INTERNATIONAL MARITIME ORGANIZATION

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MARINE ENVIRONMENT PROTECTION COMMITTEE
82nd session
Agenda item 7

MEPC 82/7/4/Add.2
26 July 2024
Original: ENGLISH
Pre-session public release: ☒

REDUCTION OF GHG EMISSIONS FROM SHIPS

Report of the Steering Committee on the comprehensive impact assessment of the basket of candidate GHG reduction mid-term measures
Executive summary of the report on Task 2 (Impacts on the fleet)

Submitted by the Secretariat

SUMMARY

Executive summary:	This document contains the executive summary of the report on Task 2 (Impacts on the fleet) of the Comprehensive impact assessment of the basket of candidate mid-term GHG reduction measures, as approved by the Steering Committee.
Strategic direction, if applicable:	3
Output:	3.2
Action to be taken:	Paragraph 2
Related documents:	MEPC 80/17, MEPC 80/17/Add.1; MEPC 81/7, MEPC 81/7/Add.1; MEPC 82/7, MEPC 82/7/1, MEPC 82/7/2, MEPC 82/7/4; MEPC 82/7/4/Add.1, MEPC 82/7/4/Add.3, MEPC 82/7/4/Add.4, MEPC 82/INF.8, MEPC 82/INF.8/Add.1, MEPC 82/INF.8/Add.2, MEPC 82/INF.8/Add.3 and MEPC.1/Circ.885/Rev.1

Introduction

1 The Comprehensive impact assessment of the basket of candidate mid-term GHG reduction measures consists of five distinct and interrelated tasks (MEPC 82/7/4, paragraph 5). This document provides the executive summary of the report of Task 2 on the assessment of the impacts on the fleet conducted by DNV, as approved by the Steering Committee, set out in the annex. The full report on Task 2 is set out in document MEPC 82/INF.8/Add.1.

Action requested of the Committee

2 The Committee is invited to consider, in conjunction with document MEPC 82/7/4, the executive summary of Task 2 (Impacts on the fleet) of the comprehensive impact assessment of the basket of candidate GHG reduction mid-term measures, taking into account the full report contained in document MEPC 82/INF.8/Add.1, and to take action as appropriate.

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ANNEX

EXECUTIVE SUMMARY OF THE REPORT ON TASK 2 (IMPACT ON THE FLEET)

Disclaimer

1 This report has been completed by DNV. It contains the report on Task 2 on the assessment of the impacts of the candidate measures on the fleet of the Comprehensive impact assessment of the basket of mid-term GHG reduction measures.

2 Whilst this report has been commissioned by the International Maritime Organization (IMO), the information contained within this report represents the view of its authors only. It should not be interpreted as representing the views of IMO, or the Steering Committee on the comprehensive impact assessment of the basket of candidate mid-term measures, or the States that are represented on the Steering Committee.

3 This comprehensive impact assessment of the basket of mid-term GHG reduction measures consists of five distinct but interrelated tasks for which different reports have been prepared. Task 2 of the Comprehensive impact assessment of the basket of candidate mid-term GHG reduction measures is being undertaken solely to assist IMO's Marine Environment Protection Committee (MEPC) in making evidence-based decisions. Any information included in this report is provided solely for analytical purposes and should not be interpreted as suggestions or recommendations for how the basket of mid-term GHG reduction measures should be designed. The policy combination scenarios and any other information included in this report are provided solely for analytical purposes and should not be interpreted as suggestions or recommendations for how the basket of mid-term GHG reduction measures should be designed.

4 The designations employed and the presentation of material on any map in this report do not imply the expression of any opinion whatsoever on the part of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Executive summary

5 This study assesses the impacts on the fleet of the basket of candidate measures designed to achieve the greenhouse gas (GHG) reduction goals set out in the 2023 IMO Strategy on Reduction of GHG Emissions from Ships (IMO GHG Strategy). It comprises Task 2 of IMO's comprehensive impact assessment of the basket of candidate mid-term GHG reduction measures.

6 The study defines two well-to-wake GHG emission trajectories to 2050, named as *Base* and *Strive* in this report, according to the indicative checkpoints and the IMO GHG Strategy's level of ambition to reach net-zero GHG emissions by or around, i.e. close to, 2050, and taking into account well-to-wake GHG emissions.

7 The *Base* trajectory reflects the lower ends of the indicative checkpoints, in other words to reduce the total annual GHG emissions from international shipping by 'at least' 20% by 2030 and by 'at least' 70% by 2040, both compared to 2008. The *Strive* trajectory reflects the upper ends of the indicative checkpoints, in other words 'striving for' reductions of 30% by 2030 and 80% by 2040 compared to 2008.

8 Sixteen policy combinations (basket of measures) have been modelled for each trajectory for a total of 32 policy combination scenarios which are compared to a BAU (business-as-usual) scenario with currently adopted policy measures. All follow a projection of low growth in seaborne trade.

9 The proposed policy measures address well-to-wake GHG emissions or tank-to-wake GHG emissions with sustainability criteria. However, for the purposes of the modelling, this study defines the GHG emission trajectories in a well-to-wake scope which should be followed regardless of the scope of the policy measures, in order to make the scenarios comparable.

Key findings

Impact on costs

10 The cost intensity of the fleet, measured in USD per tonne-mile, is expected to increase relative to a BAU scenario by 16% to 47% in 2030, 56% to 80% in 2040, and 71% to 85% in 2050.

11 In 2030, the cost intensity of the fleet is expected to increase relative to a BAU scenario by 16% to 40% across 16 policy combinations following the *Base* GHG emission trajectory of 20% reduction from 2008, and by 26% to 47% across 16 policy combinations following the *Strive* GHG emission trajectory of 30% reduction from 2008.

12 The lowest increases in cost intensity in 2030 are found in scenarios with a GHG Fuel Intensity (GFI) flexibility mechanism and no levy or feebate, while the highest increases are in scenarios with a 150–300 USD per tonne of carbon dioxide equivalent (tCO_2eq) levy due to the direct cost of the levy.

13 In 2040, the cost intensity of the fleet is expected to increase relative to a BAU scenario by 56% to 71% following the *Base* GHG emission trajectory of 70% reduction from 2008, and by 65% to 80% following the *Strive* GHG emission trajectory of 80% reduction from 2008.

14 The lowest increases in cost intensity in 2040 are found in scenarios with a GFI flexibility mechanism and a 30–120 USD/tCO_2eq levy. The range of cost-intensity increase is less in 2040 than in 2030 as the reductions in energy use across the policy combination scenarios are more similar, driven mainly by the increased costs of meeting the GFI requirements and to a lesser degree by the cost of the levy/feebate.

15 In 2050, the cost intensity of the fleet is expected to increase relative to a BAU scenario by 71% to 85% following the *Base* GHG emission trajectory, and by **73% to 83%** following the *Strive* GHG emission trajectory.

16 The *Base* and *Strive* GHG emission trajectories have similar ranges of cost-intensity increases as they both achieve close to net-zero GHG emissions in 2050. The lowest increases in cost come in scenarios with a levy and a GFI flexibility mechanism.

17 The aggregated cost per tonne GHG emission reduced over the whole period from 2023 to 2050 ranges from 292 to 354 USD/tCO_2eq. The lowest costs per tonne of GHG emission reduction are in the scenarios following the *Strive* GHG emission trajectory and in scenarios with a GFI flexibility mechanism.

Impact on energy use, fuels, and technologies

18 The results show a diverse mix of fuels and solutions both within and across scenarios where electrofuels (e-fuels) and onboard carbon capture and storage (CCS) appear to be the two most prevalent decarbonization solutions. Biofuels also have a significant contribution towards 2040 and 2050 across all policy scenarios. It should be noted that the modelled use of different feedstocks is to a large degree a result of the assumed supply constraints on bio- and blue fuel feedstocks, and also the assumed lack of constraints on e-fuels and carbon storage capacity. The projected feedstock supply and carbon storage capacity and the share available for shipping are very uncertain.

