EE APPRAISAL TOOL FOR IMO

Project report

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Objective:

Using funds provided to IMO by Transport Canada, the objective of this work is to develop a computer-based tool to appraise the technical and operational energy efficiency measures for ships. The tool is envisaged to support interested stakeholders in the investigation and assessment of the impacts of energy efficiency measures and could potentially serve as a decision making tool.

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Table of contents

1 EXECUTIVE SUMMARY

According to current estimates presented in the Third IMO GHG Study 2014 (1), international shipping emitted 796 million tonnes of CO_2 in 2012, which accounts for no more than 2.2% of the total emission volume for that year. By contrast, in 2007, before the global economic downturn, international shipping is estimated to have emitted 885 million tonnes of CO_2, which represented 2.8% of the global emissions of CO_2 for that year. The reduction in CO_2 emissions is noted in the mentioned Study to be as a consequence, in part, due to the adoption of operational measures by the international shipping fleet to reduce fuel consumption, and it shows that measures for reducing CO_2 from shipping are available.

Using funds provided to IMO by Transport Canada, the objective of this work is to develop a computer-based tool to appraise the technical and operational energy efficiency measures for ships. The tool is envisaged to support interested stakeholders in the investigation and assessment of energy efficiency measures and could potentially serve as a decision making tool.

The tool calculates the effect the measures have on Energy Efficiency Design Index (EEDI) and Energy Efficiency Operational Indicator (EEOI) and the economic cost including Marginal Abatement Cost Curve (MACC), the cost of reducing one more tonne of CO_2. The output of the tool is a list of the available measures for the chosen ship type and size, and the effect and cost for the different measures.

The tool covers the following vessel segments and size categories shown in Table 1-1 and the type of energy efficiency measures outlined in Table 1-2. The vessels are split into type and size categories representing groups of vessels sharing technical and operational characteristics.

Table 1-1: Vessel segments and size categories included in the model

Segment / Size	DWT = Dead Weight Tonnes					
Crude oil tankers	< 10 000	10 000 - 59 999	60 000 - 79 999	80 000 - 119 999	120 000 - 199 999	> 200 000
Product tankers	< 5 000	5 000 - 9 999	10 000 - 19 999	20 000 - 59 999	> 60 000	
Chemical tankers	< 5 000	5 000 - 9 999	10 000 - 19 999	> 20 000		
Dry bulk carriers	< 10 000	10 000 - 34 999	35 000 - 59 999	60 000 - 99 999	100 000 - 199 999	> 200 000
	DWT = Dead Weight Tonnes / TEU = Twenty-foot Equivalent Unit					
General cargo vessels	< 5 000 < 100	5 000 - 9 999 < 100	>10 000 < 100	< 5 000 >= 100	5 000 - 9 999 >= 100	>10 000 >= 100
	TEU = Twenty-foot Equivalent Unit					
Container ships	< 1 000	1 000 - 1 999	2 000 - 2 999	3 000 - 4 999	5 000 - 7 999	>8 000
	LM = lane meters					
Ro-Ro ships	< 2 000	>= 2 000				
	Knots					

Passenger vessels	>= 25	< 25				
Ro-Pax vessels	>= 25	< 25				
	GT = Gross Tonnes					
Cruise vessels	< 2 000	2 000 - 9 999	10 000 - 59 999	60 000 - 99 999	> 100 000	

Table 1-2: List of measures evaluated in the study (incl. naming used in the tools)

Measure category	**Measure description**	***Measure names as described in tools***
Alternative Energy Source	Kite	*Kite*
	Fixed Sails or Wings	*Fixed sails or wings*
	Solar Panels	*Solar Panel*
Technical Measures (Main Engine)	Electronic Engine Control	*Electronic engine control*
	Waste Heat Recovery	*Waste heat recovery*
	Hull Coating	*Hull coating condition*
	Air Cavity Lubrication	*Air cavity lubrication*
	Contra-Rotating Propeller	*Contra-rotating propeller*
	Propulsion Efficiency Devices	*Propulsion efficiency devices*
Technical Measures (Aux Engine)	Frequency Converters	*Frequency converters*
	Exhaust Gas Boilers	*EGB on AE*
	Efficient Lighting System	*Light systems*
Operational Improvements	Trim/Draft Optimization	*Trim&draft optimisation*
	Weather Routing	*Weather routing*
	Voyage Execution	*Voyage execution*
	Steam Plant Improvements	*Steam plant op impr*
	Propeller Condition	*Propeller efficiency*

2 INTRODUCTION

Importance of energy efficiency in the maritime industry has historically been strongly correlated with the oil price, which again affects the fuel price for ships. Some strong efforts in the early 80's was followed by 20 years of less efficiency focus, until the oil prices started to increase again in the early 2000's (Figure 2-1). Despite recent decline in oil prices, the focus on efficient operations is continuing to grow due to more environmental awareness, stricter regulations from domestic and international bodies, and a stronger cost focus in the industry.

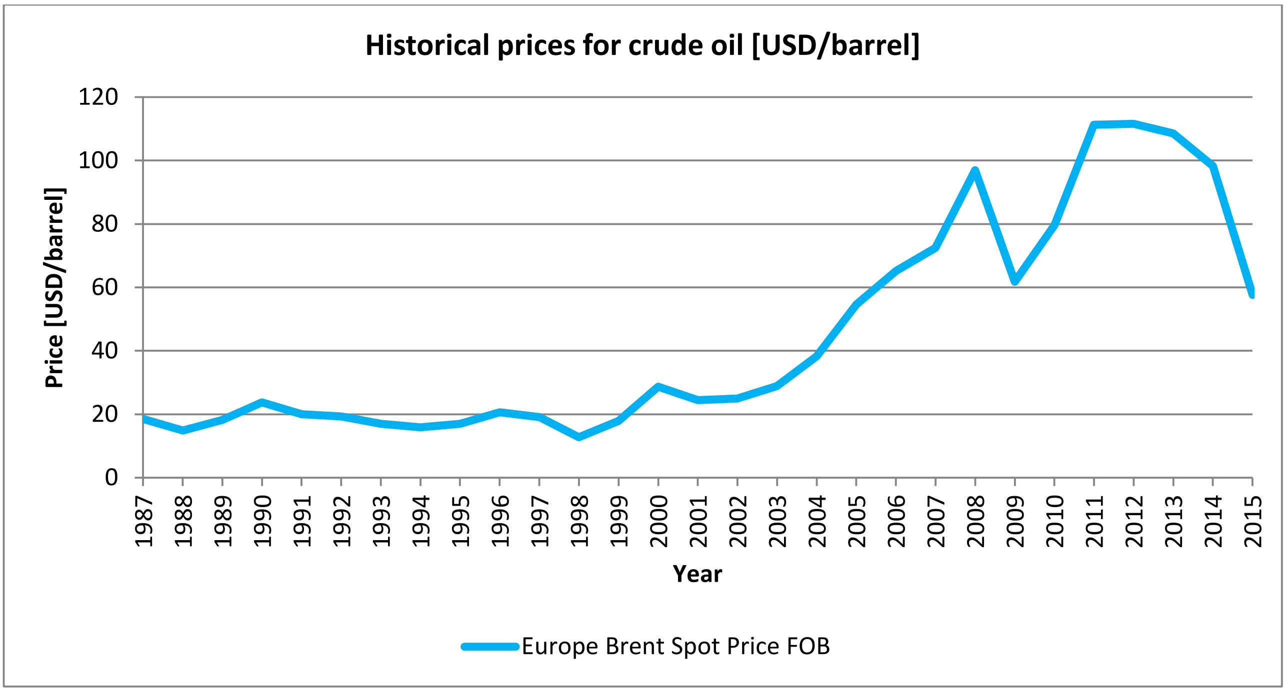

Figure 2-1: Historical prices for crude oil (2)

The motivation behind this tool, is to educate the industry on relevant energy efficiency measures, investigate costs and reduction potential, and general applicability for a given vessel type.

Chapter 3 in this report gives a description of the scope of the project, including a brief description of the model and some basic assumptions and general philosophy. This is followed by brief descriptions of each measure applied in the model in Chapter 4. Chapter 5 outlines some considerations for future work and possible extensions of the model. References used in the project are given in Chapter 6, while appendices providing a user manual for the tool are given in Appendix A and represent the very end of the report.

3 PROJECT SCOPE

The following sections outline the scope of work including a brief description of the model.

3.1 List of ship types

The tool covers the following vessel segments and size categories shown in Table 3-1. The vessels are split into type and size categories representing groups of vessels sharing technical and operational characteristics. For general cargo vessels, both dead weight tonnes and container capacity are needed to describe the vessel, because of design features. Ro-Ro ships are described by lane meters, whilst passenger vessels are best described by operating speed. According to MEPC.245(66), dead weight tonnes and gross tonnes are used for EEDI calculations of Ro-Ro ships and passenger vessels respectively.

Table 3-1: Vessel segments and size categories included in the model

Segment / Size	**DWT = Dead Weight Tonnes**					
Crude oil tankers	< 10 000	10 000 - 59 999	60 000 - 79 999	80 000 - 119 999	120 000 - 199 999	> 200 000
Product tankers	< 5 000	5 000 - 9 999	10 000 - 19 999	20 000 - 59 999	> 60 000	
Chemical tankers	< 5 000	5 000 - 9 999	10 000 - 19 999	> 20 000		
Dry bulk carriers	< 10 000	10 000 - 34 999	35 000 - 59 999	60 000 - 99 999	100 000 - 199 999	> 200 000
	DWT = Dead Weight Tonnes / TEU = Twenty-foot Equivalent Unit					
General cargo vessels	< 5 000 < 100	5 000 - 9 999 < 100	>10 000 < 100	< 5 000 >= 100	5 000 - 9 999 >= 100	> 10 000 >= 100
	TEU = Twenty-foot Equivalent Unit					
Container ships	< 1 000	1 000 - 1 999	2 000 - 2 999	3 000 - 4 999	5 000 - 7 999	> 8 000
	LM = Lane Meters					
Ro-Ro ships	< 2 000	>= 2 000				
	Knots					
Passenger vessels	>= 25	< 25				
Ro-Pax vessels	>= 25	< 25				
	GT = Gross Tonnes					
Cruise vessels	< 2 000	2 000 - 9 999	10 000 - 59 999	60 000 - 99 999	> 100 000	

3.2 List of measures

The Energy Efficiency Appraisal tool includes the measures outlined in the Table 3-2 below. Detailed descriptions and assumptions related to each measure can be found in Section 4.

