DEPARTMENT OF INTERNATIONAL AND EUROPEAN ECONOMIC STUDIES

ATHENS UNIVERSITY OF ECONOMICS AND BUSINESS

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Olympia Nisiforou

Chris Deranian

Angelos Alamanos

Jorge Andres Garcia

Phoebe Koundouri

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Olympia Nisiforou, Cyprus University of Technology, Olympia.nisiforou@cut.ac.cy
Chris Deranian, Athens University of Economics and Business, chris.deranian@gmail.com
Angelos Alamanos, Independent Researcher, Germany
Jorge Andres Garcia, The Water Institue, Univeresity of Waterloo, ja4garci@uwaterloo.ca
Phoebe Koundouri, Athens University of Economics and Business; ATHENA Research Center; Denmark Technical University, pkoundouri@aueb.gr

Overview

Shipping is a prominent sector within the Greek economy and faces several challenges in decarbonizing as prescribed by the FuelEU Maritime Regulation which is cornerstone of the EU's decarbonization efforts in the shipping sector, specifically targeting the fuels used by vessels, implemented from 1 January 2025. FuelEU Maritime aims to reduce greenhouse gas intensity in ships above 5,000 gross tonnage at European ports by aiming for a 2% decrease by 2025 and an 80% reduction by 2050. The targets cover CO2, methane, and nitrous oxide emissions over the full lifecycle of fuels used onboard. From January 1, 2030, passenger and container ships must use on-shore power supply (OPS) or alternative zero-emission technologies in ports covered under Article 9 of the Alternative Fuels Infrastructure Regulation (AFIR). Member States may apply the obligation to ports not covered by Article 9 from January 1, 2030. FuelEU Maritime's goal-based and technology-neutral approach allows for innovation and the development of new sustainable fuels and energy conversion technologies. The regulation also provides flexibility mechanisms, supporting existing fleets in compliance strategies and rewarding first-movers for early investment in energy transition (Directorate of Mobility & Transport, 2024). In this paper we present the application of a free, open-source Investment Decision Support Tool, called MaritimeGCH, to model the transition to cleaner fuels within the maritime industry. The study tests a set of scenarios from slow to fast transition to cleaner fuels within the Greek shipping sector, and explores their effect on fleet optimization decisions. This set of scenarios reflects the potential evolution of some fuels starting phasing out (e.g. Oil and RefPO), being replaced by the transition fuels (LNG and LPG), while others (green fuels) will ultimately become more prevalent in the future (MeOH, NH3 and H2).

Methods

The MaritimeGCH model is an advanced optimization Investment Decision Support Tool (IDST). The model uses linear programming (LP) to dynamically minimize the total cost of fleet operations over a user-defined planning horizon (in this case 2020-2050) and is described in more detail in Alamanos et. al. (2024). It includes decision variables (e.g., fleet composition, fuel choices), objective function (e.g., minimizing total cost), and constraints (e.g. regulations on emissions thresholds, shipping demand, technological limitations, etc.). In this study, all parameters are set to the base case scenario except the fuel costs and availability. A range of scenarios for fuel costs and availability are then tested which represent a do-nothing scenario, and then a slow, medium and fast transition scenario to cleaner fuels.

Results

The results (Figure 1) show the evolution of fuel mixes under low, base and high clean fuel penetration scenarios, based on user-defined assumptions. Under the high penetration scenario, oil and refined oil are phased out completely by 2040, while those fuels persist in small volumes through 2050 under the low penetration sceanario. Cleaner fuels gain prominence, indicating a strategic shift towards sustainability, while LNG gains a smaller portion of the overall fuel mix. The EU Emissions Trading System (ETS) has incorporated the maritime sector taking effect in 2024. It requires an offset ofgreenhouse gas (GHG) emissions that exceede a designated threshold. That is by acquiring allowances, and aling to compy leading to a substantial pentalty per tonne of CO_2 equivalent for the deficiency Effective immediately, fleets must adhere to the regulation's stipulations, requiring an incremental decrease in greenhouse gas intensity of maritime fuels. The results in Figure 2 shows that the lower penetration scenario has the fleet facing higher emissions penalties with higher fuel costs compared to the base and high penetration scenarios. This highlights the tradeoff between higher operational costs for sustainable fuels with the lower penalties the fleet is subject to in the emissions trading scheme due to phasing out dirtier fuels earlier, and should be weighed appropriately by the fleet operator.

