METHODOLOGY

METHODOLOGY FOR RETROFIT ENERGY EFFICIENCY MEASURES IN SHIPPING

SDG 13

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1| Definition

1.1.1 | For the purpose of this methodology, following definitions apply:

a. **Beaufort Scale or Beaufort Wind Force Scale** is an empirical measure for describing wind speed based mainly on observed sea.

b. **Docking cycle:** Ships are periodically placed in a dry dock in order to undertake maintenance of hulls, propellers and other surfaces that would normally be submerged, as well as to make any elective technology upgrades to the vessels. A docking cycle comprises the interval between successive dry dockings. A docking cycle for large cargo vessels is usually 60 months, though for some ships it can be 36, 30, 24, or even 12 months.

c. **Ship speed** can be defined in two ways:

   i. Speed over the ground (SOG) is the speed of the vessel relative to the surface of the earth.

   ii. Speed through water (STW) is the speed of the vessel relative to the water.

Note that in this methodology, speed refers to speed over the ground.

1.1.2 | For the purpose of this methodology, the following abbreviations apply:

BAU	Business as Usual
CDM	Clean Development Mechanism
EE	Energy Efficiency
EEDI	Energy Efficiency Design Index
ERs	Emission Reductions
ESCO	Energy Service Company
ESD	Energy Saving Device
GHGs	Greenhouse Gases
GWP	Global Warming Potential
HFO	Heavy Fuel Oil
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
LNG	Liquefied Natural Gas
MDO	Marine Diesel Oil
tkm	Ton-Kilometre
UNFCCC	United Nations Framework Convention on Climate Change

2| Scope, Applicability, and entry into force

2.1 | Scope

2.1.1 | This methodology is applicable to a wide range of retrofit technical efficiency measures in shipping which reduce fuel usage and greenhouse gas (GHG) emissions. Implementation of one or multiple measures has the potential to achieve significant efficiency improvements in shipping. This methodology therefore encompasses the application of multiple technical efficiency options measuring the compound outcome.

2.2 | Applicability

2.2.1 | The methodology allows for the application of one or multiple efficiency measures simultaneously. In most cases, the efficiency measures are applied during dry docking with docking cycles going for 12 to 60 months depending on vessel types, but it is also possible that some of these measures are applied during the docking cycle.

2.2.2 | The eligible technical efficiency measures are installed individually or as bundles custom-tailored for a given ship to improve fuel efficiency in shipping. The examples of eligible retrofit measures included[1] are summarised in the Table 1, below.

Table 1 Examples of eligible retrofit energy efficiency measures.

MEASURES TYPE	EXAMPLES
a. Design related measures	This category includes engine derating[2], reconfiguration of the bulbous bow[3], interceptor trim plates[4], optimisation of hull openings[5], superstructure aerodynamics, aft waterline extension[6], and air lubrication[7].

[1] This is a non-conclusive list of eligible measures. The project developer may submit non-listed efficiency measures with justification and clear cause-effect chain for inclusion in the Project Design Document. The listed Grouping categories are based on Wartsila, Energy Efficiency catalogue/Ship Power R&D, 2009.

[2] Adjustments in the fuel injection timing are made allowing the engine to continue operating at its P_{max} but at a lower power/speed level.

[3] A bulbous bow can potentially reduce wave-making resistance and thus the hull resistance. The bulb design needs to be in accordance with the expected range of operating drafts and speeds as it can potentially also result in increasing resistance.

[4] A metal plate fitted vertically to the transom of a ship which bends the flow over the aft-body of the ship downwards creating a lift effect similar to a conventional trim wedge.

[5] The water flow disturbance from openings to bow thruster tunnels and sea chests is minimized e.g., through installing a scallop behind each opening or a grid that is perpendicular to the local flow direction. This results in lower power demand.

[6] The effective waterline is lengthened making the wetted transom smaller and reducing the resistance of the ship.

[7] Air cavity via injection of air under/around the hull to reduce wet surface and thereby reducing the ship’s frictional resistance between the water and the hull surface.

b. Propulsion measures	This category includes pre/post-swirl devices including boss cap fins[8], vane wheel, presswork ducts, Mewis duct[9] and stator fins; propeller/rudder integration including propeller rudder bulb and propeller nozzles[10], propeller rudder matching/combination, and asymmetric rudder and propeller modifications including advanced blade sections[11], winglets/Kappel[12] and propeller section optimisation[13]; propeller modifications; Usage of wind power with sails, Flettner rotor[14], kites[15] etc.
c. Machinery measures	This category includes engine tuning[16] and common rail technology[17].
d. Operating measures	This category includes variable speed operation for controllable pitch propellers[18], propeller surface finish/polishing[19], advanced

[8] Small fins attached to the propeller hub recapturing some of the rotational energy which can then be used for propulsion work.

[9] A duct positioned ahead of the propeller and an integrated fin system within the duct. The duct straightens and accelerates the water flow into the propeller. The fin provides a pre-swirl to the ship propeller thereby increasing the propeller efficiency and reducing the hub vortex, tip vortex and rotational losses.

[10] Nozzles shaped like a wing section around a propeller can save energy at lower speeds.

[11] This improves the cavitation performance and frictional resistance of a propeller blade thus making it more efficient.

[12] Special tip shapes can improve propeller efficiency.

[13] The rudder generates about 5% of the ships overall drag. An advanced design can improve water flow and reduce drag from the rudder.

[14] Spinning vertical rotors convert wind power into thrust in the perpendicular direction of the wind i.e., in side wind the ship will benefit from the added thrust thus lowering fossil fuel consumption.

[15] Wind energy is used to add forward thrust thus reducing the fossil energy demand required for propulsion.

[16] The engine is tuned to give lower consumption at part load while still meeting NO_x emission limits by allowing higher consumption at full load which is seldom used.

[17] Common rail controls combustion so it can be optimised throughout the operation field, providing at every load the lowest possible fuel consumption.

[18] Reducing the number of revolutions at reduced ship speed will result in fuel savings.

[19] Regular in-service polishing reduces surface roughness on propellers caused by organic material and fouling.

	hull surface coatings/paints[20], part load operation optimisation[21], vessel trim[22], and lubricants and fuel additives[23]

2.2.3 | The Table 2, below presents the applicability conditions and the means of verification used to ensure compliance with the applicability condition.

Table 2 Applicability Conditions and Means of Verification

APPLICABILITY CONDITION	MEANS OF VERIFICATION
1. The project activity shall implement one or more retrofit efficiency measures. The measures may vary within ships included in the project and multiple energy efficiency measures can be applied on one individual ship.	The project design document shall describe each measure to be implemented including a cause-effect relationship which demonstrates how the efficiency measure will result in fuel savings.
2. In most of the cases, these measures shall be implemented during the dry docking, yet it is also possible to add new measures during the docking cycle.	The project design document shall include the implementation plan and details of the measures that would be implemented during the project docking cycle.
3. The methodology is not applicable to new ships. The proposed ship must have had at least one full docking cycle of operation prior to the implementation of measures.	The project developer shall provide the evidence to confirm that it had at least one full docking cycle of operation.

[20] This methodology can only be applied to hull coatings/paints that do not contain biocidal materials. Also, for qualifying under this methodology, all of the environmental benefits of hull coatings/paintings should be clearly demonstrated and be independently verified through life cycle studies following ISO 14040 and ISO 14044.

[21] Protective coating can inhibit organic and inorganic growth on ship hulls, prevent the build-up of marine organisms and reduce hydrodynamic drag.

[22] The optimum trim is hull form, speed and draught dependent. The trim can be optimised by repositioning of the cargo or rearranging bunkers (taking ballast would increase displacement and therefore fuel consumption).

[23] The project design document needs to show that proposed lubricants and/or fuel additives comply with all required environmental standards and do not create environmental hazards.

4. Biofuels can be used, however, no carbon credits are generated from the usage of biofuels through this methodology.[24]	The project developer shall provide records of fuel purchase indicating share of biofuel.
5. Only fuel consumption for ship propulsion can be used for emission reduction calculations. Fuel consumption for ship propulsion must therefore be separated clearly from fuel consumption for other uses.	The project design document shall indicate how ship propulsion fuel consumption is recorded separately from overall fuel consumption.
6. This methodology is not applicable for emissions reductions arising from fuel switching.	The project developer shall compare the propulsion fuel type used during the docking cycle before and after the implementation of efficiency measure(s) for each ship.
7. In the specific case that a project developer implements an advanced hull coating technology as a single retrofit measure, this methodology shall only be used for a crediting period limited to one single project docking cycle.	The project developer to confirm if an "advanced hull coating" is the only measure applied and in this case the crediting period shall be limited to one single project docking cycle.

2.2.4 | The methodology is not applicable to:

a. Transport efficiency improvements e.g. increased load factor of the ship resulting in lower emissions per tkm.
b. Energy savings resulting from lower speed – this is factored out in the calculations used to determine emission reductions.
c. Technologies employed to improve combustion efficiency without improvements in engine efficiency.

