Modeling Adaptive Strategies & Technologies Towards Climate-Neutral Shipping.

MaritimeGCH

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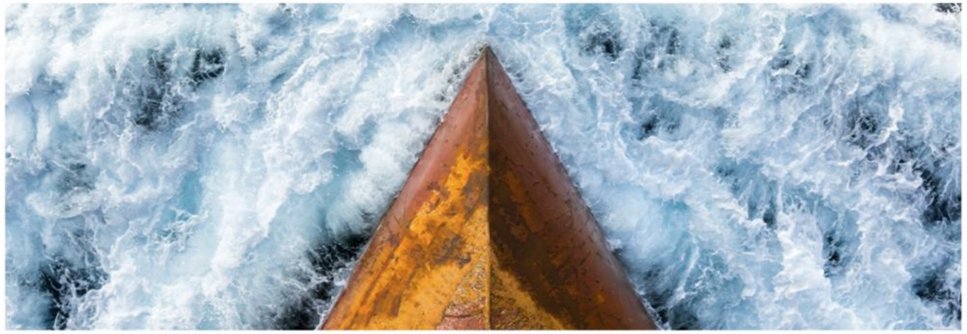
Prof. Phoebe Koundouri
Founder and Scientific Chair

Rapidly Changing Policy Landscape

International Maritime Organization's historic agreement to decarbonise shipping

Katie Kouchakji, IBA Environment Correspondent Monday 2 June 2025



Countries at the International Maritime Organization (IMO) – the UN agency responsible for regulating maritime transport – agreed in April to a draft framework intended to reach net zero emissions by or around 2050. The organisation said its Net-zero Framework is the first in the world to combine mandatory emissions limits and greenhouse gas (GHG) emission pricing across an entire industry sector.

https://www.ibanet.org/International-Maritime-Organizations-historic-agreement-to-decarbonise-shipping

IMO approves historic carbon price agreement

- *Fuel standard with credit trading system passes 63-16*
- *Baseline cost of \$380 per tonne CO2e, Direct Compliance Target cost of \$100 per tonne CO2e*
- *Petrostates decry deal as too strong; greens call it too weak; Pacific Islands abstain*

11 Apr 2025 | **NEWS**

by Declan Bush

@Declan_LL | declan.bush@lloydslistintelligence.com

Updated: The IMO has approved a J9-style credit trading plan that could raise \$30bn-\$40bn by 2030, but could allow business-as-usual trading until 2028 with stringency far below that of the IMO's 2023 GHG strategy

https://www.lloydslist.com/LL1153160/IMO-approves-historic-carbon-price-agreement

The \$800,000-per-voyage question: Will shipping face combined IMO and EU carbon costs?

If applied together at currently planned level, EU regulations make up 62% of carbon costs on transatlantic route

2 June 2025 19:08 GMT *UPDATED 3 June 2025 8:45 GMT*

By Eric Priante Martin in **Miami**

https://www.tradewindsnews.com/regulation/the-800-000-per-voyage-question-will-shipping-face-combined-imo-and-eu-carbon-costs-/2-1-1826026

Shipowners flock to understand 'complex' FuelEU Maritime rules, as the European Commission runs numbers

Policy officer urges stakeholders to back IMO's proposal as forces work against it

8 May 2025 10:29 GMT *UPDATED 8 May 2025 11:58 GMT*

By Lucy Hine in **Amsterdam**

Fuel EU Maritime Regulation: The next legislative piece to make the EU climate neutral

Environment | Published: 29 August 2024 | Updated: 14 February 2025

Image credit to: 3rdtimeluckystudio / Shutterstock.com

https://www.tradewindsnews.com/regulation/the-800-000-per-voyage-question-will-shipping-face-combine

Report: Surging shipping demand points to looming biofuel supply crunch

TRANSITION

June 2, 2025, by Sara Kosmajac

The maritime transportation industry's ambition of net-zero carbon emissions has ballooned demand for biofuels. However, the capacity to produce these sustainable fuels is not keeping pace, with *"unconstrained"* biodiesel demand exceeding total supply.

https://www.offshore-energy.biz/report-surging-shipping-demand-points-to-looming-biofuel-supply-crunch/

Motivation

- The maritime industry is undergoing significant transformation as it grapples with the need for more sustainable shipping practices.

- This transition involves a shift in fuel preferences, with traditional high-polluting fuels being phased out in favour of cleaner, more sustainable alternatives.

- Regulatory demands, coupled with the already complex techno-economic considerations for optimizing shipping operations, ***presents a set of multifaceted challenges that require comprehensive and integrated solutions***.

