



УПРАВЛЕНИЕ НА МОРСКОМ ТРАНСПОРТЕ

UDC 656.61:[628.395+62-63]:336.221.264
EDN CKHSXE

ASSESSMENT OF THE CONSEQUENCES OF THE POSSIBLE INTRODUCTION OF THE IMO NET-ZERO FRAMEWORK*

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This article examines the adequacy of the Greenhouse Gas Fuel Intensity (GFI) indicator, which is a key element of the IMO's developing Regulations on the Net-Zero Framework and the methodology for assessing Well-to-Wake (WtW) lifecycle emissions. Based on a representative sample of ships under the Russian flag (oil tankers, container ships, dry cargo ships (general cargo)) with various CII ratings, the authors performed a series of calculations for seven scenarios replacing conventional fuel with very low sulfur fuel oil (VLSFO) and biofuels (FAME, HVO).

The results of the study showed that the GFI indicator is insensitive to a ship's operational efficiency, and switching to alternative fuel types does not lead to a significant reduction in the carbon footprint under the WtW methodology. It was established that by 2030, most ships will be obliged to pay "carbon fees" to the IMO Net-Zero Fund. Paradoxically, the most economically advantageous strategy for a shipowner in the short term is to refrain from implementing biofuels, as their adoption leads to double expenses (higher fuel costs plus the IMO payments). The authors conclude that in its current form, the GFI is an instrument of fiscal, rather than direct environmental, regulation. Its effectiveness is only possible through a comprehensive approach that combines energy efficiency improvements and the use of external energy sources.

Keywords: IMO, GFI, WtW, Net-Zero Framework, CII, energy efficiency, ships under the Russian flag, Russian Maritime Register of Shipping.

For citation: Berezin A.O., Reutskii A.S., Shurpyak V.K., Tolmachev S.A. Assessment of the consequences of the possible introduction of the IMO Net-Zero Framework. *Research Bulletin by Russian Maritime Register of Shipping*. 2026. Vol. 56, No. 2. P. 25–38. EDN CKHSXE.

* Уважаемые читатели! Версия на русском языке опубликована сразу после английской версии.

INTRODUCTION

The latest studies demonstrate a significant decrease in greenhouse gas emissions from ships (GHG emissions), for example the competent assessment of INTERTANKO demonstrate reduction of international shipping GHG emissions, which reached 37,85 % from the level of 2008 [1, Table 2]. This fact shows the effectiveness of IMO measures, adopted in the last several years. These measures include decrease of content of sulphur in ship fuel, implementation of NO_x Technical Code and implementation of several design and operational coefficients (EEDI, EEXI, CII). Obviously, such measures cannot help to achieve very ambitious goals as per 2023 IMO Strategy on Reduction of GHG Emissions from Ships to reaching net zero emissions from international shipping around 2050. To this aim, the Net-Zero Framework is under consideration at IMO presently, based on WtW methodology, accounting emissions in the whole life-cycle assessment of marine fuels.

The Net Zero Framework comprises of technical and economic elements as well as different supporting guidelines. Draft work plan to prepare for entry to force of the IMO Net-Zero Framework includes 13 work streams [2], most important of those in conjunction with this study are:

- development of guidelines related to the GHG Fuel Intensity (GFI) and GFI compliance approaches;
- further development of the LCA Framework (amendments to the 2024 LCA Guidelines, development of default GHG emission factors); and
- IMO Net-Zero Fund.

The last item on the list demonstrates a very unusual phenomenon for IMO – the element of the so-called economic measure. The link between economic measures and reducing greenhouse gas emissions lies in financial mechanism which aims at equalizing the price of conventional oil fuel and alternative fuels. An IMO Fund that collects money from shipowners and distributes it among alternative (ZNZ – zero or near zero carbon) fuel producers, manufacturers of energy-efficient technologies and other stakeholders. According to the authors of these measures, such approach should pave the way for the decarbonization of maritime transport.

Thus, the main purpose of this study is to assess adequacy of the GFI from the point of its ecological effectiveness and fiscal burden to shipowners as GFI is the cornerstone of IMO respective methodology [3].

The study has several objectives:

- determination of the sensitivity of the ship operation scheme to GHG emissions in the context of GFI;
- potential reduction GHG emissions from ships in case of adoption GFI as is, in comparison with the IPCC methodology;
- financial consequences for shipowners in case of adoption of related MARPOL Annex VI amendments with GFI-related framework, such as increase in fuel costs and contributions to IMO Net-Zero Fund [3].

Based on results of this study authors made several conclusions about the content of IMO Net-Zero Framework economy measures.

1. DATA COLLECTION

For the determination of attained GFI, representative data collection of ships under the flag of the Russian Federation and classed by the Russian Maritime Register of Shipping was used. The fuel consumption data of those ships for 2024 year was submitted to the IMO Data collection system (DCS), so the ships had appropriate CII ratings (A, B, C, D, E). The parameters of the chosen ships in statistical data set provide representativeness of this set, thus results of this study can be extrapolated to ships under the flag of the Russian Federation which fall under the Regulations 27 and 29 of the Annex VI to MARPOL. Statistics contains ships of three types — oil tankers, containerships and dry cargo ships. The ships of the same type divided by their deadweight and CII rating for their check sensitiveness of operation scheme to the intensity of the GHG emissions. Anonymized ship data is presented in Table 1.

From all ways to reduce GHG emissions by sea-going ships only change of traditional fuel to various combinations of low-sulphur fuel and biodiesel (diesel fuel, containing up to 30 % of product from biogenic feedstock) does not require substantial capital investments in ship and bunkering infrastructure. Since the methodological assistance for such combinations has been fully covered by the LCA Guidelines [3], only that type of alternative fuels was considered in this study. Besides a significant potential of other alternative fuels (methanol, ethanol, methane [4, 5], hydrogen [6]) in GHG emissions reduction, a number of objective reasons make the prospect of using them at least vague at present and the foreseeable future due to their unavailability in the global bunkering

Table 1

Anonymized characteristics of some ships in statistical data DCS for 2024 year

Ship type	DWT	Power (nominal)		CII Rate	Fuel consumption (t)		Emissions of CO ₂	
		ME	ADG		MDO	HFO	MDO	HFO
Oil tanker	112 909	13 778	4 440	A	2 254	7 452	7 227	23 206
Oil tanker	156 572	18 660	3 060	B	244	7 488	784	23 318
Oil tanker	109 989	11 327	2 400	C	117	2 453	375	7 647
Oil tanker	110 119	11 327	2 400	D	102	1 292	326	4 024
Container ship	13 007	7 860	1 950	A	243	3 631	780	11 307
Container ship	12 561	7 980	1 845	B	47	3 674	151	11 476
Container ship	8 168	7 000	1 860	C	387	2 784	1 241	8 668
Container ship	8 138	7 200	1 500	D	960	2 450	3 078	7 629
Container ship	8 200	7 200	1 500	E	700	2 200	2 244	6 851
Dry cargo ship	8 168	2 400	852	A	189	689	607	2 146
Dry cargo ship	7 365	5 100	1 000	B	266	1 626	851	5 071
Dry cargo ship	7 726	2 400	720	C	174	790	558	2 460
Dry cargo ship	7 649	2 400	720	D	202	721	649	2 245
Dry cargo ship	8 825	5 440	800	E	540	1 729	1 732	5 383

market, the lack of ready-made technical means for using and a lack of understanding of their future value and necessary implication costs. Many gaps in methodology, such as the lack of certain WtT default coefficients, make their accounting in this study impossible. The characteristics of fuel used in this study are presented in Table 2.