2.2.5 | Where applicable, the project developer shall bear the cost of a professional statistician contracted by The Gold Standard for the validation of

a. The results of the regression analysis applied to the submitted project activity in line with the model(s) provided in the methodology;
b. A new regression model presented for approval by the Gold Standard. It shall be assessed by an external expert prior to the submission of a project activity.

2.2.6 | The methodology may be used to generate carbon credits to ship owners, shipping companies, charter operators, technology providers, aggregators,

[24] This methodology may be combined with another methodology to include emissions reduction for biofuel use.

energy service companies (ESCOs) or 3rd parties. Any agreement between Parties with regard to ownership of carbon credits is private and confidential, however it needs to be monitored and verified during the project approval process and prior to issuance of carbon credits to avoid potential double counting. All Parties involved must formally commit to an agreement to not claim credits from the same ships as part of activities under other schemes to eliminate potential double counting of emission reductions.

2.2.7 | It is the project developer's responsibility to ensure that all data and monitoring requirements are met. Thus, the shipping operator or charterer must make fuel consumption and other needed data available to the equipment manufacturer if the latter is the aggregation entity. To this end, an agreement is needed between the manufacturer and ship owner/operator. The detailed data would be considered confidential, and would only be shared with the validation and verification body (VVB) and Gold Standard, with the understanding that the information would not be publicly available. Summary statistics used to determine fuel savings and emissions reduction would be published in the verification reports and would be publicly available. Provided the results confirm fuel savings, they would contribute to increased confidence in efficiency measures, making them common practice.

2.3 | Entry into force

2.3.1 | The date of entry into force of this methodology is 13/12/2021.

2.4 | Normative references

2.4.1 | This baseline and monitoring methodology is based on elements from the following approved methodologies:

a. GS Methodology "Reducing Vessel Emissions Through the Use of Advanced Hull Coatings", Version 2.0 (withdrawn);

b. GS Methodology "Installation of Flow Improvement Equipment on Ships", Version 1.0;

c. CDM "Tool for the demonstration and assessment of additionality",

d. CDM "Guidelines for Determining Baselines for Measure(s)",

e. CDM Methodological Tool "Tool to determine the remaining lifetime of equipment",

3| Baseline Methodology

3.1 | Project Boundary

3.1.1 | The spatial project boundary is the geographical location of project ships in which vessels are clearly identified by their unique IMO-Number. The project boundary includes the cruising part of a ship's route, but excludes stays in ports, dry docks and manoeuvring activities (except for cases where fuel consumption for navigation is not recorded separately; in these cases, the fuel consumption would include navigation and manoeuvring). In both baseline and project scenarios, the same project boundary for fuel consumption data should be used.

3.2 | Emissions sources included in the project boundary

3.2.1 | This methodology applies to efficiency measures that would reduce the consumption of Marine Heavy Fuel Oil (HFO) or Marine Diesel Oil (MDO) consumption in ships. The combustion of these fuels primarily produces carbon dioxide (CO_2) with small amounts of other greenhouse gases i.e., methane (CH_4) and nitrous oxide (N_2O). However, the emission of these two GHGs are very minor compared to CO_2 emissions as shown in table 3. In the case of Liquefied Natural Gas (LNG) usage, CH_4 emissions are however significant and shall be included within the project boundary.

Table 3: GHG Emission Factors

GHG	MARINE HFO	MARINE MDO	MARINE LNG
	g/gfuel	g/gfuel	g/gfuel
CO_2	3.11400	3.20600	2.751
CH_4	0.00005	0.000045	0.00826
N_2O	0.000175	0.00018	0.00009

Source: IMO, 2021. 4th IMO GHG Study 2020 – Full report, Text Table 53 (p. 156) for emission factors in g/g fuel. Where IMO provides a range of values, the mid-range is used here. IMO requires the use of Very low-sulphur fuel oil (VLSFO, with sulphur content less than 0.5%) from Jan. 1, 2020. However, neither the IMO nor the IPCC has published emissions factors for VLSFO to date. The 2019 "Refinement" of IPCC (2006) did not include Vol. 2, Chap. 3 "Mobile emissions". Until such time, it is proposed that project developers using this methodology use the HFO values as listed here for VLSFO as well.

3.2.2 | Reduced fuel consumption in the project scenario will also reduce emissions of CH_4 and N_2O. Therefore, their non-inclusion in liquid fuels with exception of LNG is conservative. Emission sources and GHGs included are indicated in Table 3.

3.2.3 | In case equipment is replaced with a more efficient one, project developer shall use the latest version of the CDM "Tool to determine the remaining lifetime of the equipment" to estimate the remaining lifetime of the new equipment or to estimate the remaining time that the existing equipment could operate for in the absence of the project activity. This only needs to be performed in the case of replacing equipment or when modifications in equipment change the remaining technical lifespan.

Table 4: Emissions Sources in the Project Boundary

SOURCE	GAS	INCLUDED?	JUSTIFICATION / EXPLANATION

Fuel consumption of main ship engines used for propulsion during voyages	CO_2	Yes	Main emission source
	CH_4	No except for LNG	Excluded for simplification for liquid fuels except if LNG is used where CH_4 emissions are included as they are relevant
	N_2O	No	Excluded for simplification
Fuel consumption of main ship engines used for propulsion during voyages	CO_2	Yes	Main emission source
	CH_4	No except for LNG	Excluded for simplification for all liquid fuels except if LNG is used where CH_4 emissions are included as they are relevant
	N_2O	No	Excluded for simplification

3.3 | Demonstration of additionality

3.3.1 | The methodology allows for the implementation of one or multiple retrofit efficiency measures, some of which may be BAU. This is captured through the autonomous technology improvement rate which effectively cancels out the impact of baseline efficiency measures and takes their hypothetical impact into account, even if the specific vessel does not implement them.

3.3.2 | The project developer shall demonstrate that, at a minimum, one measure taken is at a minimum, one measure taken is additional following the most recent version of CDM Tool 01 - Tool for the Demonstration and Assessment of Additionality.

3.4 | Baseline scenario determination

3.4.1 | The baseline scenario must match the most probable case in the absence of the project activity. The baseline is developed following a step-wise approach as outlined below. Step 1 and 2 involves identifying realistic and credible alternatives to the project activity. Step 3 involves assessing consistency with current laws and regulations.

Step 1: Baseline Cycle

3.4.2 | The starting point is the individual ship's fuel efficiency based on the previous full docking cycle of operation (denominated as the "baseline docking cycle"). The baseline docking cycle is used to apply or adjust the Basic Model which, based on a regression analysis, characterises the relationship of baseline fuel to various explanatory variables. The Basic Model thereafter allows determination of the hypothetical fuel consumption during the project cycle based on monitoring the explanatory variables and the pre-established relationship of latter with fuel consumption. The baseline is thus determined in a dynamic manner based on observed variables and a regression model with parameters determined for each ship.

Step 2: Autonomous Technological Improvement

3.4.3 | It is assumed that some technical improvements will be made at each dry docking independent of the availability of carbon credits. This includes not only standard dry docking maintenance measures such as hull cleaning which effectively allow the ship to recover to near-to-original efficiency or performance levels but includes also the adoption of additional improvement or retrofit measures such as those listed in Table 5. It is therefore assumed that at least some measures of technological improvement which go beyond standard maintenance would be adopted. This process is called autonomous technological improvement. Which measure is actually adopted is dependent on current fuel prices, ship owner/charterer structure, charter costs, access to finance, cost, decision making processes and subjective factors - an objective assessment ex-ante for each ship is therefore not feasible. Also, separating the effect of different interventions is extremely difficult as measures can interact both positively and negatively and monitoring cannot isolate the effect of individual measures. In addition, values concerning the impact of efficiency measures per ship are within a large uncertainty range and dependent on vessel type, speed and voyages. Therefore, the approach is taken, as is used in other CDM transport methodologies (for example ACM0016, AM0016, AM0101), of an autonomous technology improvement factor per docking cycle.

3.4.4 | The Business as Usual (BAU) improvement rate is defined for retrofit measures and per docking cycle. The BAU rate is based on percentage rate of adopted retrofit fuel efficiency measures (based on a survey report) and the estimated impact per measure (see Table 5).

