Reducing Vessel Emissions Through the Use of Advanced Hull Coatings (Version 2.0)

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SECTION I. INTRODUCTION, SOURCE, DEFINITIONS AND APPLICABILITY

1. Introduction

The methodology comprises the application of advanced low-resistance hull coatings instead of the traditional, baseline coating. The advanced coating keeps the hull cleaner and reduces hydrodynamic resistance, compared to the traditional coating, thus reducing fuel consumption for ship propulsion.

The methodology is applicable when the baseline is determined to be a traditional biocidal coating, which was applied to the ship in the previous cycle prior to applying the advanced hull coating. The project scenario generally comprises the entire docking cycle following the application of the advanced coating. (There are some exceptions where emissions reductions would be limited by an earlier end date, for various reasons, as explained below.) The baseline corresponds to a scenario in which the hull was coated with the traditional material. The relationship between fuel consumption rate and a number of operating parameters in the previous docking cycle is determined by regression analysis from data for the previous docking cycle, i.e. when the baseline coating was in use. The parameters of the regression analysis are used to estimate baseline fuel consumption rate (or power) corresponding to the same operating parameters as actually observed in the project scenario, i.e. with the advanced coating in place. The difference between this estimate of baseline fuel consumption and the actual, measured fuel consumption in the project scenario is the fuel savings. Thus, monitoring comprises (a) recording and analyzing fuel consumption data and other relevant parameters after applying the advanced coating product and (b) analyzing enough data from the previous cycle to determine the regression coefficients to a high level of accuracy.

Performance of the hull degrades over time, following the application of the hull coating. While the hull coating is meant to keep material (especially live organisms) from sticking to the hull surface, some inevitably gets deposited. Performance also degrades over time since, besides material adhesion, hulls tend to become mechanically damaged over time, as the ship bumps into jetties, or is impacted by objects during loading, unloading and other operations. The hull coating is applied on a docking cycle, which is typically 60 months for most cargo vessels, though the docking cycle for some ships is shorter, e.g. 36, 30 or 24 months, and even as low as 12 months for small passenger ships. Since performance may degrade over time, fuel consumption and emissions must describe the full docking cycle.

The roughness of the applied coating also affects vessel efficiency. Advanced, biocide-free foul release coatings have lower hull roughness than traditional biocidal coatings and maintain this lower hull roughness more effectively, maintaining the improvement in efficiency over the docking cycle. Biocidal coatings are more prone to mechanical damage and roughening.

Since it is expected that once ship owners and operators have used the advanced hull coating and seen the documentation of energy savings through the application of this methodology, supported by a share of carbon credits, they would continue to use the advanced hull coating. Hence carbon credits would be limited to a single docking cycle following the application of the advanced hull coating.

In most cases, companies own only a few ships, so that it is unrealistic for companies to seek carbon credits. The coating manufacturer, as an aggregation entity, is in a far better position to do so, and this will allow practically all ship owners and operators to benefit from carbon credits. However, in order for ship owners and operators to benefit from carbon credits, the carbon credits would be shared between the coating manufacturer and the ship owner/operator in all cases. Moreover, since there are large fleet operators who do not need the coating manufacturer for aggregation, carbon credits may be claimed directly by ship owners/operators, and this could be relevant to large fleet owners/operators.

Ships ply the seas and other water bodies and can have an impact on the environment. Many traditional coatings are based on biocidal materials that release a toxic substance into the marine environment. One such coating material (tributyltin, TBT) was banned by the International Maritime Organization in 2003, but others remain in use. This methodology can only be applied to hull coatings that do not contain biocidal materials.

Biocide-free foul release products offer significant environmental benefits compared to traditional biocidal products that are still permitted by the IMO, such as the self-polishing copolymer (SPC) coatings. As well as significant fuel cost and emission savings, as a biocide-free product, the foul release products eliminate release of biocides in to the marine environment.

Moreover, the biocide-free foul release products have higher volume solids and lower required film thickness than biocidal systems. This results in a significant reduction in paint volume and VOC (volatile organic compound) emissions for first time application and even more so for future dockings.

For qualifying under this methodology, all of these environmental benefits should be clearly demonstrated and be independently verified through life cycle studies following ISO 14040 and ISO 14044

2. Sources

The methodology is essentially new but uses the following CDM Tools:

- Tool for the demonstration and assessment of additionality;
- Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion;
- Tool to calculate project emissions from electricity consumption;

3. Definitions

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

- **Beaufort Scale** or **Beaufort Wind Force Scale**. An empirical measure for describing wind speed based mainly on observed sea. The scale is shown in Appendix B.
- **Bunker fuel** is technically any type of fuel oil used aboard ships. It gets its name from the containers on ships and in ports that it is stored in; in the days of steam they were coal bunkers but now they are bunker fuel tanks. Since No. 6 fuel oil (**or heavy fuel oil**) is the most common, "bunker fuel" is often used as a synonym for No. 6.
- **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. 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.
- **Heavy fuel oil (HFO)**.. Fuel used in most ships. Heavy fuel oils are blended products based on the residues from various refinery distillation and cracking processes. They are viscous liquids and require heating prior to combustion. Heavy fuel oils are used in medium to large industrial

plants, marine applications and power stations, etc. Two most common types are Number 5 and Number 6 fuel oils defined below[1]. See also **Marine diesel**.

- **Number 5 fuel oil** is a residual-type industrial heating oil requiring preheating to between 170 and 220 degrees Fahrenheit (about 75 to 105 C) for proper atomization at the burners. This fuel is sometimes known as Bunker B.
- **Number 6 fuel oil** is a high-viscosity residual oil requiring preheating to between 220 to 260 degrees Fahrenheit (about 105 to 125 C). Residual means the material remaining after the more valuable cuts of crude oil have boiled off. This fuel may be known as residual fuel oil (RFO)

In recent years, low sulphur heavy fuel oils (LS HFO) have been introduced. Their lower sulphur content reduces sulphur oxide emissions from fuel combustion. The properties of LS HFO are slightly different from traditional HFO.

- **Hull coating material categories**:
  - **Biocidal antifouling coatings**. A hull coating product that releases active ingredients, biocides, into the marine environment, repelling organisms and thereby preventing their adhesion to ships' hulls. Copper forms the basis for the most widely used biocides today. Biocidal antifouling coatings may be self-polishing copolymers (SPC), rosin-based controlled depletion polymers (CDP) or combinations of the two.
  - **Silicone foul release coatings**. Unlike biocidal antifouling coatings, these do not release any active ingredients into the marine environment but work on a pure physical basis using a combination of reactive and un-reactive silicone polymers. These intermediate coatings offer improved vessel efficiency compared to biocidal coatings.
  - **Fluoropolymer foul release coatings.** These are also biocide-free coatings, which do not release any active ingredients in to the marine environment. Fluoropolymer systems use a combination of silicone and fluoropolymer materials to produce an ultra smooth fouling resistant surface. These advanced coating systems produce the smoothest surface resulting in the largest improvements in vessel efficiency.
- **International water-borne navigation (International bunkers)**. Emissions from fuels used by vessels of all flags that are engaged in international water-borne navigation. The international navigation may take place at sea, on inland lakes and waterways and in coastal waters. Includes emissions from journeys that depart in one country and arrive in a different country.[2]
- **Marine diesel.** Fuel typically used by medium speed and medium/high speed marine diesel engines. Sometimes called Marine diesel oil (MDO). A fuel with similar properties is called Marine gas oil (MGO). For the purpose of this methodology, MDO and MGO may be treated as identical since key properties (calorific value and emissions factor) are virtually identical.
- **Ship categories.** There are many types of cargo and passenger ships. Their loading characteristics are relevant for the methodology and are therefore presented in some detail below. Cargo ships include Containerships, Vehicle transporters, Dry bulk carriers, Chemical tankers, Crude oil tankers, and LNG carriers. Passenger ships include Cruise liners, Passenger ferries, as well as Roll-on Roll-off (Ro-Ro) ferries. These are illustrated below.

[1] Source: http://en.wikipedia.org/wiki/Fuel_oil
[2] Source: IPCC (2006), vol. 2, Chap. 3, Table 3.5.1, p. 3.48.

Figure 1. Containership

Figure 2. Vehicle transporter

Figure 3. Dry bulk carrier, bulk freighter, or bulker, is a merchant ship used to transport unpackaged bulk cargo, such as cereals, coal, ore, and cement.

Figure 4. Chemical tanker

Figure 5. Oil tanker

Figure 6. LNG tanker

Figure 7. Cruise ship

Figure 8. Passenger ferry, catamaran type

Figure 9. Roll-on, Roll-off (Ro-Ro) ferry

Some cargo ships only operate on loaded or empty (ballast) conditions. These ships are often operated differently when loaded compared to when they are in ballast. Other cargo ships carry variable load and the displacement depends on the weight of the load, and can vary considerably. On the other hand, the total displacement of passenger ships varies little and therefore the displacement can be considered to be constant. Keeping this in mind, ships described above can be classified in three categories, listed in the table below.

Table 1. Ship categories according to loading condition

1	High/Low displacement (either loaded or ballast)	Crude oil tankers Dry bulk carriers LNG carriers
2	Variable displacement	Liquid product tankers Chemical tankers Containerships Vehicle transporters
3	Minimal displacement change	Passenger ferries Cruise liners Ro-Ro ferries

Definitions (cont.)

- **Ship speed** can be defined in two ways:
  - *Speed over the ground* (SOG) is the speed of the vessel relative to the surface of the earth.
  - *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.

- **Slip, or propeller slip**. Each turn of the corkscrew moves it into the cork by the pitch (*p*) of the corkscrew, see Figure 11. The speed (*V*) of the corkscrew would be the product $p \times n$, where *n* is the rotation rate of the corkscrew. Since cork is a solid, and water is not, the forward speed of the ship is not exactly equal to (generally lower than) the propeller pitch multiplied by its rotation rate. The propeller slip (*S*) is defined as:

$$S = 1 - \frac{V}{p \times n}$$

Further reasoning would indicate that the speed here would be speed through water (STW, see **Ship speed** above**)**. Indeed, the issue of slip is more complex, with an apparent and a real slip, see MAN Diesel (n/d), pp. 15-16. However, for the purpose of this methodology, we will consider Slip as it is recorded in ship logs. The parameter Slip is only used in some cases, where simpler models are not statistically valid for a specific ship.

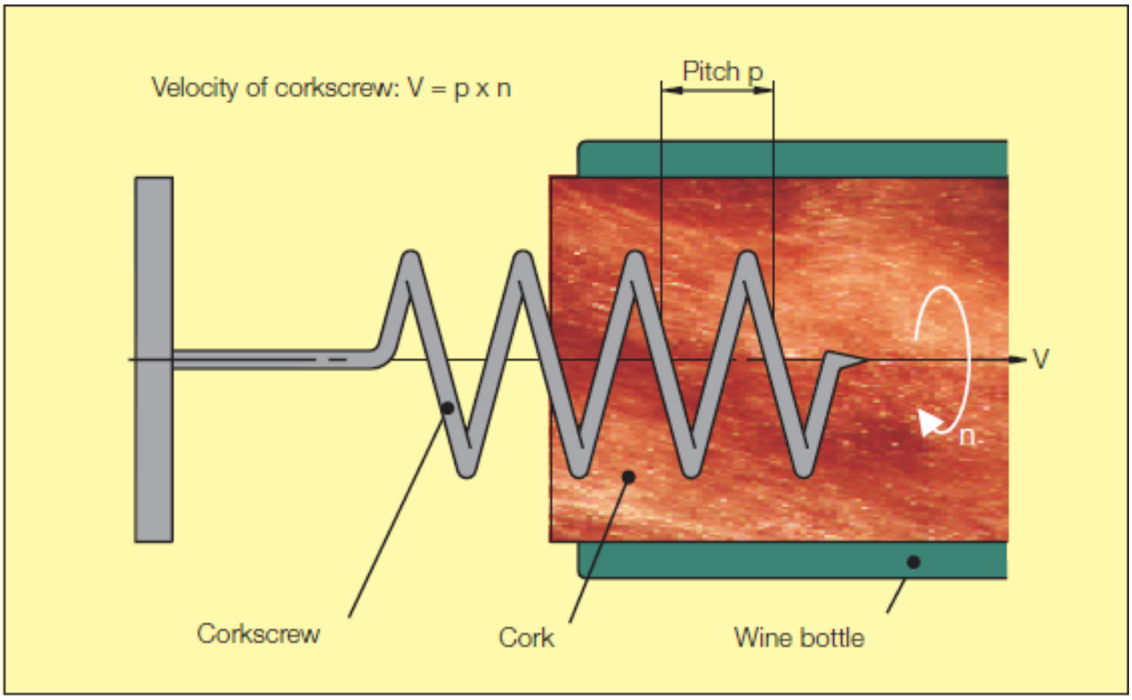

Figure 10 Movement of a corkscrew without slip

(Source: MAN Diesel (n/d), p.15, Figure 11)

4. Applicability

This methodology applies to project activities that reduce the hydrodynamic resistance of ships through fluoropolymer foul release coatings, and other advanced hull coatings.