Conceptual Description

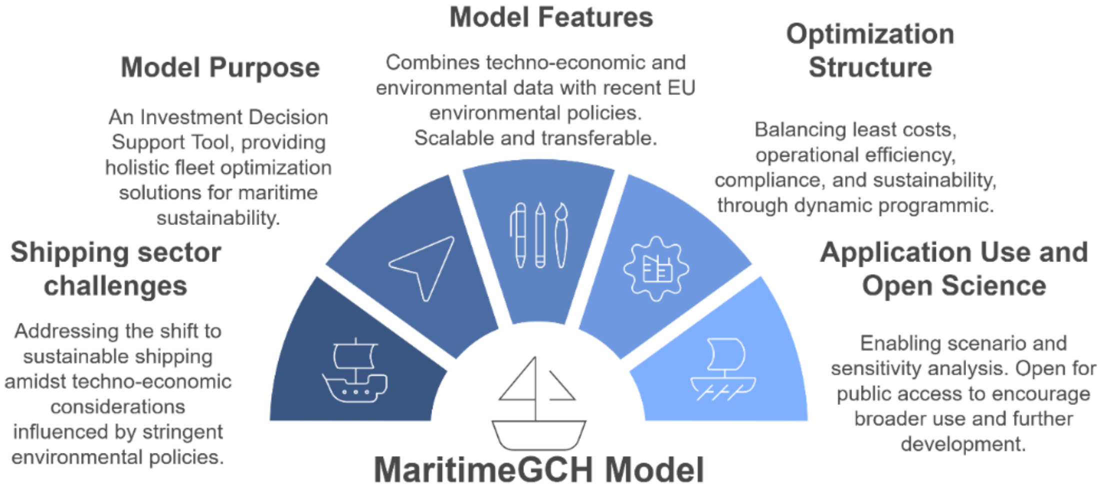
- Advanced optimization tool, designed to tackle the diverse challenges associated with maritime fleet management.

- Developed in Python - open-source. There can be different variations, depending on the studied problem and scale.

- Simple and comprehensive – Linear Programming.

- Available: https://github.com/Alamanos11/MaritimeGCH

- MaritimeGCH integrates a range of factors, including techno-economic, different fuel types, environmental, and operational elements, into a single, unified model.
- The current version takes into account the compliance to recent European regulations:
  - Emissions Trading System (ETS) – emissions threshold for penalty or allowance purchase.
  - Carbon Intensity Index (CII) – based on the performance of the Annual Efficiency Ratio (AER)



Mathematical Description

The user needs to define:

- The **time horizon** (e.g. period from 2025-2050)
- **Ship types**: E.g., Container, Tanker, Bulk, Cargo, Other, etc.
- **Fuel types**: E.g., Marine Fuel Oil or Heavy Fuel Oil (Oil), Liquefied Natural Gas (LNG), Liquefied Petroleum Gas (LPG), Methane (MET), Methanol (MeOH), Ammonia (NH3), other alternative fuels except of LNG (AllNoLNG), refined petroleum oils (RefPO), Hydrogen (H2), or other fuel blends allowing different mixes, which is often the case when ships refuel at different ports.

Decision Variables

- $\mathbf{new\_ship}_y$: Number of new ships of type s in year y.
- $\mathbf{stock\_ship}_y$: Stock of ships of type s in year y.
- $\mathbf{fuel\_demand}_{f,y}$: Fuel demand of fuel type f in year y (tonnes).
- $\mathbf{co2\_emissions}_y$: CO_2 emissions in year y (tonnes of CO_2).
- $\mathbf{excess\_emissions}_y$: Excess CO_2 emissions above the cap in year y (tonnes of CO_2).