Figure 1: Baseline Determination

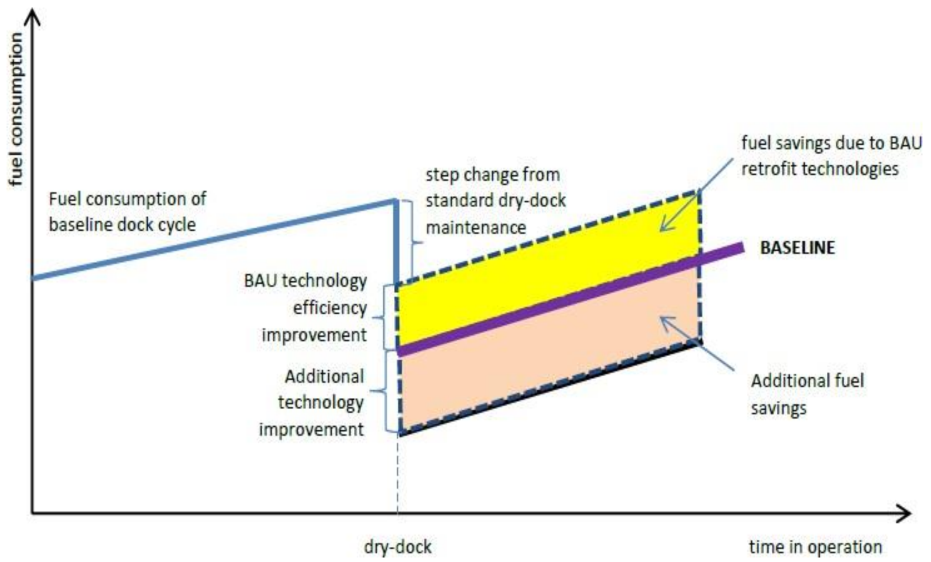


Table 5: Potential Efficiency Improvement Retrofit Measures per Docking Cycle[25]

Measure	Application share[26]	Improvement potential per docking cycle	Impact
Trailing edge, skeg shape	5%	2%	0.09%
Hull openings	2%	1%	0.02%
Aft waterline extension	2%	4%	0.09%
Shaft line arrangement	1%	2%	0.02%
Air lubrication	2%	8%	0.14%
Pre and post-swirl devices and advanced propeller blades	18%	3%	0.54%
Propeller/rudder integration and modifications	5%	2%	0.10%
Propeller modifications	10%	2%	0.21%
Hull streamlining/optimisation propeller/ hull interaction	1%	4%	0.06%
Counter-rotating propellers	2%	3%	0.05%
Engine tuning	17%	0.5%	0.08%
Common rail	3%	0.5%	0.01%
Combined electric/diesel machinery	1%	6%	0.05%

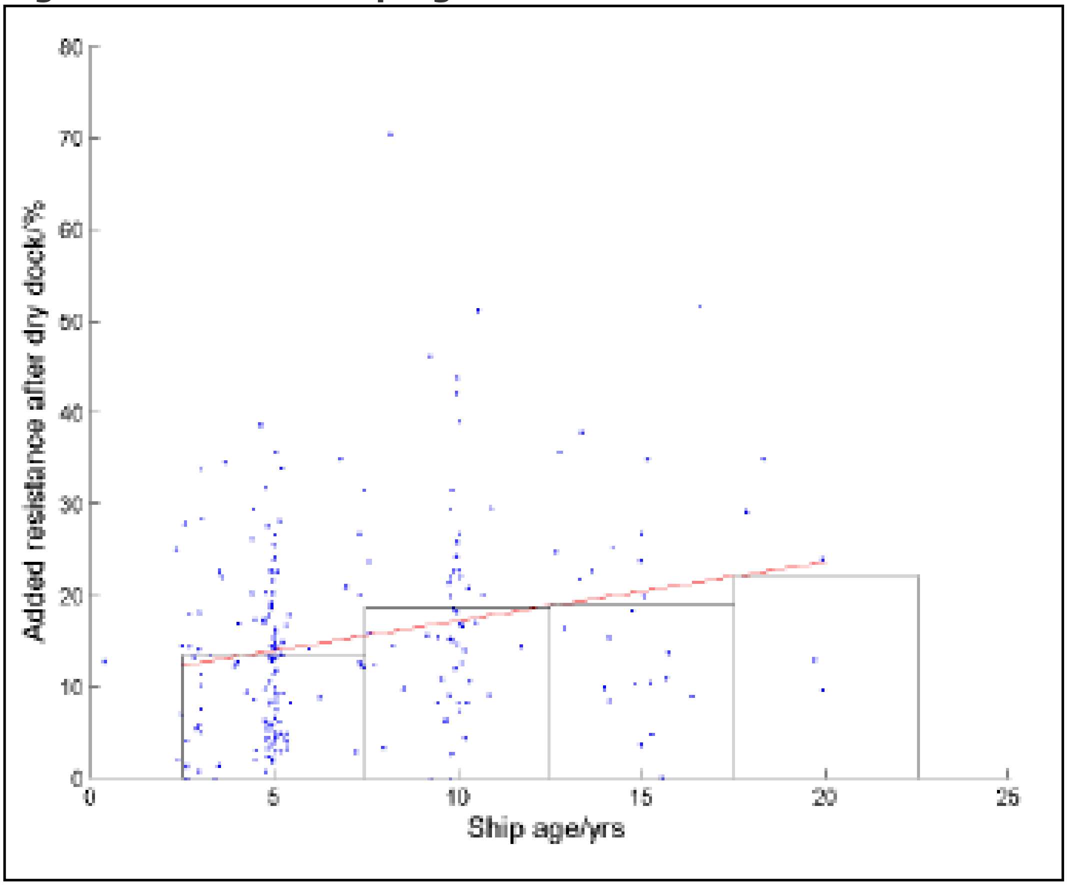
Sources: Application share calculated by Grütter using share per measure and share retrofit/new build based on N. Rehmatulla, Assessing the implementation of technical energy efficiency measures in shipping; Survey report, 05/2015, UCL Energy Institute; The improvement potential based on Wartsila, Boosting Energy Efficiency: Energy Efficiency Catalogue / Ship Power R&D, 2009; M. Khorasanchi et.al., What to expect from the hydrodynamic energy saving devices, Low Carbon Shipping Conference, London 2013; Smith et.al., Low Carbon Shipping – A systems Approach, Final Report, 2014; H. Wang et.al, Long-term Potential for Increased Shipping Efficiency through Adoption of Industry-Leading Practices, ICCT White Paper, 2013

3.4.5 | The combined result is 1.45% efficiency improvement per docking cycle. This does not take into account that the total impact might be less than the sum. Ship performance also has an underlying deterioration trend which goes beyond hull fouling as can be seen in the figure below.

[25] These are any efficiency improvement measures and not BAU measures. The BAU improvement rate is calculated by determining the actual application of these measures which, as shown below, range from 1% to 17% i.e. even the most "common" measure is NOT applied by > 80% of all ships and thus no measure in fact can be considered standard or BAU.

[26] This is defined as share of respondents who applied the measure during a retrofit (rounded values). Calculated as share of respondents who have applied this measure multiplied with share of respondents who have applied this measure as retrofit (versus application on new build ship).

Figure 2: Relation Ship Age and Increased Resistance



Source: T. Dirksen, A statistical study of dry dockings, hull cleanings, and propeller polishes, Propulsion Dynamics, 05/2015

3.4.6 | Data scattering is quite wide with low correlations, however, a certain level of wear and tear concerning not only hull and propeller but also the engine is technically undisputed. Taking a conservative estimative, a wear and tear figure of 0.5% per docking cycle is assumed.[27] The rounded BAU improvement of fuel efficiency due to retrofit measures is therefore determined as being 1% per docking cycle[28]. This factor is for fuel efficiency improvement per docking

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[27] T. Dirksen, A statistical study of dry dockings, hull cleanings, and propeller polishes, Propulsion Dynamics, 05/2015

[28] The methodology applicability is not limited to one docking cycle. The 1% BAU improvement is applied to each docking cycle. It means every time, the ship enters a docking cycle 1% BAU improvement is accounted for. For example: the ship starts with baseline emissions 100 tCO_2 eq. The baseline emissions, due to the application of BAU Improvement Factor, is 99 tCO_2 eq. Therefore, the emission reductions are the difference between baseline emissions (99 tCO_2 eq) – project emissions. At the 2 docking cycle, BAU Improvement Factor of 1% shall be applied again but to the docking cycle 1 baseline emissions (99 tCO_2 eq). It means the updated baseline emission for docking cycle 2 is 98.01 (99*0.99) and the emission reductions are emission reductions are the difference between new baseline emissions (98.01 tCO_2 eq) – project

cycle i.e. it is assumed that under an autonomous technology improvement pathway, ships would increase their fuel efficiency per docking cycle by 1%. This does not include common maintenance practice at dry dock like hull cleaning[29] and is solely the impact of retrofit measures.

3.4.7 | The baseline applied is therefore the calculated baseline using the regression model with fuel consumption reduced by 1% per docking cycle. This value can be used by projects applying this methodology up to 5 years after the date of the methodology publication. After this period the value shall be revised and project developers intending to apply this methodology shall submit a revision to the methodology for future projects. The projects already registered are not required to update the BAU improvement in their crediting period. However, at the time of 2nd crediting period the project developer shall update the BAU improvement factor based on the latest methodology version.

Step 3: Compliance with the Energy Efficiency Design Index (EEDI) Requirements

3.4.8 | The International Maritime Organization (IMO) adopted mandatory energy efficiency measures for all new ships of 400t (gross tonnage) or above built after 01.01.2013. The Energy Efficiency Design Index (EEDI) requires a minimum energy efficiency level per capacity mile according to ship type and size segments. For ships built after 01.01.2013, only energy efficiency improvements which go beyond the EEDI requirement can be taken into consideration for the generation of carbon credits. The EEDI in principle should not influence the baseline as, hypothetically, new-built ships should comply with EEDI and therefore this should be expressed in the data of the baseline docking cycle. However, the EEDI is used as minimum required baseline and in case ships built after 01.01.2013 do not comply with this measure the EEDI baseline is used as this latter is effectively a regulatory requirement. See Figure 3 for two example cases.

i. In Case 1 (EEDI standard is less strict than the baseline i.e. the energy efficiency is better under the baseline case) no adjustment is required i.e. the baseline remains as determined under Step 2.