Table 2

The fuel characteristics used in this study

№	Fuel type	GFI	LCV	Conversion factors			TtW GHG intensity	Eij = WtT + TtW	Cost*
				Cf _{CO₂}	Cf _{CH₄}	Cf _{N₂O}			
		g CO ₂ -eq/MJ	MJ/g	g CO ₂ /g fuel	g N ₂ O/g fuel	g CH ₄ /g fuel	g CO ₂ /MJ		
1	VLSFO _{S ≤ 0,50}	16,8	0,0402	3,114	0,00005	0,00018	78,68	95,48	519
2	HFO _{S > 0,50 %}	14,9	0,0402	3,114	0,00005	0,00018	78,68	93,58	444
3	MDO _{S ≤ 0,10}	17,7	0,0427	3,206	0,00005	0,00018	76,23	93,93	662
4	BioD _{FAME}	20,8	0,0372	2,834	0	0	15,24	36,04	1 450
5	BioD _{HVO}	14,9	0,044	2,834	0	0	12,88	27,78	2 400

* Average cost in 2025 by [7, 8].

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Since, according to the methodology being developed [3], the type of feedstocks and production methods of marine biofuels significantly affect WtT emissions («from well to tank»), thereby affecting GFI, these parameters are included in Table 2 to increase reproducibility and scientific validity. Emissions of CH₄ and N₂O are insignificant, but for the chosen fuels they are also included in the analysis. The calculation of the achieved value of the intensity of fuel emissions from ships is carried out in accordance with the Guidelines on life cycle GHG intensity of marine fuels [3].

2. GLOBAL WARMING POTENTIAL

Some gases, released during the production and consumption of marine fuel are associated with the process of global warming. The global warming potential (GWP) is used to quantify the impact of greenhouse gases on the climate. It shows the amount of radiation energy, absorbed by one ton of GHG compared to one ton of CO₂ over some period (20, 100 or 500 years). In IMO Guidelines a period of 100 years was chosen for the calculations of GWP. GWP is a key characteristic for comparing different GHG impacts on the climate and the use of CO₂ is equivalent to a value of 1. A higher GWP indicates that the gas has a stronger greenhouse effect compared to CO₂. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the GWP values for CO₂, CH₄ and N₂O over a 100-year period (GWP-100) are shown in Table 3 [9].

Table 3

Global warming potential of considered gases	
Gas	GWP-100
CO ₂	1
CH ₄	28
N ₂ O	265

GWP-100 of methane is 28, so it means, that in 100-year period one ton of CH₄ absorb almost 28 times more of radiation energy than equal mass of CO₂. Despite its high GWP, methane has a relatively short residence time in the atmosphere – about ten years. In contrast, nitrous oxide remains in the atmosphere for more than a hundred years and has a GWP-100 of approximately 265, which makes it significantly more potent than CO₂ in terms of long-term climate effects.

3. INTRODUCED NEW IMO REGULATIONS

The IMO Net-Zero Framework's key indicator is the Greenhouse Gas Fuel Intensity (GFI), which shifts the regulatory focus from the operational efficiency of a ship to the carbon intensity of the fuel it uses. The GFI Standard is a regulation of the carbon intensity of fuels applied to ships with a gross tonnage of more than 5 000. GFI is a fundamental element of the broader IMO decarbonization program. When determining it, the WtW methodology is used, which takes into account GHG emissions throughout the entire life cycle of marine fuels (from production and transportation to on-board combustion), which creates a comprehensive basis for assessing compliance [10]. Ships will need to calculate annually the values of the attained annual intensity of GHG fuel emissions, expressed in g CO₂-eq/MJ (1).

$$GFI_{attained} = (\sum_j EI_j Energy_j) / (Energy_{total}), \text{ g CO}_2\text{-eq/MJ}, \quad (1)$$

where j – type of fuel or source of energy;

J – the total number of fuel or energy sources used during the reporting period of the sea-going ship operation, in this study for all vessels calculated at $J = 2$ (HFO and MDO);

EI_j , g CO₂-eq/MJ is the GHG content in each j -th fuel, i.e. the amount of GHG released into the atmosphere to produce 1 MJ of energy from the fuel during the WtW process;

$Energy_j$, MJ is the amount of energy of each type of fuel j ;

$Energy_{total}$, MJ is the total amount of energy used by a sea-going ship during the reporting period.

Despite the fact that the fuel used by the ship contains a significant part of the total energy, the calculation of $Energy_{total}$ also takes into account the use of electricity generated from onshore power plants and the use of renewable energy sources.

The value of g CO₂-eq (2) is calculated based on the 100-year global warming potential of CO₂, CH₄ and N₂O (Table 3).

$$gCO_2\text{-eq} = GWP_{CO_2(100)} \cdot gCO_2 + GWP_{CH_4(100)} \cdot gCH_4 + GWP_{N_2O(100)} \cdot gN_2O. \quad (2)$$

The use of energy sources with zero or near zero emissions makes it possible to significantly reduce the $GFI_{attained}$ value and, subject to the established thresholds, ensure that ship meets prospective regulatory requirements without additional financial obligations. As part of the IMO Net-Zero Framework being developed, two tier target annual GHG fuel intensity indicator (GFI_T) has been established. For the period 2028-2035, the values of two tier of GFI_T have been determined: the GFI base Target (Base Target Annual GFI) and the GFI Direct Compliance Target (Direct Compliance Target Annual GFI). Ships whose GFI values exceed the established

thresholds are required to compensate for the difference through the IMO Net Zero Fund mechanisms. The main terms used in this system are given in Table 4.