Table 3-2: List of measures evaluated in the study (incl. naming used in the tools)

Measure category	**Measure description**	***Measure names as described in tools***
Alternative Energy Source	Kite	*Kite*
	Fixed Sails or Wings	*Fixed sails or wings*
	Solar Panels	*Solar Panel*
Technical Measures (Main Engine)	Electronic Engine Control	*Electronic engine control*
	Waste Heat Recovery	*Waste heat recovery*
	Hull Coating	*Hull coating condition*
	Air Cavity Lubrication	*Air cavity lubrication*
	Contra-Rotating Propeller	*Contra-rotating propeller*
	Propulsion Efficiency Devices	*Propulsion efficiency devices*
Technical Measures (Aux Engine)	Frequency Converters	*Frequency converters*
	Exhaust Gas Boilers	*EGB on AE*
	Efficient Lighting System	*Light systems*
Operational Improvements	Trim/Draft Optimization	*Trim&draft optimisation*
	Weather Routing	*Weather routing*
	Voyage Execution	*Voyage execution*
	Steam Plant Improvements	*Steam plant op impr*
	Propeller Condition	*Propeller efficiency*

3.3 Model description

The model is developed in MS Excel containing the main modules and information flow outlined in the chart below. The "Start-up" and "Output" are the user interfaces, and the modules within the dashed line are the underlying spreadsheets for input data and calculations. The model description is outlined in Figure 3-1.

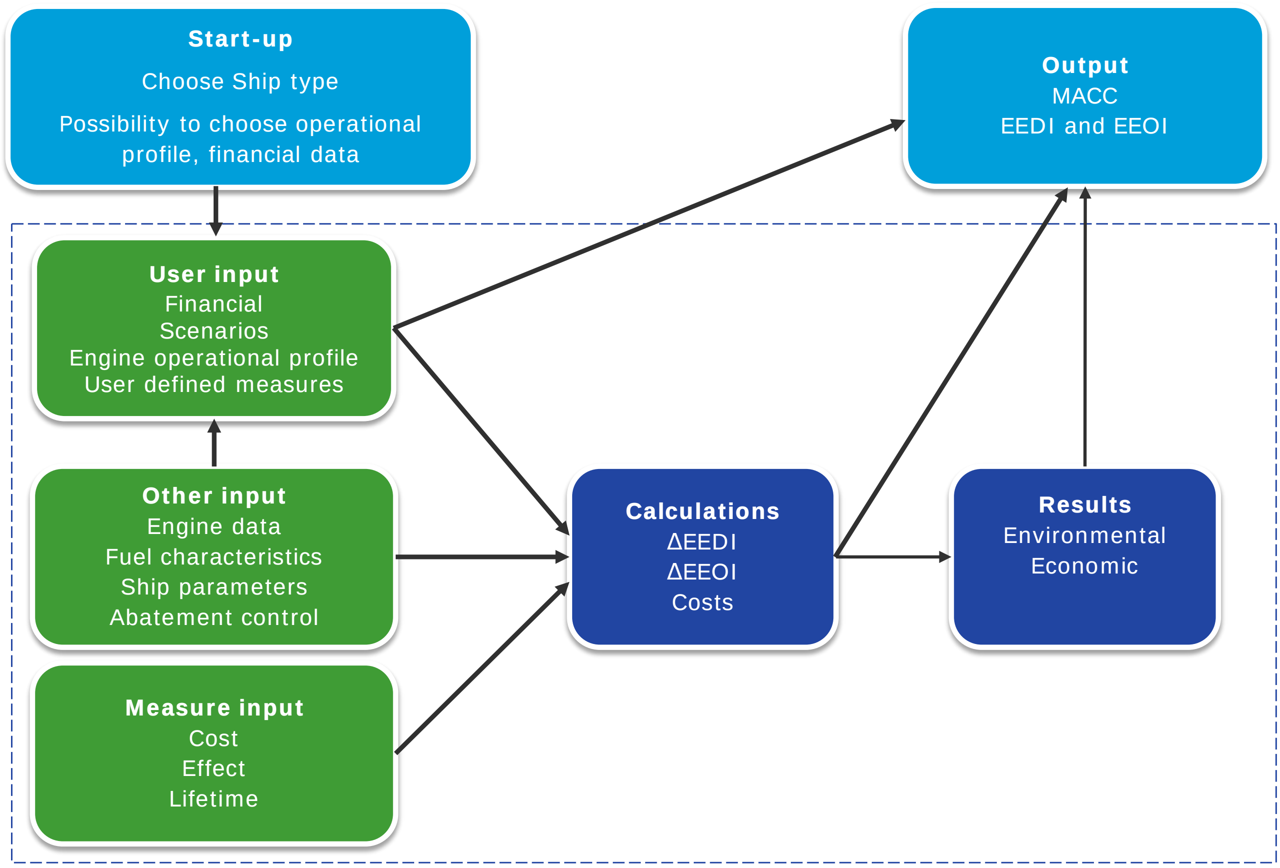

Figure 3-1: Model description

3.3.1 Start-up

The tool has two modes for user input in the “start-up” interface; “Normal” and “Advanced”. In normal mode, the ship type and size is chosen by the user and the calculations are done with a standard set of measures, fuel consumption, transport work and financial data. In the “Advanced” mode, these types of data can be specified.

This setup allows users with different needs for flexibility and complexity to use the tool. The normal mode can be used for a screening of measures and the advanced mode can be used for sensitivity analysis.

3.3.2 Databases for user, measure and other input

The tool contains three databases:

- User input
- Measure input
- Other input

The user input database contains data on engine operational profile, different scenarios on fuel price and emission tax and financial data on discount rate and time horizon.

The measure input database contains information on cost, effect and lifetime of different measures. The sources of these data are based on DNV GL R&D projects and experience gained from energy efficiency studies involving 25+ customers operating 900+ ships (see attached list of references in Chapter 6).

The other input database contains engine data, fuel characteristics and ship parameters for each ship type. This database also contains an abatement control where it is defined what measures that is applicable for the different ship types and if it has an effect on EEDI or EEOI.

3.3.3 Calculations and results

In the calculation module the following calculations are performed:

- Initial EEDI and EEOI
- New EEDI or EEOI as a result of a measure
- Cost of the measure

3.3.4 Output

The output of the tool is presented as Marginal Abatement Cost Curve (MACC) and a list of the different measures feasible for the chosen ship type, their effect on the EEDI and EEOI and the estimated investment cost and payback time.

3.4 Basic assumptions and philosophy

The following chapter outlines the underlying assumptions and philosophy used in the model.

3.4.1 Purpose and general description of the tool

The purpose of the tool is to compare different energy efficiency measures for a single ship of a chosen new build vessel. For existing vessels, operational measures could be relevant to investigate, but will in most cases experience other costs and reduction numbers due to a different reference situation. Hence, the uncertainty of the results using it for retrofit purposes can potentially be high. The tool identifies measures that are applicable for that ship and compare the cost and benefit of those measures. The tool gives the user the opportunity to evaluate which measures that will have the largest effect on energy efficiency, and which measures that are the most cost effective.

The parameters used for measuring energy efficiency improvements are changes in two energy efficiency indices EEDI and EEOI (in %). The outcome of the tool is a list of the ΔEEDI and ΔEEOI for the applicable measures and marginal abatement cost curves (MACC) for EEDI and EEOI. ΔEEDI and ΔEEOI are presented separately and not as a combined value in the tool, as operational measures such as optimal trim will only impact the EEOI. In theory, the EEOI should be the same as EEDI if the ship is operated under design conditions as the EEDI is calculated in fully loaded condition (100% DWT) running design speed and with an average specific fuel consumption.

3.4.2 Normal and advanced mode

The tool has a normal and an advanced mode. In the normal mode, the user only chooses the ship type, and the calculations are done based on predefined design, operational profile, financial parameters and a given set of measures. In the advanced mode, the user can specify the operational profile, adjust financial parameters, adjust the effect of operational measures, and change the effect and cost of immature technologies. This setup gives the user easy access to valuable, information in the normal mode and the possibility to adapt the model to a specific case in the advanced mode.

3.4.3 Reference ship and reference operation

To be able to calculate and compare changes in EEDI and EEOI a reference ship and a reference operational profile is needed. The reference cases needs to be clearly defined to ensure consistency in the model and equal and transparent evaluation of each measure.

The EEDI requirements for 2015 (“EEDI 2015”) are used as the reference design and an average yearly operational profile based on AIS data for 2014 and 2015 (3) for the ship type in question is used as the basis for the reference EEOI. The operational profile is derived by calculating average values from the world fleet based on 2014 and 2015 operation. The profile contains speed profiles (percentage of time used at different speeds), consumption figures and sailed distances for each vessel segment. EEOI used in the tool includes all modes of ship operation (laden voyage, ballast voyage, port). Note that this means that the EEOI and EEDI reference will not be the same, as the average operational profile is not the same as the design condition (fully loaded and at design speed).

All measures are evaluated in comparison with the reference ship and operation. This enables the tool to give a consistent comparison of measures that are relevant for most users of the tool. For ships that surpass the EEDI 2015 requirements, measures will have less effect than indicated in the tool.

3.4.4 Measures

The tool has both operational and design measures, and several measures affecting both EEDI and EEOI. The measure input contains information on cost, effect and lifetime of different measures. The sources of these data are DNV GL R&D projects and experience gained from energy efficiency studies involving 25+ customers operating 900+ ships across the main vessel segments, with the majority of the studies and projects from the tanker and container segment. The measures are updated to reflect the effect and cost the measures will have for the 2015 reference ship.

In addition to technological investments, operational measures require training, changes in work routines and sometimes changes that involve other parties than the ship operator. Because of this, these types of measures will have “hidden implementation costs” (follow-up from shore, documentation of use etc.). The “hidden cost” is not included in the cost estimates in the tool since it will vary greatly from ship to ship and from company to company. The effect of operational measures may vary between crews and may not reach their theoretical effect on energy efficiency for all ships. The estimates of the effect of these measures are conservative (lower than theoretically possible) to consider this.

Some of the measures in the tool are based on technologies that are new to shipping and can be seen as immature technologies. Examples of this are alternative energy sources like solar panels and kites. Immature technologies often have a high investment cost and uncertainty both in the effect it has on energy efficiency and the cost. This can rapidly change if a technology proves its potential and become a common technology.

3.4.5 Uncertainty

The measure categories listed in Table 3-2 are relatively wide spanning, and within each category, there are various versions and different ways of implementing each measure. To illustrate: within the category “propulsion efficiency devices“ there are several categories of solutions available depending on where the change is made/applied: “Rudder”, “Propeller”, “After-propeller-devices” and “In-front of propeller devices”. Furthermore, the sub-category “Rudder” would span several measures including “Costa bulbs”, “twisted rudder with costa bulb”, “costa bulb and integrated transition to propeller”, “optimized rudder”, “rudder fins”, “etc. Hull shape, operational profile and other factors would affect which of these measures would be the most efficient. The main reasons for selecting these categories are to avoid complexity in the tool and to avoid correlations between measures (see Section 3.4.6).

