HYDROGEN FUEL VIABILITY IN EU MARITIME TRANSPORT WITH EMISSIONS AND POLICY IMPLICATIONS

[1*]*Bugra Arda Zincir*, [2]*Burak Zincir*
[1] Maritime Vocational School, Galatasaray University, Besiktas, Istanbul, 34349, Türkiye
[2] Maritime Faculty, Istanbul Technical University, Tuzla, Istanbul, 34940, Türkiye

*Corresponding author e-mail: bazincir@gsu.edu.tr

ABSTRACT
The maritime industry is under increasing pressure to reduce greenhouse gas (GHG) emissions in line with EU regulations such as FuelEU and the EU Emissions Trading System (ETS). This study evaluates the environmental and economic impacts of using gray, blue, and green hydrogen as alternative marine fuels compared to marine diesel oil (MDO). Well-to-wake (WTW) emissions and associated regulatory costs were analyzed using data from the THETIS database and emission calculation models. The results show that while hydrogen-based fuels significantly lower tank-to-wake (TTW) emissions, gray and blue hydrogen still contribute to high WTW emissions due to upstream production processes. Consequently, gray hydrogen incurs the highest penalties, followed by blue hydrogen, making them less viable long-term solutions. Green hydrogen, however, demonstrates the lowest emissions and regulatory costs, emerging as the most sustainable option for decarbonizing maritime transport. The study highlights the need for policy incentives and technological advancements to enhance green hydrogen adoption.
Keywords: Decarbonization, EU ETS, FuelEU, Hydrogen fuel, Maritime emissions

1. INTRODUCTION

The maritime industry is a significant contributor to global greenhouse gas (GHG) emissions, prompting stringent regulations to reduce its environmental impact. The European Union (EU) has implemented policies such as FuelEU and the Emissions Trading System (ETS) to encourage the adoption of low-carbon fuels in shipping. As a result, alternative energy sources like hydrogen are gaining attention for their potential to decarbonize the sector. However, the environmental benefits of hydrogen vary depending on its production method. While green hydrogen, produced using renewable energy, offers the lowest emissions, gray and blue hydrogen, derived from fossil fuels, still contribute to carbon footprints. Understanding the emissions and regulatory implications of these hydrogen fuel options is crucial for assessing their viability in maritime transport.
This study assesses the well-to-wake (WTW) emissions and economic implications of hydrogen-based fuels in EU maritime transport compared to marine diesel oil (MDO). Using data from the THETIS database, the analysis explores the impact of hydrogen on tank-to-wake (TTW) emissions while accounting for upstream production emissions and regulatory costs. By evaluating policy-driven penalties and emissions performance, the research provides insights into the feasibility of hydrogen adoption in the maritime sector.

2. METHODOLOGY

In this section, gray, blue, and green hydrogen fuels are investigated regarding the GHG emissions they produce and their impacts on recent regulations in the EU region. During the analysis, data obtained from the THETIS database under the European Maritime Safety Agency (EMSA) [1] are presented in Table 1. It shows the ships involved in trading activities at EU ports in 2023. A total of 12,182 vessels arrived at or departed from EU ports in 2023, while 40,142,214 tons of fuel were combusted. Although the types of combusted fuel are not specified, it is assumed during the analysis that all the ships combusted MDO, since currently, there are 715 LNG-powered, 150 LPG-powered, and 62 methanol-powered ships [2] out of 109,000 ships [3].