Data

invest_cost$_s$: Investment cost of ship type s (in million Euros).
op_cost$_s$: Operational cost of ship type s per year (in million Euros).
fuel_cost$_f$: Fuel cost of fuel type f (in Euros per tonne).
emissions_factor$_f$: Emission factor of fuel type f (tonnes of CO_2 per tonne of fuel).
co2_cap$_y$: CO_2 emissions cap (threshold) in year y (tonnes of emitted CO_2). If the company exceeds that, then they will have to buy CO_2 emissions allowance (see next bullet), according to the ETS.
ETS_price$_y$: Cost per tonne of CO_2 for emissions exceeding the cap in year y (Euros per tonne of CO_2).
prod_capacity$_{y,s}$: Production capacity of ship type s in year y (number of ships that can be produced).
lifetime$_s$: Lifetime of ship type s (in years).
fuel_consumption$_{s,f,eng}$: Fuel consumption of ship type s using fuel type f (tonnes of fuel per year) per engine type eng.
demand_shipping$_{y,s}$: Demand for shipping services in year y [Gross Tonnage per Nautical Mile (GtNM)] of ship type s in year y.
init_capacity_fleet: Initial capacity of fleet of ship type s in the year 2020 (number of ships).
fleet_age: the initial (average) age of the fleet, per ship type (years).
fuel_avail$_{f,y}$: Available amount of fuel type f that can be used per year y (tonnes).
cap$_s$: Capacity, namely the weight of each ship types' load (GtNM).
CII$_{desired,s}$: Desired value of Carbon Intensity Indicator of ship type s (or equivalently the AER class).

The data and the parameters were collected from Clarksons Research, UNCTAD, MarineTraffic and information from legal frameworks such as FuelEU as well as the ETS and information from legal frameworks like FuelEU.

Objective Function

Objective Function = Minimize the total cost over the planning horizon (e.g., 2020-2050):

$$min \sum_{y=2020}^{2050} (total\_cost_y)$$ Total cost in year y (in million Euros)

Where:

$$total\_cost_y = \sum_s (\text{new\_ship}_{y,s} \times \text{invest\_cost}_s) + \sum_s (\text{stock\_ship}_{y,s} \times \text{op\_cost}_s) + \sum_s (\text{fuel\_demand}_{y,f} \times \text{fuel\_cost}_f) + (\text{excess\_emissions}_y \times \text{ETS\_price}_y)$$

Constraints

Fleet Capacity Constraint: The total stock of ships each year must be sufficient to meet the demand for shipping services:

$$\sum_{s} (\text{stock\_ship}_{y,s} \times \text{cap}_s) \geq \text{demand\_shipping}_y \quad \forall \text{y}$$

Ship Production Constraint: The number of new ships built each year is limited by production capacity:

$$\text{new\_ship}_{y,s} \leq \text{prod\_capacity}_{y,s} \quad \forall \text{y, s}$$

Fleet Stock Update Constraint: The stock of ships of each type in a given year is the sum of new ships built and surviving ships from previous years, based on their lifetime and age:

If y=2020, $\text{stock\_ship}_{y,s} = \text{init\_capacity\_fleet}_s$

Else: $\text{stock}_{\text{ship}_{y,s}} = \text{new}_{\text{ship}_{y,s}} + \text{stock}_{\text{ship}_{y-1,s}} - \text{retired}_{\text{ships}_{y,s}} \quad \forall \text{ y, s} > 2020$

Where: $\text{retired}_{\text{ships}_{y,s}} = \sum_{y,} \text{new\_ship}_{y\prime,s}$

for y’ ∈ [max (2020, y - lifetime[s] + 1 - fleet_age[s]), y-1]

Fuel Demand and Availability Constraints: The fuel demand is derived from the operational needs of the ships, which however, cannot exceed the available amount of each fuel type this year:

$$\text{fuel\_demand}_{y,f} = \sum_{s,eng} \text{stock\_ship}_{y,s} \times \text{fuel\_consumption}_{s,f,eng} \quad \forall \text{ y, f, s, } eng$$

And $\text{fuel\_demand}_{y,f} \leq fuel\_avail_{f,y} \ \forall \text{ y, f}$

Constraints

Emissions Constraint: The total CO_2 emissions are calculated based on fuel consumption:

$$\text{co2\_emissions}_y = \sum_f \text{fuel\_demand}_{y,f} \times \text{emissions\_factor}_f \quad \forall y$$

ETS Emissions Cap Constraint: The total CO_2 emissions in each year must not exceed the cap threshold plus any excess emissions (which will have to be then purchased): $\text{co2\_emissions}_y \leq \text{co2\_cap}_y + \text{excess\_emissions}_y \ \forall y$

With this approach we set a CO_2 emissions cap (threshold). We allow emissions to exceed this cap, but any excess is tracked, and 'penalized' with an additional cost in the objective function. This is a 'combined' approach (threshold-constraint and penalty), and it is realistic and effective, as it mirrors simply the actual ETS regulatory environment where companies can exceed their caps by purchasing allowances.