Table 4

Terms related to the GFI methodology

Термин	Определение
$GFI_{attained}$ GFI_T	The actual achieved GFI of the ship during the year, g CO ₂ -eq/MJ The GFI target for the year under review, calculated by applying a reduction factor to the base level of 2008 (93,3 g CO ₂ -eq/MJ), which includes two tiers
Base Target Annual GFI	The top-level annual GFI target (Tier 1), showing a decrease of 4 % in 2028 and 30 % in 2035 compared to the 2008 baseline
Direct Compliance Target Annual GFI	The top-level annual GFI target (Tier 1), showing a decrease of 4 % in 2028 and 30 % in 2035 compared to the 2008 baseline

When calculating GFI, the amount and intensity of emissions over the entire life cycle of each type of fuel consumed on the ship is taken into account. The actual intensity of GFI emissions is compared with two values: the target annual GFI – the "Base Target Annual GFI" – and the "Direct Compliance Target Annual GFI" (the values are tightened annually and set out in Regulation 35 of Annex VI of MARPOL for the period from 2028 to 2035, provided that by 2032 the annual reduction factors shall be determined for the period between 2036 and 2040 with due regard of already established value for 2040), thus the balance of compliance of a ship will be determined. Both the baseline and direct compliance targets, as well as the threshold for the introduction of technologies, fuels, and/or energy sources with zero or near zero greenhouse gas emissions (ZNZ), are shown in Figure 1.

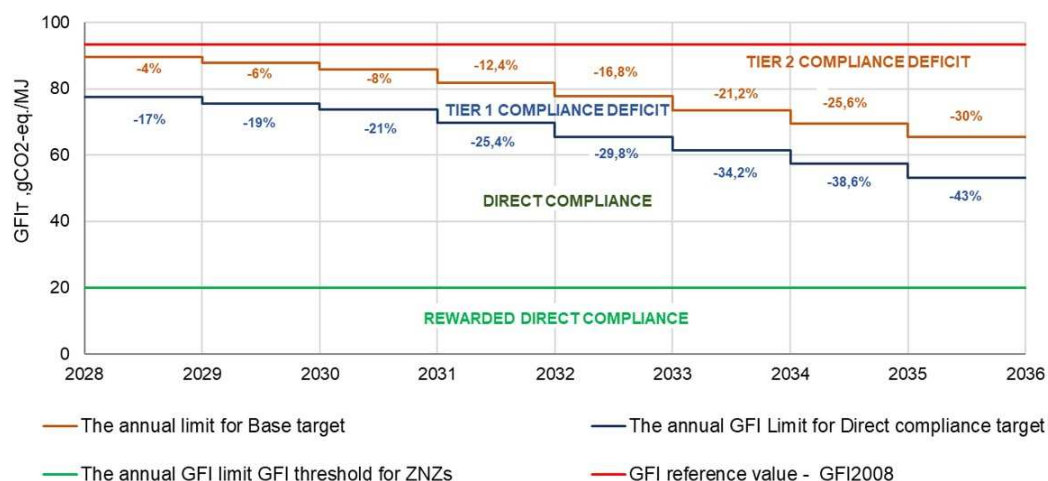


Fig. 1. Annual variation in GFI limits, incorporating base targets, direct compliance targets, and ZNZs

The baseline and direct compliance thresholds were gradually lowered from 2028 to 2035 for ships that they must meet the GFI target. Equation (3) is used to calculate the GFIT.

$$GFI = (\text{gCO}_2 - \text{equivalent}) / \text{MJ}, \quad (3)$$

$$GFI_T = (1 - Z_T/100) \cdot GFI_{2008}. \quad (4)$$

Calculation of the GFI compliance balance (in general terms):

According to the baseline and direct compliance targets shown in Figure 1, each ship's attained GFI for each year shall fall within the defined boundaries at the end of each reporting period. The ship's annual GFI compliance is determined accordingly. Equation (5) provides the method for calculating the GFI compliance balance.

$$GFI_{\text{compliance balance (tonnes of CO}_2\text{-eq)}} = (\text{Direct compliance target annual GFI} - GFI_{\text{attained}}) \cdot \text{Energy}_{\text{total}}. \quad (5)$$

If a ship's attained GFI value is lower than the annual GFI direct compliance target, that ship is considered to be in direct compliance and receives surplus units. The number of surplus units is determined by the positive GFI compliance balance. These units are to be recorded in the IMO GFI Registry at the end of each reporting period. The surplus units may be used in three different ways:

1. offset deficits of other ships (except Tier 1 deficits, which require remedial units);
2. use for future reporting periods when compliance targets become stricter;
3. cancel voluntarily to reduce GHG emissions (units expire after 2 years if unused).

If the GFI compliance balance is negative, the ship has a compliance deficit that must be addressed using the approved GFI methods. Such a deficit falls into one of two categories, as shown in Figure 1. In the first scenario, the ship's attained GFI is at or below the annual base target but still above the direct compliance target. This places the ship between blue and orange lines area of Figure 1, resulting in a Tier 1 compliance deficit (in tonnes of CO₂-eq), which is computed using Equation (6):

$$\text{Tier 1 compliance deficit (tonnes of CO}_2\text{-eq)} = (\text{Direct compliance target annual GFI} - \text{GFI}_{\text{attained}}) \cdot \text{Energy}_{\text{total}} \quad (6)$$

This results in 1 ton of CO₂-eq = 1 remedial unit, which costs \$ 100. Multiply *Tier 1 compliance deficit* by 100 USD and get the annual "carbon fee".

If the deficit is level 2, we calculate the balance of compliance by the formulas:

$$\text{Tier 1 compliance deficit (tonnes of CO}_2\text{-eq)} = (\text{Direct compliance target annual GFI} - \text{GFI}_T) \cdot \text{Energy}_{\text{total}} \quad (7)$$

$$\text{Tier 2 compliance deficit (tonnes of CO}_2\text{-eq)} = (\text{GFI}_T - \text{GFI}_{\text{attained}}) \cdot \text{Energy}_{\text{total}} \quad (8)$$

This results in one ton of CO₂-eq is equal to one compensation unit (remedial unit), which costs \$100 for *Tier 1 compliance deficit* and costs \$380 for *Tier 2 compliance deficit*. Multiply *Tier 1 compliance deficit* by \$100, *Tier 2 compliance deficit* by \$380, add them together and get the annual "carbon fee".

Thus, it becomes extremely important to evaluate several things.

1. Which part of the fleet under the flag of the Russian Federation and classed by the Russian Maritime Register of Shipping is subject to charges?
2. How does the operation scheme of a ship affect its GHG emission intensity?
3. What is the potential for reducing GHG emissions as a result of the introduction of GFI?
4. What are the financial consequences that shipowners expect as a result of the possible adoption of Amendments to Annex VI to the MARPOL Convention, in particular the GFI?
5. Under what conditions do GFI measures demonstrate a real reduction in GHG emissions?

4. CALCULATION METHODOLOGY AND ASSUMPTIONS ACCEPTED IN THIS STUDY

To solve the problems mentioned in the introduction, a series of calculations were performed using the algorithm shown in Figure 2.