Table 1. Retrieved data from the THETIS Platform

Ship types	Number of ships	Fuel consumption (mtons)	CO_2 emissions at sea (mtons)	CO_2 emissions from voyages to ports under MS jurisdiction (mtons)	CO_2 emissions from voyages to ports under a MS jurisdiction (mtons)	CO_2 emissions at ports (mtons)
Bulk carrier	3545	4,464,219	1,354,171	5,412,741	6,535,307	696,531
Chemical tanker	1304	2,445,271	2,298,620	2,083,528	2,474,135	800,205
Combination carrier	7	12,269	4,528	15,266	16,492	1,659
Container ship	1865	11,343,724	8,835,257	12,394,910	12,681,004	1,476,651

Container/ro-ro cargo ship	57	327,451	325,899	297,274	352,389	48,387
Gas carrier	330	818,207	327,530	1,029,243	1,008,145	158,722
General cargo ship	1121	1,516,878	1.326,824	1,584,990	1,599,460	261,015
LNG carrier	359	3,377,706	479,440	4,252,929	4,399,828	413,557
Oil tanker	1841	5,181,798	2,089,401	5,795,521	6,777,898	1,580,109
Other ships	343	702,907	561,915	754,448	771,614	111,704
Passenger ship	205	2,336,208	4,069,381	1,050,016	1,073,751	1,093,170
Cruise passenger ship	9	33,653	55,344	16,562	15,876	17,747
Refrigerated cargo ship	136	338,524	116,034	395,607	510,124	37,742
Ro-pax ship	391	4,214,439	9.968,419	1,153,783	1,129,187	910,712
Ro-ro ship	213	1.,700,121	2.525,124	1,289,693	1,259,570	228,942
Vehicle carrier	456	1,328,839	707,967	1,511,077	1,706,638	172,710

For hydrogen cases, hydrogen is combusted in an internal combustion engine with 85% hydrogen and 15% pilot diesel fuel developed by BeHydro [4]. Another important aspect is that, according to FuelEU and EU ETS regulations, if a ship departs from an EU port and arrives at a non-EU port, or vice versa, 50% of the emitted CO_2eq needs to be included. Once the assumptions and boundaries are defined, WTW emissions can be calculated using Equation 1.

$$WTWCO_2eq = WTTCO_2eq + TTWCO_2eq \quad (1)$$

In the equation WTT is well-to-tank and TTW is tank-to-wake. To determine WTTCO_2eq, equation 2 is used.

$$TTWCO_2eq = TTWCO_2 + TTWCH_4 \times CFCH_4 + TTWN_2O \times CFN_2O \quad (2)$$

In equation 2, the coefficient factor (CF) for CH_4 is 28, while 265 for N_2O [5]. TTW emissions for MDO are specified in FuelEU Regulation [5], but for hydrogen, it is obtained from GREET Model 2023 [6]. Additionally, WTTCO_2eq is calculated by equation 3.

$$WTTCO_2eq = (FC \times WTTCO_2eq \times LCV)_{Pilot\ fuel} + (FC \times WTTCO_2eq \times LCV)_{Primary\ fuel} \quad (3)$$

In the equation, FC represents fuel consumption and LCV is a lower calorific value. Also, during the WTT calculations, MDO and gray hydrogen are given in the FuelEU Regulation, yet for blue and green hydrogen it is gathered from GREET Model 2023. All the variables considered in the study are presented in Table 2.

Table 2. Parameters that are used in the study

Variables	**MDO**		**Gray hydrogen**		**Blue hydrogen**		**Green hydrogen**	
	WTT	TTW	WTT	TTW	WTT	TTW	WTT	TTW
CFCO₂	N/S	3.206	N/S	0	0.00006	0	0.000002	0
CFCH₄	N/S	0.00005	N/S	0	0.0000004	0	0.000000003	0
CFN₂O	N/S	0.00018	N/S	0.001037	0.000000003	0.001037	0.00000000002	0.001037
CO₂eq	14.4	3.2551	132	0.2747	75.6	0.0275	1.8	0.2747
LCV (MJ/g)	0.0427		0.12		0.12		0.12	

The WTW emissions are presented in Fig. 1, and the results show that container shipping is the highest contributor, with a 28% share. Therefore, in this paper, the calculations are made based on container ships transversing in EU regions.