19 To achieve the GHG emission trajectories within the assumed supply constraints all fuel feedstocks need to be used, complemented by onboard CCS and reduction in energy use by way of energy-efficiency measures and speed reductions. In 2030, the uptake of low GHG emission fuels is between 0.3 and 2.9 exajoules (EJ), or about 7–69 million tonnes oil-equivalents, with the lowest uptake in scenarios with high reduction in energy use or high uptake of onboard CCS. In most scenarios, except those with high reduction in energy use, the total feedstock supply and carbon storage capacity exceed the median estimated projections in the literature.

20 Reduction of energy use in the fleet can significantly reduce the need for low GHG emission fuels and onboard CCS, which will reduce overall costs and increase the ability to reach the GHG emission trajectories under fuel feedstock supply constraints. There are barriers to implementation of energy-efficiency measures and speed reductions. A high GHG price or following the more stringent *Strive* GHG emission trajectory seem to increase the costs sufficiently to incentivize energy-efficiency improvements in the early period to 2030.

Impacts of different policy combinations

21 Applying a tank-to-wake scope with sustainability criteria or a well-to-wake scope did not result in any significant differences in cost intensity as the scenarios follow the same well-to-wake GHG emission trajectory. The well-to-wake scope scenarios combined with a levy have a slightly higher cost because the absolute cost of the levy is higher when well-to-tank GHG emissions are included.

22 A GHG Fuel Intensity flexibility mechanism can reduce the total cost per tonne of GHG reduction from 2023 to 2050 by about 6%. The GFI flexibility mechanism has the greatest effect when there are capital-intensive solutions – such as ammonia or methanol engines or onboard carbon capture systems – that enable ships to run on fuels with lower prices than drop-in fuels such as bio- and e-MGO. Towards 2050, the cost impact of the flexibility mechanism is lower.

23 The GFI flexibility mechanism may also be beneficial during the build-up of production and infrastructure for alternative fuels when such fuels have limited global availability. Ships that cannot find adequate fuels may exchange emission units (i.e. join in a compliance pool) with ships trading in areas where low GHG emission fuels are more readily available. The modelling in this study does not quantify this effect.

24 The levy and feebate mechanisms generally increase the cost intensity in 2030 due to the direct cost of the levy and fee, and limited reward for eligible fuels. Scenarios with a 150-300 USD/tCO_2eq levy have a higher reduction in energy use in 2030, which counters the additional cost to some degree. Towards 2040, as the GHG emission reduces and the uptake of eligible fuels increases, the total impact on cost intensity is less. Other than the reward for eligible fuels, it should be noted that no other disbursement of revenues to shipping are included in the modelling.

25 Significant revenues can be generated by the levy or feebate mechanisms, ranging from 17 to 127 billion US dollars per year (BUSD/year) in the period 2027–2030 before these revenues decrease gradually with reduced GHG emissions towards 2050. It is estimated that about 2 to 35 BUSD/year in 2027–2030 and 15 to 42 BUSD/year in 2031–2040 will be distributed back to shipping as reward for eligible fuels. Remaining funds are available for other disbursement purposes. The GFI flexibility mechanism could also raise revenues through sale of Remedial Units to ships.

26 The reward for eligible fuels in the levy and feebate mechanisms incentivizes uptake of e-fuels, in particular e-ammonia and e-LNG. Together with bio-LNG they have the highest uptake in scenarios with a levy in combination with a reward mechanism. The modelled uptake of fuel types is very sensitive to relatively small changes in the levy and reward levels.

27 The modelling indicates that if R&D spending can result in two to three years' earlier availability of technologies as well as 20% less capital cost, the cost per tonne of lowering GHG emissions over the period 2023–2025 can be reduced by 4%. It has not been possible to ascertain the magnitude of R&D spending required to achieve the effect assumed in the modelling.

Key uncertainties

28 The main uncertainty which has the most significant impact on the results are future fuel prices. Using the projected range of fuel prices from literature, the cost intensity increases relative to BAU in 2030 ranges from 12% to 60%, somewhat larger than the range due to varying the policy combinations. Towards 2040 and 2050, the uncertainty over fuel prices increases. The cost intensity increases between 47% and 109% by 2040, and between 46% and 129% by 2050. The total cost per tonne of GHG reduction within the projected range of fuel prices ranges from 210 to 487 USD/tCO_2eq.

29 The number of retrofits to other fuel technologies or onboard CCS in the scenarios are significant, peaking between 2,000 and 3,600 retrofits per year. Due to the complexity of retrofitting ships to alternative fuel technologies and onboard CCS, it remains uncertain if these numbers are feasible for the yards and equipment manufacturers to deliver. The implication that such retrofit rates are unfeasible is that more ships have to run on more expensive drop-in fuels such as bio-MGO and e-MGO.

Approach

30 This study applies a scenario-based framework to model the effect of various policy combinations and assess the impacts on the fleet. The high-level method applied can be divided into three main steps.

31 In the first step, a Baseline fleet for 2023 is established using the MASTER (Mapping of Ship Tracks, Emissions and Reduction potentials) model, where energy consumption and ship activity are calculated based on global ship-tracking data from the Automatic Identification System (AIS) combined with ship specific data from other sources.

32 This forms the starting point for step two, the simulation of the future fleet year-by-year towards 2050 using the GHG Pathway model. For each year, the model evaluates all available GHG emission reduction solutions for each individual ship built that year or in operation. The evaluation simulates the decision from a shipowner's perspective on the use of alternative fuels, onboard carbon capture, energy-efficiency packages, and speed reduction. The proposed basket of measures is modelled in policy combination scenarios as input on regulatory requirements, costs and rewards. The ships are fitted with the most cost-effective, feasible combination of measures that fulfil the regulatory requirements.

33 Finally, in the third step, the scenario outputs are analysed with regard to GHG emission trajectories; change in cost intensity and total cost per tonne of GHG reduced relative to a BAU scenario; energy use; speed reduction; fuel mix; and revenue streams from economic elements.

Candidate mid-term GHG emission reduction measures

34 The candidate mid-term GHG reduction measures (hereafter called policy measures) assessed in this study are:

.1 a GHG Fuel Intensity (GFI) requirement;

.2 a GFI flexibility mechanism;

.3 a levy mechanism; and

.4 a feebate mechanism.

35 The policy measures assessed in this study are based on the proposals provided up until MEPC 80, as well as input provided by the Steering Committee. The descriptions and assumptions of the policy measures are adapted to align similar concepts and terminology across the proposals, and with the method applied in this study for modelling the policy measures. The descriptions and assumptions should not be construed as suggestions or recommendations for how the policy measures should be designed, but rather as necessary adaptations for the purpose of modelling and analysis which requires specific inputs and definitions:

.1 *Fleet in scope*: For the purposes of the modelling in this study, we assume that the fleet in scope of the new policy measures will be same as for Chapter 4 of MARPOL Annex VI. They will take effect on the fleet from 2027.

.2 *Well-to-wake (WtW) or tank-to-wake (TtW) scope with sustainability criteria*: The GHG emissions in scope for the policy measures in this study can either be WtW or TtW with sustainability criteria.

.3 *GFI requirement*: The GFI is a requirement on annual GHG emissions per energy unit used (gCO_2eq/MJ). The GFI requirement, applying a WtW or TtW scope, will gradually become more stringent ensuring that the WtW GHG emission trajectories are met.

.4 *GFI flexibility mechanism*: The GFI can be implemented with a flexibility mechanism which provides alternative options for compliance. The first option is for ships with attained GFI below required GFI (positive compliance balance) to sell excess emission units to, or join a pool with, ships with attained GFI above required GFI (negative compliance balance). The second option is for ships with positive compliance balance to sell excess emission units (termed as Surplus Units, SU) to a Revenue body at a set SU price, and for ships with negative compliance balance to buy deficit units (termed Remedial Units, RU) from a Revenue body at a set RU price. The SU and RU prices are set as a percentage of the estimated annual emission unit exchange price in this study.