A description of the collection of initial data on ships is provided in paragraph 1. The assessment used fuel consumption data of 14 real Russian-flagged ships with varies of CII Rate in 2024 presented in Table 1. The study considers seven options for replacing marine fuel. The reference values of the amount and nomenclature of fuel consumed by the selected ships represent Option No. 1. All ships in the statistical sample spent only high-sulfur fuel (HFO_{0.5 %S}) and marine diesel fuel / marine gas oil (MDO). Very low-sulfur heavy fuel (VLSFO), FAME biodiesel (B30 blend), marine diesel fuel (MDO), and HVO biodiesel were alternately used to replace these fuels. Thus, fuels for which the "default" GHG WtT emission factors are given in the Guidelines [3] were used as alternative fuels, thus, "exotic" options such as hydrogen, methanol, and ethanol were not considered.

Seven options available to shipowners are:

- Option № 1 – «To do nothing» – continue to use HFO and MDO, and purchase remedial units, which leads to the need of contribute to the IMO Net-Zero Fund;
- Option № 2 – change HFO to VLSFO;
- Option № 3 – change MDO to biodiesel (FAME);
- Option № 4 – change HFO to MDO – in this case ship use only MDO;

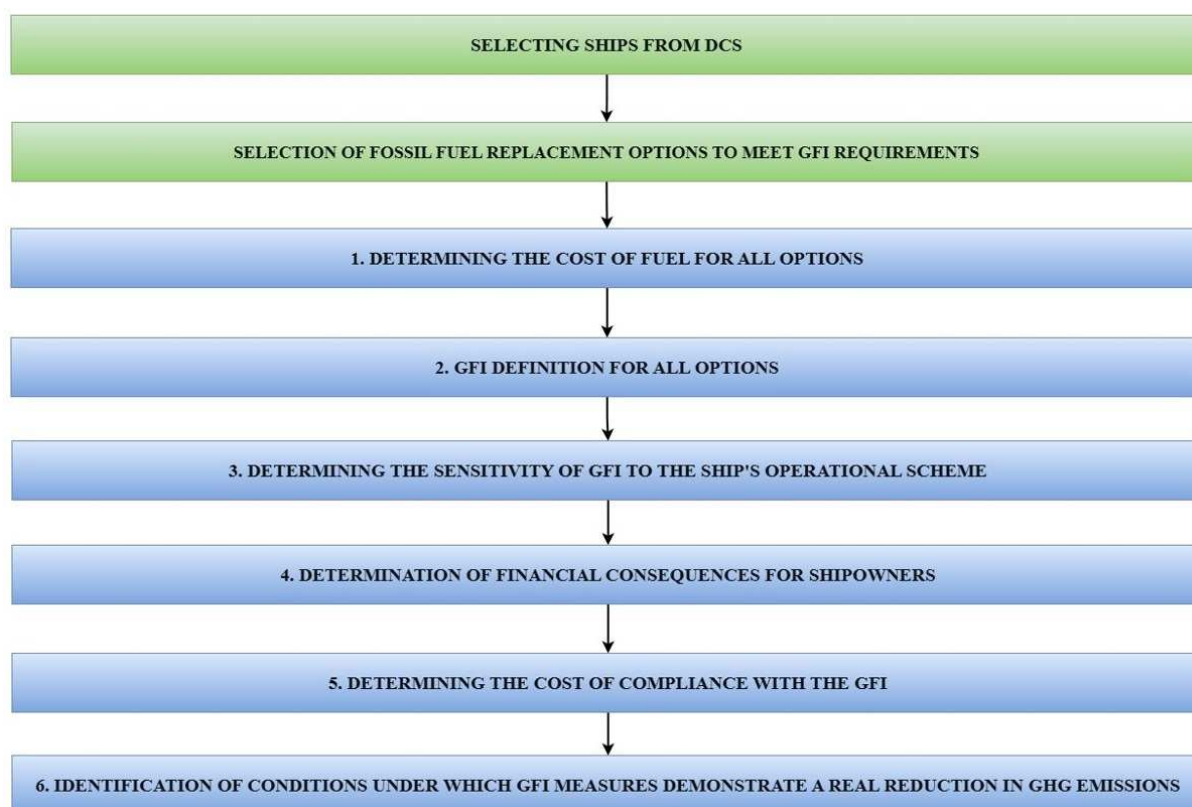


Fig. 2. Calculation algorithm implemented in the research

- Option № 5 – change HFO to VLSFO and MDO to biodiesel (FAME);
- Option № 6 – change MDO to biodiesel (HVO);
- Option № 7 – change HFO to VLSFO and MDO to biodiesel (HVO).

The options considered in the calculation are shown in Figure 3.

SELECTION OF FOSSIL FUEL REPLACEMENT OPTIONS TO MEET GFI REQUIREMENTS	
Option №1 - HFO _{0,5} +MDO	
Option №2 - VLSFO+MDO	
Option №3 - HFO _{0,5} +Diesel (FAME)	
Option №4 - MDO+MDO	
Option №5 - VLSFO+Diesel (FAME)	
Option №6 - HFO+Renewable Diesel (HVO)	
Option №7 - VLSFO+Renewable Diesel (HVO)	

Fig. 3. Options for replacing fossil fuels

The correspondence of the fuel designations selected in the calculation and the accepted designations in the basic standards are shown in Table 5.

Table 5

The correspondence of the fuel designations selected in the calculation and the accepted designations in the basic standards

Accepted designation	The basic standard
HFO	ISO 8217 Grades RME, RMG and RMK exceeding 0,50 % S
VLSFO	ISO 8217 Grades RME, RMG and RMK, 0,10 < S ≤ 0,50 %
MDO	ISO 8217 Grades DMX, DMA, DMZ and DMB maximum 0,10 % S
Diesel (FAME)	ISO 8217 Grades DMA (DF), DMF; EN 14214 or ASTM D6751
Renewable Diesel (HVO)	ISO 8217 Grades DMA (DF), DMF; EN 15940

The calculation included the following steps (in aggregate).

1. For all selected ships in the statistical sample (oil tanker, container ship and dry (general) cargo ship), the cost of spent fuel for 1 year was estimated at 2025 prices, the values found are reference values.
2. The cost of alternative fuels for replacement has been estimated.
3. A GFI attained estimate was made for all options (all ships and years for each replacement option (784 entries).
4. GFI compliance levels (Tiers 1,2) have been determined for each entry.
5. The annual GFI compliance balance has been determined for each record.
6. The cost of GFI compliance has been determined for each entry.
7. A new fuel cost and the cost of compliance (Fuel Cost + Cost GFI compliance) have been determined for each record.
8. The growth of annual fuel costs and the annual carbon fee to the IMO Fund has been determined in % relative to 2025 for each entry.

Assumptions used in the calculation: the cost of all types of fuels used in the calculation is assumed to be the average for 2025 in Singapore without changing during 2028-2029; the calculation does not take into account the cost of capital expenditures for the conversion of the ship's power plant to use alternative fuels.