After WTW emissions are determined, GHG intensity and FuelEU penalty cost can be calculated using equations 4 and 5 [5].

$$GHG_{intensity} = \frac{WTWCO_2eq}{(FC \times LHV)_{Primary\ fuel} + (FC \times LHV)_{Pilot\ fuel}} \quad (4)$$

$$Penalty\ cost = \frac{(GHG_{intensity} - TargetGHG_{intensity}) \times (FC \times LHV)_{Primary\ fuel} + (FC \times LHV)_{Pilot\ fuel}}{GHG_{intensity} \times Euro/MJ} \quad (5)$$

In Equation 5, the target GHG intensity represents the limit determined by the FuelEU regulation. Moreover, the EU ETS quota cost is calculated three times: in 2025, 40% of the CO_2eq will be reported; in 2026, 70% of the CO_2eq will be reported; and in 2027 and beyond, 100% of the CO_2eq will be reported [7]. Therefore, Equations 6–8 are utilized to determine the impact for each year.

$$EU\ ETS\ cost = 0.4 \times TTWCO_2 \times Quota\ cost \quad (6)$$

$$EU\ ETS\ cost = 0.7 \times TTWCO_2eq \times Quota\ cost \quad (7)$$

$$EU\ ETS\ cost = TTW CO_2eq \times Quota\ cost \quad (8)$$

During the calculations, quota costs are estimated at $90 as was the case in 2023 [8].