Carbon Intensity Indicator Constraint: It should not exceed a performance defined by regulations, or the user/ owner ($\text{CII}_{desired\ per\ ship\ type\ s}$) in order to ensure that the ship will remain in the 'active' fleet:

$$\text{CII}_{s,y} \leq \text{CII}_{desired,s}$$

The $\text{CII}_{desired,s}$ is actually the same/ equivalent approach as the AER, as they are based on almost the same equation and concept, to set an environmental standard to allow ships to travel. For example, in this constraint it can be reflected by setting the $\text{CII}_{desired,s}$ equal to the respective grade "C" (AER class) or better (B or A grade), because the regulation implies the ships not to travel if they are graded D (for three consecutive years) or below.

Results

Case study example:
Greek fleet with moderate fuel transition and energy efficiency technologies employed

- Stock of ships rises from 1,000 ships to just under 1,500
- New ship investment also rises steadily, spiking towards 2050 as more ships retire
- Fuel costs rise nearly 5x as lower carbon fuels (ammonia, H_2, methanol) come online in the mid-2030s
- Based on the FuelEU target of 80% emissions reduction below the baseline, under a relatively optimistic scenario the cap still cannot be reached
- Further combined efforts to implement new technologies that can be cost effective is required

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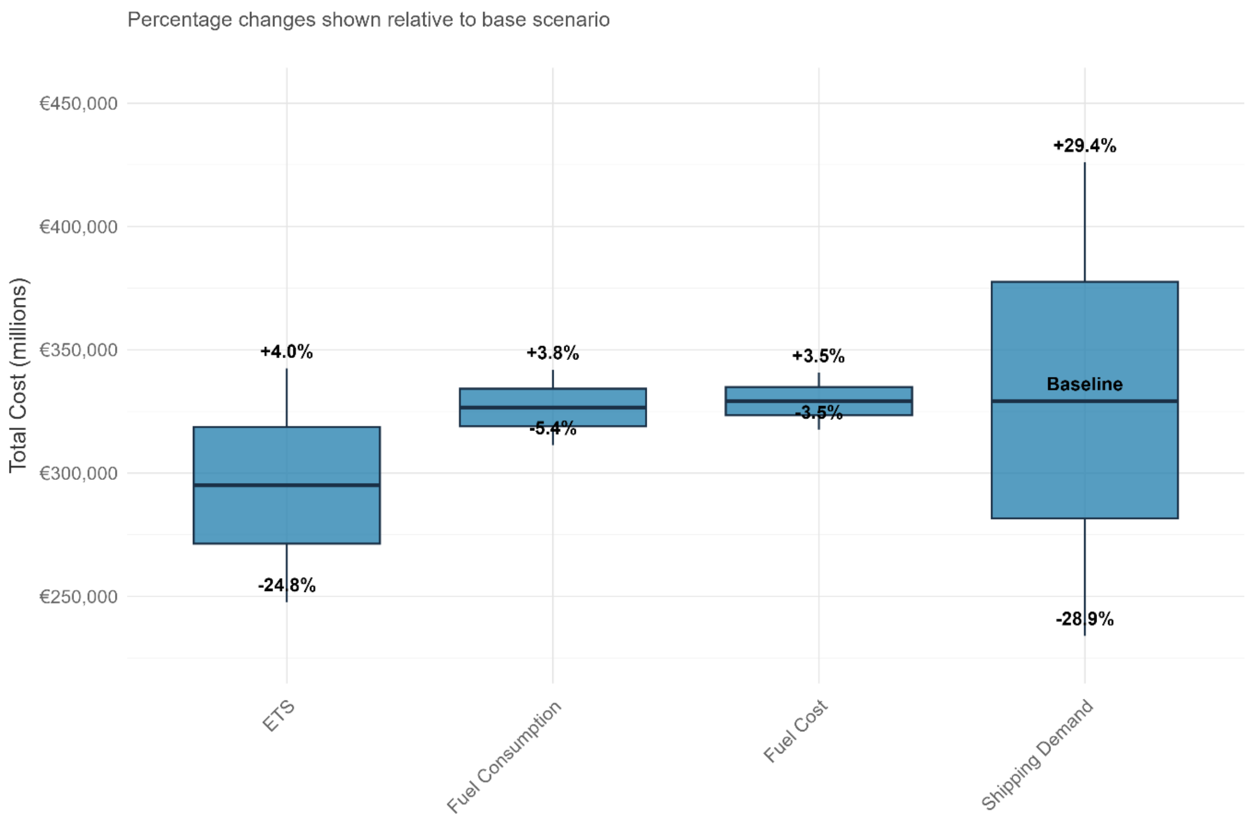
Results – Sensitivity Analysis