The methodology is however only applicable under the following conditions:

- The ship is not new, i.e. it had at least one full docking cycle of operation with the traditional biocidal hull coating.

- Evidence is provided on time for validation to demonstrate that the advanced hull coating does not contain any biocides or other toxic materials. These and other environmental benefits of the advanced hull coating should be clearly demonstrated and be independently verified through life cycle studies following ISO 14040 and ISO 14044.

- The ship did not undergo engine overhaul or replacement, or any other modification that would reduce its fuel consumption at the same time as the advanced hull coating was applied or at any time during the docking cycle for which carbon credits are being claimed. See Appendix D on "Energy efficiency measures applicable to existing ships";

- Evidence needs to be provided to indicate (underwater) hull cleaning dates in the baseline period at the time of registration for carbon credits, and records need to be kept to indicate underwater hull cleaning during the project docking cycle, following the application of the advanced hull coating. Ships that undergo hull cleaning in the project docking cycle while none occurred in the baseline docking cycle can only claim emission reductions under this methodology up to the time of the hull cleaning.

- Certain countries or groups of countries may impose fuel efficiency conditions for ships travelling to and from these countries. In those cases, emission reductions would not continue to be eligible for those routes, from the date of application of the regulations. See Step 1b of the application of the Section "Identification of the baseline scenario and demonstration of additionality".

- Emission reductions can only be claimed for one single project docking cycle for each ship included in the project activity.

- If biofuel blends are used, the % of petroleum and biofuel components of each fuel purchase should be recorded. Emissions reductions would only apply to reduced petroleum fuel consumption, with no credits for biofuel use through this methodology. However this methodology could be combined with another methodology to include emissions reduction through biofuel use.

- Data as needed for the application of the proposed methodology are available for the entire baseline docking cycle and confirmed by official documentation to be provided as evidence on time for validation (e.g. engine logs, deck logs, bunker delivery notes). Since shipping company may not have recorded all the needed data for the entire baseline period, enough data should be available for the results of the regression analysis of baseline data to be valid. Moreover, fuel supply dates and quantities are made available at the time of validation, in order to allow for cross checking ship's log data on fuel consumption.

- The fuel consumption used for navigation purpose in baseline period should be used for regression analysis. In cases, where PP can demonstrate by providing convincing and documented argumentation that navigation fuel is only used for navigation and maneuvering activities, total fuel consumption can also be used for regression analysis. In both cases, the same "boundary" for fuel consumption data should be used both in baseline and project scenario. In such cases, where the total fuel consumption also includes uses other than navigation and maneuvering, it should NOT be used for regression analysis.

- The project applicant shall bear the cost of a professional statistician contracted by The Gold Standard Foundation for the validation of:
    - The results of the regression analysis applied to the submitted project activity in line with the model(s) provided in the methodology;

- A new regression model presented for approval by The Gold Standard Foundation prior to the submission of a project activity.

- In order to aggregate emission reductions and make the project activity viable, the methodology may be used to provide carbon credits to the manufacturer of the advanced hull coating and not to the individual ships or shipping companies or charter operators, who in fact would be reducing fuel consumption and thereby reducing emissions. However, the methodology is also applicable to ship owners and operators, considering that some companies may own sufficient number of vessels for them to apply for carbon credits directly, without requiring the manufacturer as an aggregation entity.

- When the coating manufacturer is the aggregation entity, for the determination of carbon credits, shipping operator must make fuel consumption data available to the coating manufacturer. To this end, an agreement is needed between the coating manufacturer and the purchaser of the coating product that covers the following issues:

  - *Benefits to the shipping company*. The coating manufacturer would share with the shipping company or charter operator a part of the carbon credits. All must formally commit in this agreement to not claim credits from the same ships as part of activities under another scheme.

  - *Obligations of the shipping company or charter operator*. In order to determine emissions reduction, data covering ship speed, fuel consumption, days since coating application, sea condition, etc., are needed a substantial part of docking cycle with the traditional hull coating prior to the application of the advanced hull coating. These are used to determine baseline emissions. Each data item may be based on "noonday" data, voyage data, or a combination of the two. Similar data are also needed for the entire docking cycle following the application of the advanced hull coating. Furthermore information must be provided on whether any measures with a potential impact on fuel consumption have been implemented during that period. Thus, the shipping owner or charter operator is obliged to provide the needed data and information, as part of its formal agreement with the coating manufacturer. The detailed data would be considered confidential, and would only be shared with the validation and verification entities and The Gold Standard Foundation, 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 increase confidence in advanced hull coating products, making them common practice.

  While the agreement is between shipping company/operator and coating manufacturer is confidential, it needs to be monitored and verified during the project approval process and prior to the issuance of carbon credits. Hence this issue is further discussed in the section on Monitoring.

  In all cases, the contract between coating manufacturer and ship owner/operator would be made available to The Gold Standard Foundation at the latest at the time of registration of any project activity.

SECTION II. BASELINE METHODOLOGY

1. Project Boundary

The *project boundary* is the physical, geographical location of the ships to which the hull coating is applied. The project boundary covers the routes where each ship consumes fuel and where emissions occur. However, improved hull coating reduces fuel use only during movement. Moreover, time at port and docks may vary. Thus, to avoid the effect of unrelated factors, only the cruising (or navigation) part of each route will be considered (i.e. excluding ports, dry docks and manoeuvres) for the purpose of determining fuel consumption and emissions. In some cases, where fuel consumption for navigations is not separately recorded, the project boundary would include "navigation and manoeuvring." In both baseline and project scenarios, the same "boundary" for fuel consumption data should be used.

The greenhouse gases included in or excluded from the project boundary. This methodology applies to an energy efficiency measure that would reduce the consumption of marine diesel or fuel oil consumption in ships. The combustion of these fuels also produces small amounts of two other greenhouse gases: methane (CH_4) and nitrous oxide (N_2O). Insofar as less fuel would be burnt in the project scenario as in the baseline scenario, but the combustion system is not modified by the project activity, there would be reductions in methane and nitrous oxide emissions as well from reduced fuel use. However, these emissions reductions are neglected for conservativeness; the focus of the present methodology is exclusively on carbon dioxide emissions reduction.

Coating a ship involves electricity consumption at the dry dock. The amount of electricity consumed for this activity, undertaken only once for each painting cycle, typically every five years, is insignificant compared to the energy used by the ship engines. Moreover, this electricity consumption would be present and be basically independent of the type of coating applied. Therefore, for simplicity, and with hardly any loss of accuracy, the electricity consumption for coating the ship hull is excluded both from the baseline and the project scenarios.

Note that ships may be underwater cleaned during the 60-month docking cycle. This is not expected to be done for the advanced hull coating. By not counting this process and its associated emissions, present only in the baseline scenario, the methodology is being conservative in the assumptions on emissions reduction.

Emissions sources and GHGs included and excluded are also indicated in Table 2.

Table 2. Emissions sources included in or excluded from the project boundary

Source		Gas	Included?	Justification / Explanation
Baseline	Fuel consumption by ship engines (excluding rough seas)	CO_2	Yes	Major emission source.
		CH_4	No	Excluded for simplification. This is conservative.
		N_2O	No	Excluded for simplification. This is conservative.
Project activity	Fuel consumption by ship engines (excluding rough seas)	CO_2	Yes	Major emission source.
		CH_4	No	Excluded for simplification.
		N_2O	No	Excluded for simplification.

Data for fuel consumption for navigation may be available separately from other uses of the fuel in question. If such data are not available, where data is available only for *total fuel consumption for main* *engines* for navigation and maneuvering purposes may be used. In either case, the project boundary is shown in Figure 11

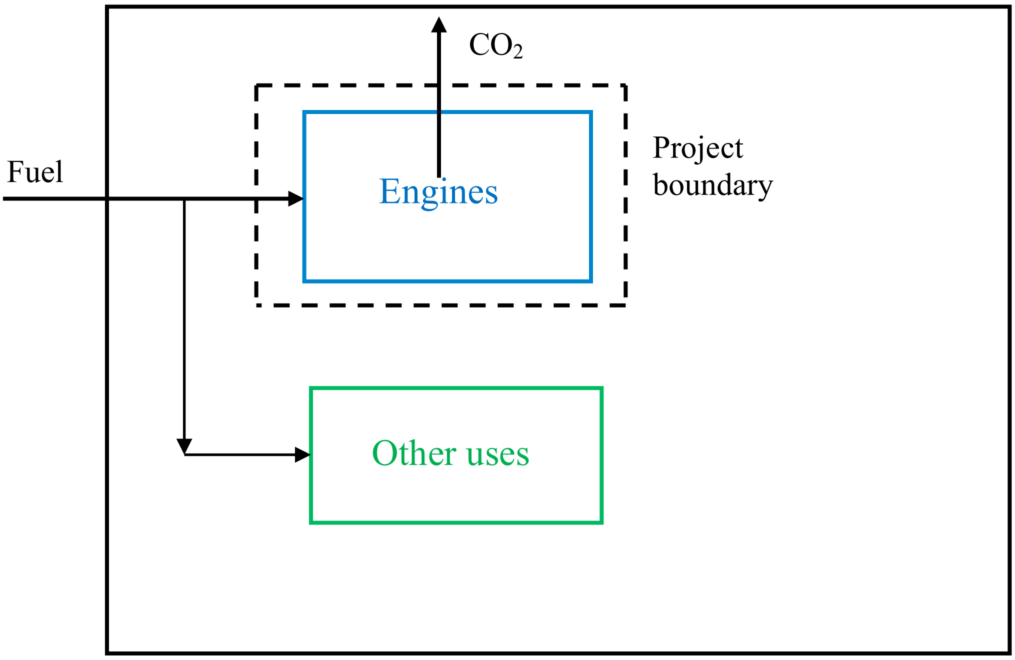

Figure 11. Project boundary where fuel consumed by main engines for navigation (or for navigation and manoeuvres) and corresponding emissions are included in project boundary. Other uses of the same fuel as that used by ship engines are excluded.

2. Identification of baseline scenario and demonstration of additionality

The CDM Tool for the demonstration and assessment of additionality is used as the basis for the identification of the baseline scenario and evaluation of additionality[3].

Step 1: Identification of alternatives to the project activity consistent with current laws and regulations

Define realistic and credible alternatives to the project activity(s) through the following Sub-steps:

Sub-step 1a: Define alternatives to the project activity:

The project activity comprises coating the hull of a ship using an advanced coating product. Possible baseline alternatives considered should at a minimum be:

1. The project activity itself, i.e. applying the advanced coating product, without carbon credits;
2. Applying a biocidal antifouling coating that was also applied in the previous hull coating cycle;

[3] The CDM includes two additionality tools: (1) Tool for the demonstration and assessment of additionality; and (2) Combined tool to identify the baseline scenario and demonstrate additionality. The first of the tools is applied in this methodology.

3. Applying a less advanced (e.g. intermediate silicone foul release coating) product, with properties between the historical product (biocidal antifouling coating) and the advanced product comprising the project activity.

Outcome of Step 1a: Identified realistic and credible alternative scenario(s) to the project activity

Sub-step 1b: Consistency with mandatory laws and regulations:

Review mandatory laws and regulations applicable to hull coatings that might eliminate one of the alternative baseline scenarios. For instance, if a law prohibits the use of a certain hull coating material, then the corresponding alternative can be excluded from the list of possible baselines.

On the other hand, if there are laws and regulations that require fuel savings compared to an earlier period, or some other condition, which implies that one of the coating products cannot be applied, then again, the corresponding alternative can be excluded from the list of possible baselines.

At the time of releasing this methodology there are no laws and regulations requiring the use of advanced coatings.

The IMO has been and remains in charge of greenhouse-gas (GHG) emissions regulation in shipping following the UNFCCC meeting in Cancún in December 2010. So far the IMO has imposed no mandatory limits on shipping emissions. Thus there are no requirements that favour advanced hull coatings. However, the International Maritime Organization (IMO) imposed a worldwide ban on the application of coatings comprising self-polishing polymers (SPC) with tributyltin (TBT), in effect since 2003. This coating can therefore not be considered either for the baseline or project scenario.

