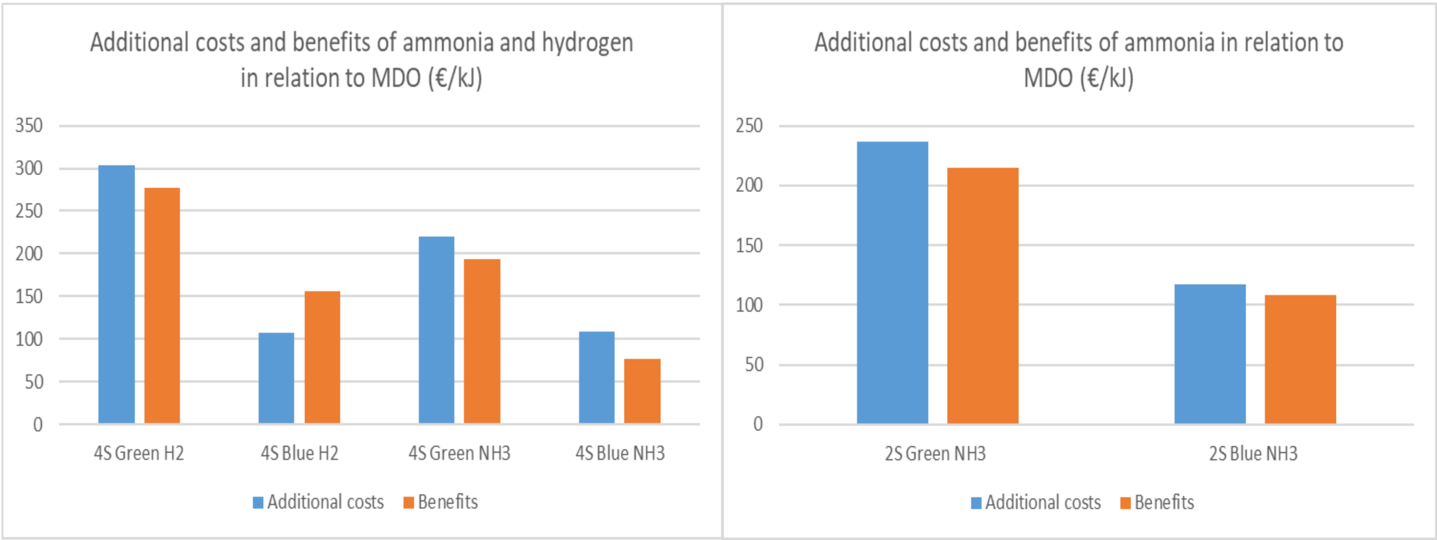


Figure 4: Additional costs and benefits of ammonia and hydrogen in relation to MDO (€/kJ)

Conclusions and policy implications

- *Green hydrogen is by far the most costly option* followed by green ammonia, blue hydrogen and blue ammonia.
- *The emission costs of green hydrogen (followed by green ammonia) are minimal* compared to conventional – and even blue – fuels.
- The use of renewable energy sources for the production of fuels is critical.
- The high total expenditure associated with the use of green fuels turns the *introduction of MBMs* - carbon taxes on marine fuels based on their GHG energy intensity or through the subsidization of renewable fuels, at least in the initial phase of their uptake - essential.
- Although the production costs of green fuels are expected to decrease in the long run due to technical maturity and increased demand, for the time being *their high CAPEX and OPEX represent the greatest challenge* for their wide adoption by the industry.

Conclusions and policy implications

- Additional challenges; safety concerns, regulatory aspects, restricted availability and an uncertain regulatory framework.

- *Safety concerns* for the use of both ammonia and hydrogen due to their particular properties, *the high explosivity of hydrogen and the corrosion and toxicity of ammonia*.

- In this direction, their employment is *not allowed under the current IMO regulations and the relevant safety protocols need to be revised accordingly*.

- Not all renewable fuels are considered suitable for use for all maritime segments. Especially with regards to short sea shipping, electrification is gaining momentum while the use of ammonia for passenger transport is not considered as a feasible option.

Conclusions and policy implications

- At the moment, *the production of renewable fuels is limited and the refueling infrastructure at ports is currently being developed*.
- A number of shipping companies around the globe have already invested in alternative fuels ordering *newbuildings with dual engines* that can use both conventional fuel and ammonia (Christodoulou and Cullinane, 2021).
- *Shipping industry coalitions* can also play a critical role.
- *Green corridors* – an industry-driven initiative that seeks to create "specific trade routes between major port hubs where zero-emission solutions have been demonstrated and are supported" – can *pave the way for the development of ecosystems 'with targeted regulatory measures, financial incentives, and safety regulations that can also put conditions in place to mobilise demand for green shipping on specific routes*' (Getting to Zero Coalition, 2020).

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