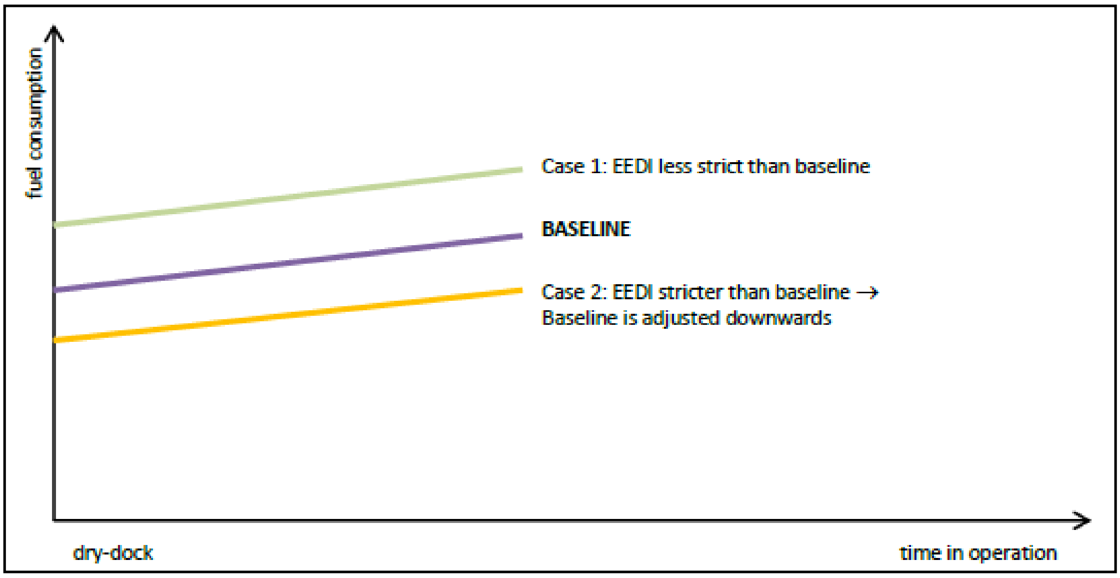
ii. In Case 2 (EEDI standard is stricter than the baseline i.e. the energy efficiency is better under the EEDI case) the baseline is adjusted downwards to the EEDI standard.

Step 3 therefore ensures that a conservative baseline value is chosen for vessels impacted by EEDI requirements.

emissions. Since, the BAU Improvement Factor (%) is a percentage of a docking cycle the methodology can be applied to various docking cycles.

[29] This is made at all cycles and therefore the impact is already included in baseline data.

Figure 3: EEDI and Baseline



Step 4: Compliance with National Regulations

3.4.9 | Countries or group of countries may impose fuel efficiency conditions for ships travelling to/from these countries which might go beyond the baseline as determined under Step 2. In these cases, the stricter (more ambitious) fuel efficiency standard of these countries is taken for the distance the vessel moves within the boundaries of these countries.

3.4.10 | The baseline developed is thus a dynamic vessel related baseline using a regression model with parameter values specific for each ship determined through the previous docking cycle. An autonomous technology improvement factor expressed as a percentage rate is introduced to account for BAU energy efficiency improvements.

3.4.11 | No common practice analysis is required for this methodology. This is embedded in the autonomous technology improvement factor which has included energy efficiency improvements that are common practice and subtracted their impact from the emission reductions.

3.4.12 | The separation is therefore based on the estimated average overall impact of applying BAU retrofit energy efficiency technologies. This allows for a bundled energy efficiency approach commensurate with industry practice.

3.5 | Baseline Emissions

3.5.1 | Baseline emissions are those that would have occurred after BAU retrofit energy efficiency measures have been implemented. Baseline emissions are calculated separately for individual project ship. If a project or programme involves a number of ships the baseline emissions must be calculated per ship.

3.5.2 | Baseline emissions are determined in a dynamic manner and involve the following steps:

1. Determination of the ship-specific relationship between baseline fuel consumption and explanatory variables (as detailed below) based on historical data of the last docking cycle;

2. Application of the regression model using the coefficient values determined under the step 1 and thereby determining the hypothetical baseline emissions for the project docking cycle under the vessels actual, monitored, operating conditions. The fuel used to operate the ship under project scenario, but without efficiency improvements is calculated;
3. Apply the BAU technological improvement factor to baseline emissions i.e., baseline emission calculated under step 2 are multiplied with the factor 0.99 per docking cycle;
4. Application of the emission factor per fuel type to calculate GHG emissions.

3.5.3 | The approach used under step 1, 2 and 4 are identical to the approved Gold Standard methodology "Reducing Vessel Emissions Through the Use of Advanced Hull Coatings (version 2.0)".

$$BE_y = \sum BFC_{i,y} \times COEF_{i,y} \times IF \quad \text{Eq. 1}$$

Where:

BE_y	=	Baseline emissions in year *y* (tCO_2e)
$BFC_{i,y}$	=	Baseline fuel consumption of fuel type *i* in year *y* (t)
$COEF_{i,y}$	=	GHG emission coefficient of fuel type i in year y (tCO2e/t fuel)
IF	=	BAU improvement factor of 0.99 per docking cycle

The GHG emission coefficient ($COEF_{i,y}$) is determined by:

$$COEF_{i,y} = NCV_{i,y} \times \left(EF_{CO2,i,y} + EF_{CH4,LNG,y}\right) \quad \text{Eq. 2}$$

Where:

$COEF_{i,y}$	=	GHG emission coefficient of fuel type i in year y (tCO2e/t fuel)
$NCV_{i,y}$	=	Net Calorific Value of fuel type *i* in year *y* (GJ/t)
$EF_{CO2,i,y}$	=	CO_2 emission factor of fuel type *i* in year *y* (tCO_2/GJ)
$EF_{CH4,LNG,y}$	=	CH_4 emission factor of *marine LNG* in year *y* (tCO_2e/t fuel)
		CH_4 emission factor is only included in case of using LNG.

The baseline fuel consumption ($BFC_{i,y}$) is based on a statistical model called the "Basic Model" approved under Gold Standard approved methodology[30]. The relationship is:

[30] The Basic Model is included in Appendix A of "Reducing Vessel Emissions Through the Use of Advanced Hull Coatings (version 2.0)" and is not repeated here. Identical to the approved cited methodology the project proposal can also be based on another model to determine the

$$FC_y = a \times V^n \qquad \textit{Eq. 3}$$

Where:

FC_y	=	Fuel consumption in year y for a 24 hour period (t)
V	=	Average daily speed through water
a,n	=	Coefficients a and n determined through regression analysis of previous docking period Regression coefficients a and n are only valid over the range of speeds in the data set upon which the regression is based. Therefore, this range of speed should be noted, together with the estimation of the coefficients. The regression model is valid for predicting fuel consumption only in this range of valid ship speeds.

3.5.4 | The "Basic Model" or any other mathematical model which is used to determine the relationship between fuel consumption and other observed variables including but not limited to speed shall have a coefficient of determination (R^2-value) for the generated speed-fuel consumption curves above 0.8.

3.5.5 | Only days which fulfil the statistical requirements of the "Basic Model" (filter conditions) are included. Any days that are excluded, are excluded for both baseline and project emissions which is therefore conservative. The filter conditions for the Basic Model are described in "Data Filtering" (page 45) of Appendix A "Reducing Vessel Emissions Through the Use of Advanced Hull Coatings (version 2.0)" and summarised below. Fuel consumption is excluded for baseline and project emissions for:

1. Stormy days – Beaufort Scale > 6;
2. For ships operating on long voyages, and recording "Noonday data", days with less than 23 hours of voyage on the day are excluded from the analysis.
3. For ships operating on short voyages, and recording "Voyage data", this exclusion is not applicable.

3.5.6 | The filtering approach is commensurate with the new ISO Standard ISO/DIS 19030- 3 for "Ship and marine technology – Measurement of changes in hull and propeller performance" Part 3 alternate methods. The decision on whether to use the filters and procedures in Part 2 (default) or Part 3 (alternate) of ISO 19030 is informed by the specification of the data that is available:

– Part 2: data must be available that is acquired at high frequency (at least once every 15 seconds), and include a set of primary parameters (vessel

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relationship between fuel consumptions and other observed variables including but not limited to speed if this model can explain and determine better the relationship and reduce uncertainty. Any model which is not the "Basic Model" needs to be approved by the Gold Standard prior to application.

speed through water, delivered power) as well as a number of secondary parameters (defined in Section 5.1 of ISO 19030-2)

– Part 3: data can be acquired at lower frequency (for example every 24 hours), and whilst vessel speed and delivered power are still required, the number of secondary parameters and their specifications are less onerous (defined in Section 5.1 of ISO 19030-3)

3.5.7 | Thus, the baseline fuel consumption ($BFC_{i,y}$) is estimated as below:

$$BFC_y = \sum_k BFC_k \qquad \text{Eq. 4}$$

Where:

BFC_y	=	Baseline fuel consumption in year y (t)
BFC_k	=	Baseline fuel consumption in day k for a 24 hour period (t)
k	=	Days which fulfil the criteria of the Basic Model and are not filtered out

3.5.8 | Vessels and ship owners who manage and collect data according to the ISO/DIS 19030-2 default approach should use the default approach as determined in the ISO standard Part 2 to determine baseline fuel consumption.