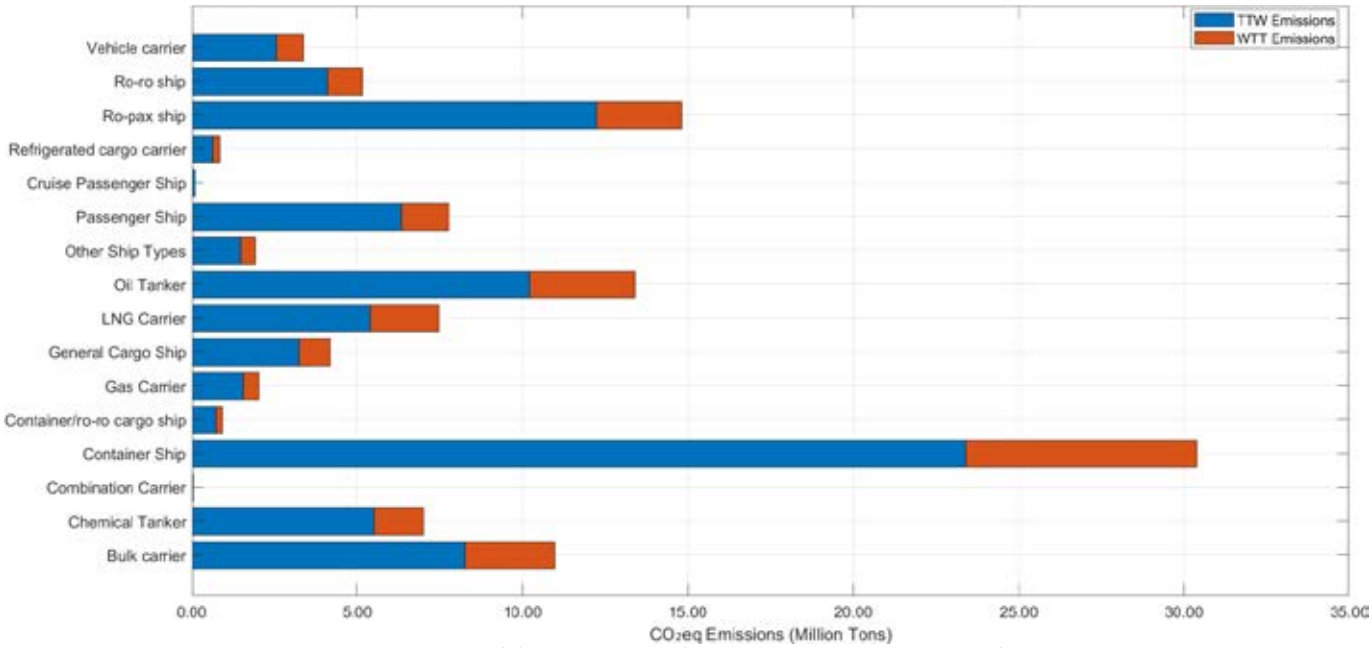


Fig. 1. TTW CO_2eq emissions for each vessel type using MDO

3. RESULTS AND DISCUSSION

Fig. 2 shows the FuelEU penalty costs for each fuel selection. The findings highlight that gray hydrogen has the highest GHG impact, resulting in higher penalties, followed by blue hydrogen and MDO, while no additional expenses arise from utilizing green hydrogen. Despite the TTW CO_2eq for hydrogen options being almost one-fourth of MDO's—23,406,842 tons for MDO and 6,481,237 tons for hydrogen derivatives—the WTT CO_2eq of gray hydrogen is 694% higher and that of blue hydrogen is 361% higher than the MDO option. On the other hand, green hydrogen WTT CO_2eq is 74% lower compared to MDO's. The cumulative outcomes indicate that by using gray hydrogen, penalties will begin in 2025, for blue hydrogen in 2035, and for continued use of MDO, penalties will start after 2040.

In Fig. 3, EU ETS quota prices are illustrated for each case. According to the results, MDO incurs the highest expense, while the others have the same outcome since the EU ETS considers TTW emissions rather than WTW emissions. Consequently, the outcome does not change because each case utilizes a fuel blend of 15% pilot diesel and 85% hydrogen. However, in 2025, only CO_2 emissions are considered; thus, MDO has 319% higher costs, while in subsequent years, the cost difference decreases to 261% as N_2O and CH_4 emissions are also included.

In Table 3, costs are listed for all fuel options. FuelEU and EU ETS costs are annual costs, and penalties will be paid each year. The findings reveal that compared to FuelEU costs, EU ETS costs are much lower; therefore, gray hydrogen does not provide the desired benefits. Additionally, blue hydrogen is only attractive in the period between 2035 and 2040, as the EU ETS benefit outweighs the harms from FuelEU penalties. However, green hydrogen is a prominent choice across all years.

Table 3. Fuel EU penalty and EU ETS quota costs for each fuel choice

Fuel types	FuelEU 2025	FuelEU 2030	FuelEU 2035	FuelEU 2040	Fuel EU 2045	FuelEU 2050	EU ETS 2025	EU ETS 2026	EU ETS 2027
MDO	-	-	-	-	$12,686M	$20,099M	$822M	$1,474M	$2,106M
Gray Hydrogen	$8,518M	$9,327M	$11,046M	$14,383M	$20,651M	$24,291M	$196M	$408M	$583M
Blue hydrogen	-	-	$650M	$5,992M	$16,031M	$21,859M	$196M	$408M	$583M
Green hydrogen	-	-	-	-	-	-	$196M	$408M	$583M