.5 *Levy mechanism*: The levy mechanism consists of two elements. The first is the levy, which is a predetermined price set by the IMO, or by criteria in the regulation, on annual GHG emissions (USD/tCO_2eq) from a ship, collected by a Revenue body. The second element is a reward which is a predetermined rebate to ships per energy unit of eligible fuel used (USD/GJ). The total reward is distributed from the Revenue body to the ships using eligible fuels at the end of the year, based on the reported annual consumption.

.6 *Feebate mechanism*: The feebate mechanism consists of two elements, a reward (rebate) to ships using eligible fuels, and a fee per tonne GHG emitted (USD/tCO_2eq). The mechanism is similar to the levy with the key differences that the fee is calculated based on the total reward and that the revenues and expenses balance each other, as opposed to the levy, which is determined in advance and which can raise additional revenue.

.7 *Revenue body*: The GFI flexibility, levy, and feebate mechanisms all rely on a body to manage collection and disbursement of revenues. The setup of this body is yet to be determined and since it is not expected to have a material impact on the assessment in this study, it is generically referred to as the *Revenue body* in this report.

.8 Eligible fuels and cost gap: The levy and feebate mechanisms provide a reward for ships using certain fuels. As no criteria were available at the time of the study, we apply a simplified criterion for fuels eligible for rewards based on fuel feedstock. We assume all e-fuels as eligible for the reward, and the reward is set as a percentage of the cost gap between the lowest cost e-fuel (i.e. e-ammonia) and the lowest cost biofuel (i.e. bio-LNG).

.9 Revenue streams and disbursements: The GFI flexibility, levy, and feebate mechanisms will provide a revenue stream which can be distributed according to seven revenue disbursement categories (D1 to D7). Of these, D1 (research, development & deployment – RD&D) and D4 (reward for eligible fuels) would have an impact on the shipping fleet and are relevant for this study. Due to a knowledge gap that has meant that the impacts of a certain amount of R&D spending cannot be modelled, D1 disbursement is set to zero for all scenarios (see Section 6.4, Impact of research and development, for an explanation). Disbursement for other categories (D2–D3 and D5–D7) is passed to UNCTAD for incorporation into the modelling of impact on states in Task 3 of the comprehensive impact assessment.

Well-to-wake GHG emissions in 2008 and 2023, and trajectories to 2050

36 This study assesses the impact on the fleet under the scope of Chapter 4 of MARPOL Annex VI* of following two WtW GHG emission trajectories (*Base* and *Strive*) according to the ambitions and indicative checkpoints of the IMO GHG Strategy. The *Base* trajectory is based on the lower ('at least' hence *Base*) targets, and the *Strive* trajectory on the higher ('striving for') targets of the indicative checkpoints for GHG emission reduction by 2030 and 2040 compared to 2008. Both the *Base* and *Strive* trajectories include the ambition to reach net-zero GHG emissions by or around, i.e. close to, 2050.

* All ships under the scope of Chapter 4 of MARPOL Annex VI, which are ships above 400 GT except ships solely trading domestically and ships not propelled by mechanical means, and platforms including FPSOs and FSUs and drilling rigs, regardless of their propulsion.

37 The proposed policy measures may address well-to-wake (WtW) GHG emissions or tank-to-wake (TtW) GHG emissions with sustainability criteria. However, the IMO GHG Strategy states that the levels of ambition and indicative checkpoints should take into account the well-to-wake GHG emissions. So, for the purposes of the modelling, this study defines the GHG emission trajectories in a WtW scope which should be followed regardless of the scope of the policy measures, in order to make the scenarios comparable.

38 The ambitions related to carbon intensity and the uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources in 2030 are, for the purposes of the modelling in this study, not included as mandatory targets and may not be reached in the modelled scenarios.

39 To set the trajectories for 2030 and 2040 relative to 2008 for the fleet in scope of this study, we estimate the WtW GHG emissions for 2008 for the fleet based on the TtW GHG emission estimate for international shipping in 2008 from the Fourth IMO GHG study, and we add the WtT GHG emissions based on the estimated fuel mix in 2008 from the Third IMO GHG study.

40 The WtW GHG emission for the fleet in scope of this study is estimated to be 964 $MtCO_2eq$ in 2008 and to have reduced by 3.6% to 928 $MtCO_2eq$ in 2023. The emissions are projected to increase to 994 $MtCO_2eq$ and 1,383 $MtCO_2eq$ in 2050 in the low- and high-growth BAU scenarios, respectively. This corresponds to a 3% increase in the low-growth BAU scenario and 43% under high-growth BAU, both compared with 2008.

41 Following the *Base* trajectory, the WtW GHG emissions targets for the fleet in scope of this study are 771 $MtCO_2eq$ in 2030 and 289 $MtCO_2eq$ in 2040. For the *Strive* trajectory, the targets are 674 $MtCO_2eq$ in 2030 and 193 $MtCO_2eq$ in 2040. The target for 2050, which is the same for both trajectories, is set close to zero; but, due to a small amount of methane (CH_4) and nitrous oxide (N_2O) emissions from internal combustion engines, which with current technologies and knowledge cannot be eliminated, the emissions are not set to exactly zero.

42 Table 1 shows the estimated WtW GHG emissions in 2008 and 2023, and the *Base* and *Strive* GHG emission reduction trajectories for the fleet in scope of this study, compared to the projected GHG emissions according to the results from the two BAU scenarios in 2030, 2040, and 2050.

Table 1: Estimated well-to-wake (WtW) GHG emissions in 2008 and 2023, and the *Base* and *Strive* GHG emission reduction trajectories for the fleet under the scope of Chapter 4 of MARPOL Annex VI, compared to the projected business-as-usual (BAU) GHG emissions in 2030, 2040, and 2050; percentage reductions are relative to 2008

<table>
<tr><th>WtW GHG emissions ($MtCO_2eq$)</th><th>2008</th><th>2023</th><th>2030</th><th>2040</th><th>2050</th></tr>
<tr><td>BAU low growth</td><td rowspan="4">964 (reference)</td><td rowspan="4">928 (–3.7%)</td><td>959 (–0.5%)</td><td>1,020 (+12%)</td><td>994 (+3%)</td></tr>
<tr><td>BAU high growth</td><td>1,079 (+12%)</td><td>1,290 (+34%)</td><td>1,383 (+43%)</td></tr>
<tr><td>Base trajectory</td><td>771 (–20%)</td><td>289 (–70%)</td><td>~0 (–100%)</td></tr>
<tr><td>Strive trajectory</td><td>674 (–30%)</td><td>193 (–80%)</td><td>~0 (–100%)</td></tr>
</table>

Scenarios

43 The study is based on 16 policy combinations scenarios, assessing the impact of following the *Base* (numbered 21 to 36) and *Strive* (numbered 41 to 56) GHG emission trajectories to 2050 using a low seaborne trade growth projection, for a total of 32 scenarios. These scenarios are compared to a BAU scenario with currently adopted policies using the same low-growth assumption (BAULG). A BAU scenario with high-growth seaborne trade (BAUHG) has also been included and is used for comparison with relevant scenarios in the sensitivity analysis. The scenarios are listed in Table 2.

44 To assess the sensitivity of key inputs and assumptions beside the policy combinations, 36 additional sensitivity scenarios have been run. These investigate 9 different changes in input, combined with 4 representative policy scenarios (numbered 23, 32, 46 and 55). In addition, 18 preliminary scenarios (numbered 1 to 18 – not included in Table 2) were initally run during the study. However, inputs on fuel prices and policy combinations were updated together with other adjustments in subsequent scenarios, and the results presented in this study are based on scenarios 21 to 56 only. In total, 88 scenarios have been modelled in this study.