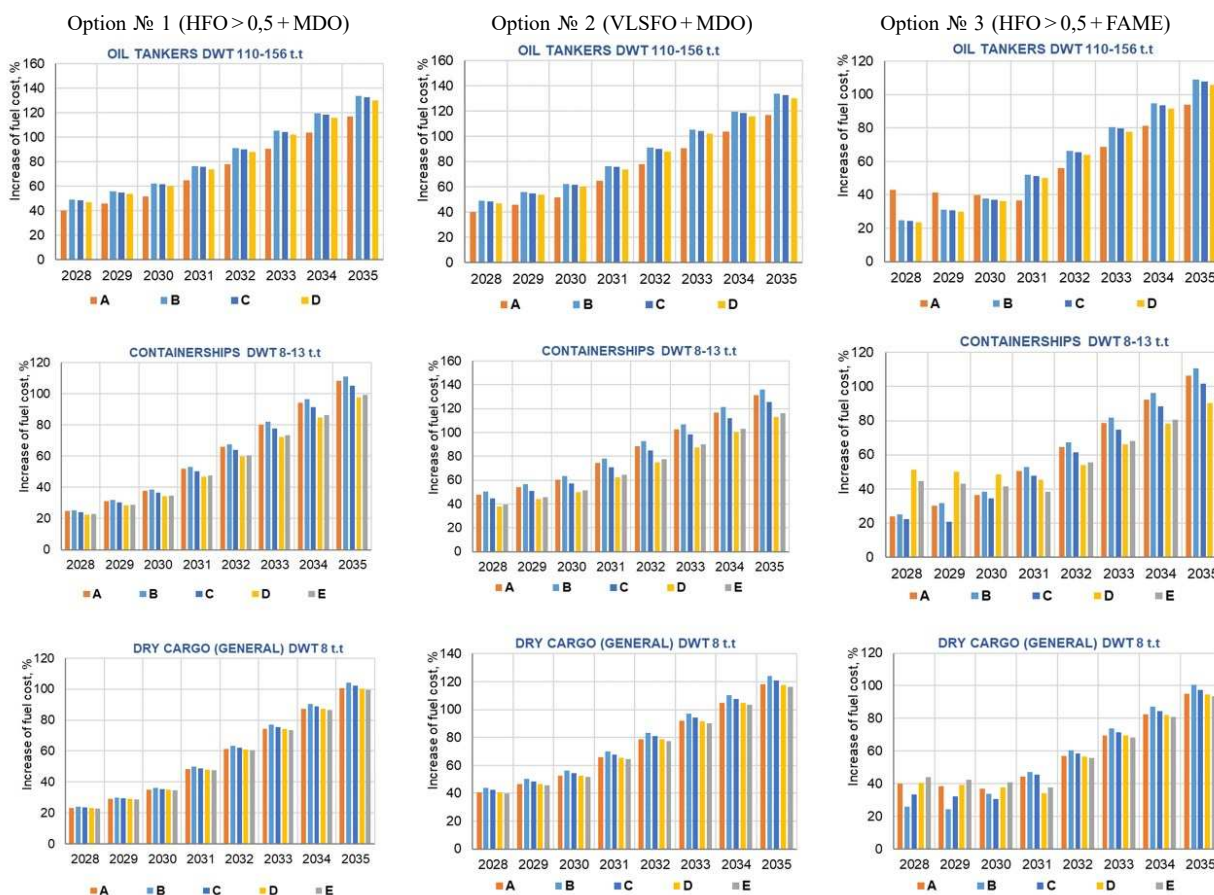
5. RESULTS OF THE CALCULATIONS

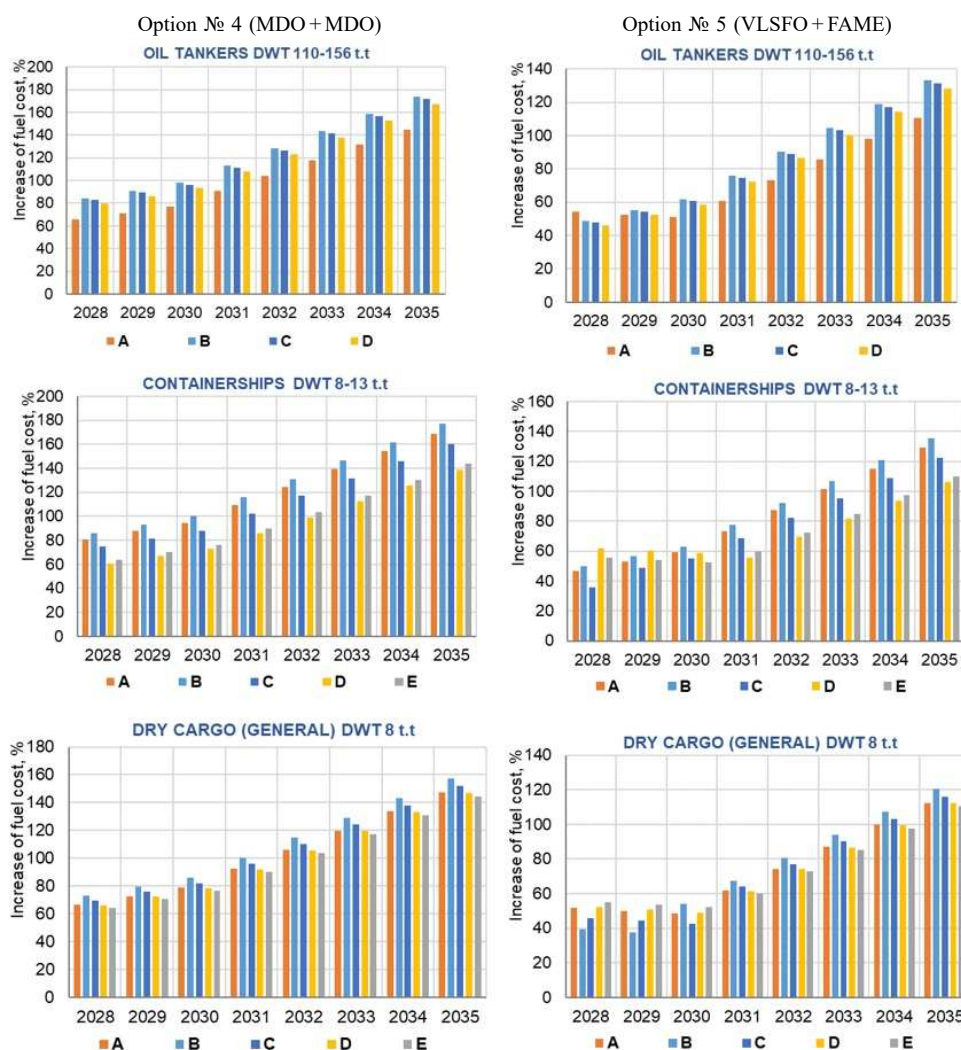
The results of mass calculations.