The tool is designed to approximate savings and costs related to each measure and give an indication on how each of them contributes to the overall savings and costs. However, it should be noted that within each vessel and size segment, there are significant variations on trade, operational profiles, and other vessel specifics. This will influence the applicability and effectiveness of the measures.

Hence, the model applies a representative set of values describing each vessel, its operation and the cost and effect of the measures. The results should therefore be perceived as indications and valuable guidance, rather than exact numbers for a specific vessel and measure. Table 3-3 describes the assumed uncertainty in the underlying values for each measure, including cost and effectiveness applying it on a vessel. Alternative energy sources have generally high uncertainty due to its very limited uptake and experience in the maritime sector. Even though some vessel segments have applied some technologies more than others have, the uncertainties are assumed to be the same across vessel types and size categories. The ranges are based on DNV GLs general knowledge of each measure, its maturity in the maritime market, and experiences from land based appliances.

Table 3-3: Uncertainty related to underlying numbers for each measure

Measure category	Measure description	Uncertainty
Alternative Energy Source	Kite	> 30 %
	Fixed Sails or Wings	> 30 %
	Solar Panels	> 30 %
Technical Measures (Main Engine)	Electronic Engine Control	< 10 %
	Waste Heat Recovery	< 10 %
	Hull Coating	< 10 %
	Air Cavity Lubrication	10-30 %
	Contra-Rotating Propeller	10-30 %
	Propulsion Efficiency Devices	< 10 %

Technical Measures (Aux Engine)	Frequency Converters	10-30 %
	Exhaust Gas Boilers	< 10 %
	Efficient Lighting System	< 10 %
Operational Improvements	Trim/Draft Optimization	< 10 %
	Weather Routing	10-30 %
	Voyage Execution	10-30 %
	Steam Plant Improvements	< 10 %
	Propeller Condition	< 10 %

3.4.6 Measure correlations

Investigating and applying multiple measures on the same vessel can potentially lead to a change in effect of each measure, i.e. applying speed reduction and trim optimization at the same time would likely change the saving potential of one or more of the measures.

However, the measures proposed in this study are perceived as relatively independent of each other, in the sense that the uncertainty of the effect of applying several measures on the same vessel would not exceed the uncertainty within each measure category (as explained in Section 3.4.5). To give the end-user an understanding of how the different measures correlates with each other, the matrix listed in Table 3-4 indicates which measures that are most likely to affect the others and expected uncertainty in combining the measures.

Table 3-4: Measure correlations and corresponding uncertainty from applying multiple measures (Letter “W” indicates “warning”)

Measure combination	Kite	Fixed Sails or Wings	Solar Panels	Electronic Engine Control	Waste Heat Recovery	Hull Coating	Air Cavity Lubrication	Contra-Rotating Propeller	Propulsion Efficiency Devices	Frequency Converters	Exhaust Gas Boilers	Efficient Lighting System	Trim/Draft Optimization	Weather Routing	Voyage Execution	Steam Plant Improvements	Propeller Condition
Kite	x	W	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fixed Sails or Wings	W	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar Panels	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electronic Engine Control	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-
Waste Heat Recovery	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Hull Coating	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Air Cavity Lubrication	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-
Contra-Rotating Propeller	-	-	-	-	-	-	-	x	W	-	-	-	-	-	-	-	-
Propulsion Efficiency Devices	-	-	-	-	-	-	-	W	x	-	-	-	-	-	-	-	-
Frequency Converters	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-
Exhaust Gas Boilers	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-
Efficient Lighting System	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-
Trim/Draft Optimization	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-
Weather Routing	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-
Voyage Execution	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-
Steam Plant Improvements	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-
Propeller Condition	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x

From Table 3-4, there are only two combinations of measures that should be treated with care:

- **Fixed sails or Wings and Kite:** Both measures utilizes the energy conserved in the wind to replace propulsion power. Combining the two will not necessarily add the individual effects, but potential even reduce the total effect depending on the arrangement.
- **Contra-rotating Propeller and Propulsion Efficiency Devices:** The contra-rotating propeller is a technique whereby propellers or fan blades mounted on a common axle rotate in opposite directions. Applying this together with modifications or replacements on the propeller and rudder arrangement would in most cases reduce the effect and even be impossible to combine.

3.4.7 Important input parameters

By default, the model operates with the following important input assumptions:

- Standard discount rate: 8% per annum (only used for cash flow calculations – not for fuel or emissions)
- Investment horizon: 25 years
- Carbon content of HFO: 3.114 g CO_2/g HFO

4 MEASURE DESCRIPTION

In this section, the 17 measures included in the model are described. The description includes a discussion on reduction potential, installation and operation costs.

4.1 Kite

The kite works from wind power which is transferred to the ship and results in less engine power needed to move the ship. The system works best for ships over 30 meters and in speeds less than 16 knots. One example of a ship with kite is the MV “Beluga” (4) where a test installation has been used since 2008.

Emission reduction potential

The kite will under normal conditions generate a pulling force on the ship, which can be translated into an equivalent engine power generated. In Table 4-1 an overview of the different sizes of kites applied in the model and the equivalent power generated is presented.

Table 4-1 Overview of size of kite and power generated ((5))

Size of kite [m²]	Power generated [kW]
160	600
320	1 200
640	2 500
1 280	4 900
2 500	9 600
5 000*	19 200

* Assumed not to be available until 2020

The larger the ships are the bigger a kite they can use, e.g. for crude oil tankers only a VLCC can use the 5,000 m^2 kite.

Another important factor is the amount of time the kites can be used and yield an effect. Due to prevailing winds and other limitation of the kite system, it is assumed that the kites can only be used 20% and 30% of the time for small and large ships, respectively. Kites are more favourable on long international trades where larger ships tend to trade.

Costs and benefits

The main cost elements for the kite will be purchase, installation and operational expenses and these are expected to increase with the size of the kite (Table 4-2).

Table 4-2 Overview of size of kite and cost elements (5)

Size of kite [m²]	Purchase cost [1 000 $]	Installation cost [% of purchase cost]	Operational cost [% of purchase cost per year]
160	280	7.5 %	4 %
320	480	7.5 %	6 %
640	920	7.5 %	8 %
1 280	1 755	7.5 %	10 %
2 500	2 590	7.5 %	12 %
5 000*	3 430	7.5 %	14 %

* Assumed not to be available until 2020

Sources

The main sources of information are (4) and (5).

4.2 Fixed sails or wings

Fixed installations on the ship in form of a flexible sail, rigid sail, turbosail or flettner rotor can make use of the wind to replace some of the propulsion power needed. All the possibilities will have pros and cons and must be chosen to best suit the ship type, trade and size. The savings are highly dependant on the wind conditions in which the ship operates.

The measure has been modelled after fixed masts with sails and is used as one example of these technologies.

Assumptions

These initiatives are only applicable for ships with enough space and therefore not container ships.

Stability due to the high placement of additional weight and force from the sails is not assumed to be an issue for the ships included in this study.

Prices are based on ships not needing changes in design in order to fit the masts.

Emission reduction potential

The masts and sails used here are assumed to have a potential of providing about 710 kW of power per installed mast which will result in a forward trust and reduce the power needed from the main engine. The effect of each mast is assumed to improve to 1,200 kW in 2020 and keep constant after that.

The number of masts which can be installed per ship will depend on the size of the ship and has been modelled as per Table 4-3.

Table 4-3 Number of masts installed on ships based on gross ton

Ship gross ton	Number of masts
< 4 000	1
4 000-19 999	2
20 000-49 999	4
>= 50 000	6

The effect of each mast will vary with the prevailing wind and therefore will not be effective in great parts of the time. It is assumed that the sails only will be operational 15% of the time.

Costs and benefits

The price per mast (including installation) is expected to decrease dependent on how many masts are installed on board. Thus the capital cost involved will range from $ 170,000 - 300,000 per mast depending on the number of masts installed. The cost of installation is assumed to be constant over the time period.

The operational cost for the masts is estimated to be around 10 % of the installation cost.

Sources

DNV GL has done several projects aiming at studying potential emission reducing technologies on different ships segments. One of these projects (“Momentum”) (6) looked at a large vehicle carrier. Among the measures were fixed masts with sails, findings from this project have been used as the source for this measure.

4.3 Solar panels

Solar power on ships is not very common at present, but some installations have been done over the last years. This has been in the form of solar panels installed on a vehicle carrier. In order for solar panels to work on board ships and in a relative harsh environment, the panels have to be extra sturdy compared to land based installations.

Assumptions

A large area for installation is required and therefore only ships that are not dependent on deck space can utilise the system (e.g. car carriers).

The solar panel technology is expected to become less expensive over time, but the panels unlikely to become much more efficient or less space consuming.

The lifetime of a solar panel installation is set to 10 years.

Emission reduction potential

The solar panels installed are set to produce 40-50 kW (7), (8) and will be used to supplement the diesel generators and thus reduce the power required from these units. The solar power units can produce energy both at sea and in port, but only during daylight and therefore the solar panels are set to only produce power 50% of the time. It is noted that this percentage is high, but solar panels produces power also in cloud cover though not at full capacity.

Costs and benefits

The current cost of installing solar panels on board a ship is quite significant and set to $1,020,000 for a 40 kW installation. This value is expected to decrease over time, based on what have been seen for land based installations.

Sources

The main sources of information are (7) and (8).

4.4 Electronic engine control

In the electronically controlled combustion engine ("electronic engine"), the camshaft functions are replaced by an electronically controlled set of actuators. These actuators control the starting air valves, start and reversing sequences, governor function, auxiliary blowers, fuel injection and exhaust valve actuation. This is done with far greater precision than camshaft-controlled engines. Latest intelligence from MAN Norway (9) indicates that this measure is considered standard on new build vessels considered in this study. For retrofit purposes however, it may still be a relevant measure. In the advanced mode the user have the flexibility to investigate EEC for new builds and retrofit cases considering a baseline vessels with mechanical camshaft controlling governing functions of the engine.

Electronic diesel engines have documented lower specific fuel oil consumption especially on part load.

Emission reduction potential

The estimated reduction in fuel oil consumption is estimated to 2-3 %, higher reduction potential at low load operation both for 2 and 4 stroke engines.

Costs and benefits

The additional costs for an electronic engine compared with a normal mechanical engine are dependent on engine size, but will vary from $400,000-700,000. One example shows an additional cost of $600,000 on a 30 MW engine.