The PDD shall analyze the regulations applicable at the time of submission of a project activity, including those regulations that have been established but not yet gone into effect to evaluate their impact on the baseline and additionality. For instance, following the application (i.e. date of going into effect) of any regulations from the EU, say, that would favour advanced hull coatings, any ships applying the coatings would only be able to obtain carbon credits on routes not affected by the regulations. Since the emissions reductions are determined from actual ship fuel consumption on a daily/ voyage basis, subject to certain data filters to eliminate “invalid” data, it would be a fairly straightforward procedure to eliminate all the days corresponding to voyages affected by regulations. For instance, it is possible that the European Union limits emissions from certain categories of ships travelling to and from EU member states, to be effective from a certain date. Since the advanced hull coating can help meet this regulation, in order to be conservative, fuel savings and emissions reductions for those voyages would not count towards carbon credits from the date that the regulations go into effect. Emission reductions which exceed regulatory requirements would still be eligible under this methodology. Thus if regulations require, e.g. a 5% reduction in emissions for certain routes, then any emissions reduction over this value, would count toward carbon credits.

This process eliminates double counting of emissions reductions that are also part of a compliance regime.

If no alternative baselines are eliminated by applicable laws and regulations, all three alternatives remain valid and need to be considered in the following steps.

Outcome of Step 1b**:** Identified realistic and credible alternative scenario(s) to the project activity that are in compliance with mandatory legislation and regulations taking into account the enforcement in the region or country and EB decisions on national and/or sectoral policies and regulations.

Step 2: Investment analysis

Details of this step are omitted here but are meant to be followed as in the CDM Additionality Tool

AND/OR Step 3: Barrier analysis

Details of this step are omitted here but are meant to be followed as in the CDM Additionality Tool.

Step 4: Common practice analysis

Step 4.1: Identify the total number of ships in category "i" that have already applied an advanced hull coating of level "j" and have started commercial operation before the start date of the project. Note their number $N_{all,i,j}$. Project activities registered under Gold Standard shall not be included in this step.

Clearly the self-polishing, biocidal coating, which is the baseline for this methodology to be applicable, is excluded. Also excluded are any non biocidal coatings that do not claim to save fuel. Advanced hull coatings that do not contain biocidal materials and reduce hull resistance can be further subdivided into two levels. The first level comprises "silicone based combined foul release coatings" which do not contain biocides and provide a certain, intermediate level of fuel savings. The second level comprises "fluoropolymer based foul release coatings".

Projects previously registered under the Gold Standard on the basis of fuel savings from advanced hull coatings are excluded from the calculation. However, projects registered under other voluntary markets are not, since the applicability conditions may be very different.

Step 4.2: Within ships identified in Step 4.1, identify those that apply technologies different than the technology applied in the proposed project activity. Note their number N_{diff}.

Since level two coatings provide superior performance, when the project activity (as described in the PDD) comprises the level two coating, N_{diff} is considered to be all ships that have the baseline biocidal coating or a level one coating. However, if the project activity comprises a level one coating, then N_{diff} would only consider ships with biocidal coating. Any ships with level 2 coatings would be included within the project activity group, since their performance is superior to that of the project activity. This can be illustrated by an example involving one category of ships: cruise ships. Suppose there are 2000 cruise ships in all, of which 40 already have the Level 2 (fluoropolymer) coating and another 70 have the Level 1 (silicone) coating. Then if the project activity comprised ships with fluoropolymer coating, N_{diff} would be 2000 - 40 = 1960. However, if the project activity comprised ships with silicone coating, N_{diff} would be 2000 – (70 + 40) = 1890. Clearly if a ship is even more advanced than the proposed project, it cannot be considered to be a part of the baseline.

Step 4.3: Calculate factor $F=1-N_{diff}/N_{all}$ representing the share of ships using technology similar to the technology used in the proposed project activity in all ships of same category as in the proposed project activity. The proposed project activity is a "common practice" if the factor F is greater than 0.2 and $N_{all}-N_{diff}$ is greater than 3.

Considering the previous example, if the proposed project activity comprises cruise ships with the Level 2 (fluoropolymer) coating, F = 1 – 1960/2000 = 0.02. On the other hand, if the project activity comprises cruise ships with Level 1 (silicone) coating, F = 1 – 1890/2000 = 0.055.

In neither of the two cases, the project activity would be considered common practice. *However, once a value of F has been reached for any ship category for either a level 1 or level 2 coating, as explained above, no further ships from that category would qualify for carbon credits under this methodology.*

Note that the application of the above procedure could determine that (1) the project activity is in fact the baseline, and therefore it is not additional. The analysis can indicate that (2) the baseline is the application of the historical coating product. Finally, the analysis could indicate that (3) that the application of an intermediate coating product is the baseline.

In both cases (2) and (3), the project activity is additional, but the baseline is different. This methodology is only applicable if the baseline scenario is case (2), i.e. the second alternative listed in Step 1(a): "Applying a biocidal antifouling coating that was also applied in the previous hull coating cycle"

As noted earlier, some or all ships, or ships on certain voyages, may be disqualified from carbon credits as a result of regulatory changes. Moreover, a quantitative common practice analysis also limits the number of ships in each category that may qualify for carbon credits in the future.

3. Project emissions

Project emissions are determined by emissions associated with actual fuel consumption in ship propulsion (specifically for navigation, i.e. excluding port and manoeuvres) following the application of the advanced coating product. In cases, where PP can demonstrate by providing convincing and documented argumentation that navigation fuel is only used for navigation and maneuvering activities, total fuel consumption can also be used for regression analysis. In both cases, the same "boundary" for fuel consumption data should be used both in baseline and project scenario. Project emissions are determined directly and are discussed first. Baseline emissions correspond to the emissions for the same energy service (voyage, distance, etc.) that would have happened in the baseline scenario. Thus, baseline emissions are obtained in a dynamic manner from project emissions. In fact emissions reductions are obtained directly from project emissions (see section II.4).

Project emissions accrue from fuel combustion. Hence the CDM "Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion" may be directly applied. Eq. (1) of the Tool determines CO_2 emissions from fossil fuel combustion in process j as follows:

$$PE_{FC,j,y} = \sum_i FC_{i,j,y} \times COEF_{i,y} \qquad \text{(TF.1)}^4$$

Where

$PE_{FC,j,y}$	=	CO_2 emissions from fossil fuel combustion in process j during year y (tCO_2/yr)
$FC_{i,j,y}$	=	Quantity of fuel type i combusted in process j during year y (mass or volume unit/yr)
$COEF_{i,y}$	=	CO_2 emission coefficient of fuel type i in year y (tCO_2/mass or volume unit)
I	=	Fuel type combusted in process j during year y.

For this specific methodology,
i would be the fuel used;
j would correspond to each ship;

Fuel consumption would normally be measured in weight units, tonnes.

Thus, ***COEF*** would be measured in tCO_2/tonne of fuel.

[4] "TF" refers to equation numbers from this Tool.

The Tool offers two options for determining COEF:

Option A: The CO_2 emission coefficient $COEF_{i,y}$ is calculated based on the chemical composition of the fossil fuel type ***i***, using the following approach, when fuel is measured in mass unit:

$$COEF_{i,y} = w_{C,i,y} \times 44/12 \quad \text{(TF.2)}$$

where

$COEF_{i,y}$	=	CO_2 emission coefficient of fuel type *i* in year y (tCO_2/tonne)
$w_{C,i,y}$	=	Weighted average mass fraction of carbon in fuel type *i* in year y (tC/tonne of fuel)
i	=	Fuel type combusted in process (ship) during year y.

Option B: The CO_2 emission coefficient $COEF_{i,y}$ is calculated based on net calorific value and CO_2 emission factor of the fuel type *i*, as follows:

$$COEF_{i,y} = NCV_{i,y} \times EF_{CO_2,i,y} \quad \text{(TF.4)}$$

where

$COEF_{i,y}$	=	CO_2 emission coefficient of fuel type *i* in year *y* (tCO_2/tonne)
NCV	=	Weighted average net calorific value of the fuel type *i* in year *y* (GJ/tonne)
$EF_{CO2,i,y}$	=	Weighted average CO_2 emission factor of fuel type *i* in year *y* (tCO_2/GJ)

For ships operating on long voyages, where ship logs record "Noonday data", total fuel consumption by ship's engines is recorded daily together with key parameters, specifically average speed, date, hours of voyage during 24 hour period, sea condition (Beaufort Scale), vessel condition (loaded, ballast, or cargo weight, if variable). For ships operating on shorter voyages, e.g. less than two days, where ship logs record data per voyage, fuel consumption and average speed would be recorded for each voyage. Some ships may operate in both long and short voyages. In this case, the records in ship logs may be a combination of "noonday" and voyage data. Data other than fuel consumption are needed to estimate ship fuel consumption in the baseline scenario for the same conditions, specifically at the same speed and at the same time after coating was applied.

The model for determining baseline fuel consumption savings is described in Appendix A, and applied in the following section.

According to the model, for some days, fuel consumption is excluded from the analysis, both for the determination of project as well as baseline emissions:

- Stormy days - Beaufort Scale (wind force) above 6 are excluded, so that for a day to be included Beaufort Scale (wind force) should be ≤ 6.
- For ships operating on long voyages, and recording "Noonday data", days without a full day of sailing should be excluded. In this case, data corresponding to days in which voyaging time was below 23 hours on the day are excluded from the analysis. For ships operating on short voyages, and recording Voyage data, this exclusion is not applicable.

This data exclusion is called a *filter condition.* The reason why these filter conditions are applied are given in Appendix A, where the model used in the methodology is developed. Note that excluding days is conservative since any fuel savings achieved on those days with the advanced coating product are not counted for the determination of emissions reduction.

Because of data filtering, Eq. (TF.1) needs to be modified as follows:

$$PE_{j,y} = \sum_i \left(\sum_k FC_{i,j,k} \right) \times COEF_{i,y} \quad (1)$$

Where

k = Days meeting filter conditions described above, and

Note that since the only emissions are from fuel combustion, the subscript "FC" (for PE) is removed from Eq. (1) and subsequent equations.

4. Baseline emissions and emission reductions

Baseline emissions correspond to baseline fuel consumption, which is the fuel that the ship would have consumed if it had the historical, baseline, coating. Thus, baseline emissions would be given by the following relationship similar to Eq. (1) above:

$$BE_{j,y} = \sum_i \left(\sum_k BFC_{i,j,k} \right) \times COEF_{i,y} \quad (2)$$

where the days excluded from the determination of project emissions are also excluded from the determination of baseline emissions.

Historical data on daily fuel consumption and various explanatory variables are analysed using a regression approach in order to characterise the relationship of baseline fuel use to these explanatory variables.

A number of modelling approaches were tested using data from several ships in order to reach a robust statistical model. The results of this analysis are presented in Appendix A.

The exploratory data analysis and modelling led to the development of a *Basic Model* that is statistically valid and provides reasonable estimates of baseline fuel consumption.

The *Basic Model* considers the following relationship:

$$FC = a \times V^n \quad (3)$$

Taking natural logs of both sides of Eq. (3), we have:

$$\ln(FC) = \ln(a) + n \ln(V) \quad (4)$$

with daily average data for fuel consumption (FC) and ship speed (V), corresponding to the Pre-period, a regression of **ln (FC)** versus **ln (V)** would give 'n' as a slope and 'ln (a)' as intercept. The regression yields an estimate of 'n' directly while the value of 'a' can be calculated from the estimate of 'ln (a)'.

Since FC is the fuel consumption in a 24-hour period, this fuel consumption rate may be denominated “power” and represented by “P”. Eq. 4 becomes:

$$\ln (P) = \ln (a) + n \ln (V) \quad (5)$$

The basic model may use another explanatory variable, days since coating application (D), considering that the hull would degrade over time.

Project developers shall first apply the Basic Model to the data set corresponding to the docking cycle prior to the application of the advanced hull coating.

If the model does not adequately fit the data, either the ship must be dropped from further analysis, or an alternative model may be used to estimate fuel savings. The alternative model could be a more complicated model, e.g. with a non linear dependence of ln (FC) vs. (ln V), taking into account that data on consecutive days show similar behaviour, or include other explanatory variables, e.g. displacement, in order to provide a better representation of reality. Project proponents shall provide and discuss the new model and indicate in what way they improve predictability relative to the Basic Model. Each model, either the Basic Model or any alternative model, needs to be tested on each ship to make sure that it is statistically valid according to criteria described in Appendix A, prior to being used in order to predict baseline fuel consumption. Prior to being applied within a project activity, a new regression model shall first be submitted for approval. The Gold Standard Foundation contracts a professional statistician for the validation of the regression analysis and the applicant must bear the cost of the assessment by the statistician.

Prior to applying the regression analysis, certain data filtering is applied Days or voyages with wind force exceeding Beaufort Scale 6 are excluded. In the case of noonday data, days with less than 23 hours of sailing should be excluded, since these days include port and manoeuvre activities. In the case of voyage data, where data are available, fuel consumption and speed for the navigation component of the voyage should be used for analysis. However, if such data are not available for the baseline period, total consumption of the fuel used for propulsion may be used[5]. This would include port and manoeuvre activities. However, in all cases, the data boundary should be consistent for the entire data analysis covering all of the baseline and project cycles.