Table 2: List of the two BAU scenarios and 32 policy scenarios analysed in this study; the policy codes are according to the Working Document on Value Ranges for Scenario Development (MEPC 81/7, Annex 4)

Scenario number	Emission trajectory	Seaborne trade growth	Policy combination						
			Policy code	GFI scope	GFI flexibility		Levy		Feebate
					RU % of price	SU % of price	Levy USD/ tCO_2eq	Reward % of cost gap	Reward % of cost gap
BAULG	BAU	Low	None						
BAUHG	BAU	High	None						
21	*Base*	Low	X.1	TtW	No flexibility		No levy		No feebate
22	*Base*	Low	Y.1	WtW	No flexibility		No levy		No feebate
23	*Base*	Low	X.4	TtW	120%	80%	No levy		No feebate
24	*Base*	Low	Y.4	WtW	120%	80%	No levy		No feebate
25	*Base*	Low	X.2	TtW	No flexibility		150–300	90% to 65% to 2040	No feebate
26	*Base*	Low	Y.2	WtW	No flexibility		150–300	90% to 65% to 2040	No feebate
27	*Base*	Low	X.5	TtW	120%	80%	150–300	90% to 65% to 2040	No feebate
28	*Base*	Low	Y.5	WtW	120%	80%	150–300	90% to 65% to 2040	No feebate
29	*Base*	Low	X.2	TtW	No flexibility		30–120	105% to 2040	No feebate
30	*Base*	Low	Y.2	WtW	No flexibility		30–120	105% to 2040	No feebate
31	*Base*	Low	X.5	TtW	120%	80%	30–120	105% to 2040	No feebate
32	*Base*	Low	Y.5	WtW	120%	80%	30–120	105% to 2040	No feebate
33	*Base*	Low	X.3	TtW	No flexibility		No levy		105% to 2040
34	*Base*	Low	Y.3	WtW	No flexibility		No levy		105% to 2040
35	*Base*	Low	X.6	TtW	120%	80%	No levy		105% to 2040

Scenario number	Emission trajectory	Seaborne trade growth	Policy combination						
			Policy code	GFI scope	GFI flexibility		Levy		Feebate
					RU % of price	SU % of price	Levy USD/ tCO_2eq	Reward % of cost gap	Reward % of cost gap
36	*Base*	Low	Y.6	WtW	120%	80%	No levy		105% to 2040
41	*Strive*	Low	X.1	TtW	No flexibility		No levy		No feebate
42	*Strive*	Low	Y.1	WtW	No flexibility		No levy		No feebate
43	*Strive*	Low	X.4	TtW	120%	80%	No levy		No feebate
44	*Strive*	Low	Y.4	WtW	120%	80%	No levy		No feebate
45	*Strive*	Low	X.2	TtW	No flexibility		150–300	90% to 65% to 2040	No feebate
46	*Strive*	Low	Y.2	WtW	No flexibility		150–300	90% to 65% to 2040	No feebate
47	*Strive*	Low	X.5	TtW	120%	80%	150–300	90% to 65% to 2040	No feebate
48	*Strive*	Low	Y.5	WtW	120%	80%	150–300	90% to 65% to 2040	No feebate
49	*Strive*	Low	X.2	TtW	No flexibility		30–120	105% to 2040	No feebate
50	*Strive*	Low	Y.2	WtW	No flexibility		30–120	105% to 2040	No feebate
51	*Strive*	Low	X.5	TtW	120%	80%	30–120	105% to 2040	No feebate
52	*Strive*	Low	Y.5	WtW	120%	80%	30–120	105% to 2040	No feebate
53	*Strive*	Low	X.3	TtW	No flexibility		No levy		105% to 2040
54	*Strive*	Low	Y.3	WtW	No flexibility		No levy		105% to 2040
55	*Strive*	Low	X.6	TtW	120%	80%	No levy		105% to 2040
56	*Strive*	Low	Y.6	WtW	120%	80%	No levy		105% to 2040
Key: business-as-usual (BAU); BAU high growth (BAUHG), BAU low growth (BAULG); GHG Fuel Intensity (GFI); Remedial Units (RU); Surplus Units (SU); tank-to-wake (TtW); well-to-wake (WtW)									

Impacts on costs

45 Figure 1 shows the range of increases in cost intensity in 2030, 2040, 2050 and the cost per tonne of GHG reduced in the period 2023–2050 relative to BAU for the 16 policy combination scenarios for each of the *Base* and *Strive* trajectories (blue boxes) and the 36 sensitivity scenarios (whisker diagrams). The cost intensity is the annual total cost, which includes annualized capital, operational, and fuel expenses, as well as regulatory incomes and expenses imposed by the policy measures, divided by the total transport work (based on cargo carried).

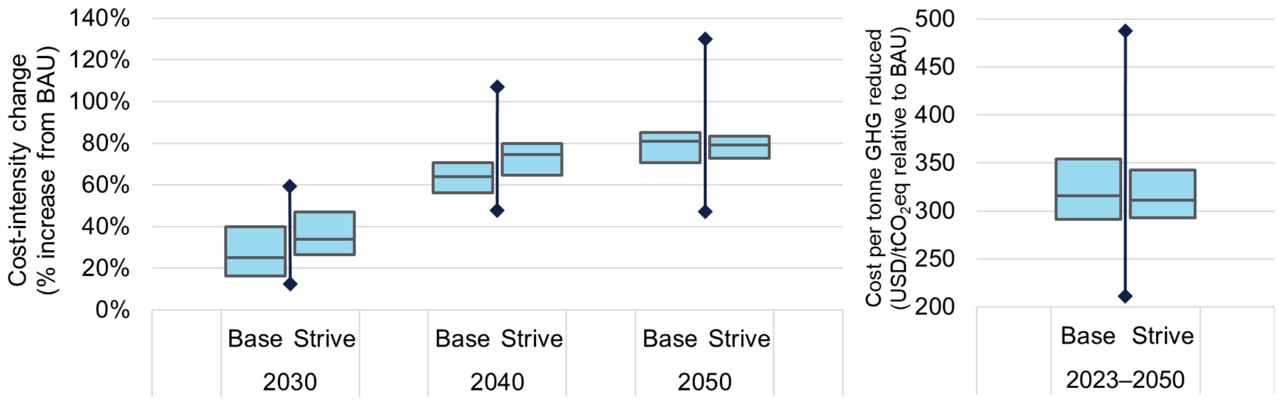

Figure 1: Range of cost-intensity increases in 2030, 2040, and 2050 (left panel) and cost per tonne of GHG reduced in the period 2023–2050 (right panel) and relative to BAU. The blue boxes show the range and median of the 16 policy combination scenarios for each of the *Base* and *Strive* trajectories, while the whiskers show the minimum and maximum of the 36 sensitivity scenarios, regardless of emission trajectory

46 The increase in cost intensity, measured in cost per tonne-mile relative to BAU, of achieving the *Base* GHG emission trajectory across the 16 policy combination scenarios, is 16% to 40% in 2030, increasing to 56% to 71% in 2040 and 71% to 85% in 2050. Similarly, for achieving the *Strive* GHG emission trajectory, the increase in cost intensity is 26% to 47% in 2030, increasing to 65 to 80% in 2040 and 73% to 83% in 2050. The cost per tonne of GHG reduced over the entire period 2023–2050 is between 292 and 354 USD/tCO_2eq.

47 The lowest increases in cost intensity in 2030 are found in scenarios with a GFI flexibility mechanism and no levy or feebate, while the highest increases are in scenarios with a 150–300 USD/tCO_2eq levy due to the direct cost of the levy. The range in cost-intensity increase is less in 2040 than in 2030 as the reductions in energy use across the policy combination scenarios are more similar, driven mainly by the increased costs of meeting the GFI requirements and to a lesser degree by the cost of the levy/feebate.