Electronic technology does require increased level of service and maintenance when compared to the mechanical diesel engine. The engines themselves require synthetic oils and better maintenance due to the increased working pressures and temperatures throughout the engine. Additional costs for maintaining the electronic engines is estimated to be additional $10,000 per year and are considered to be approximately constant over the next 20 years.

The benefit from the measure will come in terms of reduced fuel consumption due to higher engine efficiency leading to lower main engine fuel consumption.

Sources

Cost figures have been estimated based on discussions with MAN Norway and the reduction potential has been estimated based on various articles and papers ((9), (10) and (11)).

4.5 Waste heat recovery

Waste heat recovery systems recover the thermal energy from the exhaust gas and convert it into electrical energy and the residual heat can further be used for ship services (such as hot water and steam). The system can consist of a an exhaust gas boiler (or combined with oil fired boiler), a power turbine (PT) and/or a steam turbine (ST) with alternator. Redesigning the ship layout can efficiently accommodate the boilers on the ship.

Waste heat recovery is well proven onboard ships, but the potential can be variable depending on the efficiency of the engines onboard.

Assumptions

It is assumed that this technology can be applied to all ships regardless of size and type even though it seems to be a practical lower limit on the engine size of 10 MW at present.

As per MAN Diesel & Turbo advice (12), the engine size governs what type of WHR system to be utilized. And, engine size assumption according to vessel type has been estimated through the use of IHS Fairplay database.

Table 4-4: Waste Heat Recovery - technology and potential savings

Main engine power	Assumed WHR system applicable	Assumed % saving on main engine fuel oil consumption	Assumed annual maintenance/operational cost
> 25,000 kW	Combined ST and PT	8% (up to 11%)	$30,000
< 25,000 kW	ST	5% (up to 8%)	$20,000
< 15,000 kW	PT	3% (up to 5%)	$10,000

The assumed saving from WHR systems are stated in % efficiency increase of the main engine (as one recovers more of the energy losses from its combustion).

The effect is assumed to be constant, as the vessels are assumed to be operating at a high enough engine load when in operation for the PT/ST to work efficiently. Note that in reality a slow steaming vessel initially designed for e.g. 80% engine load on main engine would not be able to utilize a PT/ST.

Furthermore, the measures are usually not relevant for retrofitting, and therefore only applied to new vessels.

Emission reduction potential

The installation of exhaust waste heat recovery system on board can increase the efficiency of the main engine by more than 10%, and which is projected to increase up to 15% until 2020. The increased efficiency of the main engine is modelled to result in a similar decrease in the overall fuel consumption for the ships and thus reducing the emissions, although the real fuel saving would be on the auxiliary engines on vessels without shaft generators.

Costs and benefits

The installation cost for this measure is estimated to a range of M$ 5 – 9.5 per ship from the smallest up to the largest installations. There are a lot of costs involved with installing such a system which are more or less independent of size, and a cost element which is modelled linearly with ship size.

There will be some annual maintenance needed, mainly for the boiler and the steam turbine, in order to keep up the performance of the WHR-system and this cost has been estimated at an annual cost of $20,000 per ship independent of size. For the power turbine $10,000 has been estimated as an annual maintenance cost, and for the combined power and steam turbine system $30,000 USD has been estimated. It is however recognised that these figures may be in the lower end.

The benefit from the measure will come in terms of reduced fuel consumption due to higher engine efficiency leading to lower main engine fuel consumption.

Sources

The main sources of information are (12) and (13).

4.6 Hull coating

Several tests on commercial ships and laboratories have showed that high end products are able to reduce the overall ships resistance by up to 8%. This goes both for silicone based and self polishing types of coatings. The coatings will reduce the resistance of the ship hull through water, and reduce the needed engine power, and thus reduce the fuel consumption.

The savings of applying advanced hull coatings is difficult to measure, but there is no doubt a possible saving by applying high end products. In combination with good hull condition monitoring and maintenance, savings will be achieved.

Emission reduction potential

Ships are generally recoated every fifth year and by applying high performance coating, hull resistance can be reduced. The reduction potential in frictional resistance will be higher for full bodied ships such as bulkers and tankers.

For existing ships there is also a higher potential on segments with a relatively high average ship age. For these segments it is assumed that hull sandblasting will be needed in order to obtain the full effect.

It is assumed an emission reducing effect of hull coating from 1.5-2% up to 2.5-4% for all ship segments.

Costs and benefits

The additional operational cost between dockings for ships with a high performance coating compared to a standard coating is assumed to be negligible.

The measure will have a capital expense every fifth year when the ship is in dry dock and this cost has been modelled as a function of gross ton ($100,000-$500,000 per ship). This cost has been applied to new ships as well as existing ships and is assumed to not change for the time period.

For existing ships with a high age an additional cost of sandblasting the hull has been assumed at $75,000 per ship.

The benefit from this measure will come in terms of reduced fuel consumption and thus a lower fuel cost.

Sources

The main sources for effect and cost of this measure are (1) and (14).

4.7 Air cavity lubrication

The technique is to use air injection on the wetted hull surfaces to improve a ship's hydrodynamic characteristics. The system creates an air cushion on the flat bottom part of the ship. Air-cavity systems are already in place today.

Providers of the system claim to be able to achieve 15-40% drag reduction. Air cavity systems will only affect the viscous part of the total resistance. Viscous resistance will account for 50-70% of the total resistance on most ships. Note, however, that speed vs. stability considerations should be considered.

Less than 3% of the total ship power is needed to support the air cavity system.

Fouling growth on the hull is reduced due to decreased wetted surface when operating an air cavity system helping to minimise the drag resistance.

Depending on the design, such a system may require protected propellers or other means of avoiding air to stream to the propeller.

Assumptions

The auxiliary engine is producing the power for the air cavity system, but this measure has been modelled on the main engine only, i.e. taking the additional power required from the main engine.

Emission reduction potential

The maximum reduction potential can be achieved for "low Froude number" ships for which frictional resistance dominates.

The reduction potential for crude and product tankers and bulk vessels and has been assessed in the range of 7 – 10 %, while for other ship segments has been assessed to a range of 3 – 5%.

Costs and benefits

The air cavity system requires installation of additional pumps and piping for the air in addition to changes in the hull shape in order to trap the air and create the air cushion. The cost is estimated to be 2-3% of new building cost for each ship segment.

The benefit from the measure will come in terms of reduced fuel consumption due to hull resistance and therefore the decrease of the main engine load at similar speeds as without air cavity system installed.

Sources

The main sources are (15), (16), (17) and (18).

4.8 Contra-rotating propeller

Contra-rotating, also referred to as coaxial contra-rotating, is a technique whereby propellers or fan blades mounted on a common axle rotate in opposite directions. Contra-rotating propellers are also common in some marine transmission systems, in particular for large speed boats with planning hulls. Two propellers are arranged one behind the other, and power is transferred from the engine via planetary gear transmission.

Contra-rotating propellers also exist as a pod solution. In these cases the contra rotating propeller is mounted and powered by a pod, but such solutions are only applicable for ships that are to be built with an electric propulsion system.

Assumptions

The measure has only been installed with the twin shaft solution and thus the costs are based upon that.

Ships can realize the reduction potential depending on their propeller arrangement, and some ship segments will have a lower utilisation due to these ships often running with pod solution.

Emission reduction potential

The emission reduction potential has been estimated to 5-10% and is believed to be quite stable.

Costs and benefits

The installation cost of a twin shaft contra rotating propeller solution is estimated to be approximately twice the cost of a standard single propeller solution. The additional cost for this measure is therefore modelled after the cost of a standard single propeller solution. The cost of the propeller on the smallest ships (based on size of main engine) has been estimated to $300,000 per ship and increasing linearly with size of main engine at $15 per kW installed power.

The operational cost will be higher than for the standard propeller solution because this is a new and more complicated technology. The additional operational cost is estimated at a range of $20,000-30,000 dependent on ship size.

Sources

The main sources are (19) and (20).

4.9 Propulsion efficiency devices

Many different designs exist for ducts or fins in front and aft of the propeller for improving the inflow of water to the propeller or utilising rotational energy behind the propeller, thus improving the overall propeller efficiency. Systems in front of the propeller will improve the inflow, and will be more efficient on ships with a high block coefficient. More recent design is the Becker Mewis duct which combines pre swirl fins and a wake equalizing duct. When a propeller is acting behind a hull, a portion of the energy is lost in the rotation that the propeller gives to the flow behind it. The overall efficiency of the propulsion can be improved by recapturing this rotational energy. By setting up rotation ahead of the propeller the loss can be reduced. By using fins or Grim wheels behind the propeller the rotational flow can be used to create more forward thrust.

Many different designs exist and all aim at utilizing the rotational flow to either improve the propeller efficiency or use the rotation to create more forward thrust. Separate fins or the rudder may be used for this.

Such devices have proven to improve the propeller efficiency in tests. The effect can be found on all ship segments, and therefore this measure has been applied to all segments. It will not be explicitly stated which technology should be installed for each ship segment. The different technologies listed above are expected to be suitable for different ship segments, but the performance and the price is not expected to deviate substantially.

The positive effects are obtained by the change of the radial distribution of the circulation or loading. Compared to a conventional propeller with a normal load distribution, the induced tangential velocities and thus the tangential losses are smaller for a Tip Vortex Free (TVF) propeller, while the axial losses remain unchanged.

Operating at speeds that are different from the design speed for any of these devices will certainly have detrimental effects to their efficiency.

Emission reduction potential

The emission reduction has been estimated to be in the range of 1-7% for existing ships, with higher potential on some smaller bulker and tankers. Furthermore, the measure is assumed to be already applied or not applicable on some container, roro and passenger ships.

The most recent and most tested type of propeller winglet is the Kappel propeller and JJ Kappel state that such devices will save between 3-5%. However, full-scale tests on two bulk ships have shown savings of up to 15% both in ballast and in laden condition. In order to be conservative a 3% saving has been used.

Cost and benefits

The propulsion efficiency devices can be installed during dry dock for a fixed cost of $ 17,000 plus $6.4 per kW installed main engine effect ($ 20,000 – 800,000 per ship).

The cost of installing propeller winglets has been estimated to 20% of the cost of a standard propeller cost. Cost of propellers is dependant of the weight of the raw material used. A standard 20MW propeller will cost $600,000. The cost of the propeller on the smaller ships (based on size of main engine) has been estimated to $300,000 per ship and increasing linearly with size of main engine at $15 per kW installed power and the propeller winglet installation cost has been modelled accordingly.

Once the device has been installed there will be no additional operational costs compared to a standard propeller.

The device will reduce the fuel cost by improving the propulsion efficiency and thus leading to reduced CO_2 emissions.