3.6 | Project emissions

3.6.1 | Project emissions are determined by emissions associated with actual fuel consumption for ship propulsion (specifically for navigation, i.e. excluding port and manoeuvres). In cases, where the project can demonstrate that navigation fuel is only used for navigation and manoeuvring activities, total fuel consumption can also be used. In both cases, the same "boundary" for fuel consumption data must be used both in the baseline and project scenario.

3.6.2 | Project emissions are determined using the same process as for baseline emissions:

$$PE_y = \sum_i PFC_{i,y} \times COEF_{i,y} \qquad \text{Eq. 5}$$

Where:

PE_y	=	Project emissions in year y (tCO_{2e})
$PFC_{i,y}$	=	Project fuel consumption of fuel type i in year y (t)
$COEF_{i,y}$	=	GHG emission coefficient of fuel type i in year y (tCO_{2e}/t fuel)

3.6.3 | Project fuel consumption is excluded for the same days as for baseline fuel consumption. Therefore:

$$PFC_y = \sum_k PFC_k \qquad \text{Eq. 6}$$

PFC_y	=	Baseline fuel consumption in year y (t)
PFC_k	=	Baseline fuel consumption in day k for a 24 hour period (t)

k	=	Days which fulfil the criteria of the Basic Model and are not filtered out

3.6.4 | Project emissions are calculated per ship. If the activity includes a number of ships, project emissions must be calculated per ship.

3.7 | Leakage emissions

3.7.1 | The rebound or take-back effect is included as a leakage source. This refers to the phenomena that financial savings due to lower fuel consumption can be used to cruise at a higher speed thus offsetting the fuel savings.

3.7.2 | The approach used to compensate for this rebound effect is based on the regression model which is only valid for a specific range of speeds. For ship speeds above the specified range of valid speeds, i.e. the ship has significantly increased speeds compared to the previous docking period, the model is not valid. The days when this occurs are excluded and no credits are gained. The same is applied for lower speeds, although in this case this is not a rebound effect but might be caused by economic circumstances and low travel demand.

3.7.3 | The valid days are included in the baseline and project emission determination under the parameter k. All other days including those which could be attributed to a rebound effect, are already filtered out at the level of project and baseline emissions.

3.7.4 | Upstream leakage effect of gaseous fuel usage is not included as this occurs in the baseline and project case. Due to fuel savings, leakage in the baseline case will be higher than in the project case thus its non-inclusion is conservative.

3.8 | Emission reductions

3.8.1 | Emission reductions are the difference between baseline and project emissions per ship. As a control measure, emission reductions can be calculated on a daily basis thus ensuring the exclusion of the same days for baseline and project fuel consumption. Emission reductions are calculated per ship. If the activity includes a number of ships the total emission reductions are the sum of individual ship emission reductions. The emission reductions are calculated as follows:

$$ER_y = BE_y - PE_y - LE_y \quad \text{Eq. 7}$$

Where:

ER_y	=	Emission reductions in year y (tCO_2e/yr)
BE_y	=	Baseline emissions in year y (tCO_2e/yr)
PE_y	=	Project emissions in year y (tCO_2e/yr)
LE_y	=	Leakage emissions in year y (tCO_2e/yr)

3.9 | Data and parameters not monitored

Parameter ID	REEM 1

Data/Parameter:	NCVi
Data unit:	GJ/t
Description:	Net calorific value of fuel type i
Source of data:	IPCC default values at the lower limit of the uncertainty at a 95% confidence interval as provided in Table 1.2 of Chapter 1 of Vol. 2 (Energy) of the 2006 IPCC Guidelines on National GHG Inventories
Measurement procedures (if any):	None
QA/QC procedures:	None
Any comment:	Any future revision of the IPCC Guidelines should be taken into account at the time renewal of crediting period. The parameter is used for baseline and project emissions.

Parameter ID	**REEM 2**
Data/Parameter:	$EF_{CO2,i,y}$
Data unit:	tCO_2/GJ
Description:	CO_2 emission factor of fuel type *i* in year *y*
Source of data:	IPCC default values at the lower limit of the uncertainty at a 95% confidence interval as provided in Table 1.4 of Chapter 1 of Vol. 2 (Energy) of the 2006 IPCC Guidelines on National GHG Inventories
Measurement procedures (if any):	None
QA/QC procedures:	None
Any comment:	Any future revision of the IPCC Guidelines should be taken into account at the time renewal of crediting period. The parameter is used for baseline and project emissions.

Parameter ID	**REEM 3**
Data/Parameter:	$EF_{CH4,LNG}$
Data unit:	tCO_{2e}/t fuel
Description:	CH_4 emission factor of marine LNG
Source of data:	IMO, 2021. 4th IMO GHG Study 2020 – Full report, Text Table 53 (p. 156) for emission factors in g/g fuel.

Measurement procedures (if any):	None
QA/QC procedures:	Any future revision of the CH4 emissions from LNG from ships published by IMO should be taken into account
Any comment:	IMO value for CH4 emissions: 0.00826 gCH4 per gfuel. Where IMO provides a range of values, the mid-range is used here. The parameter is used for baseline and project emissions; The parameter is only applied in case marine LNG is used a fuel for propulsion

4| Monitoring methodology

4.1 | Data and parameters monitored

4.1.1 | Vessels and ship owners which manage and collect data according to the ISO/DIS 19030-2 default approach shall follow the data measurement procedures, data acquisition, storage, preparation and quality control as detailed in the aforementioned ISO standard, whilst other project developers shall follow either those parameters detailed below, or as detailed in the standard ISO.

Parameter ID	**REEM 4**
Data/Parameter:	Ship identification number
Data unit:	n/a
Description:	Unique ship identification numbers assigned by the International Maritime Organisation (IMO)
Source of data:	Ship operator, IMO, third party websites
Measurement procedures	n/a
Monitoring frequency:	n/a
QA/QC procedures:	None
Any comment:	Each IMO number is a unique reference for a ship, registered ship owners and management companies. IMO numbers were introduced under the International Convention for the Safety of Life at Sea (SOLAS) to improve maritime safety and security and to reduce maritime fraud. For ships, the IMO number remains linked to the hull for its lifetime, regardless of a change in name, flag, or owner.

Parameter ID	**REEM 5**
Data/Parameter:	V
Data unit:	Knots (nautical miles per hour)
Description:	Average daily speed over the ground

Source of data:	Ship operator
Measurement procedures	Calculated from daily distance operated and daily steaming time (DD/DT; see below) e.g. based on noonday reports
Monitoring frequency:	Daily
QA/QC procedures:	None as calculated
Any comment:	The parameter is used for baseline and project emissions and is measured for a full docking cycle (baseline period) prior project activity start (if available) and for docking cycles after retrofit (project crediting period). If full baseline docking cycle data is not available, enough data must be available for the regression to be valid. The criteria for a valid regression analysis are set out in the approved GS methodology "Reducing Vessel Emissions Through the Use of Advanced Hull Coatings (version 2.0)" in Annex A.

Parameter ID	**REEM 6**
Data/Parameter:	DD
Data unit:	Nautical miles
Description:	Daily distance travelled
Source of data:	Ship operator
Measurement procedures	AIS /GPS
Monitoring frequency:	Daily
QA/QC procedures:	None
Any comment:	For ships that operate mostly on shorter distances, "Voyage data" are recorded in ship logs. The objective is the same as in the case of Noonday data, to determine the rate of fuel consumption and average speed. In this case DD is recorded per voyage and corresponds to the distance between departure and arrival ports. The parameter is used for baseline and project emissions and is measured for a full docking cycle (baseline period) prior project activity start (if available) and for docking cycles after retrofit (project crediting period). If full baseline docking cycle data is not available, enough data must be available for the regression to be valid.

Parameter ID	**REEM 7**
Data/Parameter:	DT
Data unit:	Hours
Description:	Daily hours of sailing
Source of data:	Ship operator

Measurement procedures	GPS
Monitoring frequency:	Daily
QA/QC procedures:	None
Any comment:	For ships that operate mostly on shorter distances, "Voyage data" are recorded in ship logs. The objective is the same as in the case of Noonday data, to determine the rate of fuel consumption and average speed. In this case DT is recorded per voyage and corresponds to the hours of navigation between departure and arrival port (if not available the total voyage time). The parameter is used for baseline and project emissions and is measured for a full docking cycle (baseline period) prior project activity start (if available) and for docking cycles after retrofit (project crediting period). If full baseline docking cycle data is not available, enough data must be available for the regression to be valid. The criteria for a valid regression analysis are set out in the approved GS methodology "Reducing Vessel Emissions Through the Use of Advanced Hull Coatings (version 2.0) in Annex A .