48 Both the *Base* and *Strive* GHG emission trajectories achieve close to net-zero GHG emissions in 2050 and have similar ranges of cost-intensity increases. However, the scenarios following the *Strive* GHG emission trajectory can in some cases result in lower costs due to the trajectory leading to an earlier uptake of energy-efficiency measures and fuel technologies. The lowest increases in cost come in scenarios with a levy and a GFI flexibility mechanism.

49 The aggregated cost per tonne of GHG emission reduced over the period 2023–2050 ranges from 292 to 354 USD/tCO_2eq. The lowest cost per tonne of GHG reduced are in the scenarios following the *Strive* GHG emission trajectory and in scenarios with a GFI flexibility mechanism.

50 While the other sensitivities investigated can have a significant impact, the minimum and maximum costs are determined by the variation in fuel prices. If including the changes in inputs and assumptions from the sensitivity scenarios, the cost intensity change in 2030 ranges from 12% to 60%, somewhat larger than the range due to the various policy combinations. Towards 2040 and 2050 the uncertainty of the fuel prices increases. The range in cost intensity change increases to between 47% and 109% in 2040 and to between 46% and 129% in 2050. The total cost per tonne of GHG reduced over the period 2023–2050 ranges from 210 to 487 USD/tCO_2eq.

Impact on energy use, fuels, and technology uptake

51 Figure 2 shows the range of reductions in speed and energy use, and on the use of ammonia, methanol, methane/LNG and onboard CCS for the 16 policy combination scenarios for each of the *Base* and *Strive* trajectories (blue boxes) and the 36 sensitivity scenarios (whiskers).

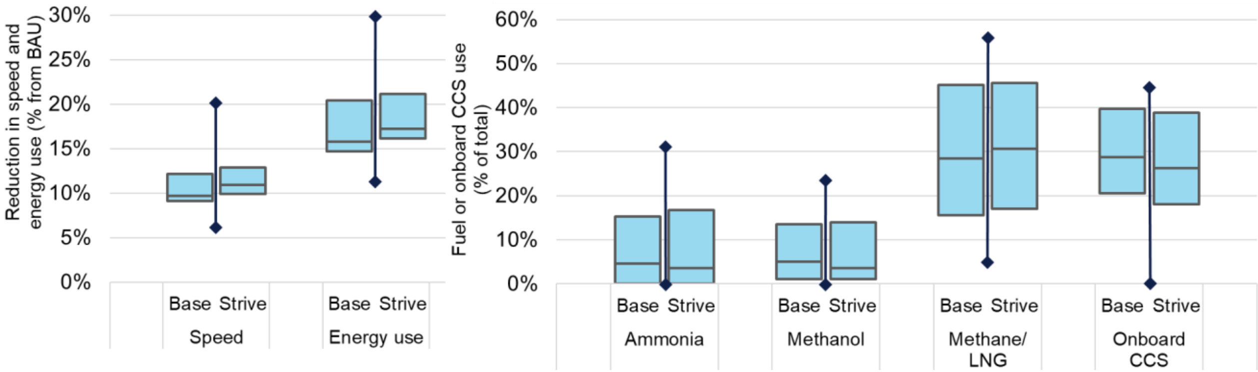

Figure 2: Range of reduction in speed and energy use relative to BAU (left panel) and in fuel uptake relative to total energy use and onboard CCS use relative to GHG emission reduced (right panel) in the period 2023–2050. Blue boxes show the range and median of the 16 policy combination scenarios for each of the *Base* and *Strive* trajectories, while the whiskers show the minimum and maximum of the 36 sensitivity scenarios, regardless of emission trajectory.

52 The average speed across the period 2023–2050 is reduced by 9% to 13% relative to BAU while energy use is reduced by 15% to 21% across all policy combination scenarios. It is notable that the GFI requirement does not directly incentivize improvements in energy efficiency. Initially, to 2030, the GFI requirements under the *Base* GHG emission trajectory are not sufficient to increase the total fuel costs to incentivize the uptake of energy-efficiency measures. The *Strive* trajectory scenarios have a somewhat greater reduction in speed and energy while the differences in fuel mix is small, indicating that the required amount of low GHG emission energy to reach the GFI requirements and related costs may be sufficient to drive a higher uptake of energy-efficiency measures and speed reduction. Towards 2050, the difference between the *Base* and *Strive* trajectory scenarios become smaller. This indicates that there are barriers to implementation of energy-efficiency measures and speed reductions. Other policy measures, beyond those investigated in the scenarios, to overcome these barriers have not been investigated in this report.

53 With the sensitivity scenarios, the speed reduction ranges from 6% to 20% while the reduction in energy use is between 11% and 30%. The upper range is determined by the forced uptake of energy-efficiency measures and speed reduction, while the lower range is determined by low fuel prices. Forcing the uptake of speed reduction and energy-efficiency packages has a significant impact leading to a 15% reduction on cost per tonne of GHG reduction, and a lower use of methane/LNG and onboard CCS.

54 The uptake of ammonia and methanol, regardless of feedstock, in the policy combination scenarios is between 0% and 17% of total energy use, while for methane/LNG it is between 16% and 46%. The uptake of onboard CCS is between 18% and 40% in term of CO_2 captured relative to total GHG emission reduced. In the sensitivity scenarios, the uptake of ammonia can reach 31% if onboard CCS is not available; methanol can reach 24% with lower fuel prices; and with high fuel prices, methane/LNG can reach 57% and onboard CCS use can reach 45%.

55 Removing the option of onboard CCS in the sensitivity scenarios on average increases the cost intensity in 2030 as ships must instead use low GHG emission fuels, which are more expensive initially. Over time, as these fuels decrease in cost, the impact is reversed, with a lower cost-intensity increase in 2050. The overall cost per tonne of GHG reduction in the period 2023–2050 increases by 1% if the CCS option is removed.

56 Onboard CCS remains a viable option even if it becomes 50% more expensive, though its use is then about halved. Ammonia and methanol are used more, to replace onboard CCS, while methane/LNG use is reduced as these fuels are used in combination with onboard CCS. For some of the sensitivity scenarios with high use of onboard CCS, the cost intensities and total cost increase, and are even higher than in the scenarios where onboard CCS is not an option. This indicates a certain lock-in effect where ships choose onboard CCS initially because it has a lower cost than other options. Over time, as the price of other low GHG emission fuels such as e-ammonia reduces, onboard CCS is not the most optimal solution in a total cost perspective. However, ships that have installed this solution remain committed to it, meaning that the capital cost of changing solution is too high.

57 The scenarios analysed here include constraints on feedstock supply with the bio- and blue fuel prices adjusted to be on a par with those of e-fuels. This results in a diverse fuel mix where e-fuels and onboard CCS appear to be the two most prevalent decarbonization solutions across all policy scenarios. However, biofuels also have a significant contribution toward 2040 and 2050. It should be noted that this fuel mix is to a large degree a result of the supply constraints on bio- and blue fuel feedstocks, and also the lack of constraints on e-fuels and carbon storage capacity.

58 In 2030, the uptake of low GHG emission fuels is between 0.3 and 2.0 EJ in the *Base* trajectory scenarios, and 1.5 to 2.9 EJ in the *Strive* trajectory scenarios. The lowest uptakes are seen in *Base* trajectory scenarios with high reduction in energy use (scenarios with 150-300 USD/tCO_2eq levy) or high uptake of onboard CCS (TtW scenarios and scenarios with a GFI flexibility mechanism). In most scenarios, except those with high reduction in energy use, the total feedstock supply and carbon storage capacity exceed the median estimated projections in the literature.

59 To achieve the GHG emission trajectories under the assumed constraints, all available fuel feedstocks would need to be used, complemented by onboard CCS and reduction in energy use by uptake of energy-efficiency measures and speed reductions.

Impact of policy combinations

Well-to-wake and tank-to-wake GHG emissions scope

60 There are only small differences between the cost intensities in the well-to-wake and tank-to-wake scenarios because they follow the same GHG emission trajectory taking into account WtW GHG emissions, The WtW scenarios combined with a levy have a slightly higher cost, as the absolute cost of the levy is higher in WtW scenarios due to the levy also covering WtT GHG emissions. This also causes a slightly higher reduction in speed and energy use in the WtW scenarios compared to the TtW scenarios.