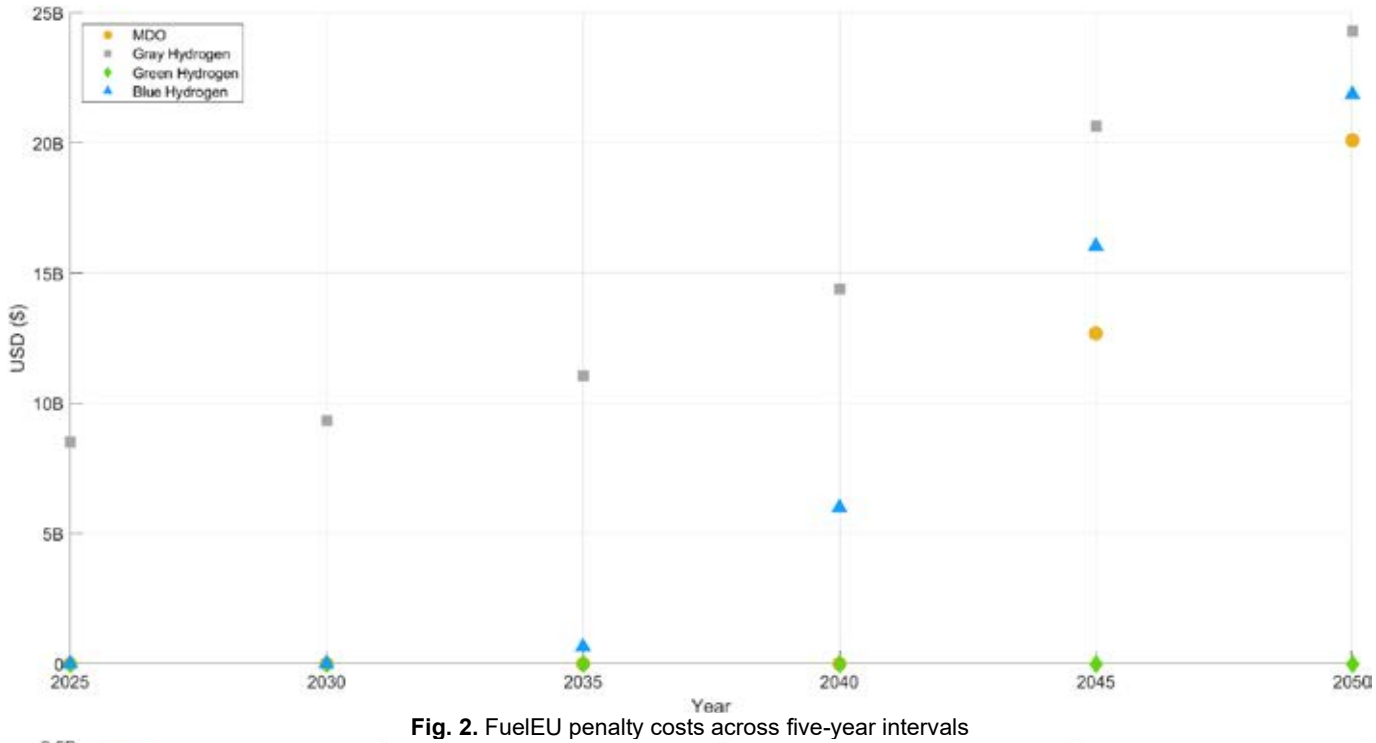


Fig. 2. FuelEU penalty costs across five-year intervals

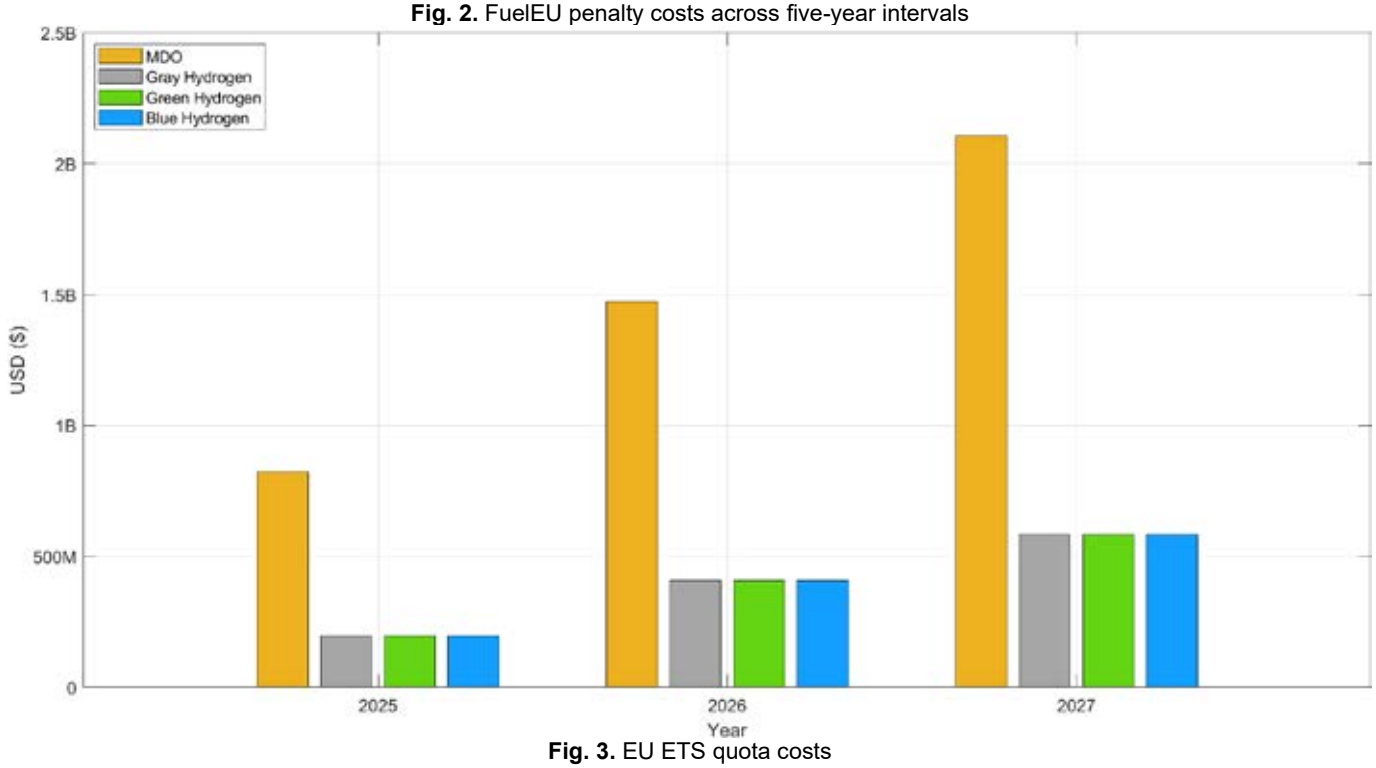


Fig. 3. EU ETS quota costs

4. CONCLUSIONS

This study evaluated the GHG emissions and regulatory impacts of using gray, blue, and green hydrogen fuels in maritime transport within the EU. The findings indicate that while hydrogen-based fuels significantly reduce TTW emissions compared to MDO, their WTW emissions and associated costs vary substantially. Gray hydrogen has the highest GHG intensity and incurs the highest penalties under FuelEU and EU ETS regulations, making it an unfavorable option. Blue hydrogen offers moderate benefits, particularly between 2035 and 2040, but its long-term viability remains limited due to rising penalties. In contrast, green hydrogen emerges as the most sustainable alternative, with the lowest emissions and regulatory costs, making it a viable solution for decarbonizing the maritime sector. In future research, various ammonia production pathways will be considered to evaluate the environmental impact of ammonia as a fuel. Additionally, an economic analysis will be conducted, encompassing both capital and operational expenditures.

Furthermore, while this study focuses solely on container ships, future studies will expand the analysis to include all types of vessels to determine whether the outcomes differ across ship types.

REFERENCES

1. https://portal.emsa.europa.eu/web/thetis/home. Accessed on October 11, 2024.
2. Det Norske Veritas (DNV). 2024. Energy Transition Outlook 2024.
3. United Nations Conference on Trade and Development (UNCTAD). 2024. Review of maritime transport.
4. https://www.abc-engines.com/en/news/launch-behydro-si-hydrogen-engine. Accessed on November 7, 2024.
5. European Union (EU). 2023. Regulation (EU) 2023/1805 of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC.
6. https://greet.anl.gov/. Accessed on November 8, 2024.
7. European Union (EU). 2023. Commission Implementing Regulation (EU) 2023/2449 laying down rules for the application of Regulation (EU) 2015/757 of the European Parliament and of the Council as regards templates for monitoring plans, emissions reports, partial emissions reports, documents of compliance, and reports at company level, and repealing Commission Implementing Regulation (EU) 2016/1927.
8. https://icapcarbonaction.com/en/ets/eu-emissions-trading-system-eu-ets. Accessed on December 2, 2024.