Table 6 shows the results of calculating the growth of annual fuel costs and the IMO annual carbon tax in 2028-2035.

Table 6

The results of calculating the growth of annual fuel costs and annual carbon tax IMO





The sensitivity of the ship operation scheme to its greenhouse gas emission intensity.

The calculation results showed that the GFI parameter is insensitive to the ship operation scheme, i.e. within the same type of ships with different CII ratings (A-E), there is no correlation between the CII rating and the $GFI_{attained}$ value. This is primarily due to the very structure of the $GFI_{attained}$ (1) formula, which does not include the transport work performed by ship.

The potential to reduce GHG emissions as a result of the introduction of the GFI compared to the current methodology for estimating emissions based on the IPCC emission factors.

To determine the potential for reducing GHG emissions as a result of the introduction of GFI compared to the current IPCC emission assessment methodology based on emission factors, an oil tanker with a CII rating A was selected and a comparative carbon footprint calculation (in t CO₂-eq) was performed for all seven fuel replacement options considered (Figure 4).

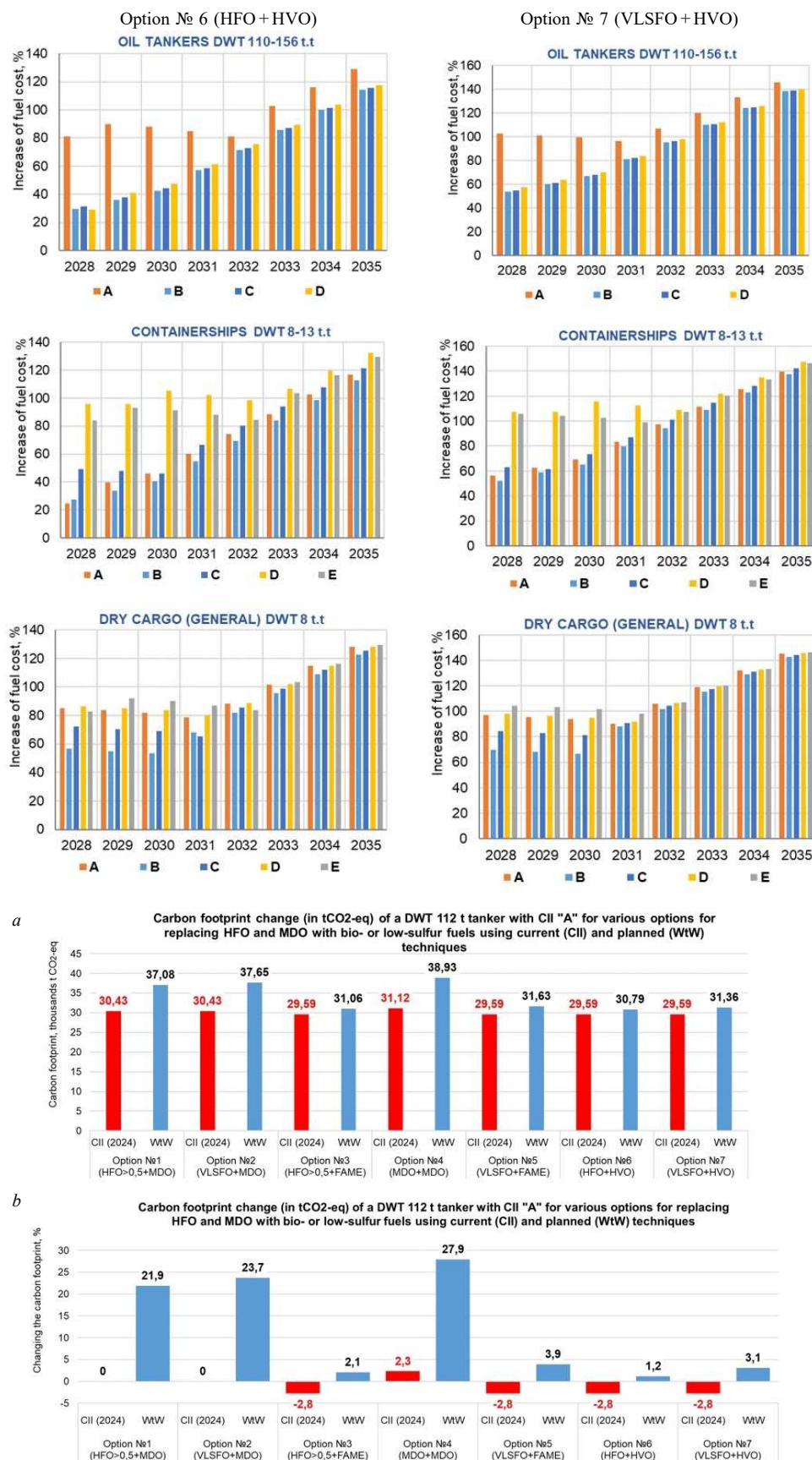


Fig. 4. Change in the carbon footprint (in t CO₂-eq) of a 112 000 DWT tonnage tanker with CII rating A with various options for replacing HFO and MDO with bio- or low-sulfur fuels using current (CII) and planned (WtW) methods in physical (a) and percentage (b) terms

As a result, it is shown that with any option of replacing conventional fuels with various bio- or low-sulfur fuel options, there is no significant reduction in the ship's carbon footprint (compared to 2025). This is due to a new method for calculating GHG emissions from the combustion of marine fuel ("well to wake"), which takes into account not only emissions on the ship (TtW), but also emissions that occurred during the production and transportation of fuel (WtT), and it also takes into account not only CO₂ emissions as before, but also methane and nitrogen oxide, meaning that the scope and nomenclature of emissions to be accounted have been significantly expanded.

The financial consequences that shipowners expect as a result of the possible adoption of amendments to Annex VI to MARPOL, in particular GFI.

In order to determine the financial implications for shipowners, minimum and maximum GFI values were determined for all ships and fuel replacement options, and the results are shown in Figure 5.