Levy and feebate mechanisms

61 Figure 3 shows the range of changes in cost intensity in 2030, 2040, and 2050, and the total cost per tonne of GHG reduced for the period 2023–2050 relative to business-as-usual across the policy combinations having a levy or feebate mechanism and scenarios without such mechanisms.

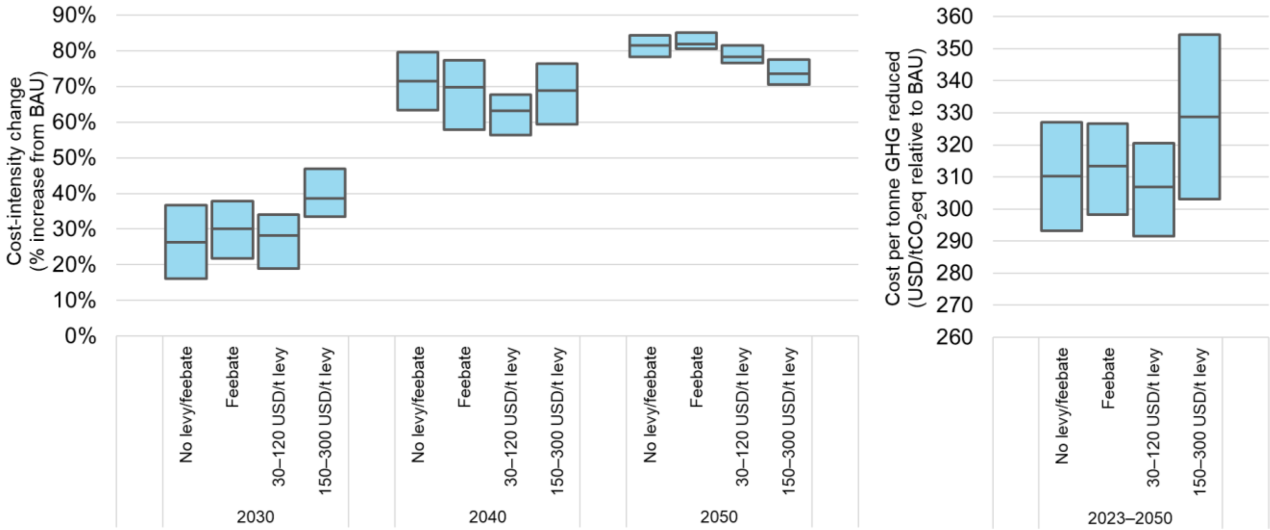

Figure 3: Range of cost-intensity increases in 2030, 2040, and 2050 (left panel), and total cost per tonne of GHG reduced in the period 2023–2050 (right panel) and relative to business-as-usual (BAU) for each levy/feebate mechanism, and without a levy/feebate mechanism

62 It should be noted that the feebate scenarios result in a fee of 40 to 56 USD/tCO_2eq in 2030, increasing to 72 to 144 USD/tCO_2eq in 2040. The fee is generally lower than the levy in the scenarios with a 30–120 USD/tCO_2eq levy.

63 Scenarios with a 150–300 USD/tCO_2eq levy have a significantly higher cost intensity in 2030 with a 33% to 47% increase compared to 16% to 38% for the other scenarios. In 2040, scenarios with a levy of 30–120 USD/tCO_2eq have the lowest cost-intensity increase of 56% to 68% compared to 58% to 80% for the other scenarios. In 2050, scenarios with a levy have a lower cost intensity increase of 71% to 81% while the feebate scenarios and scenarios without any levy or feebate mechanism see an increase of 78% to 85%. Overall, the 303 to 354 USD/tCO_2eq cost per tonne of GHG reduced is higher for the scenarios with a 150–300 USD/tCO_2eq levy, while the other scenarios have a cost of 292 to 327 USD/tCO_2eq reduced.

64 If only considering the abatement costs and not the costs and rewards from the economic elements (i.e. the cost of the levy and Remedial Units, and the income from the reward and sale of Surplus Units), the cost-intensity increase in 2030 in scenarios with a 150-300 USD/tCO_2eq levy following the *Base* GHG emission trajectory would be only 1% to 9%. This is due to the lower energy use and consequently lower requirement for uptake of low GHG emission fuels. In the scenarios with a 150–300 USD/tCO_2eq levy following the *Strive* GHG emission trajectory, the abatement cost in 2030 is higher due to the greater uptake of low GHG emission fuels, which again leads to a lower cost of the levy and a higher reward for eligible fuels. It should be noted that the effect of the economic elements is necessary in the modelling to achieve the reduced abatement costs, but it illustrates the potential for lower abatement costs through reduced energy use.

65 Figure 4 shows the range of reductions in speed and energy use, and in the use of ammonia, methanol, methane/LNG and onboard CCS across the policy combinations having a levy or feebate mechanism and scenarios without such mechanisms, in the period 2023-2050.

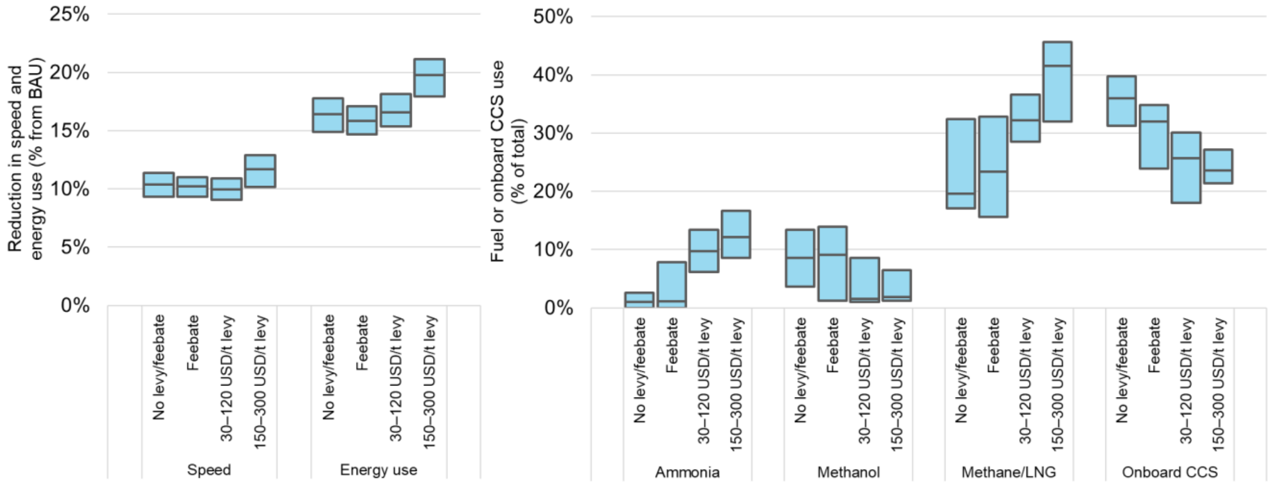

Figure 4: Range of reduction in speed and energy use relative to BAU (left panel); range of fuel use relative to total energy use, and of onboard CCS use relative to GHG emission reduction (right panel) – all charts for the period 2023–2050 for each levy/feebate mechanism, and without a levy/feebate mechanism

66 The feebate and 30–120 USD/tCO_2eq levy mechanism have little impact on the speed and energy use compared to the scenarios without such mechanisms, and all result in a 9% to 11% speed reduction and 15% to 18% less energy use. The scenarios with a 150–300 USD/tCO_2eq levy show a higher speed reduction of 10% to 13% and energy use reduction of 18% to 21%. The primary reason for this is the implementation of speed reductions as soon as the levy is introduced. The lower energy use reduces the need for low GHG emission fuels to reach the GHG trajectory in 2030. Towards 2040 and 2050, and in the *Strive* trajectory scenarios in 2030, the effect of the levy and feebate mechanism on energy use is less pronounced. As the GHG trajectories become more stringent, the energy use is reduced in all scenarios regardless of policy combination. The cost impact of the levy is also reduced with lower GHG emissions.