The filter conditions noted in the previous paragraph should be applied to exclude days from the historical (baseline) data as well as data in the project scenario, following the application of the advanced hull coating. The regression analysis is conducted on the historical data, and as part of this analysis other anomalous data are also excluded, e.g. sailing hours exceeding 24 hours per day, ship speed or fuel consumption equal to zero, and obvious data errors. However, outliers other than these “obvious” ones should only be removed on the basis of the following objective statistical tests.

Some errors, e.g. year, month or day incorrectly recorded (as can be easily detected by looking at the days before and after the day/voyage in question) may be corrected prior to analysis. A record should be kept so that it is clear which data have been modified.

Objective statistical test for detecting outliers. Determine the average (Vav) and standard deviation (s) of the daily or voyage ship speed over the data set in question. If the recorded value of speed is outside the range (Vav - 3s, Vav + 3s), then the day/voyage may be eliminated. In both cases, the average speed recorded for the “outlier” day/voyage was below the lower limit. A similar objective test can be based on daily or voyage fuel consumption rate or power data. In this case, since the standard deviation tends to be a larger proportion of average (higher coefficient of variation), a narrower range is proposed, going from

[5] The consumption of any fuel not used for propulsion should be excluded in all cases.

two standard deviations below to two standard deviations above the average. If the recorded fuel consumption rate or power on a given day or voyage is outside this range the day or voyage can be eliminated from the regression analysis. For examples of outliers, see Appendix A.

Note that the limits +/- 3s for speed, and +/- 2s for ship power are somewhat arbitrary. In some cases, applying these limits leads to many valid days being removed. Especially noteworthy are cases where both speed and fuel consumption rate (power) are above or below the limits. Or cases, where a sequence of days, one or other variable is too high or too low. In these cases, the analyst may modify the range to include additional days/voyage. However, the use of other limits should be noted and the values explicitly stated.

Even if the above tests are applied, fuel consumption rate or power versus speed should be graphed, before and after removing outliers. This procedure is not intended to remove "inconvenient" points but merely to improve the regression analysis, since this would certainly distort the results. A complete record of the data highlighting days excluded forms part of the monitoring procedure that is described later. Thus a complete record of data before and after filtering and other data exclusion is maintained to ensure transparency in the data removal process, and to permit validation and verification.

For ships characterized by a single loading condition, a single set of regression coefficients are obtained from the entire baseline data. For high/low displacement ships, the baseline data are first separated into days/voyages operating under ballast condition and days/voyages operating loaded.

The regression coefficients are 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.

Once the regression has been applied using the Basic Model listed above, regression coefficients are used to determine Baseline Power for each day/voyage following the application of the advanced hull coating. Here Baseline Power refers to the Power that would have been needed by the ship under the same conditions if the baseline coating were in place instead of the advanced coating. This is sometimes referred to as a dynamic baseline, since it is determined by the project conditions, in this case, speed, days since coating, etc. for the ship operating after the advanced (Project) coating has been applied.

The process is illustrated below for the Basic Model.

$$BP = a \times V^{n} \qquad (6)$$

where BP is the baseline power corresponding to the day/voyage in question when average speed is V, and a and n were determined from the regressions.

Note that project fuel consumption together with average speed is measured and recorded on a daily basis for "Noonday" data or per-voyage or a combination of the two. The relationship between baseline power and average speed or adjusted speed is determined using regression analysis of baseline data of daily power or voyage power and average speed or adjusted speed, except for days/voyages in which the measured ship speed is outside the range of validity, as explained above. This relationship, combined with measured daily average speed or voyage average speed in the project scenario, i.e. with the advanced hull coating, is used to estimate baseline fuel consumption for each day or voyage in the project scenario.

Fuel savings are determined as the difference between estimated baseline fuel use and actual project fuel use for each valid day or voyage of project voyages. Valid data may exclude stormy and incomplete days or voyages, as well as days or voyages with anomalous data, following the same rules as were used to filter data in the baseline period. The process is illustrated in the table below. The data columns shown in italics are determined by calculation. The shaded row indicates a day excluded by the filters (i.e. stormy, incomplete or with anomalous data).

Date or Voyage	Project power of all ship engines, measured	Average speed over ground, V	Vessel condition, L, = 0 for ballast, 1 for loaded	*Baseline power from regression*	*Fuel savings, (Baseline power less Project power) X 24 hours (for daily data), or X voyage duration (voyage data)*
1					
2					
3					

Because of the similarity between equations (1) and (2) for project and baseline emissions, it is clear that emissions reductions are determined basically by summing the fuel savings for each valid day of data.

$$ER_{j,y} = \sum_i \left(\sum_k FS_{i,j,k} \right) \times COEF_{i,y} \qquad (7)$$

where:

$ER_{j,y}$ = Reduction in CO_2 emissions in ship j during year y (tCO_2/yr)

$FS_{i,j,k}$ = Savings of fuel type i combusted in ship j during day k (mass unit), counting only valid days, i.e. applying the filter described above.

$COEF_{i,y}$ = CO_2 emission coefficient of fuel type i in year y (tCO_2/mass or volume unit)

i = Fuel type combusted in ship j during year y.

Rebound effect and slow speeds. It is possible that ship operators “take back” a part of the fuel savings obtained through the advanced hull coating, by operating the ship at a higher speed after the project implementation. To compensate for any “take back” or “rebound” effect, the following approach shall be followed. For some days or voyages the measured ship speed (in the project scenario) may be above the range of ship speeds for which the regression model is valid. For these days or voyages, any fuel savings should be excluded from the determination of overall fuel savings, e.g. in the summation of Eq. (7). On other days, the average speed on a given day may be below the valid range of speeds. This is not a case of rebound effect, since lowering the speed would reduce fuel consumption. However the regression model is not valid for speeds below the valid range. For these days, BP cannot be determined using the regression coefficients, given by Eq. (6), and these days are eliminated from the summation in Eq. (7), and are not counted towards emissions reduction. *In summary, all days or voyages in the post period where the average speed/adjusted speed is outside the range of values used in the baseline regressions are excluded from the total fuel savings.*

Once fuel savings have been estimated for each day, total savings may be determined by summing over the days in each year. Emissions reductions can then be determined from the second line of Eq. (7):

While it is possible to sum project and baseline fuel consumption separately and taking the difference of the sums in order to estimate overall fuel savings, this is not recommended. This is to ensure that any days excluded from project fuel use are also excluded from the determination of baseline fuel use. This end is better served by *first* determining fuel savings for "valid" days *and then summing*, as indicated in Eq. (7).

An alternative way of viewing this is that fuel savings are determined for each valid day or voyage in the project period, by comparing the baseline fuel consumption and the actual fuel consumption for that day or period. Emissions reductions are determined by multiplying fuel savings by an emissions factor for the fuel. Total emissions reductions are obtained by summing fuel savings over the monitoring period in question.

Note that Eq. (7) considers each ship (j) separately. Since different ships are on different locations on any given day, the excluded days for each ship will be different. Moreover, ship speed, days since last coating and whether it is loaded, etc. would be different for each ship. Hence it is reasonable to determine ER for each ship during each calendar year (or other monitoring period) and then add all ships together to get overall emissions reduction for the calendar year (or other monitoring period).

The overall project emissions reductions in year "y" would be given by the sum of ERs for all the ships in the year:

$$ER_y = \sum_j ER_{j,y} \tag{8}$$

5. Leakage

Since the project activity comprises the use of one coating product instead of another, no leakage effects are expected.

Note: the discussion of the rebound effect is considered in the section on Project Emissions, and therefore is not a part of leakage.

6. Data and parameters not monitored during the crediting period

Data and parameters monitored include the properties of fuels used for marine propulsion, allowing the determination of emissions from the combustion of these fuels. One source of the parameters is IPCC (2006) where the parameters are the net calorific value (NCV_i) of each fuel "i" expressed in TJ/Gg (terajoules per gigagramme or gigajoules per tonne) and the CO_2 emissions factor of the fuel "i", expressed in kg/GJ. The values for the main marine fuels from this source are given below.

Data / parameter:	i = Residual fuel oil
Data unit:	TJ/Gg = GJ/tonne
Description:	Net calorific value of the fuel type i = Residual fuel oil
Source of data:	IPCC, 2006, Volume 2, Table 1.2
Value applied:	40.4
Measurement procedures (if any):	None
Any comment:	Standard fuel, hence IPCC data used. Alternatively, IMO data may be used, see below.

Data / parameter:	i = Marine diesel
Data unit:	TJ/Gg = GJ/tonne
Description:	Net calorific value of the fuel type i = Marine diesel
Source of data:	IPCC, 2006, Volume 2, Table 1.2
Value applied:	43.0
Measurement procedures (if any):	None
Any comment:	Standard fuel, hence IPCC data used. Alternatively, IMO data may be used, see below.

Data / parameter:	i = Low sulphur heavy fuel oil
Data unit:	TJ/Gg = GJ/tonne
Description:	Net calorific value of the fuel type i = Low sulphur heavy fuel oil
Source of data:	IPCC, 2006, Volume 2, Table 1.2 for residual fuel oil
Value applied:	40.4
Measurement procedures (if any):	None
Any comment:	Standard fuel, hence IPCC data used. Alternatively, IMO data may be used, see below.

Data / parameter:	i = Liquefied natural gas
Data unit:	TJ/Gg = GJ/tonne
Description:	Net calorific value of the fuel type i = Liquefied natural gas
Source of data:	IPCC, 2006, Volume 2, Table 1.2 for natural gas
Value applied:	48.0

Measurement procedures (if any):	None
Any comment:	Standard fuel, hence IPCC data used. Alternatively, IMO data may be used, see below.

Data / parameter:	i = Residual fuel oil
Data unit:	kg/GJ
Description:	CO_2 emission factor of fuel type i = Residual fuel oil
Source of data:	IPCC, 2006, Table 3.5.2
Value applied:	77.4
Measurement procedures (if any):	None
Any comment:	Standard fuel, hence IPCC data used. Alternatively, IMO data may be used, see below.

Data / parameter:	i = Marine diesel oil
Data unit:	kg/GJ
Description:	CO_2 emission factor of fuel type i = Marine diesel
Source of data:	IPCC, 2006, Table 3.5.2
Value applied:	74.1
Measurement procedures (if any):	None
Any comment:	Standard fuel, hence IPCC data used. Alternatively, IMO data may be used, see below. Note that Marine diesel oil (MDO) can be considered to be identical to Marine gas oil (MGO).

Data / parameter:	*i* = Low sulphur heavy fuel oil
Data unit:	kg/GJ
Description:	CO_2 emission factor of fuel type *i* = Low sulphur heavy fuel oil
Source of data:	IPCC, 2006, Table 3.5.2 for residual fuel oil
Value applied:	77.4
Measurement procedures (if any):	None
Any comment:	Standard fuel, hence IPCC data used. Alternatively, IMO data may be used, see below.

Data / parameter:	*i* = Liquefied natural gas
Data unit:	kg/GJ
Description:	CO_2 emission factor of fuel type *i* = Liquefied natural gas
Source of data:	IPCC, 2006, Table 3.5.2 for natural gas
Value applied:	56.1
Measurement procedures (if any):	None
Any comment:	Standard fuel, hence IPCC data used. Alternatively, IMO data may be used, see below.

Another source of data for parameters to determine emissions from the combustion of marine fuels is the International Maritime Organisation (IMO, 2009b). In this case, the emissions factors are given directly in terms of tonnes of CO_2 per tonne of fuel, for five possible marine fuels, see last column in table below.

Type of fuel	Reference	Carbon content	C_F (t-CO_2/t-Fuel)
1. Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3. Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400
4. Liquified Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
5. Liquified Natural Gas (LNG)		0.75	2.750000

Source: IMO, 2009b, p. 10.

Note that IMO gives the emissions factors directly in terms of tonnes of CO_2 per tonne of fuel. In the case of the IPCC data, obtaining this value requires multiplying the two parameters and dividing by 1000 to match the units. The resulting IPCC values are given below.

	NCV		
	GJ/tonne	kg/GJ	t CO_2/t fuel
Residual fuel oil	40.4	77.4	3.127
Marine diesel	43	74.1	3.186
Low-sulphur heavy fuel oil	40.4	77.4	3.127
Liquefied natural gas	48	56.1	2.693

Source: IPCC (2006), see tables above.

A comparison of the last columns of the two tables above indicates that the emissions factors determined from the two data sources are similar but not identical.

1. Within each category of fuel, small differences in composition would imply that the emissions factors are not always the same. However, as vessels are trading internationally with the capability to pick up bunker fuels at any port in the world, a set of internationally recognized average values is the appropriate way to go.
2. Either the IPCC or the IMO values may be used for any given ship. However, for consistency, the same data source should be used for all ships in a given project activity for the determination of baseline and project emissions, in order to avoid bias. The data source and values should be clearly indicated in data analysis presented.