Parameter ID	**REEM 8**
Data/Parameter:	DT
Data unit:	Hours
Description:	Daily hours of sailing
Source of data:	Ship operator
Measurement procedures	GPS
Monitoring frequency:	Daily
QA/QC procedures:	None
Any comment:	For ships that operate mostly on shorter distances, "Voyage data" are recorded in ship logs. The objective is the same as in the case of Noonday data, to determine the rate of fuel consumption and average speed. In this case DT is recorded per voyage and corresponds to the hours of navigation between departure and arrival port (if not available the total voyage time). The parameter is used for baseline and project emissions and is measured for a full docking cycle (baseline period) prior project activity start (if available) and for docking cycles after retrofit (project crediting period). If full baseline docking cycle data is not available, enough data must be available for the regression to be valid. The criteria for a valid regression analysis are set out

	in the approved GS methodology "Reducing Vessel Emissions Through the Use of Advanced Hull Coatings (version 2.0) in Annex A .

Parameter ID	**REEM 9**
Data/Parameter:	Beaufort Scale
Data unit:	Beaufort number
Description:	Sea state based on Beaufort scale
Source of data:	Ship operator
Measurement procedures	Observation
Monitoring frequency:	Daily
QA/QC procedures:	None
Any comment:	Used to determine k for days which are filtered out (Beaufort scale > 6 are days filtered out). For ships that operate mostly on shorter distances, "Voyage data" are recorded in ship logs. In this case the observations per voyage are included. Any voyage with 1 or more observations of a Beaufort scale > 6 is filtered out. The parameter is used for baseline and project emissions and is measured for a full docking cycle (baseline period) prior project activity start (if available) and for docking cycles after retrofit (project crediting period). If this information is not available, the days for which information is missing shall be excluded from the assessment in both baseline and project scenario.

Parameter ID	**REEM 10**
Data/Parameter:	BFCi
Data unit:	Tons
Description:	Baseline fuel consumption of fuel type i
Source of data:	Ship operator
Measurement procedures	Fuel flow meter Only inclusion of main engine fuel consumption for propulsion
Monitoring frequency:	Daily
QA/QC procedures:	Calibration of fuel flow meter; periodic dip test on tanks (if tanks are also used for auxiliary engines then dip tests need to be compared with the total of fuel flow measurements)
Any comment:	For ships that operate mostly on shorter distances, "Voyage data" are recorded in ship logs. The objective is the same as in the case of Noonday data, to determine the rate of fuel consumption and average speed. In this case PFC corresponds to the fuel consumption for the voyage.

	The parameter is used for baseline and project emissions and is measured for a full docking cycle (baseline period) prior project activity start (if available) and for docking cycles after retrofit (project crediting period). If this information is not available, the days for which information is missing shall be excluded from the assessment in both baseline and project scenario.

Parameter ID	**REEM 11**
Data/Parameter:	PFCi
Data unit:	Tons
Description:	Project fuel consumption of fuel type *i*
Source of data:	Ship operator
Measurement procedures	Fuel flow meter Only inclusion of main engine fuel consumption for propulsion
Monitoring frequency:	Daily
QA/QC procedures:	Calibration of fuel flow meter; periodic dip test on tanks (if tanks are also used for auxiliary engines then dip tests need to be compared with the total of fuel flow measurements)
Any comment:	For ships that operate mostly on shorter distances, “Voyage data” are recorded in ship logs. The objective is the same as in the case of Noonday data, to determine the rate of fuel consumption and average speed. In this case PFC corresponds to the fuel consumption for the voyage. The parameter is used for baseline and project emissions and is measured for a full docking cycle (baseline period) prior project activity start (if available) and for docking cycles after retrofit (project crediting period). If this information is not available, the days for which information is missing shall be excluded from the assessment in both baseline and project scenario.

ANNEX 1: SGDL MODEL

SUMMARY:

This Annex provides an alternative method and model to monitor and calculate baseline and project fuel consumption, and fuel consumption savings, that is based in part on regression models (however in a different context to the regression model within the main body of the methodology), and also based on ship hydrodynamics, the physics and resistance of a ship traveling through the water.

The SGDL model is based on a code/software that has been developed by the Sea Grant Design Laboratory (SGDL) at the Massachusetts Institute of Technology (MIT) and it has been made publicly available at no cost via the MIT Sea Grant website.

Reference: The computer code, report ("Decarbonization of the Cargo Shipping Fleet") and user's guide can be downloaded via the following link:

https://seagrant.mit.edu/decarbonization/

The "Basic Model" described within the methodology[31] evaluates a reduction in fuel consumption as a result of retrofit measures by relying on historical "noon reports" from the ship prior to the retrofit measures being installed to provide a baseline statistical model of the relationship between fuel consumption and speed. The fuel consumption savings are thereafter derived by subtracting fuel consumption measurements from post-retrofit noon report data from fuel consumption estimates calculated with the baseline statistical model.

The "SGDL Model" relies on a model of ship fuel consumption as a function of a ship's physical characteristics together with its speed and loading condition (draft). The model generates ship-specific speed/power curves to support the relationship between these factors, and is then validated by direct comparison with sea trial data on speed, power, and fuel consumption that is collected and verified according to well-established industry standards. Post-retrofit, the model generates new speed/power curves and these are then validated by using updated speed trial data. The model requires the ships to monitor loading (draft) and speed in the project phase, and this process of estimating fuel consumption and emission reductions as a function of loading (draft) and speed is less time-consuming without any loss of accuracy, because those estimates are derived directly from a verified model of the ship's fuel consumption.

The following sections outline the approach to calculate the baseline and project emissions using the SGDL model, while the rest of the requirements of methodology applies as it is. The section numbering is the same as main methodology for ease of reference. Where applicable, the reference to main methodology has been included in the text to provide further clarity.

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[31] "Reducing Vessel Emissions Through the Use of Advanced Hull Coatings (version 2.0)

3.5 BASELINE EMISSIONS

Baseline emissions are those that would have occurred after BAU retrofit energy efficiency measures have been implemented. Baseline emissions are calculated separately for each individual project ship. If a project or Programme involves a Number of ships the baseline emissions must be calculated per ship.

Baseline emissions are determined via the following steps:

Step 1:

Input data for a broad range of parameters will be collected for each ship, based on the ship's pre-retrofit condition. These parameters must cover aspects, such as, the ship's hull, propeller, engine, and other installed equipment (see "Monitoring methodology" below for the input data requirements). These input data parameters are normally included in the ship's sea trial reports[32], which will be provided in every case. Missing parameters may be estimated using conservative assumptions consistent with naval architecture.

Step 2:

Using these input parameters describing the ship's baseline, pre-retrofit condition, speed/power curves will be calculated for a range of loading/draft[33] (hereinafter "draft") conditions based on the SGDL model outlined below.

Step 3:

The baseline speed/power curves for sea trial drafts shall be cross-checked against sea trial reports for the ship. The normal process is for sea trial measurements to be carried out at several engine load levels, resulting in brake power measurements at several different speeds. For this purpose, we define "sea trial speed" as the trial speed that is closest to the ship's design speed. If the modeled brake power value at the sea trial speed differs from the sea trial brake power by more than +/-3%, the model speed/power curve will be shifted by a constant percentage across the full speed range, where that percentage is chosen to be the minimum necessary to bring the modeled curve within +/-3% of the sea trial data at the sea trial speed. Modeled speed/power curves for other draft levels are shifted by the same percentage.

Step 4:

Speed/fuel consumption curves will be calculated for a range of draft conditions using the speed/power curves, either as modelled or adjusted as per step 3 above to align with sea trial results, together with engine specific fuel consumption data from manufacturer's specifications and trial documents. Because the speed/power curves are aligned with sea trial data (see step 3. above), and specific fuel consumption data

[32] https://rules.dnv.com/docs/pdf/gl/maritimerules/gl_vi-11-3_e.pdf

[33] Vessel draft is one of the principal dimensions of any waterborne ship and is defined in technical terms as the distance between the ship's keel and the waterline of the vessel.

are reported for the specific engine in the ship, the resulting speed/fuel consumption curves will reflect consumption accurately.

Step 5:

The speed/fuel consumption curves will be used to determine the baseline fuel consumption at project operating parameters (speed, draft). The relevant emission factor per fuel type is then applied to calculate GHG emissions.

The use of speed/power curves generated at the beginning of the baseline, pre-retrofit docking cycle (i.e. based on the ship's baseline, pre-retrofit condition) reflects the ship's performance at peak fuel efficiency, with a clean hull and propeller. Fouling of the hull and propeller, deformation of hull panels, and wear and tear on the engine and mechanical systems will cause fuel efficiency to decrease over time. As a result, the use of these speed/power curves reflecting the ship's baseline, pre-retrofit condition is conservative. It will typically lead to an underestimation of actual pre-retrofit fuel consumption, and thus an underestimation of emission reductions. Therefore, the BAU technological improvement factor will be excluded from the initial baseline emissions calculation and applied to the baseline emissions starting only in the subsequent docking cycle. Application from the outset would be overly conservative and result in baseline emissions that were even lower than when the ship was in its original baseline, pre-retrofit condition.