67 The reward for eligible fuels in the levy and feebate scenarios incentivizes uptake of e-fuels. Together with bio-LNG, e-ammonia and e-LNG seem to be the fuels with the highest uptake in scenarios with a levy in combination with a reward mechanism. The use of ammonia, regardless of feedstock, is between 6% to 17% of total energy use, while the use of methane/LNG is between 29% to 46% in the levy scenarios. The use of onboard CCS is also

much lower in these scenarios, providing 18% to 30% of the GHG emission reduction compared with 31% to 40% when there is no levy or feebate mechanism. The reason is likely to be that, unlike other carbon-based biofuels and e-fuels, e-ammonia cannot be combined with onboard CCS. In scenarios with a feebate mechanism, the use of ammonia and methane/LNG is lower, while the use of methanol is up to 14%. The use of onboard CCS is between 24% and 35%.

68 Regardless of the mechanism, the uptake of the various fuel types is very sensitive to relatively small changes in the levy and reward levels. The reward rate relative to the cost gap would need to be set precisely to give the necessary incentive for uptake of eligible fuels. If it is set too low, no eligible fuels are taken up. If it is set too high, the uptake exceeds what is available for rewards.

GHG Fuel Intensity flexibility mechanism

69 Scenarios with a GFI flexibility mechanism have on average about 4% lower cost intensity in 2030 compared to scenarios without the flexibility mechanism. In 2040 and 2050, the effect of the flexibility mechanism is less, with about 1% lower cost intensity on average. The aggregated impact is about a 6% lower cost per tonne of GHG reduced compared with the scenarios without the flexibility mechanism.

70 The reason for the lower cost is that with the flexibility mechanism, initially, relatively few ships can install, for example, ammonia or methanol fuel technologies, or onboard carbon capture, and run fully on fuels with lower cost (e.g. e-methanol has lower costs than e-MGO), instead of all ships having to reduce GHG intensity individually by going for more expensive drop-in fuels such as bio- and e-MGO.

71 Towards 2040 and 2050, the effect of the flexibility mechanism is reduced because with more stringent requirements, each ship must reduce its own emissions further before being able to contribute emission units to other ships. The impact of the flexibility mechanism on energy efficiency and speed reduction is small.

72 The flexibility mechanism may also be beneficial during the build-up of production and infrastructure for alternative fuels when such fuels have limited global availability. Ships that cannot find adequate fuels may exchange emission units (i.e. join in a compliance pool) with ships trading in areas where low GHG emission fuels are more readily available. This effect has not been quantified in the modelling.

Revenue streams and disbursements

73 Figure 5 shows the range of average annual revenues from the levy/feebate mechanism and from sale of Remedial Units (RU) under the GFI flexibility mechanism in the three periods 2027–2030, 2031–2040, and 2041–2050.

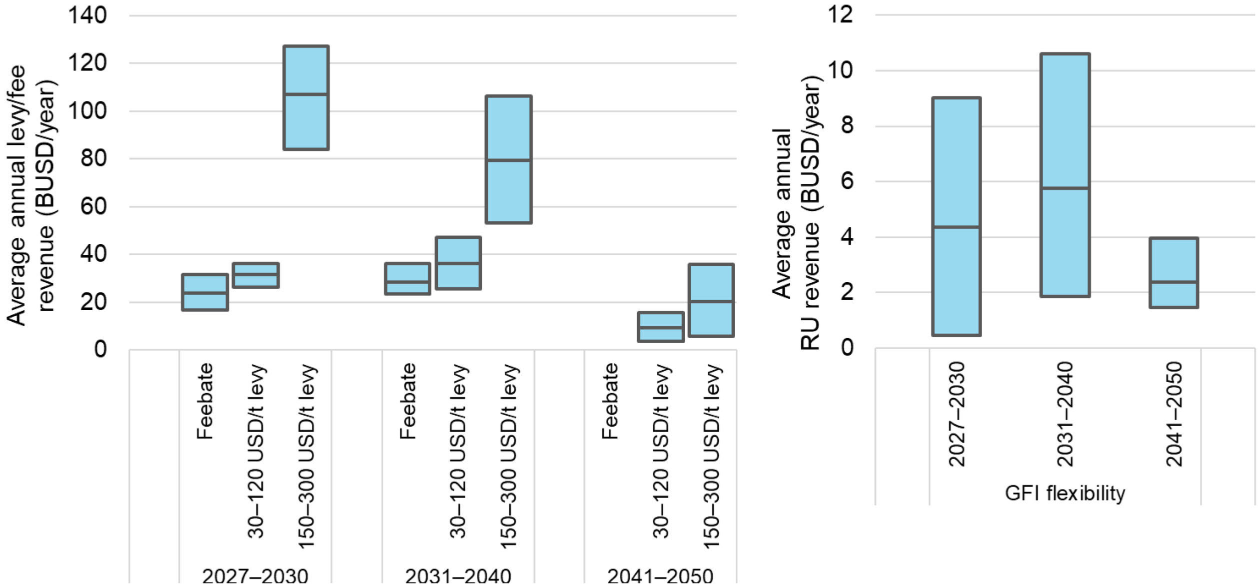

Figure 5: Range of average annual revenues (billion USD) from the levy/feebate mechanism (left panel) and sale of Remedial Units (RU) under the GHG Fuel Intensity (GFI) flexibility mechanism (right panel) in the periods 2027–2030, 2031–2040, and 2041–2050; note the difference in the scale of the y-axis between the two panels.

74 A levy of 150–300 USD/tCO_2eq results in an average annual revenue stream of 84 to 127 BUSD/year in the period 2027–2030, decreasing to 53 to 106 BUSD/year in 2031–2040, and to 6 to 36 BUSD/year in 2041–2050.

75 A levy of 30–120 USD/tCO_2eq creates an average annual revenue stream of 26 to 36 BUSD/year in the period 2027–2030, increasing to 25 to 47 BUSD/year in 2031–2040, and then decreasing to 3 to 16 BUSD/year in 2041–2050.

76 The feebate mechanism creates an average annual revenue stream of 17 to 32 BUSD/year in the period 2027–2030, increasing to 23 to 36 BUSD/year in 2031–2040 before it is stopped from 2041 onwards.

77 The GFI flexibility mechanism could also raise revenues through sale of Remedial Units to ships. We have applied a simplified method for estimating the potential revenue where sale of Remedial Units results in an average annual revenue stream of 0.5 to 9 BUSD/year in the period 2027–2030, increasing to 2 to 11 BUSD/year in 2031–2040 and then decreasing to 2 to 4 BUSD/year in 2041–2050.

78 Figure 6 shows the range of average annual disbursements for reward for eligible fuels and for purchase of Surplus Units under the GFI flexibility mechanism (D4 category), and for other disbursement categories (D2–D3 and D5–D7) in the periods 2027–2030, 2031–2040 and 2041–2050. Note that disbursement for RD&D (D1) is set to zero as further explained in Section 6.4 Impact of research and development.