SECTION III. MONITORING METHODOLOGY

All data collected as part of monitoring should be archived electronically and be kept at least for 2 years after the end of the crediting period. 100% of the data should be monitored if not indicated otherwise in the tables below. All measurements should be conducted with calibrated measurement equipment according to relevant industry standards.

In addition, the monitoring provisions in the tools referred to in this methodology apply.

First each participating ship in the project is recorded, with the following data:

Data / parameter:	j
Data unit:	None
Description:	Ship identification number for the jth ship in the project activity. Also name of ship.
Source of data:	Ship owner / or coating manufacturer
Measurement procedures (if any):	None
Monitoring frequency:	Once, when the ship is coated.
QA/QC procedures:	None
Any comment:	This is a record of the ships where the advanced coating product is applied.

Data / parameter:	Date_prev(j)
Data unit:	Date
Description:	Date on which the *previous* coating application was finished on ship j.
Source of data:	Ship owner and / or coating manufacturer
Measurement procedures (if any):	Recorded at the dry dock where the coating is applied.
Monitoring frequency:	Once, when the ship is coated.
QA/QC procedures:	None
Any comment:	Corresponds to baseline scenario

Data / parameter:	*Previous* coating material (j)
Data unit:	-
Description:	*Previous* coating material on ship j.
Source of data:	Ship owner and / or coating manufacturer
Measurement procedures (if any):	Recorded at the dry dock where the coating is applied.
Monitoring frequency:	Once, when the ship is coated.
QA/QC procedures:	None
Any comment:	Corresponds to baseline scenario

Data / parameter:	Hull cleaning (underwater) in *baseline* period (j)
Data unit:	Date
Description:	Hull cleaning date during baseline coating cycle on ship j.
Source of data:	Ship owner and / or dry dock operator
Measurement procedures (if any):	Recorded at the dry dock where hull is cleaned.
Monitoring frequency:	As needed
QA/QC procedures:	None
Any comment:	

Data / parameter:	Date_adv(j)
Data unit:	Date
Description:	Date on which the *advanced* coating application is finished on ship j.
Source of data:	Ship owner and / or coating manufacturer
Measurement procedures (if any):	Recorded at the dry dock where the coating is applied.
Monitoring frequency:	Once, when the ship is coated.
QA/QC procedures:	None
Any comment:	Corresponds to *project* scenario

Data / parameter:	*Advanced* coating material (j)
Data unit:	-
Description:	*Advanced* coating material on ship j.
Source of data:	Ship owner and / or coating manufacturer
Measurement procedures (if any):	Recorded at the dry dock where the coating is applied.
Monitoring frequency:	Once, when the ship is coated.
QA/QC procedures:	None
Any comment:	Corresponds to *project* scenario

Data / parameter:	Main engine fuel (j)
Data unit:	-
Description:	Main engine fuel in ship j.
Source of data:	Ship operator
Measurement procedures (if any):	
Monitoring frequency:	
QA/QC procedures:	Fuel type should be confirmed with fuel purchase invoices.
Any comment:	Corresponds to both *baseline* and *project* scenarios. Any changes from baseline to project scenario should be noted.

Data / parameter:	Auxiliary engine fuel (j)
Data unit:	-
Description:	Main engine fuel in ship j.
Source of data:	Ship operator
Measurement procedures (if any):	
Monitoring frequency:	
QA/QC procedures:	Fuel type should be confirmed with fuel purchase invoices.
Any comment:	Corresponds to both *baseline* and *project* scenarios. Any changes from baseline to project scenario should be noted.

Data / parameter:	Engine or other modifications undertaken at the same time as the application of advanced hull coating
Data unit:	-
Description:	Any other measures that would reduce fuel consumption
Source of data:	Ship operator with documentation from third party (where applicable), e.g. Dru Dock Work Scope
Measurement procedures (if any):	See list of other measures in methodology Appendix D.
Monitoring frequency:	Once at time of hull coating
QA/QC procedures:	N.A.
Any comment:	Ship would not be eligible for carbon credits, if there were any other energy efficiency measures applied

Data / parameter:	Change in fuel at the same time as the application of advanced hull coating
Data unit:	-
Description:	Engine or other modifications to allow for a different fuel to be used
Source of data:	Ship operator with documentation from third party (where applicable)
Measurement procedures (if any):	None
Monitoring frequency:	Once at time of hull coating
QA/QC procedures:	None
Any comment:	Ship would not be eligible for carbon credits, if there were any other energy efficiency measures applied

For long voyages, ships are at sea between ports, and certain data are recorded in ship logs. These are normally called “Noonday data”, since the data are recorded at noon of each day. For ships operating in long routes, for each day of both the baseline and the project period, each of the following data variables should be recorded. For ships operating on shorter voyages, typically lasting less than a couple of days, “Voyage data” need to be recorded, as described further below.

Data / parameter:	Date
Data unit:	-
Description:	Calendar date
Source of data:	Ship operator
Measurement procedures (if any):	None
Monitoring frequency:	Daily
QA/QC procedures:	None
Any comment:	

Data / parameter:	Daily distance (nautical miles)
Data unit:	Nautical miles
Description:	Distance travelled in last day, since last daily record
Source of data:	Ship operator supplemented by charter party agreements, (as applicable)
Measurement procedures (if any):	AIS / GPS
Monitoring frequency:	Daily
QA/QC procedures:	None
Any comment:	

Data / parameter:	Daily steaming time (hours)
Data unit:	Hours
Description:	Hours of sailing since last daily record
Source of data:	Ship operator
Measurement procedures (if any):	None
Monitoring frequency:	Daily
QA/QC procedures:	None
Any comment:	

Data / parameter:	V
Data unit:	Knots
Description:	Average daily speed through water since last daily record
Source of data:	Ship operator
Measurement procedures (if any):	Calculated from previous two data variables.
Monitoring frequency:	Daily
QA/QC procedures:	None
Any comment:	

Data / parameter:	Sea state (Beaufort scale)
Data unit:	Beaufort number
Description:	Sea state, noted at the time of daily data recording
Source of data:	Ship operator
Measurement procedures (if any):	Observation
Monitoring frequency:	Daily
QA/QC procedures:	None
Any comment:	

Data / parameter:	Vessel condition
Data unit:	Ballast/Loaded, or displacement
Description:	Loading condition of ship at the time of data recording
Source of data:	Ship operator
Measurement procedures (if any):	As appropriate
Monitoring frequency:	Daily. However, value will not change significantly during any voyage
QA/QC procedures:	None
Any comment:	

Data / parameter:	FC(ME)
Data unit:	Tonnes
Description:	Fuel consumption of the main engine since last daily record
Source of data:	Ship operator
Measurement procedures (if any):	Fuel flow meter
Monitoring frequency:	Daily
QA/QC procedures:	Calibration of fuel flow meter, periodic dip test on tanks
Any comment:	When same tank supplies for than one engine, or other non-engine equipment, the dip test can only be compared with the sum of all flow meters

Data / parameter:	FC(AE)
Data unit:	Tonnes
Description:	Daily fuel consumption of the auxiliary engine(s) since last daily record
Source of data:	Ship operator
Measurement procedures (if any):	Fuel flow meter
Monitoring frequency:	Daily
QA/QC procedures:	Calibration of fuel flow meter, periodic dip test on tanks
Any comment:	When same tank supplies for than one engine, or other non-engine equipment, the dip test can only be compared with the sum of all flow meters

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 per voyage, instead of per 24-hour period. For ships operating in shorter routes, for each voyage of both the baseline and the project period, each of the following data variables should be recorded.

Data / parameter:	Date of voyage start and end
Data unit:	-
Description:	Calendar date
Source of data:	Ship operator
Measurement procedures (if any):	None
Monitoring frequency:	Per voyage
QA/QC procedures:	None
Any comment:	

Data / parameter:	Distance between departure port and arrival port
Data unit:	Nautical miles
Description:	Distance between departure port and arrival port
Source of data:	Ship operator supplemented by charter party agreements, (as applicable)
Measurement procedures (if any):	Ship log data on distance actually travelled.
Monitoring frequency:	Per voyage
QA/QC procedures:	None
Any comment:	If actual distance along sea route for the voyage is unavailable, a typical distance between departure and arrival ports (from other voyage records) may be used.

Data / parameter:	Voyage time
Data unit:	Hours
Description:	Hours of navigation between departure and arrival ports
Source of data:	Ship operator
Measurement procedures (if any):	Ship log data on departure and arrival times, preferably from when ship leaving port starts navigation to when ship stops navigation at arrival port.
Monitoring frequency:	Per voyage
QA/QC procedures:	None
Any comment:	If data not available, total voyage time may be used.

Data / parameter:	V
Data unit:	Knots
Description:	Average navigation speed during voyage
Source of data:	Ship operator
Measurement procedures (if any):	Calculated from previous two data variables.
Monitoring frequency:	Per voyage
QA/QC procedures:	None
Any comment:	In some cases, the ship log may record the average speed directly. Preference will be given to data based on distance and time, since these are likely to be primary data.

Data / parameter:	Sea state (Beaufort scale)
Data unit:	Beaufort number
Description:	Sea state
Source of data:	Ship operator
Measurement procedures (if any):	Observation, recorded in ship log
Monitoring frequency:	Per voyage
QA/QC procedures:	None
Any comment:	

Data / parameter:	Vessel condition
Data unit:	Ballast/Loaded, or displacement
Description:	Loading condition of ship at the time of data recording
Source of data:	Ship operator
Measurement procedures (if any):	As appropriate
Monitoring frequency:	Per voyage
QA/QC procedures:	None
Any comment:	Loading condition is only relevant for certain ship categories, such as bulk loader, tanker, etc.

Data / parameter:	FC (ME)
Data unit:	Tonnes
Description:	Fuel consumption of the main engine for navigation part of voyage
Source of data:	Ship operator
Measurement procedures (if any):	Fuel flow meter
Monitoring frequency:	Per voyage
QA/QC procedures:	Calibration of fuel flow meter, periodic dip test on tanks
Any comment:	If fuel consumption for the navigation part of the voyage is not available separately, total fuel consumption in voyage may be used. However, the data should be consistent for the entire analysis period, including baseline and project. When same tank supplies more than one engine, or other non-engine equipment, the dip test can only be compared with the sum of all flow meters.

Data / parameter:	FC (AE)
Data unit:	Tonnes
Description:	Fuel consumption of the auxiliary engine(s) for navigation part of voyage
Source of data:	Ship operator
Measurement procedures (if any):	Fuel flow meter
Monitoring frequency:	Per voyage
QA/QC procedures:	Calibration of fuel flow meter, periodic dip test on tanks
Any comment:	If fuel consumption for the navigation part of the voyage is not available separately, total fuel consumption in voyage may be used. However, the data should be consistent for the entire analysis period, including baseline and project. When same tank supplies more than one engine, or other non-engine equipment, the dip test can only be compared with the sum of all flow meters

If there are additional underwater hull cleanings following the application of the advanced hull coating, the following data tables should be filled out.

Data / parameter:	Hull cleaning (underwater) in *project* period (j)
Data unit:	Date
Description:	Hull cleaning date following application of advanced coating on ship j.
Source of data:	Ship owner and / or dry dock operator.
Measurement procedures (if any):	Recorded at the dry dock where hull is cleaned.
Monitoring frequency:	As needed
QA/QC procedures:	None
Any comment:	If hull was cleaned in the baseline period, a hull cleaning is allowed in the project period as well, i.e. carbon credits are not affected. *Note that all hull cleaning would be underwater.*

Regulations
There are no current regulations affecting the fuel efficiency of existing ships, so that the eligibility of carbon credits as determined by this methodology is not affected. However, future regulations may be relevant. Thus, all future regulations relating to fuel efficiency or CO_2 emissions from shipping should be monitored on a continual basis and reported annually, as part of the Monitoring Report. Regulations that might affect carbon credits, to be included, *inter alia*, are listed below:

- *EU ETS regulations on ships travelling to and from EU ports*. These could require that certain classes of ships travelling to and from ports in EU member countries must comply with regulations affecting their GHG emissions. If such regulations were put into place, certain voyages would not be eligible to claim carbon credits under this methodology, or be limited to regulatory surplus. Thus, for each voyage, ports of departure and arrival will need to be recorded. Thus days of sailing for the affected voyages would be excluded from the determination of project and baseline emissions, and emissions reductions, or emissions reductions limited to regulatory surplus.
- *Regulations from other entities*. Review the regulations in order to determine the impact, if any, of these regulations on carbon credits under this methodology.
- *New IMO standards on energy efficiency of new ships, that may require or imply the use of advanced hull coatings*. Recall that IMO (2011) specifies mandatory energy efficiency measures for

international shipping, but these regulations do not require the use of advanced hull coatings. If these regulations change or new regulations are introduced, eligibility for carbon credits through advanced hull coatings may be affected. Therefore future IMO regulations should be monitored.