Sources

The main sources are (15) and (21).

4.10 Frequency converter

Many of the auxiliary systems onboard are in continuous operation, like seawater and freshwater pumps, fans, compressors, etc. These are designed for full speed operation and high air and sea water temperature. This equipment is hence over dimensioned for the operational pattern of the fleet as the need for full capacity is in the range of 25% - 45% of the operating time.

Traditional electrical motors can not vary their motor load based on the actual demand and, therefore, the motor is running on too high load most of the time. Frequency converted motors will regulate the frequency in order to adapt the motor load to the actual need at all times. Then the total energy consumed by all the electrical motors onboard can be reduced significantly. This technology can be applied to all electrical motors onboard, but normally will be applied to motors over a certain size.

Assumptions

It is assumed that motors with frequency converters can be installed for all electrical motors onboard all ships in each included segment and that there are no limitations on type and sizes of such motors.

Emission reduction potential

A frequency converter will enable the electrical motors on most equipment on board to run on part loads instead of on/off as is the case today and this is estimated to lead to a reduction potential of 30 % of the total auxiliary power. This measure could be applicable to 60-70% of the energy consumers relying energy produced by the auxiliary engine. Thus the, measure is expected to reduce the energy consumption of these consumers by up to 50%.

The effect is assumed not to increase over time as this is fairly standard equipment which has been available for on shore applications for many years.

Costs and benefits

Estimated extra cost for installing frequency controlled electrical motors compared to traditional motors are set to $250 per kW installed auxiliary engine power on board.

It is assumed that the installation cost will decrease over time to half by 2030 due to the increased demand, more modern technology and more producers of ship equipment.

An estimate of $5,000 extra operational costs per year for maintenance of the more sophisticated equipment compared to standard equipment is used.

Sources

The estimates above are based on (21).

4.11 Exhaust gas boilers on auxiliary engines

Exhaust gas boilers recover the heat from the flue gas of auxiliary diesel engines to generate steam and/or hot water or useful heat for process heating. Depending on system design, these boilers can enhance the efficiency of the auxiliary engine system by up to 20%, leading to lower overall process costs.

Assumptions

For ships not fitted with shaft generator, an auxiliary (aux) engine will be in service in all operation modes (seagoing and in port). Excessive heat from the engine exhaust could then be utilised.

In case of ship fitted with shaft generator, the aux engines will normally be in service in port. Excessive heat is then only available when in port.

Aux engines are usually run at 70 - 80% load. The average load is therefore assumed to be approx 600 - 650kW for a conventional ship with 3 auxiliary engines.

For reference, the expected steam production at 80% load on an averaged size auxiliary engine would be between 450 kg/h and 500 kg/h at 7 barG.

Emission reduction potential

The reduction potential has been estimated to 5% for steam production on ships that have oil fired boilers installed.

The reduction potential has been estimated to 1% on ships without an oil fired boiler installed.

Costs and benefits

The additional installation cost for an extra exhaust gas boiler on the auxiliary engines is estimated to $50,000-$75,000 based on size and that this measure is only for new ships where this can be installed during building.

The extra operational cost on maintenance is estimated to $10,000 per year, independent of size and unchanged until 2030.

The benefit from the measure will come either in terms of reduced fuel consumption due to lower need for auxiliary power for e.g. process heating, and thus lower fuel consumption for auxiliary engines. Alternatively, the benefit may come as reduced fuel oil consumption on oil fired boiler in cases of insufficient steam production from main engine exhaust gas economizer. To simplify the benefit, the savings are modelled as total percentage saving of the auxiliary engine's fuel oil consumption.

Sources

The estimates above are based on intelligence from Alfa Laval (22). This is combined with calculations made during one energy management project for an oil tanker company where the capacity and steam need has been used.

4.12 Energy efficient light system

Use of energy efficient lighting equipment such as low energy halogen lamps, fluorescent tubes and LED (Light emitting diode) in combination with electronically controlled systems for dimming, automatic shut off etc. is continuously developed as the focus on energy and environment has increased. The new technology has been applied only to a limited extent to the shipping industry and standard normal design does not include low energy lighting.

Assumptions

The total energy consumed for lighting on a normal merchant ship can be estimated to 5 % of the total electrical power consumed (see Table 4-5) and is believed to be higher for cruise and passenger ships (>10%).

Emission reduction potential

The emission reduction potential is estimated to 3% of the total auxiliary engine consumption on normal merchant ships.

Costs and benefits

Installation cost is estimated to $100,000 extra compared to the traditional lighting installations on normal ships and $200,000-$1,000,000 on passenger and cruise ships.

Since most of the energy lighting systems has an equal or longer lifetime than normal lighting systems, the additional operational costs are set to zero.

Sources

OSRAM, one of the big companies within the lighting market claim that the total energy for light onboard a ship can be reduced by 50% based on various articles (24), together experience from the Norwegian NOx Fund (23).

The estimated load from the lighting systems onboard a normal ship is taken from the electrical load distribution list for a Multi Purpose Cargo (MPC) ship that can be seen as representative for normal ships., as described in Table 4-5:

Table 4-5 Power balance for auxiliary equipment for an example ship

Equipment	kW	% of total
AC	65	2%
Blower	180	4%
Bow thruster*	903.5	22%
Compressor	115.2	3%
Containers	7.5	0.2%
Crane	354	9%
Fan	440	11%
Galley	98	2%
Heater	30	1%
Light	213	5%
Nautical equipment	8	0.2%
Pump	1 334	32%
Separator	56	1%
Winch	289	7%
Workshop equipment	22	1%
Total	**4 114**	**100%**

* It is noted that many ships will not have a bow thruster

The cost estimated for installations are based on (21) and is assumed to be an additional $ 300 per lighting point.

4.13 Trim / draft optimization

The trim and/or draft of the ship influence the hull resistance and therefore the fuel consumption. In general limited regard to optimal trim and draft is taken when loading the ship and therefore optimal conditions will most often not be achieved. By actively planning cargo loading and by that optimising the trim and draft, one can save fuel and reduce the emissions accordingly.

Emission reduction potential

Optimising the trim and draft has been estimated to reduce the fuel consumption by 0.5 – 2 % for most ship types. Though for ships which often trade in partial load conditions (e.g. container, roro) the effect can be up to 5 %. These numbers are based on full scale test and detailed calculations performed on a number of different ships in different trades (21).

Full-body ships where resistance from viscous friction is higher than wave friction (e.g. tank and bulk) will generally have a less reduction by optimising the trim and draft and similarly for ships with limited ballast flexibility.

Costs and benefits

In order to be able to optimise the trim and draft additional equipment is required (such as a better loading computer or a dedicated trim optimizer) and in addition the crew need training in the use of such equipment. The installation of system and training of crew has been estimated to $25,000 per ship. Once the equipment is installed there is no additional operational cost.

Better trim and draft will reduce the resistance and therefore less engine power is required which leads to a lower fuel consumption.

Sources

The estimates above are based on (25).

4.14 Weather routing

The weather (wind and waves) will together with ocean currents influence the power needed to propel a ship at a given speed over ground. Therefore, it is important to take these factors into consideration when planning a voyage and to try to minimise the negative influence.

The longer the voyages are the more route choice flexibility the ship has in order to avoid unwanted weather conditions. Also longer voyages most often include time spent in unsheltered waters where the influence from weather is making weather routing important. Therefore, the biggest potential could be realised in intercontinental trades and for larger ships.

Emission reduction potential

All ships can potentially install the system, and therefore it is assumed that the entire fleet can install the measure. However, for existing ships, some ship segments (e.g. large container and roro) have to a certain degree already implemented weather routing and, therefore, have a lower potential for emission reduction. This is also assumed to be the case for new ships coming into service in this period.

The potential has been assessed to between 0 – 5% dependent on ship size and type and the typical trade for the different ship segments.

Costs and benefits

In order to improve the weather routing a new system will have to be installed on board all ships. This system is assumed not to become standard in the future and will come at a premium for the time period studied. The system is estimated to cost $15,000 per ship to install and in addition an annual subscription of $3,000 per ship is needed to keep the software up to date and get the latest weather information.

The benefit from the measure will come in terms of reduced fuel consumption due to reduced resistance from wave and wind.

There might also be a benefit from less fatigue and weather damages, but this has not been included in this study.

Sources

The estimates above are based on (21).

4.15 Voyage execution

Voyage execution as a measure covers the planning and execution of individual voyages from port to port. The fuel consumption on an individual voyage is strongly related to speed, engine load and use of autopilot (related to number of rudder turns). Recent projects where DNV GL have assisted clients in fuel consumption reductions have shown a potential for improving the voyage execution by systematically running the ships at more economical speeds and at steady engine loads.

Emission reduction potential

The longer the voyages are the more flexibility in route choice the ship has and therefore the biggest potential will be seen in intercontinental trades and for larger ships. However for ships in liner services (e.g. container, roro) the time schedule will restrict the possibility to improve.

The potential has been assessed to be between 1 – 10%, dependent on ship size and type.

Costs and benefits

Voyage execution will need additional equipment (basically hardware and software programs) installed which is assumed not to become standard over the time period and therefore the installation cost is kept fixed. The installation of systems including some initial training of crew is estimated at $10,000 per ship and in addition annual training and software upgrades are needed and estimated at $5,000 per ship.

The benefit from the measure will come in terms of reduced fuel consumption due to lower and more constant speed and still meeting the arrival time at destination.

Sources

The estimates above are based on (21).

4.16 Steam plant operation improvement

Experience has shown that there is an improvement potential for boiler operation in terms of general use of the boiler. The improvements have been seen in areas such as: improved procedures for tank cleaning, general reduction of the steam consumption, monitoring and tuning of the boiler performance, optimal cargo heating, efficient use of cargo pumps.

Assumptions

This measure is only valid for crude and product tankers as they are the only ship types modelled to have boilers (1). It is recognised that other ship segments have steam plants installed, but this as not been included here.

The improvements have generally been implemented on larger ships and, therefore, the potential is greater for smaller ships.

Emission reduction potential

The reduction potential for boiler consumption has been assessed to be in the range of 10 – 30 %, with larger reductions on smaller ships than larger ships. The improvements have been assessed to be unchanged for new ships as this is an operational measure and it is assumed that new tankers will have the same operational pattern as the existing ships.

Costs and benefits

The measure involves change of procedures, training of crew and some additional maintenance which all are assumed to have to be done yearly in order to get the full reduction potential. The cost of these initiatives has been estimated at $20,000 per ship per annum.

The benefit from the measure will come in terms of reduced fuel consumption due to less steam needed on board in addition to more effective production of steam.