Baseline emissions are calculated in the same manner as in Section 3.5 | of main methodology, with the exception that the BAU improvement factor is not included in the initial baseline emission calculation under the SGDL model approach, as explained later in this Annex.

The baseline fuel consumption is based on the following model:

Baseline fuel consumption during a given hour of operations is calculated as the product of the specific fuel consumption (SFC) of the main engine and the brake power required to drive the ship during that hour. The fuel type used in the calculations must be that fuel type in use by the ship during the baseline period.

Both SFC and brake power are modeled for the baseline, pre-retrofit condition of the ship as a function of mean draft and speed, including allowances for sea margin (15%), engine margin (10%), propeller margin (5%), and shaft efficiency (99%). These allowances are commonly used in naval architecture and ship design to better estimate real-world (also known in naval architecture as "heavy running") results from the "trial condition" results measured under ideal conditions, with clean hull and propeller, in sea trials. Sea margin accounts for waves and wind, engine margin accounts for engine performance variations, and propeller margin accounts for variability in the flow to the propeller. The shaft efficiency adjustment accounts for losses between the engine and the propeller.

The SFC and speed/power curves are verified against baseline, pre-retrofit sea trial data, and must be within +/-3% of sea trial data, thus the availability of sea trial data from new-build delivery is a requirement in this approach. In the event that modifications have been made to the ship since new-build delivery, then the baseline, pre-retrofit condition is considered to be the modified condition of the ship prior to project retrofits, which is a conservative approach. In such a case, a ship would be required to provide a speed trial data report, which is a report similar to the new-build sea trial report, but based on a trial that would have been carried out following the retrofits. In the event that sea or speed trial data are not available for a specific ship, but a sea or speed trial report for an identical sister ship[34] is provided, the modeled fuel consumption savings estimate will be decreased by 5% to account for any inaccuracies introduced.

Baseline fuel consumption for a year is the sum of hourly fuel consumption during all allowable underway hours, calculated as:

$$BFC_{i,y} = \sum_{i,h} SFC0_{i,t,v} \times BPHR0_{t,v,h}$$ *Eq. 8*

Where;

$BFC_{i,y}$	=	Baseline fuel consumption of fuel type *i* in year *y* (t)
$SFC0_{i,t,v}$	=	specific fuel consumption in the pre-retrofit condition at draft t and speed v (g/kWh)
$BPHR0_{t,v,h}$	=	brake power in heavy running in the pre-retrofit condition at draft t and speed v (kW)
h	=	allowable underway hour
t	=	mean draft at hour h (m) (mean draft is average of draft at forward and aft ends of the ship)
v	=	ship speed at hour h (knots)

Since the baseline speed/power curves are generated for a wide range of ship speeds and draft conditions and provide a conservative estimate, the existing speed range limitation within the Basic Model would not apply here; this approach will provide accurate fuel consumption estimates across a full range of ship speeds. In addition, the model will compare the ship's performance and fuel consumption at the same speeds before and after the installation of the retrofit measures, so emission reductions from slow steaming will be correctly accounted for via this approach.

The weather and filtering conditions remain unchanged from section 3.5 | of main methodology.

[34] For this purpose, an "identical sister ship" is defined as a ship with principal dimensions and form coefficients within +/-3% of the project ship, and with identical engine and propeller.

3.6 PROJECT EMISSIONS

Project emissions are determined following the installation of the retrofit measures and the generation of new speed/power curves validated by a post-retrofit ship speed trial. The ships must then monitor ship speed and draft condition; and the model uses these as input data, together with the new post-retrofit speed/power curves, to calculate project fuel consumption.

Project emissions are those emissions associated with the navigation portion of a ship's journey, i.e. excluding port and manoeuvres. For the purposes of this model and approach, a ship is considered to be engaged in "navigation" when average main engine load during that hour is greater than 10% of the engine's specified maximum continuous rating (SMCR; its maximum power output), as reflected by its average speed during that hour, which must be at least 7 knots. (Note that this requires accurate data on SFOC down to loads of 10% of SMCR in the engine input data for the model. If those low load SFOC data are not available, the minimum "navigation" load level must be raised accordingly.)

As with baseline speed/power curves, the project speed/power curves will be verified against the post-retrofit speed trial report for the ship. Here, the reference speed is the speed for which the ship has been optimized in its project (retrofit) condition. If the modeled brake power value at this reference speed differs from the post-retrofit speed trial brake power by more than 3%, the model brake power curve will be shifted by a constant percentage across the full speed range, where that percentage is chosen to be the minimum necessary to bring the modeled curve within 3% of the speed trial data at the reference speed. Modeled speed/power curves for other draft levels are shifted by the same percentage.

As with baseline emissions, project fuel consumption during a given hour of operations is calculated as the product of the specific fuel consumption (SFC) of the main engine and the brake power required to drive the ship during that hour in the post-retrofit condition. The fuel type used in the calculations must be that fuel type in use by the ship during the project monitoring period. Using the same procedure as outlined for Baseline Emissions, both SFC and speed/power curves are modeled via the SGDL model approach for the post-retrofit condition of the ship as a function of mean draft and speed, including allowances for sea margin (15%), engine margin (10%), propeller margin (5%), and shaft efficiency (99%). (See section on Baseline Emissions, above for more details.) The SGDL model will again calculate speed/fuel consumption curves for a range of draft conditions using the speed/power curves, either as modelled or adjusted as per Step 3 in the Baseline Emissions section of this Annex to align with the speed trial results.

Project fuel consumption for a year is the sum of hourly fuel consumption during all allowable underway hours, calculated as:

$$PFC_{i,y} = \sum_{i,h} SFC1_{i,t,v} \times BPHR1_{t,v,h} \qquad \text{Eq. 9}$$

Where;

$PFC_{i,y}$	=	Project fuel consumption of fuel type *i* in year *y* (t)
$SFC1_{i,t,v}$	=	specific fuel consumption in the post-retrofit condition at draft t and speed v (g/kWh)
$BPHR1_{t,v,h}$	=	brake power in heavy running in the post-retrofit condition at draft t and speed v (kW)
h	=	allowable underway hour
t	=	mean draft at hour h (m) (mean draft is average of draft at forward and aft ends of the ship)
v	=	ship speed at hour h (knots) Option 1: Ship speed and draft data should be collected in accordance with the ISO/DIS 19030-2 standard. The most accurate calculation of fuel consumption is based on speed through the water (STW) as opposed to speed over ground (SOG), since resistance and brake power are determined by STW. Option 2: If the ship does not have the capability to collect STW data, SOG data, commensurate with ISO 19030-3, can be used in this model if required.

Project emissions are determined using the same process as outlined in the main body of the methodology.

3.7 LEAKAGE EMISSIONS

The rebound or take-back effect is included as a leakage source. This refers to the phenomena that financial savings due to lower fuel consumption can be used to cruise at a higher speed thus offsetting the fuel savings.

The approach with this SGDL model will compare the ship's performance and emissions at the same speeds before and after the installation of the retrofit measures, so the rebound or take-back effect of a ship cruising at a higher speed post-retrofit due to the financial savings from lower fuel consumption is correctly accounted for in the calculation of emissions and emission reduction.

Upstream leakage effect of gaseous fuel usage is not included as this occurs in the baseline and project case. Due to fuel savings, leakage in the baseline case will be higher than in the project case, and thus its non-inclusion is conservative.

3.8 EMISSION REDUCTIONS

Emission reductions are the difference between baseline and project emissions per ship. As a control measure, emission reductions can be calculated on an **hourly basis** thus ensuring the exclusion of the same time periods for baseline and project fuel consumption. Emission reductions are calculated per ship. If the activity includes a number of ships the total emission reductions are the sum of individual ship emission reductions.

3.9 OTHER CHANGES

The following provides a further explanation of two differences between SGDL model and the Basic Model approach:

1. The condition in the approved methodology concerning the regression analysis fit of $R^2 > 0.8$ is not required under the SGDL model approach. For greater clarity, in the SGDL model approach, the modeled speed/fuel consumption curves are not derived from a regression analysis of noonday fuel consumption data, but from the principles of hydrodynamics and a regression of model test data, and are then verified against sea trial data. Therefore, the requirement to achieve a regression analysis fit of R2 > 0.8 for the speed/fuel consumption curve with noon report FOC data is not included in the SGDL model approach.

The purpose of the inclusion of the BAU Autonomous Technological Improvement Factor in the baseline emission calculation is to ensure that the baseline is sufficiently conservative in the overall calculation of emission reductions. The use of modeled speed/power curves generated at the beginning of the baseline, pre-retrofit docking cycle (i.e. based on the ship's baseline, pre-retrofit condition) reflects the ship's performance at peak fuel efficiency, with a clean hull and propeller. Fouling of the hull and propeller, deformation of hull panels, and wear and tear on the engine and mechanical systems will cause fuel efficiency to decrease over a docking cycle. As a result, the use of these speed/power curves reflecting the ship's baseline, pre-retrofit condition at the beginning of the baseline docking cycle is already conservative: it will typically lead to an underestimation of actual pre-retrofit/baseline fuel consumption, and therefore an underestimation of emission reductions. In addition, several of the factors that might deteriorate during the docking cycle mentioned above are the same or similar to those that would be addressed by the inclusion of the BAU factor. The fact that the SGDL-modeled baseline is conservative because it eliminates the deterioration in performance that will typically occur during a docking cycle, and that the BAU technological improvement factor is intended to address relatively minor maintenance carried out during a typical dry docking to offset this type of deterioration, means it is no longer appropriate to apply the BAU technological improvement factor at the time of the first baseline emissions calculation by the SGDL model, as this would be a duplication of the conservativeness effect built into the SGDL model. The BAU factor will be applied, but starting only in the subsequent docking cycle.