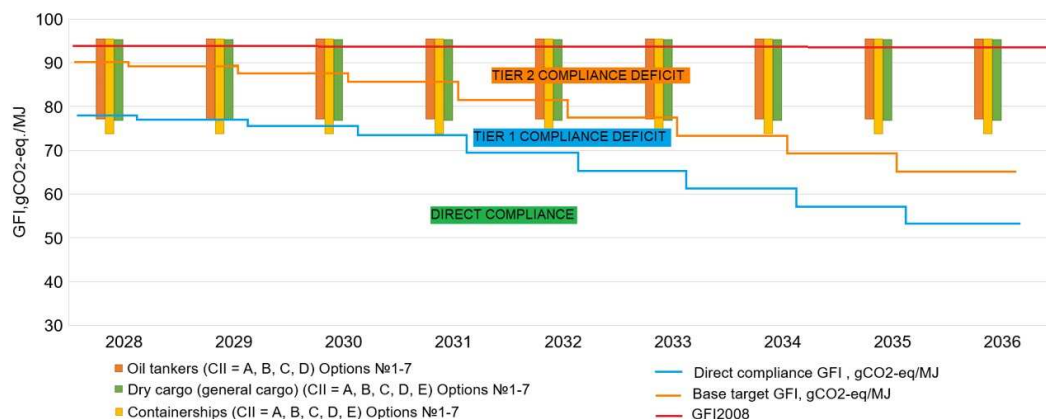


Fig. 5. Minimum and maximum GFI values for all ships and fuel replacement options

It follows from Figure 5 that for almost all ships in the statistical sample, regardless of their CII, the $GFI_{attained}$ value is higher than the basic compliance target for all selected fuel replacement options. Thus, by 2030, almost all ships subject to NZF Regulations will be required to pay "carbon fees" in the form of contributions to the IMO Net-Zero Fund. Thus, the introduction of the GFI methodology will lead to an increase in shipowners' operating costs.

What is the extent of the increase in the costs associated with the NZF Regulations? From the summary table 6 with all the options, the "best and "worst" fuel replacement options were selected for 3 selected groups of ships (Figure 6).

The results of the assessment demonstrate that the annual cost of IMO "carbon fees" to shipowners by 2035 will increase by 110 % at best compared to 2026. The most economically advantageous option is to "do nothing", i.e. not to introduce alternative fuels, since if they are introduced, you will still have to acquire remedial units and at the same time use more expensive fuel.

Additionally, it is necessary to highlight the trend according to which the new measure "hits" those ships in whose fuel consumption structure diesel fuel prevails and which operate in emission control areas (ECA).

The conditions under which GFI measures demonstrate a real reduction in GHG emissions.

So according to formula (1), where the denominator of the fraction contains the value of $Energy_{total}$, MJ, representing the total amount of energy used by the ship during the reporting period. In this calculation, the total energy spent by the ship per year is equal to the sum of the energy spent by the fuel $Energy_{total} = \sum_j EI_j \cdot Energy_{y,j}$, while it can take into account the use of electricity received from onshore power plants and the use of renewable energy sources. An attempt to take this additional energy into account in the calculation is presented as follows: for the recognized "best" and "worst" options (in terms of increased compliance costs, Option № 1 and Option № 7), the $Energy_{total}$ value was increased sequentially to 110 % in 2 % increments. Such an increase in energy is possible both by increasing the total energy consumed by the ship via onshore power supply (at the moment when the vessel is in port) and/or by using technologies to increase the energy efficiency of the ship (Energy Efficiency Technologies – EETs): increasing the efficiency of the propulsion system (screw attachment), hydrodynamic qualities of the hull (installation of a bulb), use of renewable energy sources (wind, solar), IT systems (voyage planners), etc.

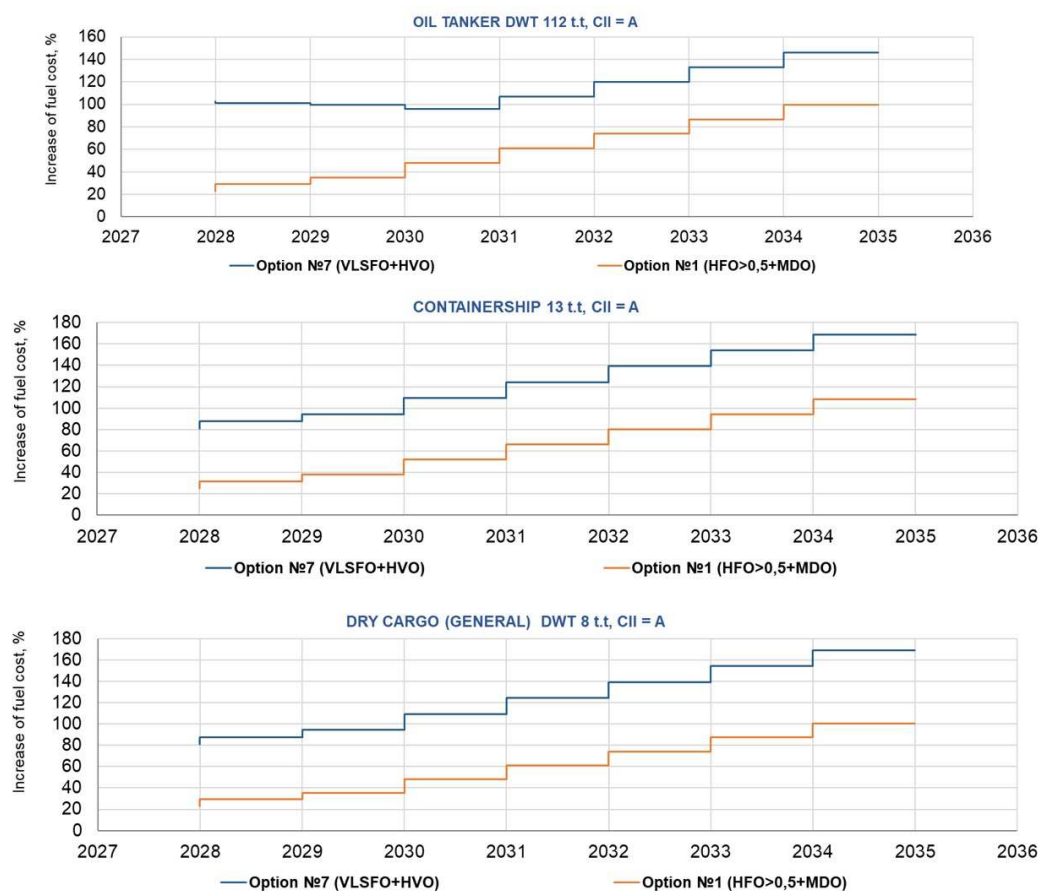


Fig. 6. Minimum and maximum increases in the cost of "carbon fees" to the IMO Net-Zero Fund

Many of EETs existing at this moment can't provide a significant reduction of fuel consumption for all types of ships and its operation schemes. For example, ships operating on ocean lines, such as ore carriers, can significantly save fuel by installing wind-propulsion systems, which is confirmed by theoretical and practical research [11]. However, there are groups of ships for which these energy-efficient solutions are simply not applicable due to their design, operational and cargo characteristics. F.e. bunkering ships spend considerable energy on cargo preparation and at the same time do not make long voyages. That puts many ships in a vulnerable position and can't provide a sufficient fuel economy even in case of implementation a numerous EETs. The calculation results are shown in the diagrams in Figure 7.

