Master Thesis in Marine Technology - 2023

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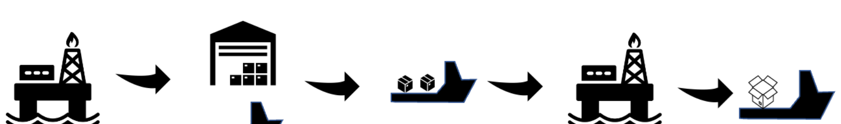
# Decision support for renewal and retrofitting of the platform supply vessels fleet to guide the transition towards zero-emission logistics

## Introduction

Norway has for decades been one of the major exporters of oil and gas through high activity from drilling and production platforms across a large part of the North Sea. A crucial part of maintaining a reliable production is effective logistics planning. Every day, even in extreme weather conditions, voyages must be scheduled for a large fleet of platform supply vessels (PSVs) to service the installations with the required demands for technical equipment, chemicals, and consumable cargoes.

The offshore supply sector is increasingly becoming a contributor to global emissions of air pollutants and greenhouse gases. As long as there is demand for oil and gas, the need for ships to transport goods and services to and from offshore locations is still there. These vessels are responsible for a portion of 1.2-1.4\% of Norway's $CO_2$ emissions[2], and the industry as a whole is working to reduce its impact on the environment. New industries will emerge in the future when the oil and gas stops, like offshore wind production, which will require many complex maritime operations.

Even though the ambitions and goals are well defined, there is a lack of knowledge on how to reach them. Furthermore, technology development is subject to a large degree of uncertainty. Lastly, the timing of the decisions to make is important. A large fleet of conventional vessels is still in operation, and many of them will continue to operate for several years. A more economically reasonable option than scrapping these vessels is to modify their fuel and propulsion system to more sustainable alternatives. We need a decision support tool to guide when the changes to the fleet should happen.




## Model

**objective function:**

$$min \sum_{v\epsilon\mathcal{V}} \sum_{r\epsilon\mathcal{R}_v} \sum_{t\epsilon\mathcal{T}} C^s_{vrt} x_{vrt} + \sum_{v\epsilon\mathcal{V}} \sum_{t\epsilon\mathcal{T}} C^{TC}_{vt} y_{vt}, \tag{6.1}$$

**s.t.**

$$\sum_{v\epsilon\mathcal{V}} \sum_{r\epsilon\mathcal{R}_v} x_{vrt} E_{vrt} \leq G_{vt}, \quad t\epsilon\mathcal{T}, \tag{6.2}$$

$$\sum_{v\epsilon\mathcal{V}} \sum_{R\epsilon\mathcal{R}_v} Q_{ir} x_{vrt} \geq D_{it}, \quad i\epsilon\mathcal{I}, t\epsilon\mathcal{T}, \tag{6.3}$$

$$\sum_{r\epsilon\mathcal{R}_v} T_{vr} x_{vrt} \leq T^{max}, \quad v\epsilon\mathcal{V}, t\epsilon\mathcal{T}, \tag{6.4}$$

$$x_{vrt} \quad integer \quad v\epsilon\mathcal{V}, r\epsilon\mathcal{R}_v, t\epsilon\mathcal{T}, \tag{6.5}$$

$$y_{vt} \epsilon \{0,1\}, \quad v\epsilon\mathcal{V}, t\epsilon\mathcal{T}, \tag{6.6}$$

$$\sum_{v'\epsilon V^C_v \cup V^R_v} y_{v't} \leq 1 \quad v\epsilon V^C, t\epsilon T, \tag{6.7}$$

$$\sum_{R\epsilon\mathcal{R}_v} x_{vrt} \leq M y_{vt}, \quad v\epsilon\mathcal{V}, t\epsilon\mathcal{T}, \tag{6.8}$$

$$y_{v't'} \geq z_{vv't}, \quad v\epsilon V^C, v'\epsilon V^R, t\epsilon T, t'\epsilon T | t' \geq t, \tag{6.9}$$

$$\sum_{v'\epsilon V^R} \sum_{t\epsilon T} z_{vv't} \leq 1, \quad v\epsilon V^C, \tag{6.10}$$

$$y_{v't} \leq \sum_{t'=1}^{t} z_{vv't'}, \quad t\epsilon T, v\epsilon V^C, v'\epsilon V^R, \tag{6.11}$$

**Sets:**

| | |
|---|---|
| $\mathcal{V}$ | Set of vessels |
| $\mathcal{V}^c \subset \mathcal{V}$ | Subset of current vessels in fleet |
| $\mathcal{V}^R \subset \mathcal{V}$ | Subset of retrofitted vessels |
| $\mathcal{V}^N \subset \mathcal{V}$ | Subset of newbuild vessels |
| $\mathcal{I}$ | Set of installations to visit from the base |
| $\mathcal{R}_v$ | Set of routes that can be sailed by vessel $v$, $r \in \mathcal{R}_v$ |
| $\mathcal{T}$ | Set of discrete time periods in years |