4.0 Monitoring methodology

4.1 SGDL MODEL INPUT DATA/PARAMETERS

The minimum required input parameters to apply SGDL model are indicated by * in the table below; all others are optional and/or can be estimated by the model.

Table A1.1 : SGDL model input data/parameters

	DATA/PARAMETERS
1. Hull	a. Deadweight (cargo capacity, dwt; can be provided in place of displacement) b. Displacement loaded, or lightship (tonnes; if deadweight is provided instead of displacement)* c. Length between perpendiculars (LBP, m)* d. Length over all (LOA, m) e. Beam (m)* f. Draft loaded forward and aft (m)* g. Draft in ballast forward and aft (m) h. Wetted surface area loaded (m^2) i. Wetted surface area in ballast (m^2) j. Transverse (forward-facing) area above surface for wind resistance (m^2) k. Distance from longitudinal center of buoyancy (LCB) to after perpendicular, loaded and in ballast (m) l. Distance from AP to aftmost point of wet hull (m) m. Block coefficient n. Midship section coefficient o. Waterplane area coefficient p. Bulbous bow: Bulb length from forward perpendicular (FP) (m) q. Bulbous bow: bulb surface area (m^2) r. Bulbous bow: bulb volume (m^3) s. Bulbous bow: transverse sectional area of bulb (m^2) t. Bulbous bow: vertical centroid of transverse sectional area u. Coefficient of friction of underwater coating in new (out of dock) condition
2. Engine	a. Design/make/model b. # of cylinders c. RPM, kW, and specific fuel consumption (sfoc) @ L1, L2* d. RPM, kW, and specific fuel consumption (sfoc) @ L3, L4* e. Number of turbochargers f. Fuel type (fuel energy content)
3. Propeller	a. # blades b. Diameter (m) c. Hub height above baseline (m) d. Expanded area ratio e. Pitch to diameter ratio at 0.7R f. Ship design speed (knots)*
4. Operating profile	a. Laden or heavy load condition i. Days at sea/year ii. Average speed (knots) iii. Typical draft (forward, aft) b. Ballast or light load condition i. Days at sea/year ii. Average speed (knots) iii. Typical draft (forward, aft

4.2 CROSS CHECK FOR FUEL CONSUMPTION FOR VERIFICATION:

The aggregate project fuel consumption calculated via the SGDL model for the reporting period will be cross-checked against the aggregate fuel consumption reported by the ship's owner for the reporting period, based on measurements made in conformance with the European Union (EU) MRV Regulation (Regulation (EU) 2015/757 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport, amending Directive 2009/16/EC) and the similar, mandatory IMO Fuel Oil Data Collection System (Regulation 22A as an amendment to MARPOL, entered into force on March 1, 2018), to ensure that the modeled aggregate fuel consumption is within 5% of that reported by the ship owner. The same filtering criteria are applied to the owner's FOC data to exclude days of extreme weather and operations in port/maneuvering. If the reported fuel consumption exceeds the modeled value by more than 5%, the reported fuel consumption value is used for the purpose of calculating FOC savings for the reporting period. If the modeled value exceeds the reported FOC by more than 5%, the modeled value is used for the purpose of calculating FOC savings for the reporting period. If the difference between modeled and reported consumption is greater than 10%, and this difference cannot be reconciled (reconciliation could involve, for example, the identification and correction of errors in the noon report consumption data, or the identification and correction of an error in the ship input data to the FOC model), then the ship is not eligible to participate in the carbon credit project during the monitoring period.

The following list of data parameters to be monitored remain unchanged and shall be monitored as described in section 4| of the methodology:

- Ship identification number (**REEM 4**)
- DD (daily distance traveled, nautical miles) (**REEM 6)**
- DT (daily hours of sailing) (**REEM 7** & **REEM 8**)
- Beaufort scale (**REEM 9**)

4.3 ADDITIONAL DATA AND PARAMETERS MONITORED

Parameter ID	**REEM 12**
Data/Parameter:	V
Data unit:	Knots
Description:	Speed over ground (SOG) of the ship if using noonday data
Source of data:	Ship operator
Measurement procedures	Monitoring equipment or noonday reports
Monitoring frequency:	Daily; data would be converted to hourly data for the purposes of the SGDL model, taking into account data filtering criteria contained within the methodology.
QA/QC procedures:	As per the filtering criteria within the methodology, For ships operating on long voyages and recording noonday data, days with less than 23 hours of voyage on the day are excluded from the analysis.
Any comment:	

Parameter ID	REEM 13
Data/Parameter:	V
Data unit:	Knots
Description:	Speed through water (STW) of the ship if reporting hourly data.
Source of data:	Ship operator
Measurement procedures	Monitoring equipment or hourly reports
Monitoring frequency:	Hourly
QA/QC procedures:	None
Any comment:	

Parameter ID	REEM 14
Data/Parameter:	T (forward, aft)
Data unit:	Meters
Description:	Draft forward, draft aft
Source of data:	Ship operator
Measurement procedures	Observation of ship draft measure markings and codes
Monitoring frequency:	Hourly or daily
QA/QC procedures:	None
Any comment:	Draft readings are usually taken by visual inspection of the waterline relative to the draft measures painted on the sides of the ship. Since rapid changes in draft occur only when the ship is taking on or discharging cargo of ballast water, daily observations of draft are acceptable, and can be taken as valid for all hourly calculations.

Parameter ID	REEM 15
Data/Parameter:	Sea trial report
Data unit:	n/a
Description:	Report includes details of trial conditions (including trial speeds, duration, weather conditions, etc.) and ship particulars, engine and propeller details, information on appendages, rudder, etc.
Source of data:	Ship owner/operator
Measurement procedures	n/a
Monitoring frequency:	n/a
QA/QC procedures:	None

Any comment:	The sea trial report documents the ship's performance during the sea trials in terms of speed, power and propeller revolutions under prescribed ship conditions, and thereby verifying the satisfactory attainment of the contractually stipulated Ship Speed and to provide the Ship Speed for the calculation of the Energy Efficiency Design Index (EEDI) as required by IMO.

Parameter ID	**REEM 16**
Data/Parameter:	Baseline speed/power curves cross check
Data unit:	n/a
Description:	Cross check of the SGDL-modeled baseline speed/power curves for sea trial drafts against the sea trial reports for the ship
Source of data:	SGDL model; user cross check
Measurement procedures	n/a
Monitoring frequency:	once
QA/QC procedures:	The baseline speed/power curves for sea trial drafts shall be cross-checked against sea trial reports for the ship. If the modeled brake power value at the sea trial speed differs from the sea trial brake power by more than +/-3%, the model speed/power curve will be shifted by a constant percentage across the full speed range, where that percentage is chosen to be the minimum necessary to bring the modeled curve within +/-3% of the sea trial data at the sea trial speed. Modeled speed/power curves for other draft levels are shifted by the same percentage.
Any comment:	

Parameter ID	**REEM 17**
Data/Parameter:	ME Fuel consumption (cross check for fuel consumption for verification)
Data unit:	Tonnes
Description:	Tonnes of fuel consumed by main engine(s)
Source of data:	Ship owner/operator, IMO-DCS or EU-MRV reports
Measurement procedures	Fuel consumption monitoring and reporting procedures as per the IMO-DCS or EU-MRV programs
Monitoring frequency:	Once at verification
QA/QC procedures:	The aggregate project fuel consumption calculated via the SGDL model for the reporting period will be cross-checked against the aggregate fuel consumption reported by the ship's owner for the reporting period, to ensure that the modeled aggregate fuel consumption is within 5% of that reported by the ship

	owner. The same filtering criteria are applied to the owner's FOC data to exclude days of extreme weather and operations in port/maneuvering. If the reported fuel consumption exceeds the modeled value by more than 5%, the reported fuel consumption value is used for the purpose of calculating FOC savings for the reporting period. If the modeled value exceeds the reported FOC by more than 5%, the modeled value is used for the purpose of calculating FOC savings for the reporting period. If the difference between modeled and reported consumption is greater than 10%, and this difference cannot be reconciled (reconciliation could involve, for example, the identification and correction of errors in the noon report consumption data, or the identification and correction of an error in the ship input data to the FOC model), then the ship is not eligible to participate in the carbon credit project during the monitoring period.
Any comment:	

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Document History

VERSION	DATE	DESCRIPTION
2.1	10/04/2024	• Correction in equation 2
2.0	13.12.2021	• Inclusion of SGDL model • Editorial changes
1.0	02.08.2017	1st version