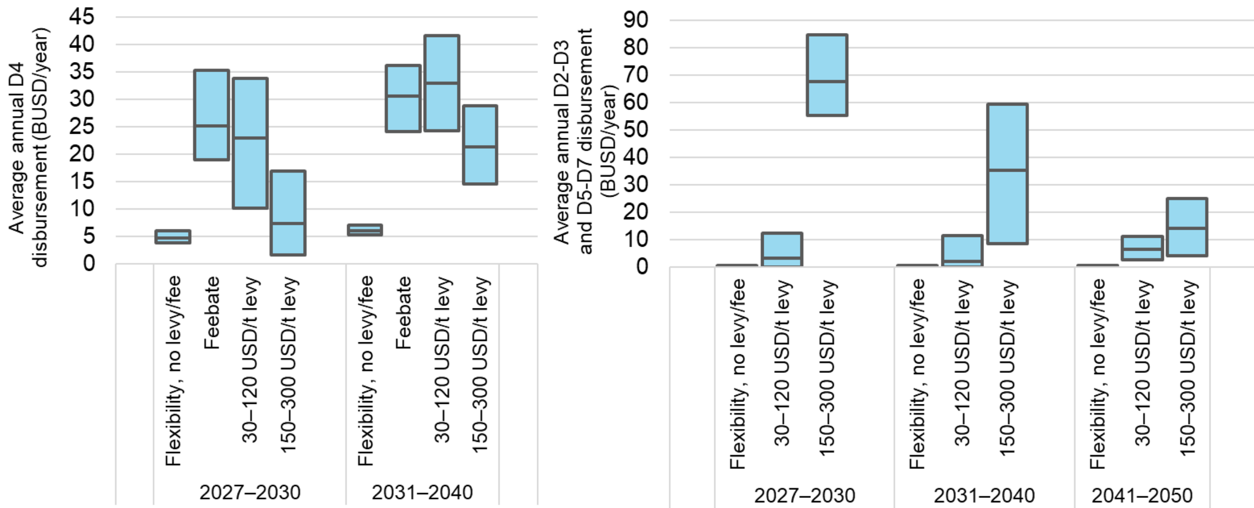

Figure 6: Range of average annual disbursement for reward for eligible fuels and for purchase of Surplus Units under the GFI flexibility mechanism (D4) (left panel), and other disbursements (D2–D3 and D5–D7) (right panel) for groups of scenarios in the periods 2027–2030, 2031–2040, and 2041–2050

79 The D4 disbursement for eligible fuels and Surplus Units is lower in the scenarios with a 150–300 USD/tCO_2eq levy at 2 to 17 BUSD/year in 2027–2030 and 15 to 29 BUSD/year in 2031–2040, compared to scenarios with a feebate mechanism or a 30–120 USD/tCO_2eq levy which see disbursement of 10 to 35 BUSD/year in 2027–2030 and 24 to 42 BUSD/year in 2031–2040. The disbursement for Surplus Units in scenarios without a levy or feebate is 4 to 6 BUSD/year in 2027–2030 and increasing to 5 to 7 BUSD/year in 2031–2040.

80 The reason for the lower D4 disbursement is that the reward is set to a lower percentage of the cost gap between the lowest cost e-fuel (e-ammonia) and lowest cost biofuel (bio-LNG). Otherwise, in combination with the high levy, the cost gap between fossil fuels and bio- and e-fuels would be more than covered, leading to an accelerated uptake of low GHG emission fuels and GHG emissions beyond the trajectory and likely beyond the capacity to produce such fuels.

81 The amount available for other disbursements (D2–D3 and D5–D7) are significantly higher in scenarios with a 150–300 USD/tCO_2eq levy at 55 to 85 BUSD/year initially in 2027-2030, then decreasing to 9 to 59 BUSD/year in 2031–2040 and 4 to 25 in 2041–2050. The scenarios with 30–120 USD/tCO_2eq levy see a disbursement from 0 to 12 BUSD/year across all periods.

82 The disbursement from scenarios with only a GFI flexibility mechanism is in the range 0.1 to 0.2 BUSD/year. For the feebate scenarios, the revenues raised equal the rewards for eligible fuels exactly and there are no other disbursements in these scenarios except if combined with the flexibility mechanism.

Other impacts

Number of newbuilds and retrofits

83 The scenarios see a peak of around 1,700 and 3,100 annual newbuilds, with the highest peak seen in scenarios with large speed reductions to compensate for lost transport work. The average number of newbuilds delivered from 2002 to 2022 was 2,053 vessels per year, peaking at 3,965 ships in 2010, indicating that the number of newbuilds required in the scenarios should be within the capacity of the yards, given time to scale up the production.

84 The retrofitting of fuel technologies and onboard CCS peaks between 2,000 and 3,600 ships per year, while retrofitting to energy-efficiency packages peaks between 400 and 1,900 ships per year. The peak annual number of retrofits to other fuel technologies or onboard CCS, and to some degree energy-efficiency measures, are significant. Due to the complexity of retrofitting ships to these technologies it remains uncertain if these numbers are feasible for the yards and equipment manufacturers to deliver. The implication if these retrofit rates are not feasible is that more ships have to run on more expensive drop-in fuels such as bio-MGO and e-MGO.

Impact of research and development

85 It has not been possible based on a literature review to determine an explicit link between a certain magnitude of spending for R&D and the effect it would have on technology maturity and costs, and consequently to quantify the effect it would have on the cost intensity of the fleet. Given this knowledge gap, to maintain comparability between the scenarios which will raise very different amount of revenues, we have set the D1 disbursement to zero for the purposes of this modelling; and, all revenues beyond those required for D4 are allocated to the other disbursements categories (D2–D3 and D5–D7) which are taken into account in the modelling by UNCTAD.

86 To provide an indication of the potential cost savings that can be achieved with increased R&D spending, we have instead run sensitivity scenarios where we made assumptions about certain conditions, such as accelerated technology development and learning effects, that are achieved through R&D funding.

87 The sensitivity scenarios indicate that if the R&D spending results in two to three years' earlier availability of technologies and 20% reduced capital costs, the cost per tonne of GHG reduced can reduce by 4%. This amounts to about 200 BUSD saved over the whole period 2023–2050. It has not been possible to ascertain the magnitude of spending required to achieve the effect assumed in the sensitivity scenarios.

Carbon intensity and uptake of zero or near-zero GHG emission technologies, fuels, and/or energy sources in 2030

88 The ambitions related to carbon intensity and the uptake of zero or near-zero GHG emission technologies, fuels, and/or energy sources in 2030 are not included as mandatory targets and may not be reached in the modelled scenarios. The majority of scenarios achieve both 40% carbon intensity reduction and the 5%, striving for 10%, uptake of zero or near-zero GHG emission technologies, fuels, and/or energy sources. Scenarios 46 to 48, each with a 150–300 USD/tCO_2eq levy, have a high reduction in energy use and do not need to meet the 5% uptake ambition in order to reduce GHG emissions to below the trajectory. Scenarios 43 and 44, which include a GFI flexibility mechanism and no levy or feebate, have a high uptake of onboard CCS in 2030 and are very close to or do not meet the carbon intensity reduction ambition.

Uncertainties

89 Although the inputs and assumptions are within likely ranges as provided in literature and by the stakeholder feedback, there are significant uncertainties when modelling the fleet emissions and impact of policy measures 27 years into the future. The main uncertainties which could have a significant impact on the results are future fuel prices; availability of low GHG emission fuel feedstocks and carbon storage capacity; uptake of energy-efficiency measures; seaborne trade growth; cost and availability of onboard CCS; and yard retrofit capacities.

90 The results from one specific scenario should not be considered a most likely outcome, as the inputs and assumptions provide only a snapshot of one possible future. As each scenario is given equal weight, the set of scenarios cannot be used to establish a likelihood distribution of the impacts.

91 The 88 scenarios run during the course of the study give a good basis for assessing the impact of various policy combinations through analysing the differences between groups of scenarios. Although, the sensitivity analysis has not investigated the full expected range of all inputs and assumptions, it covers a likely range of fuel prices identified as the most sensitive input parameter.

92 The results of the sensitivity scenarios provide a likely range of impact for some key indicators such as total cost, cost intensity, and energy use. For other indicators, such as the uptake of certain fuels and technologies, the sensitivity analysis has shown that small changes in inputs on fuel prices and policy combinations such as the levy and reward levels can give very different outputs. Also, the potential constraints of feedstock supply and carbon storage capacity indicate that the results are less robust on the energy mix and uptake of onboard CCS.