SECTION IV. REFERENCES

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Appendix A

Modelling fuel consumption by regression analysis

This Appendix describes the development of the statistical, regression model recommended in the new methodology as the *Basic Model* for establishing the relationship of fuel consumption rate to explanatory variables using historical data. This relationship determines baseline fuel consumption as a function of the values of the explanatory variables. Using the monitored values of these explanatory variables in the project scenario, i.e. after the application of the improved hull coating, and the coefficients determined by the regression analysis, the baseline fuel consumption for each day is determined. Comparing this baseline fuel consumption with the actual, monitored fuel consumption for each day, yields fuel savings. Daily fuel savings may be summed over extended periods, e.g. a year, in order to obtain total energy savings and emissions reduction for the period.

The starting point of this exercise is a basic understanding of hydrodynamics.

A ship moving at a constant velocity faces hydrodynamic drag force from frictional resistance given by the following equation:

$$F_D = \frac{1}{2}\rho A C_d V^2 \qquad \text{(A.1)}$$

Where

F_D = Drag force

ρ = Density (water)

A = Area

C_d = Drag coefficient

V = Velocity

The power required to overcome hydrodynamic drag is given by:

$$P = F_D V \qquad \text{(A.2)}$$

Where

P = Power

Combining Eq. (A.1) and (A.2) we have:

$$P = \frac{1}{2}\rho A C_d V^3 \qquad \text{(A.3)}$$

The above equation represents the power dissipated by the ship hull in overcoming frictional resistance. Power must also be dissipated to overcome wave-making resistance. Wave-making resistance is more important at higher speeds. The ship also faces air resistance, which is much smaller in magnitude than frictional and wave-making resistance; it is not relevant for the project activity, and is not considered in the methodology.

Power is energy over time, and one unit of measurement is tonnes of fuel consumed by engines per day. Ship power requirements are determined not only by the power required to overcome frictional and wave-making resistance (and aerodynamic resistance) but also by other parameters. The engines are most efficient at the rated speed, with efficiency falling off for higher and lower RPM. The propeller is optimised for a certain forward motion and efficiency falls off for higher and lower speeds.

Equation A.3 indicates that ship power requirements to overcome frictional resistance scales as the cube of the ship speed. The relationship of the wave-making resistance and other parameters to ship speed are not as clear.

A number of models were tested in order to determine the best relationship between historical fuel consumption and explanatory variables.

The first model is a procedure[6] often used by the shipping industry to determine fuel savings from energy efficiency measures. This model builds on the fact that fuel consumption mainly depends on the cube of the ship speed. The fuel consumption in one period is adjusted by the cube of average ship speed in order to estimate fuel consumption at another period characterised by a different average ship speed. This procedure yields a single estimate with no statistical parameters to support the estimation. For ships where displacement is relatively constant, each interval is characterized by a single average value of ship speed and of fuel consumption. For ships that can be considered by a high or low displacement (corresponding to loaded and ballast operation), the data set for each time interval can be divided into loaded (L) and ballast (B) subsets, and the fuel consumption adjusted by speed cubed for each subset separately. This simple model cannot be applied to variable displacement ships, except by ignoring the variation and considering a single data set.

This procedure can be used to determine fuel savings as illustrated below. First the fuel consumption rate (tonnes of fuel per 24-hour period) is adjusted for differences in the average speed in the Pre and Post periods as follows:

$$FC_{Post,adj} = FC_{Post} \times \left(\frac{V_{Pre}}{V_{Post}} \right)^3 \qquad \text{(A.4)}$$

Where the subscripts "Pre" and "Post" indicate data averages over extended Pre and Post periods. The 'adjustment' is based on the assumption that fuel consumption is proportional to speed cubed.

A % fuel savings is given by:

$$\%FS = \frac{FC_{Pre} - FC_{Post,adj}}{FC_{Pre}} \times 100 \qquad \text{(A.5)}$$

The results are shown below for a number of ships.

[6] This was referred to as Model 3 in the original methodology submission.

Ship 1. Pure Car Carrier, PCC.1

Historical data for this ship were available from 1998. Until the installation of the advanced hull coating in April 2008, the ship had been coated with the traditional, baseline, SPC coating. However, the data set selected to define baseline ship operation was limited to the docking cycle immediately before April 2008, extending from Nov. 2005 to April 2008. This is called "Pre 3". The period following the application of the advanced hull coating, called "Post", extends from May 2008 to Dec. 2010. The data for each interval may be separated into two operating conditions: ballast and loaded. Thus the procedure explained above in terms of Eqs. (A.4) and (A.5) was applied separately for the data in ballast and loaded conditions. The results are shown below.

Table A.1. Adjusted fuel consumption and fuel savings for Pure Car Carrier PCC.1 using Eqs. (A.4) and (A.5).

PCC.1	**Pre-3, 11/2005 – 3/2008**			**Post, 5/2008 - 12/2010**		
	Ballast	Loaded	Combined	Ballast	Loaded	Combined
Average Speed (knots)	18.12	17.81		16.81	16.32	
FC (tonnes/ 24 hours)	39.74	40.07		34.18	33.48	
Adjusted FC (t/24 h)				42.81	43.51	
Savings, %				-7.7%	-8.6%	

A significant decrease in the average fuel consumption was observed in the Post period compared to the Pre period. However, the average speed was also lower in the Post period, and once the Post fuel consumption is adjusted for differences in average speed, the fuel savings indicated are negative for both ballast and loaded conditions.

Ship 2. LNG Carrier, LNG.1

A similar analysis was conducted for this ship, which can also be characterized as operating in either ballast of loaded conditions. The most recent "Pre" data is called "Pre B", and extends from July 2008 to August 2010.

Table A.2. Adjusted fuel consumption and fuel savings for LNG Carrier LNG.1

LNG.1	**Pre-B 7/2008 to 8/2010**			**Post 9/2010 to 6/2011**		
	Ballast	Loaded	Combined	Ballast	Loaded	Combined
Average Speed (knots)	17.22	18.49		19.39	18.48	
FOC (tonnes/ 24 hours)	146.16	171.29		163.12	154.63	
Adjusted FOC (t/24 h)				114.25	154.88	
Savings, %				21.8%	9.6%	

For the second ship, LNG.1, fuel consumption increased for the ballast data set, and decreased in the loaded data set. For the *loaded* condition, the average speed Pre and Post were about the same, the adjusted FC is essentially the same as the measured FC, and a 9.6% savings is determined using the adjusted value. For the ballast condition, average FC increased considerably in the Post period. However once adjusted for change in average ship speed, one obtains a large savings of 21.8%.

Ship 3. Roll-on, Roll-off ferry, Ro-Ro.1

For this type of ship, displacement is relatively constant. Thus, the data set cannot be divided into a loaded and ballast conditions, so consider a single "combined" data set for each of the Pre and Post periods. The results are shown below.

Table A.3. Adjusted fuel consumption and fuel savings for Ro-Ro.1

Ro-Ro.1	Pre, 5/2004 to 6/2007			Post, 6/2007 to 12/2009		
	Ballast	Loaded	Combined	Ballast	Loaded	Combined
Average Speed (knots)			15.29			16.20
FOC (tonnes/ 24 hours)			37.39			35.56
Adjusted FOC (t/24 h)						29.87
Savings, %						20.1%

The actual fuel consumption in the Post period is 4.9% lower. The average speed in the Post was slightly higher than in the Pre period. After adjustment for speed differences using the cubic formula as before, a large fuel savings, 20.1% were observed.

Ship 4. Very Large Crude Carrier, VLCC.1

An oil tanker generally operates only on ballast and loaded modes. Therefore the data set was divided into these categories. The results are shown below

Table A.4. Adjusted fuel consumption and fuel savings for VLCC.1

VLCC.1	Pre 3/2006 to 7/2008			Post 9/2008 to 6/2010		
	Ballast	Loaded	Combined	Ballast	Loaded	Combined
Average Speed (knots)	16.83	15.52		15.93	15.94	
FOC (tonnes/ 24 hours)	98.72	107.20		81.87	102.47	
Adjusted FOC (t/24 h)				96.47	94.57	
Savings, %				2.3%	11.8%	

Average fuel consumption went down in the Post period compared to the Pre period, in both ballast and loaded conditions, whereas average speed (Post) was somewhat lower in the ballast mode, and only slightly higher in the loaded case. Adjusting fuel consumption by the cube of ship speed suggests a 2.3% decrease in fuel consumption in the ballast case and an 11.8% decrease in the loaded case.

Looking at the set of four ships analyzed above, using the adjustment for fuel consumption based on the cube of ship speed, suggest the following conclusions:

1. When the ship speed decreases from Pre to Post period, e.g. PCC.1 (B&L), VLCC (B), % fuel savings are small or negative.
2. When ship speed increases, e.g. LNG.1 (ballast) and Ro-Ro.1 (combined), % fuel savings are large.

3. When ship speed remains the same from Pre to Post period, e.g. LNG.1 (loaded), or change by small amounts, e.g. VLCC.1 loaded, % fuel savings are about 10%, similar to by the manufacturer of advanced coatings, based on detailed measurements.
4. For the same ship, where separate data sets were available for ballast and loaded conditions, but ship speed changed to a different degree from Pre to Post periods, e.g. LNG.1 and VLCC.1, % savings were different for ballast and loaded conditions. In the case of PCC.1, ship speed for ballast and loaded conditions fell by similar % from Pre to Post period, and adjusted fuel consumption increased in both cases, as per conclusion 1 of this list

These conclusions are not reasonable in physical terms. The overall conclusion from this exercise is that, at least in typical operating conditions for these ships, fuel consumption does not appear to scale as the cube of the ship speed.

Therefore a Basic Model is proposed in which fuel consumption rate scales as the n^{th} power of ship speed. This model[7] may be expressed as:

$$FC = a \times V^n \qquad \text{(A.6)}$$

Where:
FC = Total fuel consumption of main and auxiliary engines during a day, tonnes
V = Average daily speed through water of ship (knots)
a = constant
n = constant

As noted at the start, this Appendix is a record of the model development process followed during the version 1 of this methodology. The notation in Eq. (A.6), and later equations based on this, is different from that used in the main body of current version of the methodology (Version 2.0). However, the parameters in this Appendix are all defined explicitly and used in a consistent manner throughout the Appendix.

The criteria used to determine the validity of this model (and other models tested in the process leading up to the identification of Basic Model indicated above) comprised the following components:

a) *The model chosen should be statistically valid*. For instance, when a linear regression model is used, the residuals should be independent, should have a mean of zero and constant variance, and normally distributed. A good fit should yield a small standard error, i.e. the actual data would be close to the best-fit line or curve. In all cases, the regression is valid for the range of the independent variable, i.e. ship speed. Over this range, the coefficients estimated by regression analysis may be used to estimate fuel consumption as a function of ship speed.
b) The fuel consumption values estimated using the regression model should be *consistent*, e.g. the consumption should be higher for the ship in a loaded condition versus the same ship in the ballast condition. The ship should use less fuel with the advanced hull coating. However, in order not to assume this outcome, and allow for the situation that the advanced hull coating does not improve performance, this is not a criterion for consistency check. Instead a reasonable check is applied, see below.
c) The estimates are considered to be *reasonable* if, applying them in order to compare project and baseline fuel consumption you get similar % savings values for the same ship in different operating conditions, e.g. ballast and loaded. It is unreasonable if the model indicates that the advanced hull coating reduces fuel consumption in the ballast mode and increases fuel consumption, when loaded, or vice versa. Moreover, the % savings in ballast and loaded modes

should be similar. For instance it is not reasonable for a ship to save, say 2% in the ballast mode and 22% in the loaded mode. The reasonableness condition can also be applied in comparing different ships, though here more variation from ship to ship may be expected. Nevertheless it would be unreasonable if the model shows large savings for one ship and small or negative savings for others. Note that this criterion does not assume that the advanced hull coating in fact saves fuel. The estimates would also be statistically reasonable if there were little or no savings for all ships, and indeed if fuel consumption went up by comparable % values for each ship.

d) Finally, the simplest possible model was chosen, one where fuel consumption is explained to the same accuracy with the fewest number of explanatory variables. This is an *Occam's razor* condition.

In each case the model was validated using historical data for a number of ships of different categories. Where available, the data covered one or more "Pre-" periods (i.e. with the hull coating with the baseline coating) as well as periods following the application of advanced hull coatings, for ships where such a data set was available. The latter analysis was mainly to test the validity of the regression model. The estimates would have no value in the methodology which applies regression analysis only to historical ('Pre") data (i.e. before the application of the advanced hull coating) in order to obtain coefficients that are applied to daily data for the Post period.

The regression would be conducted with daily data: total fuel consumption during the day and average daily speed for that day. Note that the data set would be divided into Ballast and Loaded subsets prior to data analysis.