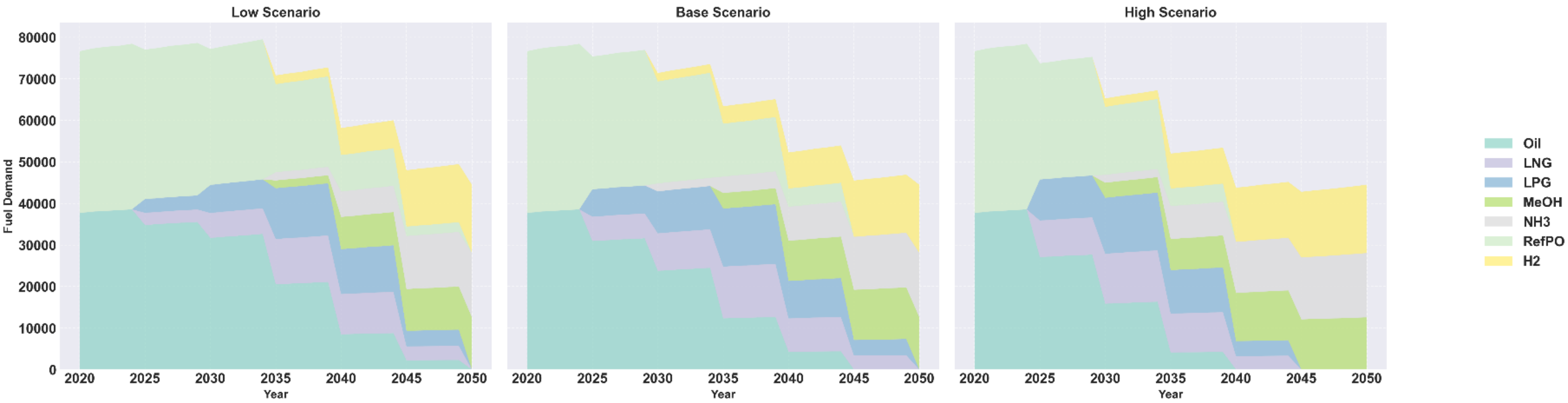

Figure 1: Results of of optimal fuel mix under low, base and high penetration scenarios of clean fuels.

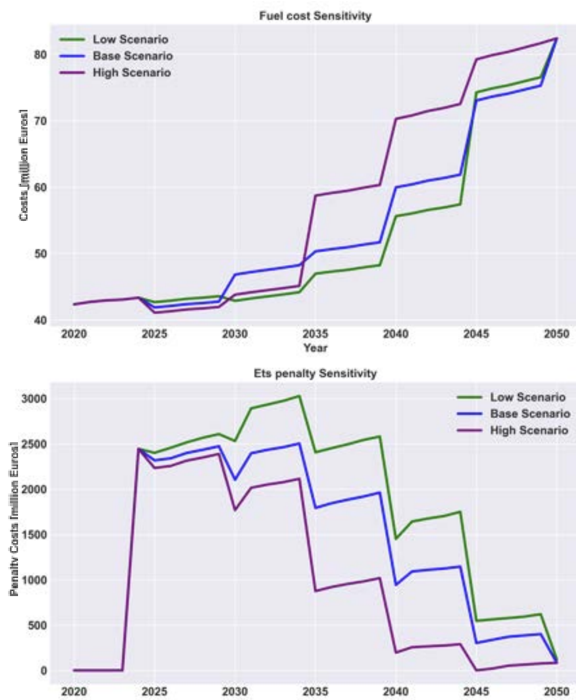

Figure 2: Fuel Cost and ETS Penalty Sensitivities. The low penetration scenario results in the highest ETS penalties with the lowest fuel costs, reflecting the tradeoff in clean fuel transition costs.

Conclusions

Our optimization model reveals that the transition to cleaner fuels represents a complex economic and environmental challenge for shipping fleets. By testing scenarios ranging from business as usual to rapid transition, our analysis demonstrates that while initial implementation costs are significant, long-term benefits, including reduced emissions and potential regulatory compliance advantages, can offset these expenses. The model suggests that strategic fuel transition approaches can minimize economic disruption while progressively reducing the fleet's carbon footprint. These findings provide critical insights for shipping companies and policymakers seeking to balance economic feasibility with environmental sustainability in maritime transportation.

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