- Extreme ETS price scenarios effect costs disproportionately

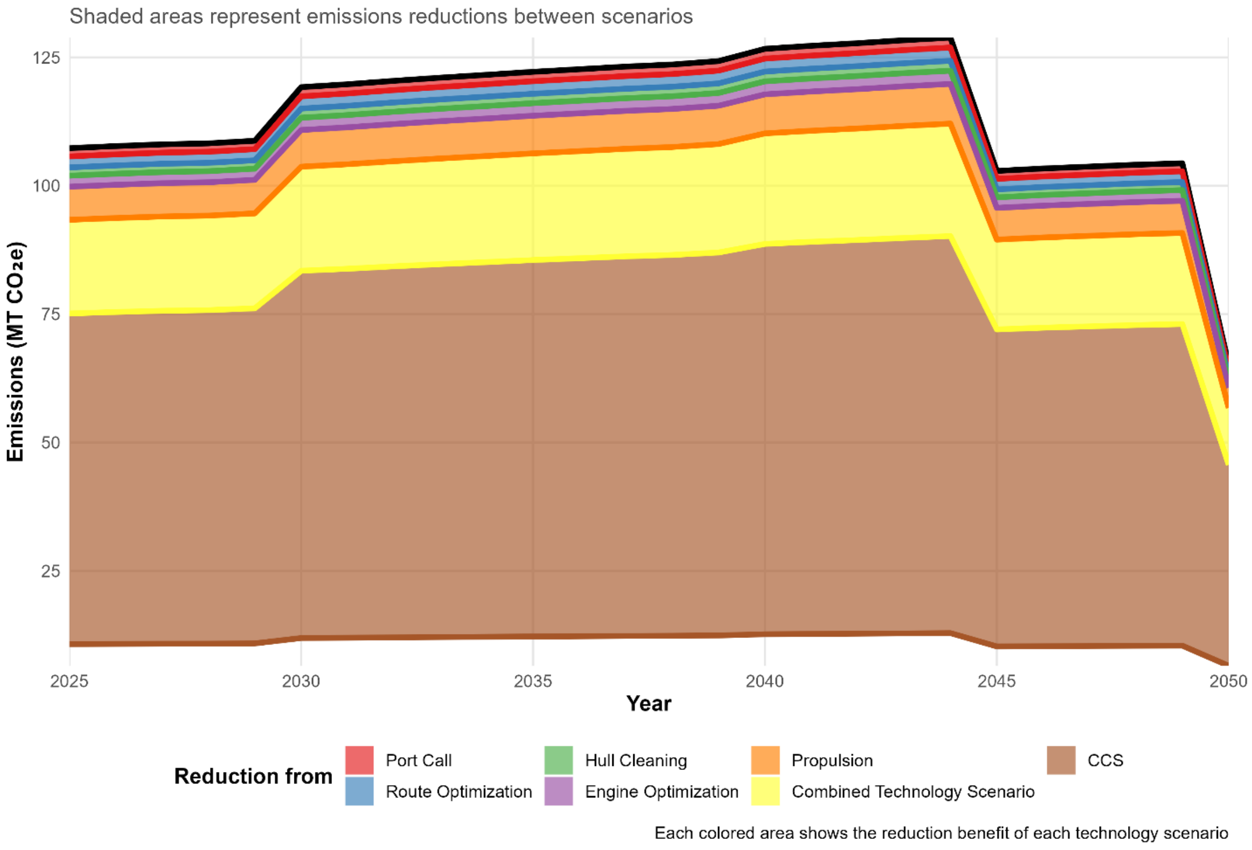
- Shipping demand has the largest effect on total cost of the entire fleet

- High and low fuel consumption and cost scenarios do not affect total fleet costs significantly



Results – Emissions Reduction

- CCS offers the largest carbon abatement potential, but at large cost
- The combined technology scenario achieves 30% carbon abatement
- Digital technologies (port call, route optimization) can be easy wins



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Thank you for your attention

Further reading:

- Alamanos, A., Nisiforou, O., Deranian, C., Garcia, J.A., Papadaki, L. & Koundouri, P. (2024). *Integrated fleet optimization under techno-economic shipping and environmental constraints: the MaritimeGCH model.* DOI: 10.13140/RG.2.2.35892.87680. Available at: https://github.com/Alamanos11/MaritimeGCH

- Alamanos, A. (2025). MaritimeGCH model: The WebApp. Available at: https://maritimegch-webapp-ihivvudpv9bo6lgzwqmuqc.streamlit.app/