Sources

A study has been made on 2 chemical ships during an energy management project and this revealed that the steam loss due to poor insulation, poorly maintained steam traps could be around 10 %. In addition, the crew doing the tank cleaning had no understanding of their use of steam and just by focusing on this, the total steam consumption could be reduced by up to 30 % since as much as 70 % of the total steam consumption is used for tank cleaning on chemical vessels. The estimates above are based on (21).

4.17 Propeller condition

The measure is related to the condition of the surface of the propeller which influences the efficiency of the propeller. The surface of a propeller will become less smooth due to strain and cavitation damage, whereas growth will start to develop over time. This can be avoided by regular polishing or coating of propeller. This measure has been set twice yearly. This has been found to have the optimal balance between cost and effect.

Emission reduction potential

By regularly polishing or coating the propeller, tests have shown that the fuel consumption can be reduced by 0.5-1.5%, with the effect decreasing with size of the ship in question.

Costs and benefits

The cost of polishing or coating the propeller twice yearly, is estimated to $8,000 per ship with no additional operational cost involved. This cost is mainly from having a diver perform the work on the propeller while the ship is berthed and loading cargo.

The fuel cost for the ship will be reduced from improved propeller efficiency since the power loss in the system will be decreased.

Sources

The estimates above are based on (21) and (26).

5 POSSIBLE MODEL EXTENSIONS

This section outlines possible model extensions including new measures, new features and other aspects relevant for extending the study.

Relevant additional measures:

- Aerodynamic superstructure
- Culture and awareness
- Energy system optimization
- Engine performance testing
- Engine tuning
- Fuel change (Bio fuels, LNG, electric, nuclear, hydrogen)
- Hybridization (plug-in or conventional)
- Improved logistics in port
- Optimized vessel design (hull) specific to trade and operation
- Performance monitoring
- Slow steaming

Relevant new features and other aspects:

- Improved retrofit applicability
- Extended vessel list
- Improved end-user applicability

6 REFERENCES

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(21)

Project Nr	Resp unit	Segment	Description	Fleet
31100363	MA Norway	Tank	Greek tank operator	45 ships
31407090	MA Singapore	Container	Asian container operator	70+ ships
31100261 31100269	MA Norway	Chem	European chemical operator	80 ships
31407035	MA Singapore	Container	Asian container operator	100+ ships
31100350	MA Norway	Cruise	European cruise operator	13 ships
31100381	MA Norway	Ro-Ro	European short sea car carrier	27 ships
31100347	MA Norway	Container	European container operator	100+ ships
31400156 Ph1 31406021 Ph 2 31407083 Ph 3	MA Singapore	Container, chemical & LNG	Asian shipping company with multiple fleet	60+ ships
582603	MA London	Container	European commercial mgmt short sea container	29 Ships
31100451	MA Norway	Tank	Scandinavian Tanker operator	30 Ships
31100461 31100496 31100571 31100575	MA Norway	Ro-Ro	Scandinavian RoRo company	75 ships
31408021	MA Singapore	Ro-Ro	Asian Car Carrier operator	50+ ships
31407037	MA Singapore	Dry bulk & Chemical	Singapore, Chemical, OBO, bulk	17 ships
36111116	MA Norway	Container	European Container operator	100+ ships
582664	MA London	Tank	Greek tank operator	20 ships
582672	MA London	Tank	Greek tank operator	
31100621 31100699	MA Norway	Seismic	European Seismic operator	20 ships
31100624 31100678	MA Norway	Open hatch & container	European project cargo and container operator	80+ ships
31100686	MA Norway	Seismic	European Seismic operator	16 ships
31100694	MA Norway	Cruise	European Cruise operator	4 ships

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APPENDIX A
User manual - Normal mode

0 USER MANUAL

The following chapter includes a user manual for the normal mode of the tool.

0.1 General requirements

- MS Excel 2007 or newer installed
- General understanding of MS Excel
- Macros enabled (prompted when opening the document)

0.2 Dashboard overview

The following sections explains the different objects on the model dashboard and how they should be interpreted

0.2.1 Dashboard

Figure 0-1 shows the user dashboard and explains the general setup of the model

Output data calculated based on the input values provided

Input data to change vessel segment, vessel size and fuel price

Cost efficiency curves for each measure evaluated in the model (ranked from left to right). Each bar represents a measure (color coded and numbered) represented in the table below.

The height of the bar indicates the cost efficiency of the measure [$/ton CO_2] over the lifetime of the vessel while the width represents the effect measured in ΔEEDI (left) and ΔEEOI (right)

Reference values based on the vessel type and size segment applied

Instructions providing guidance on how to use the model.

Measure selection chosing what measure to include in the model

Resulting table with more detailed information on each measure evaluated in the model

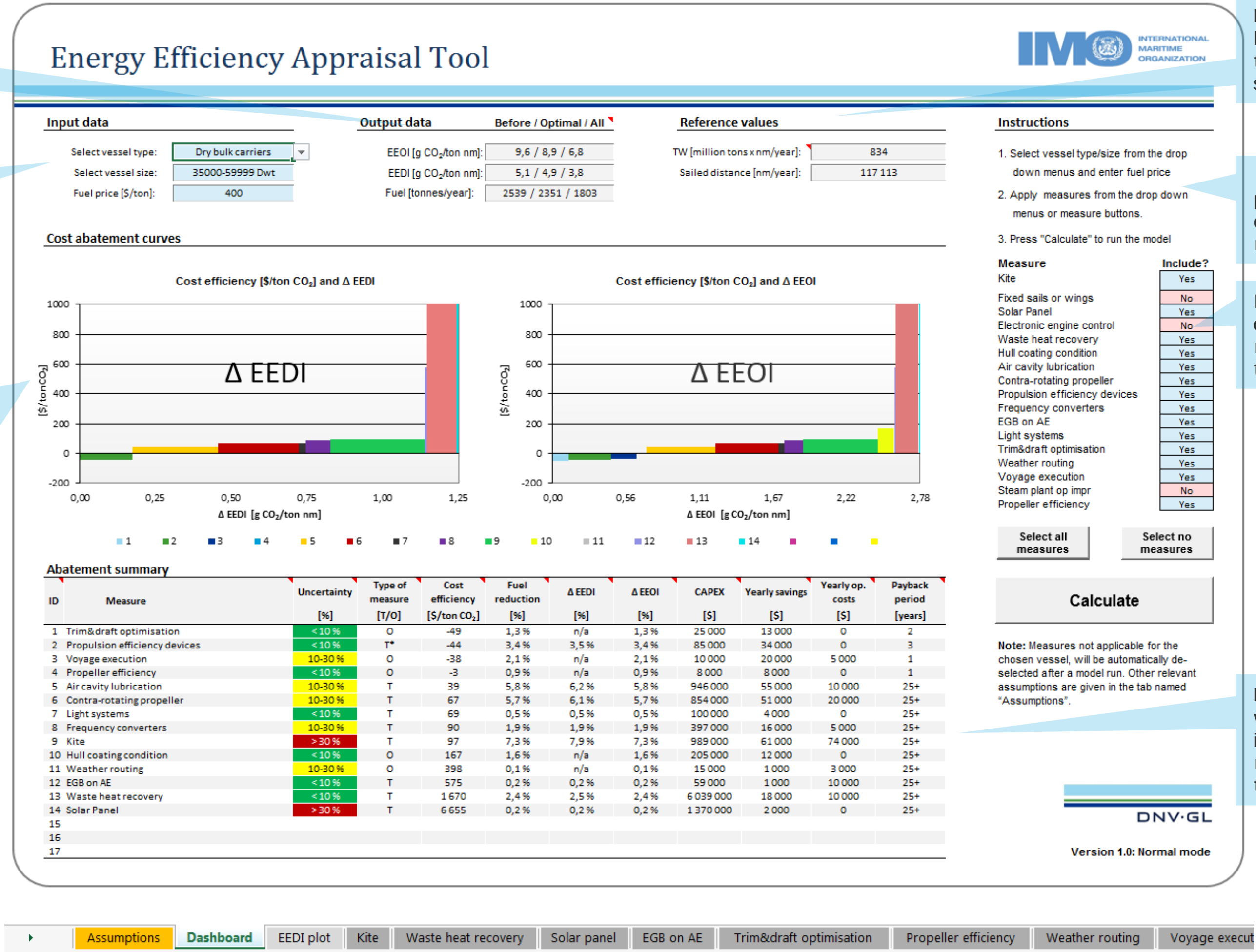
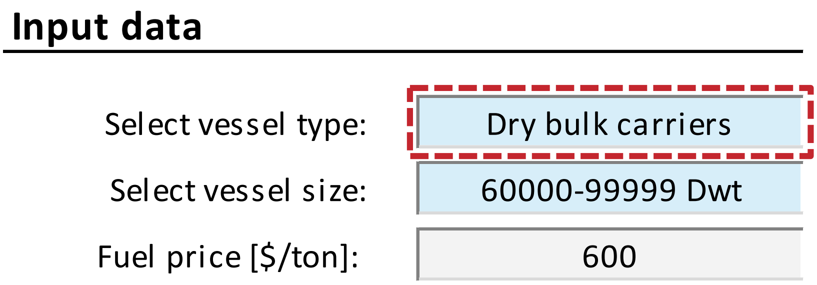


Figure 0-1: Dashboard overview

0.2.2 Input data

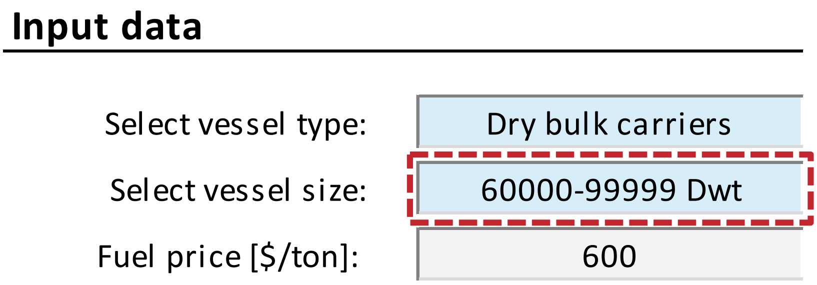
The normal mode of the tool has four input elements highlighted with **light blue** cell colors in the model dashboard.