**Parameters:**

| | |
|---|---|
| $C^s_{vrt}$ | Fuel cost for vessel v sailing route $r$ in time period $t$ |
| $C^{TC}_{vt}$ | Time charter cost for new build or retrofit for vessel $v$ in time period $t$ |
| $D_{it}$ | Monthly cargo demand for installation $i$ in period $t$ |
| $T_{vr}$ | Time duration for route $r$ using vessel $v$ |
| $E_{vrt}$ | Emission for vessel v sailing route $r$ in time period $t$ |
| $G_t$ | Emission reduction goal in time period $t$ |
| $Q_{ir}$ | Nr of cargo taken to node $i$ in route $r$ |

**Decision variables:**

| | |
|---|---|
| $x_{vrt}$ | Integer variable vessel v sails route r, in time period t |
| $y_{vt}$ | 1 if vessel v is used in time period t, otherwise 0 |
| $z_{vv't}$ | 1 if retrofit of vessel $v$ to vessel $v'$ in time period $t$, otherwise 0 |

## Problem

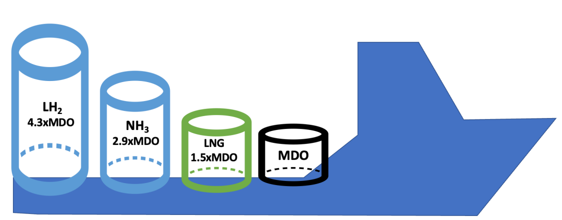
The model's primary objective is to support decision-making for ship owners by determining the optimal time to renew the fleet to reduce $CO_2$ emissions. The model serves as a strategic planning tool for ship owners, ensuring that contracts to offshore installations are fulfilled while transitioning the fleet to be more environmentally friendly.

In order to meet the demand for offshore installations, the fleet must supply each installation with supplies from the onshore base. Vessels in the fleet have specific cargo capacities and ranges, which are utilized to determine feasible preset routes for each vessel. Even though the model does not directly handle route planning, it considers different preset routes for each vessel, handling the problem as a set partitioning problem.

Each preset route and vessel has a corresponding investment cost, voyage cost, and $CO_2$ emission. The goal is to minimize the total cost of owning and operating a fleet of vessels over the set time horizon while achieving set emission reduction goals for each time period. To accomplish this objective, ship owners have five alternatives for vessel types: a conventional vessel fueled by MDO, a vessel fueled by LNG, a vessel fueled by liquid hydrogen, a vessel fueled by ammonia, and a conventional MDO-fueled vessel equipped with carbon capture and storage systems on board.

The model uses discrete time periods, in years. Within each time period, a 30-day operation of the fleet is analyzed. CO2 emissions, VOYEX, and CAPEX are analyzed during the operational time.

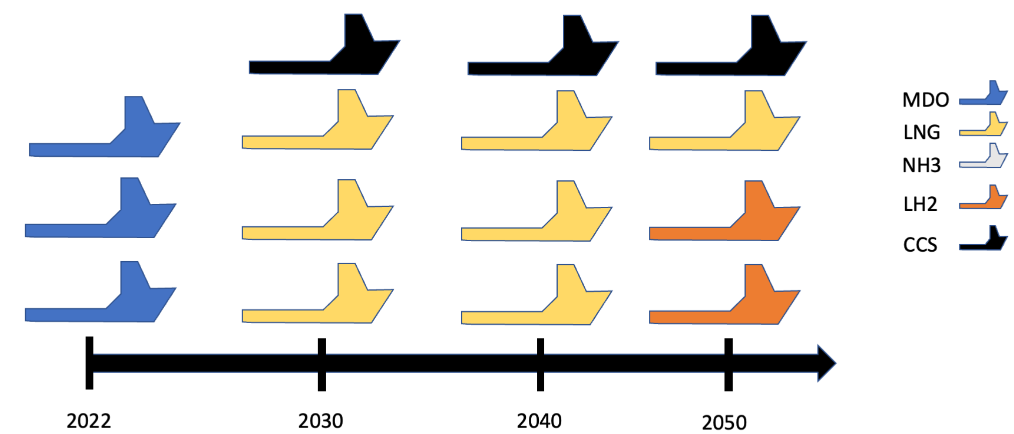
By employing this model, ship owners can make informed decisions regarding fleet composition throughout different time periods, with new regulations for emissions on the way.




## Results

| Emission strategic | Reduction by 2030 | Reduction by 2050 |
|---|---|---|
| 1 | 0% | 0% |
| 2 | 10% | 20% |
| 3 | 20% | 50% |
| 4 | 40% | 70% |
| 5 | 50% | 100% |

By implementing emission strategy 4, aligned with the International Maritime Organization's (IMO) 2030 and 2050 emission reduction goals [1], the model selects the optimal fleet development. The figure below demonstrates the fleet configuration chosen by the model.




By comparing various fuel strategies in 2050, it becomes feasible to assess the cost-effectiveness of each metric ton of CO2 saved relative to one another. The outcomes are illustrated in the figure depicted below.

| Emission strategy | Emission[t] | Total cost[$] | $\$/tCO_2$ saved |
|---|---|---|---|
| 2 | 1015 | 376265 | 511 |
| 3 | 870 | 468005 | 531 |
| 4 | 215 | 841445 | 548 |
| 5 | 0 | 1364575 | 780 |

## References:


1) IMO(2023). IMO's work to cut GHG emissions from ships. url: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx (visited on 2nd Oct. 2023)
2) Risholm, André(2020).'2030 Offshore market NH3 fuel demand'