Eq. (A.6) is a non-linear relationship between FC and V. Taking natural logs of both sides of Eq. (A.6), we have:

$$\ln (FC) = \ln (a) + n \ln (V) \qquad (A.7)$$

With daily average data for FC and V, corresponding to the Pre-period, a regression of **ln (FC)** versus **ln (V)** would give 'n' as a slope and 'ln (a)' as intercept. The regression yields an estimate of 'n' directly while the value of 'a' can be calculated from the estimate of 'ln (a)'.

In order to apply the regression analysis, Eq. (A.7) needs to be reformulated as follows:

$$\ln (FC) = \ln (a) + n \ln (V) + e \qquad (A.8)$$

The error term (e) in the regression equation represents the departure of actual data from the regression fit, and uncertainty in the estimate of fuel savings using the regression. Below it is discussed how these uncertainties may be reduced through data filtering.

The error term (e) arises through factors that affect daily fuel consumption other than daily average ship speed.

The error term appears as "residuals" in the regression analysis. As noted above, and as pointed out by a reviewer of the initial submission of this methodology:

"*A linear regression model states explicitly the following **assumptions about the residuals**:*

- *they are independent;*
- *they have a mean of 0 (if not, then model is biased) and constant variance;*
- *they are normally distributed.*

If these assumptions hold, the linear regression model is a ***valid statistical model*** *and inferences ("t-value") can be based on it and goodness of fit criteria can be computed ("R^2"). If these assumptions do not hold, the linear regression model is not a valid statistical model and should not be used, as this may lead to serious deficiencies in the estimation of n and in the related interpretations.*"

Therefore, in the analysis that follows, the residuals of the regression analysis are examined, before the estimates obtained from the regression analysis are presented.

Data filtering

Any statistical analysis suffers from certain dangers. The most common are outliers that can seriously affect the results. While certain so-called "robust" statistical techniques reduce the impact of outliers[8], most traditional procedures, e.g. multiple linear regression, do not. Thus a certain amount of data filtering is needed prior to conducting the regression analysis. This is described in the section below.

One way of possibly reducing outliers and improving the estimation of the coefficients is to eliminate stormy days from the regression analysis. On such days, the ship faces unusual forces from wind and wave, and the relationship with ship speed (which basically determines hull resistance) may not hold. The analysis that follows, and the proposed methodology, limits data to days with Beaufort Scale (wind force) ≤ 6. All days with wind force of 6 or more are removed and not included in the regression analysis. This is to examine the performance of the vessel under normal commercial operating parameters. The Beaufort Scale is explained in Appendix B.

Another factor of relevance is that fuel consumption is different during port manoeuvring, engine start-up and shallow water effects. These can be eliminated by another data filter. Data corresponding to days in which voyaging time was below 23 hours on the day are excluded from the regression analysis. Again, the same filter would be applied to the Post period, so the results are conservative.

By excluding stormy days (wind force 6 or above) and days that are less than 23 hours, the accuracy of the regression coefficients is expected to improve. However, they also limit the validity of the model to the days allowed by the filter. Therefore, the same filter conditions must be applied to exclude days in the Post period. Such days are excluded from the analysis, and any fuel savings on these days are counted in determining overall fuel savings in the Post period. Thus, this filtering condition is conservative in estimating fuel savings and emissions reduction from the project activity.

Finally, there may be data entry errors in the ship's log. Some of these errors can be detected by simple visual inspection and the corresponding days can be eliminated from the regression analysis. For instance, even after applying the previous filter and consider only full day's sailing, if either fuel consumption or average speed are found to be zero, the data for that day are eliminated. One of the data parameters recorded in the ship's log is the hours per day of sailing. This is the parameter used to screen out days with less than 23 hours of sailing. If it is found that the record indicates a value much greater than 24 hours, then again the day are eliminated. Since this level of filtering is to be done manually, as described in the monitoring procedure described in the methodology, it is easy to see if the anomaly can be explained or adjusted for. For instance, if the data for a given day was recorded an hour later than usual, one day might be 25 hours long while the next was 23 hours long. This is not an error and does not justify either day to be eliminated. Again, one may find that the number of hours recorded is 240 and that the average speed calculated for that day is a tenth of the value on other days. In this case, clearly the error was the extra zero, and that eliminating it corrects both the day length and the average speed.

[8] See, e.g. Tukey, John W (1977). *Exploratory Data Analysis*. Addison-Wesley.

There may be major data outliers that affect the regression analysis, but are not easy to detect by visual inspection. Therefore it is recommended that an initial step in data analysis would be to plot fuel consumption against ship speed, since the latter is the most important factor determining fuel consumption. Such graphs may indicate outliers that need consideration and may need to be eliminated. For instance, in the course of analysis, it was found that on most days, a ship (PCC.1, Data set: Pre 3L) consumed over 35 tonnes of fuel, whereas on one day it consumed only 19. It was noticed that the single outlier appeared to have a major impact on the regression. Therefore this outlier was noted and removed, prior to further analysis.

Another ship (Bulk.1, Data set Pre L) only travelled 100 nautical miles on one day in the data interval, while a typical day's journey covered about 300 n. miles. Since this represents some sort of special circumstances (wind force of 6, swells of 6 m), or perhaps a data entry error, one could remove this data point from the regression analysis. Without this data point, the residuals were independent of ship speed over the entire range of speeds remaining. Thus the model improved.

Note that in the two examples quoted in the previous two paragraphs, only a single data point was removed in each case.

An objective test that would have removed the above outliers is as follows. Determine the average (Vav) and standard deviation (s) of the daily ship speed over the data set in question. If the recorded value of speed is outside the range (Vav - 3s, Vav + 3s), then the day may be eliminated. In both cases, the average speed recorded for the "outlier" day was below the lower limit.

A similar objective test can be based on daily fuel consumption data. In this case, since the standard deviation tends to be a larger proportion of average (higher coefficient of variation), a narrower range is proposed, going from two standard deviations below to two standard deviations above the average. If the recorded fuel consumption on a given day is outside this range the day can be eliminated from the regression analysis.

Even if the above tests are applied, fuel consumption versus speed should be graphed, before and after removing outliers.

This procedure is not intended to remove "inconvenient" points merely to improve the regression analysis, since this would certainly distort the results. It is therefore important to record the exact date(s) for which outliers were removed and why, so that the procedure is transparent and can be verified prior to the issuance of carbon credits.

While removing specific anomalous data as in the two ships mentioned above improve the regression model, there is no *exact* equivalent in the Post period since no regression is involved, and indeed baseline fuel consumption is estimated on a day-to-day basis without looking at long series of data that would allow the identification of outliers. However, carbon credits would be based on monitoring reports covering extended time periods, e.g. a year, so that it is viable to graph fuel consumption and speed over the entire monitoring interval in order to identify and exclude specific data points. Once again it is important to limit data removal to one or two points, and keep complete records, as in the Pre data set.

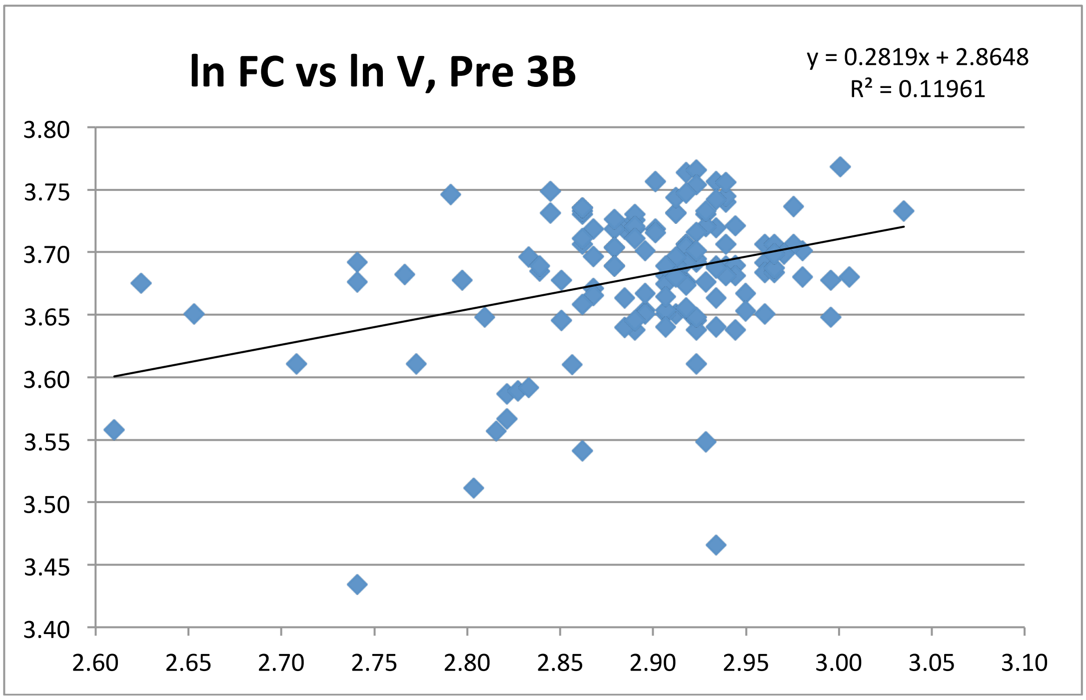
The results of the analysis for the four ships mentioned above are given below.

Ship 1. Pure Car Carrier, PCC.1

The regression undertaken with the "ballast" subset of the "Pre 3" set, immediately prior to the application of the advanced hull coating was considered.

Data set: Pre 3B

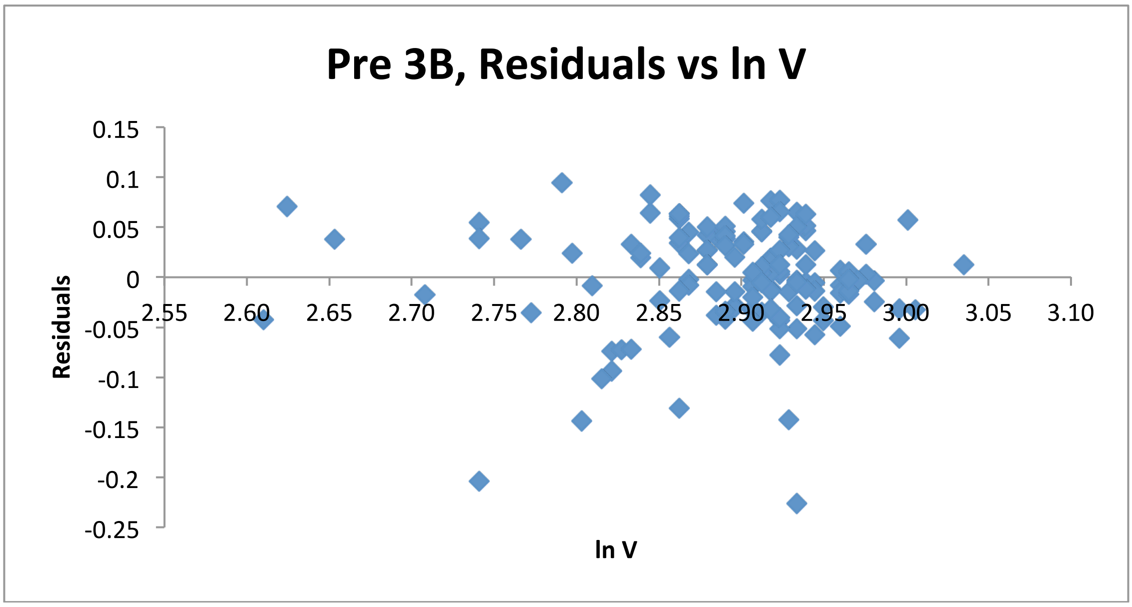
First, the dependent variable (ln FC) are plotted against the independent variable (ln V).



Note the expanded scale on both axis, indicating that the ship operates over a relatively narrow range of speed and corresponding fuel consumption. No unusual outliers are noted, so no data points were excluded from the analysis.

The figure above shows a trend line and the coefficients of a linear regression similar to Eq. (A.7). These are common accessories to the plotting functions of Excel. However, detailed statistics are not provided in this process, so the coefficients in the equation are indicative.