1. **Vessel type:** Pre-defined vessel segments available for investigation



   a. Crude oil tankers
   b. Dry bulk carriers
   c. Container ships
   d. Ro-Ro ships
   e. General cargo vessels
   f. Passenger vessels
   g. Ro Pax vessels
   h. Cruise vessels
   i. Chemical tankers
   j. Product tankers

2. **Vessel size:** Different vessel sizes based on vessel type



3. **Fuel price:** Chosen fuel price for the fuel applied on the investigated vessel

Input data

Select vessel type:	Dry bulk carriers
Select vessel size:	60000-99999 Dwt
Fuel price [$/ton]:	600

4. **Measure:** Chosen measures to be applied on the investigated vessel

    a. Kite
    b. Fixed Sails or Wings
    c. Solar Panels
    d. Electronic Engine Control
    e. Waste Heat Recovery
    f. Hull Coating
    g. Air Cavity Lubrication
    h. Contra-Rotating Propeller
    i. Propulsion Efficiency Devices
    j. Frequency Converters
    k. Exhaust Gas Boilers
    l. Efficient Lighting System
    m. Trim/Draft Optimization
    n. Weather Routing
    o. Voyage Execution
    p. Steam Plant Improvements
    q. Propeller Condition

Instructions

1. Select vessel type/size from the drop down menus and enter fuel price
2. Apply measures from the drop down menus or measure buttons.
3. Press "Calculate" to run the model

Measure	Include?
Kite	Yes
Fixed sails or wings	No
Solar Panel	Yes
Electronic engine control	No
Waste heat recovery	Yes
Hull coating condition	Yes
Air cavity lubrication	Yes
Contra-rotating propeller	Yes
Propulsion efficiency devices	Yes
Frequency converters	Yes
EGB on AE	Yes
Light systems	Yes
Trim&draft optimisation	Yes
Weather routing	Yes
Voyage execution	Yes
Steam plant op impr	No
Propeller efficiency	Yes

Select all measures

Select no measures

Calculate

0.2.3 Output data

The normal mode of the tool has three output elements highlighted with **grey** cell colors in the model dashboard. Each element is evaluated for:

- Before: The condition before any measures are applied (baseline values)

- Optimal: The condition given that only profitable measures out of the chosen selection of measures are applied (cost efficiency < 0)
- After: The condition after all measures selected are applied

1. **EEOI:** The calculated EEOI value

Output data	Before / Optimal / All
EEOI [g CO_2/ton nm]:	50,3 / 42 / 40,9
EEDI [g CO_2/ton nm]:	4,1 / 3,5 / 3,4
Fuel [tonnes/year]:	25491 / 21275 / 20690

2. **EEDI:** The calculated EEDI value

Output data	Before / Optimal / All
EEOI [g CO_2/ton nm]:	50,3 / 42 / 40,9
EEDI [g CO_2/ton nm]:	4,1 / 3,5 / 3,4
Fuel [tonnes/year]:	25491 / 21275 / 20690

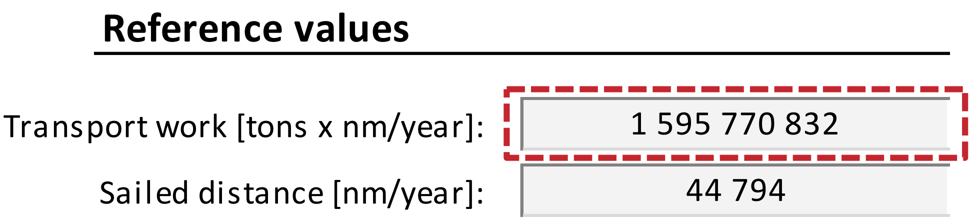
3. **Fuel:** The calculated fuel consumption

Output data	Before / Optimal / All
EEOI [g CO_2/ton nm]:	50,3 / 42 / 40,9
EEDI [g CO_2/ton nm]:	4,1 / 3,5 / 3,4
Fuel [tonnes/year]:	25491 / 21275 / 20690

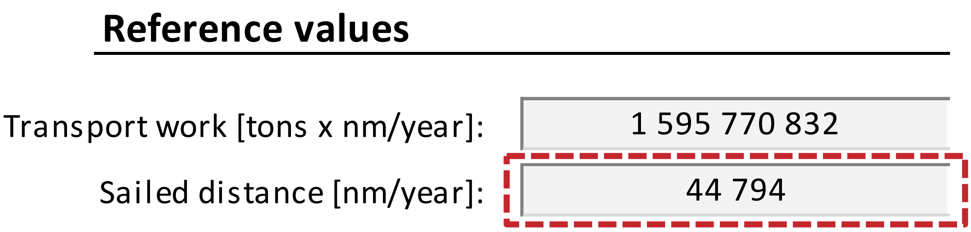
0.2.4 Reference values

The normal mode of the tool has three reference value elements highlighted with **grey** cell colors in the model dashboard. They represent default values for the vessel type/size chosen as input values.

1. **Transport work:** The estimated transport work for the chosen combination of vessel type/size



2. **Sailed distance:** The estimated sailed distance for the chosen combination of vessel type/size



0.2.5 Cost abatement curves

The normal mode of the tool has two cost abatement curves as illustrated in the dashboard (Figure 0-2):

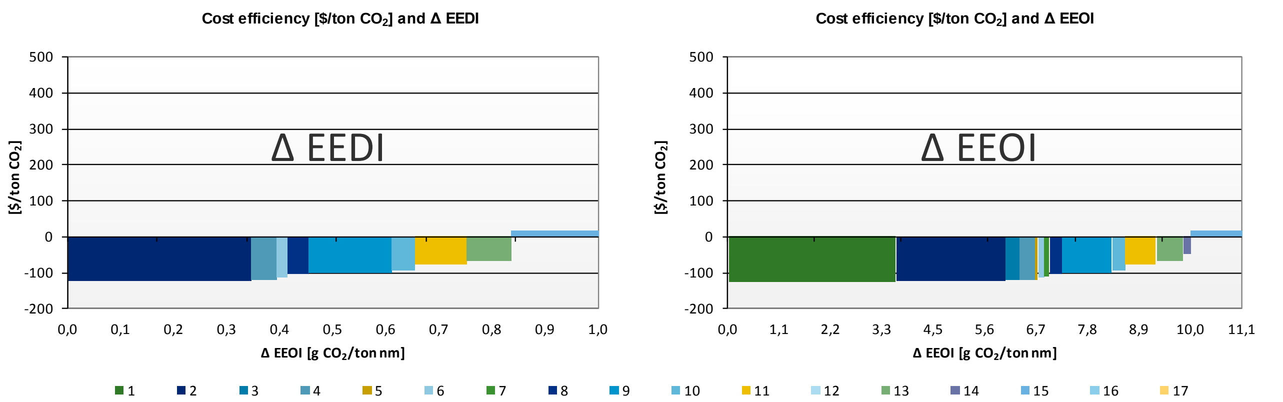


Figure 0-2: Cost abatement curves

ΔEEDI: The left graph represents the cost efficiency of each applied measure over the lifetime of the vessel against the effect on EEDI.

Each measure is represented with a bar, where the height of the bar shows the cost efficiency of the measure (positive values indicate a cost over the lifetime, while negative values indicate savings). Wide bars indicate large impact on EEDI, whilst thin bars indicate marginal impact on EEDI. All measures are ranked from high cost efficiency (left) to low cost efficiency (right).

Note: Only measures affecting EEDI are represented in the graph. Hence, only technical measures listed with a [T/T*] in the Abatement summary table are shown.

ΔEEOI: The right graph represents the cost efficiency of each applied measure over the lifetime of the vessel against the effect on EEOI.

Each measure is represented with a bar, where the height of the bar shows the cost efficiency of the measure (positive values indicate a cost over the lifetime, while negative values indicate savings). Wide bars indicate large impact on EEOI, whilst thin bars indicate marginal impact on EEOI. All measures are ranked from high cost efficiency (left) to low cost efficiency (right).

Note: <u>All</u> measures are affecting EEOI, hence, represented in the graph. Therefore, all operational and technical measures, listed with an [O] and [T/T*] in the Abatement summary table are shown.

0.2.6 Abatement summary

The normal mode of the tool has an abatement summary table as illustrated in the dashboard (Figure 0-3) including the following parameters:

1. **ID:** The measure ID used to link and recognize the measure in the graphs.
2. **Measure:** Name of the applied measure.
3. **Uncertainty:** The estimated uncertainty of cost or effect of the measure.
4. **Type of measure:** Indicates whether the measure is technical [T] (relevant for newbuilds and/or operational [O]. Note than only technical measures will affect the EEDI, while both technical and operational measures will affect the EEOI. Propulsion efficiency devices is marked with a [T*] due to its applicability for existing vessels, even though it is listed as technical.
5. **Cost efficiency:** The cost efficiency (height of each bar) measured in net present cost divided by ton CO_2 reduced (width of each bar) over the lifetime of the vessel or measure (whatever is the shortest) from applying a specific measure, given that the above measures are implemented. Negative values represent profitable measures.
6. **Fuel reduction:** The percentage reduction in fuel from applying a specific measure given that the above measures are implemented.
7. **ΔEEDI:** The percentage reduction in EEDI from applying a specific measure. “n/a” represents measures not affecting EEDI.
8. **ΔEEOI:** The percentage reduction in EEOI from applying a specific measure.
9. **CAPEX:** The associated investment cost [USD] from applying a specific measure.
10. **Yearly savings:** The yearly savings [USD] from applying a specific measure.
11. **Yearly operational costs:** The yearly operational costs [USD] from applying a specific measure.
12. **Payback period:** The time it takes to recover the cost of the investment from applying a specific measure.