Thus, the implemented GFI measures will begin to "work" only if the value of the total energy spent by the ship relative to the fuel energy is increased, or, more simply, ways are found to save fuel (improve propulsive characteristics, improve hydrodynamic qualities of the ship's hull) and/or receive energy from outside – electrical (coastal supply in the port, electrical tanks), mechanical (sails).

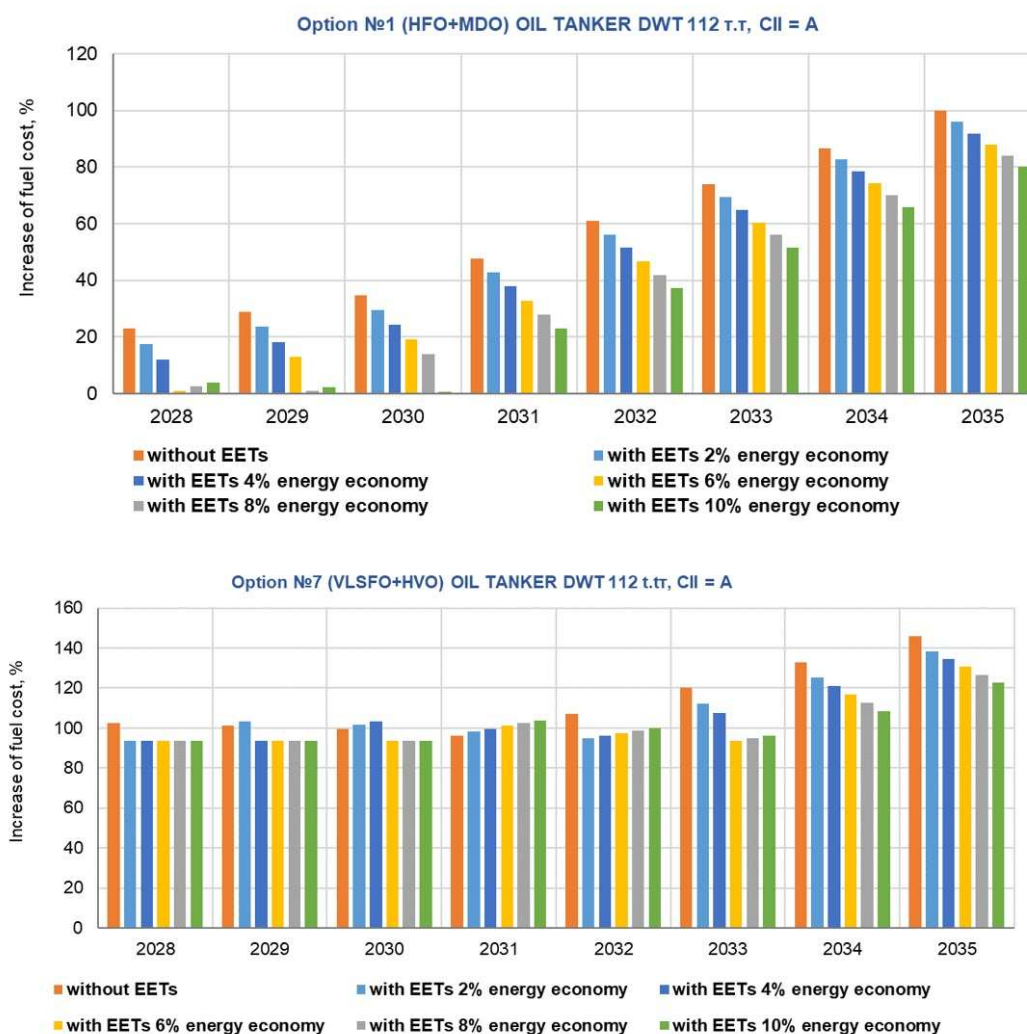


Fig. 7. Dependence of increased fuel and remedial units' costs on the use of energy-efficient technologies

CONCLUSIONS

Based on the conducted research, the following key conclusions can be drawn:

Insensitivity to operational efficiency. The indicator of the intensity of fuel greenhouse gas emissions (GFI) is practically insensitive to the operational efficiency of the ship. The study did not reveal a correlation between the carbon intensity rating (CII) of the ship and the achieved GFI value. This is explained by the structure of the GFI formula, which takes into account only the carbon intensity of the fuel and the total energy consumed, but does not take into account the transport work performed by the ship.

Low emission reduction potential when changing fuels to affordable alternatives. Switching to very low-sulfur fuels (VLSFO) or blends with bio-components (FAME, HVO) does not significantly reduce the ship's carbon footprint when assessed using the WtW methodology. This is due to the fact that the new methodology takes into account emissions not only from fuel combustion on board a ship (TtW), but also at the stages of its extraction, production and transportation (WtT), and also includes accounting for methane and nitrous oxide. As a result, the benefits of using biofuels are offset by emissions from previous stages.

Unavoidable financial costs. Regardless of the type of fuel chosen and the CII rating, all ships included in the sample will exceed the basic GFI targets by 2030. This means that almost all ships with a gross tonnage of more than 5,000 will be subject to mandatory financial contributions to the IMO Net-Zero Fund.

The paradox of economic efficiency. From an economic point of view, the most profitable strategy for a shipowner in the short term is to avoid the use of alternative fuels (Option № 1 is to use only traditional HFO and MDO). Any switch to more expensive biofuels or VLSFO still does not eliminate the need to acquire remedial units, which leads to double costs: for more expensive fuels and contributions to the IMO Net-Zero Fund.

Disproportionate impact on ships operating in ECA. The new measures have the strongest negative financial impact on those ships whose fuel consumption structure is dominated by expensive diesel fuel (MDO/MGO) used for operation in emission control zones (ECA). Their operating costs increase most significantly.

Conditions for the effectiveness of GFI measures. The study showed that the GFI methodology begins to demonstrate a real environmental effect only if the value of the total energy consumed by the vessel ($Energy_{total}$) increases relative to the energy obtained solely from fuel combustion. This is achieved through the implementation of energy efficiency measures (improvement of propulsive characteristics, hull hydrodynamics, etc.) and the use of external energy sources (onshore power supply, batteries, wind traction, etc.).

Thus, a numerical analysis of the adequacy of the IMO-developed GFI indicator has shown that in its current form it is an instrument of fiscal rather than direct environmental regulation. It creates a significant financial burden on shipowners, while not guaranteeing a commensurate reduction in greenhouse gas emissions with a simple fuel change. A real reduction in emissions within the framework of this paradigm is possible only with an integrated approach combining the use of alternative energy sources with a fundamental increase in the energy efficiency of ships, economic attractiveness (and therefore feasibility). Specific solutions to this problem are the subject of future research.

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Статья поступила в редакцию 02.04.2026.

Принята к публикации 31.05.2026.