ID	Measure	Uncertainty [%]	Type of measure [T/O]	Cost efficiency [$/ton CO_2]	Fuel reduction [%]	Δ EEDI [%]	Δ EEOI [%]	CAPEX [$]	Yearly savings [$]	Yearly op. costs [$]	Payback period [years]
1	Trim&draft optimisation	< 10 %	O	-49	1,3 %	n/a	1,3 %	25 000	13 000	0	2
2	Propulsion efficiency devices	< 10 %	T*	-44	3,4 %	3,5 %	3,4 %	85 000	34 000	0	3
3	Voyage execution	10-30 %	O	-38	2,1 %	n/a	2,1 %	10 000	20 000	5 000	1
4	Propeller efficiency	< 10 %	O	-3	0,9 %	n/a	0,9 %	8 000	8 000	0	1
5	Air cavity lubrication	10-30 %	T	39	5,8 %	6,2 %	5,8 %	946 000	55 000	10 000	25+
6	Contra-rotating propeller	10-30 %	T	67	5,7 %	6,1 %	5,7 %	854 000	51 000	20 000	25+
7	Light systems	< 10 %	T	69	0,5 %	0,5 %	0,5 %	100 000	4 000	0	25+
8	Frequency converters	10-30 %	T	90	1,9 %	1,9 %	1,9 %	397 000	16 000	5 000	25+
9	Kite	> 30 %	T	97	7,3 %	7,9 %	7,3 %	989 000	61 000	74 000	25+
10	Hull coating condition	< 10 %	O	167	1,6 %	n/a	1,6 %	205 000	12 000	0	25+
11	Weather routing	10-30 %	O	398	0,1 %	n/a	0,1 %	15 000	1 000	3 000	25+
12	EGB on AE	< 10 %	T	575	0,2 %	0,2 %	0,2 %	59 000	1 000	10 000	25+
13	Waste heat recovery	< 10 %	T	1 670	2,4 %	2,5 %	2,4 %	6 039 000	18 000	10 000	25+
14	Solar Panel	> 30 %	T	6 655	0,2 %	0,2 %	0,2 %	1 370 000	2 000	0	25+
15											
16											
17											

Figure 0-3: Abatement summary

0.3 User instructions – Normal mode

The following chapter is meant to educate the user on how the normal mode of the tool should be used correctly, step by step (Figure 0-4):

1. Click on the tab named “Dashboard”, if not already present
2. Select relevant vessel type from the drop down menu
3. Select relevant vessel size from the drop down menu
4. Enter relevant fuel price
5. Select/de-select measures from the list by choosing “Yes” or “No” from the drop down menus
6. Press “Calculate” to run the model under the assumptions made from (1-5)

Note that measures not applicable for the chosen vessel, will be automatically de-selected after a model run. Other relevant assumptions are given in the tab named “Assumptions”

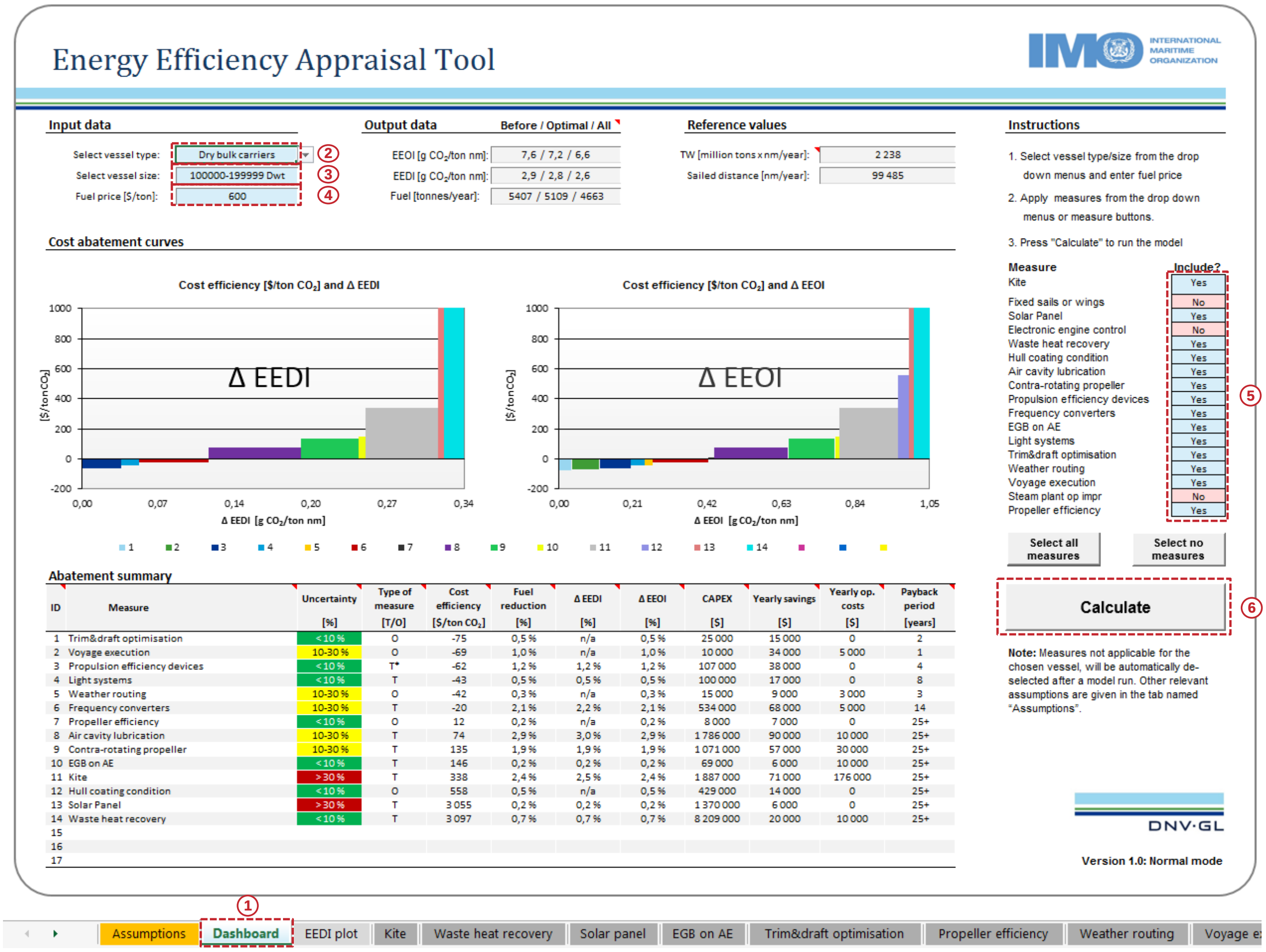


Figure 0-4: User instructions – Normal mode

0.4 User instructions – Advanced mode

The following chapter is meant to educate the user on how the advanced mode of the tool should be used correctly, step by step (Figure 0-5):

1. Click on the tab named "Dashboard", if not already present
2. Select relevant vessel type from the drop down menu
3. Select relevant vessel size from the drop down menu
4. Select/de-select measures from the list by choosing "Yes" or "No" from the drop down menus
5. Click on the tab named "Advanced input"
6. In order to override default values, enter relevant
    a. Discount rate
    b. Investment horizon
    c. Fuel consumption
    d. Transport work
7. Enter fuel price development
8. Click on relevant measure tab
9. Adjust measure input as preferred
    a. Applicable to ship type [0,1]: Indicates whether the measure is relevant for the vessel type
    b. Measure applicability to engines [0,1]: Indicates which producer will get the % saving
    c. Installation cost [$]: Indicates the initial CAPEX from investing in the measure
    d. Operational cost [$/year]: Indicates the yearly/5-yearly cost of operating the measure (maintenance/repairs/overhauls etc.)
    e. Lifetime [years]: Indicates the expected lifetime of the measure
    f. Fuel reduction [%]: Indicates the percentage reduction in fuel from applying a measure on the given producer specified in (b)
10. Click on the tab named "Dashboard"
11. Press "Calculate" to run the model under the assumptions made from (1-8)

Default values are always chosen if not overrun in Advanced mode.

Note that measures not applicable for the chosen vessel, will be automatically de-selected after a model run. Other relevant assumptions are given in the tab named "Assumptions".

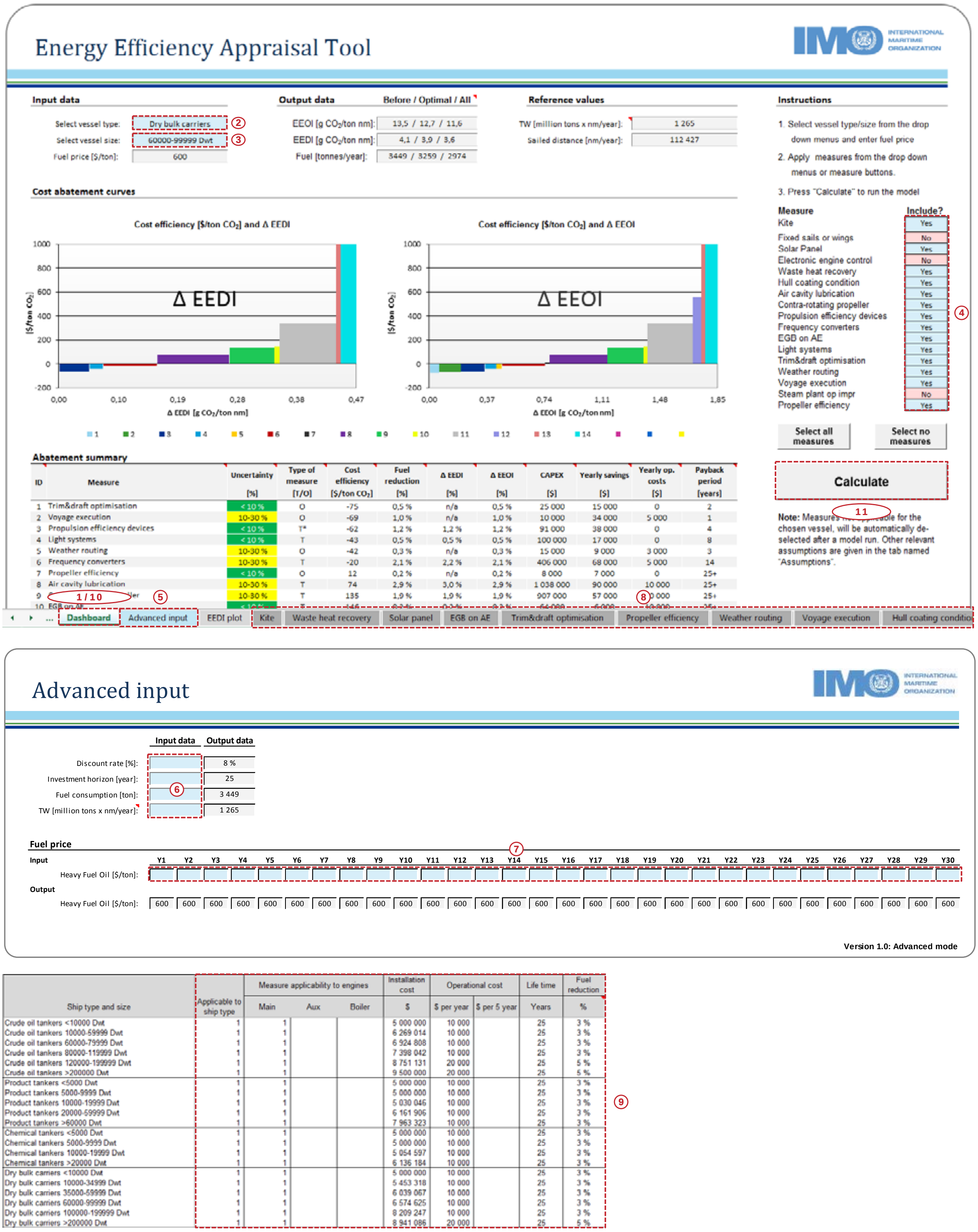


Figure 0-5: User instructions – Advanced mode

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.