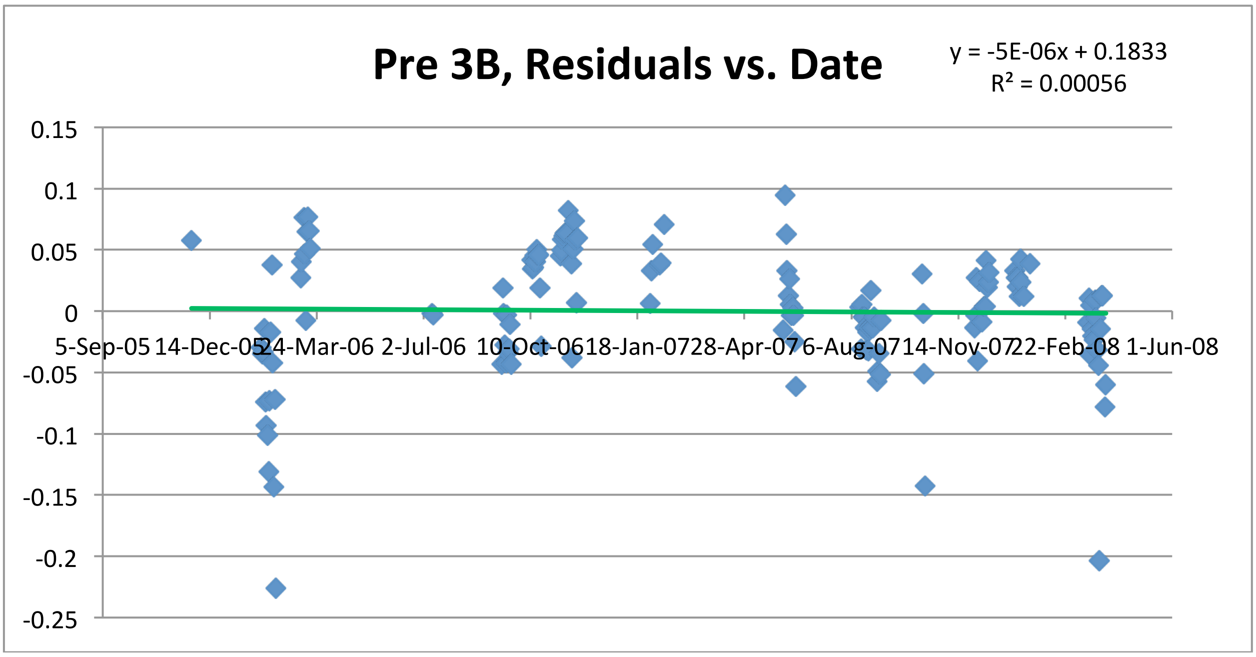
The first set of residuals drawn is to plot them against the independent variable "ln V", as shown below.



The residuals appear to be symmetrically distributed above and below zero over the whole range of ln V, indicating that the model used appears to capture the relationship between FC and V.

The scatter of residuals above and below zero could be the result of factors other than ship speed that determine fuel consumption, as well as errors in instruments, data entry, etc.

One possibility is that the ship performance in general, and hull resistance in particular, degrades over time, so that one would expect fuel consumption to increase over time. In that case the residuals would be expected to slowly increase over time. To explore this, the residuals were plotted against date over the entire 3-year Pre 3 period.



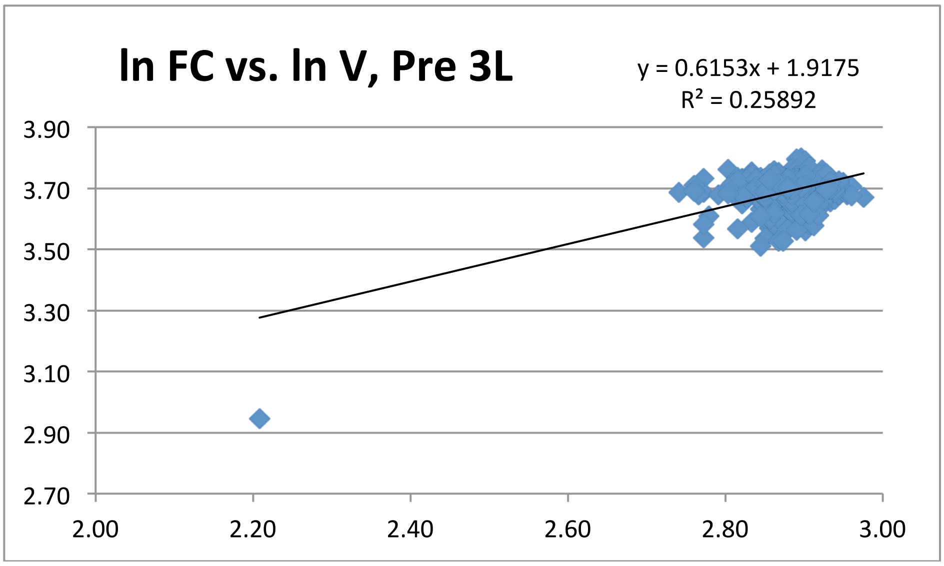
Gaps in the Date correspond to days in which the ship was operating in the other mode (Loaded), as well as a few days filtered out for reasons explained earlier.

Once again, Excel provides a trend line, shown in green in an attempt to distinguish it from the x-axis. The trend line appears to coincide with the x-axis, showing no overall change in performance over the years.

While there is no long-term trend, patterns in the residuals over short intervals, specifically consecutive days were noticed. These patterns are seen for all ships analyzed, and are commented later.

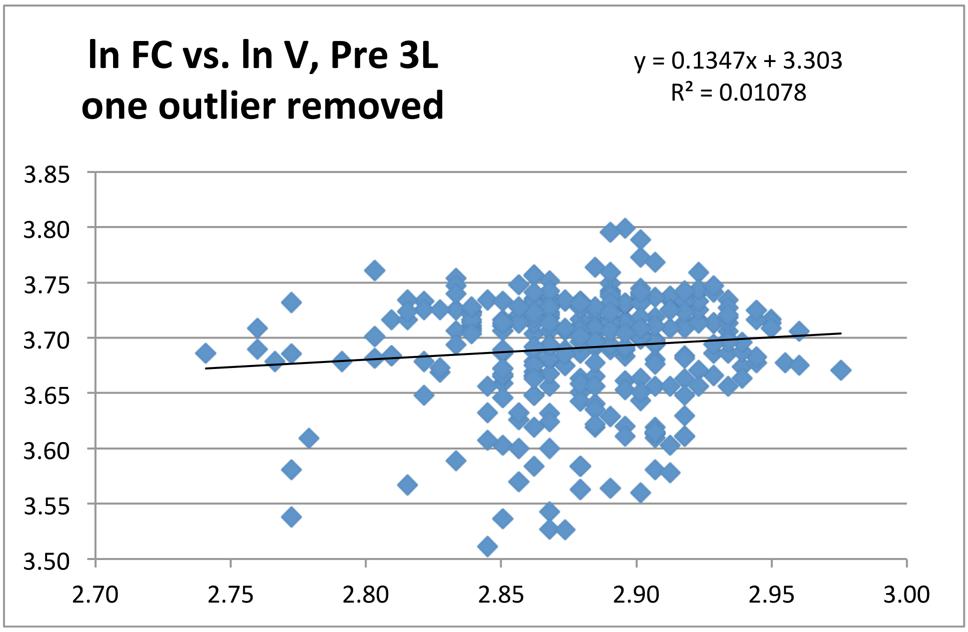
Ship 1. Pure Car Carrier, PCC.1
Data set: Pre 3L

Now the loaded (L) subset of the same "Pre 3" period, for the same ship. A graph of ln FC versus ln V is shown below.

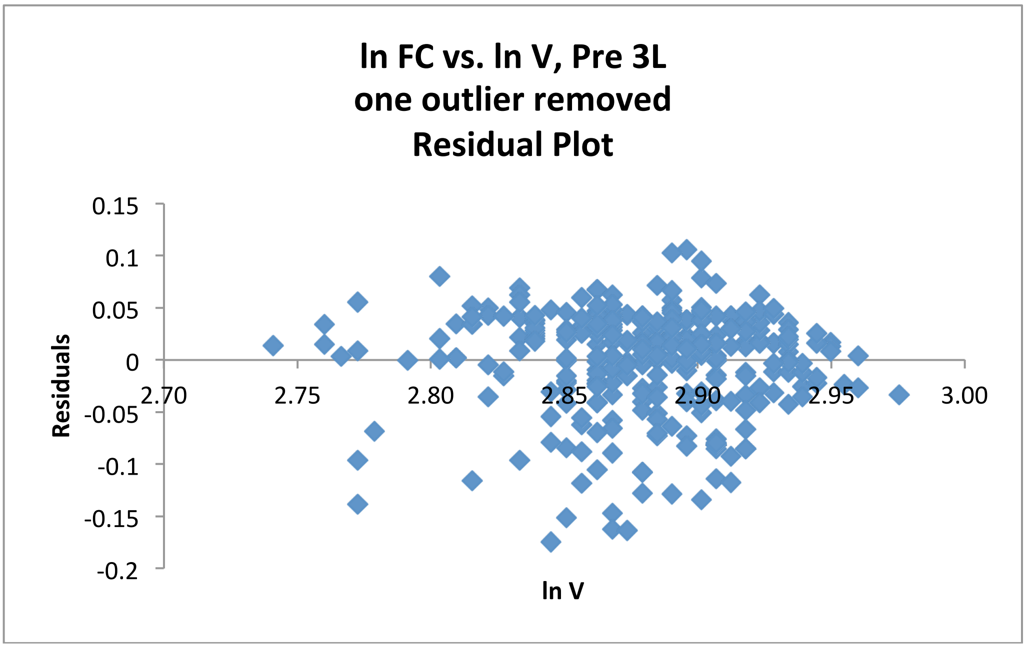


The figure shows a major outlier. While on most days, the ship consumed over 35 tonnes of fuel oil, on this day it consumed only 19. It is in fact far from the range of the remainder of the FC and V values. Thus, not only is it a major outlier, it is a high-leverage point in the sense that a least-square fit would give considerable weight to this single data point. This outlier can also be detected by considering the range (average speed +/- 3 standard deviation).

Therefore, this outlier was noted (October 1, 2007), eliminated from the data set and continued with the analysis.

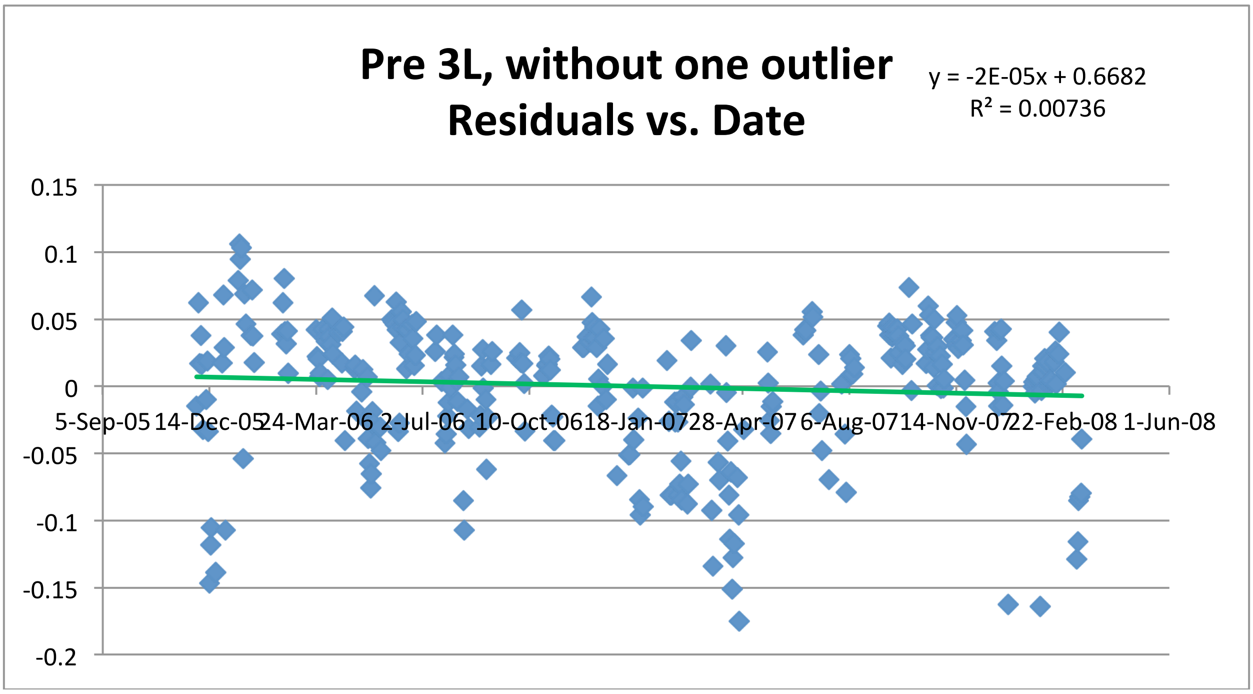


The figure, above, is drawn with a much narrower range of values on both axes, compared to the original one.



The residuals are not distorted with respect to variations in ln V. However, the points above zero appear to be of a smaller magnitude compared to the points below. One possible interpretation is that the upper limit of fuel consumption is limited by the engines operating at maximum power over the entire period. Notice that over the entire range of ln V, there are ln FC values in the 3.75 to 3.80 range. However, the residuals appear not to be normally distributed around zero, so that some distortion exists.

Residuals against date were plotted to see long and short term time trends, below.

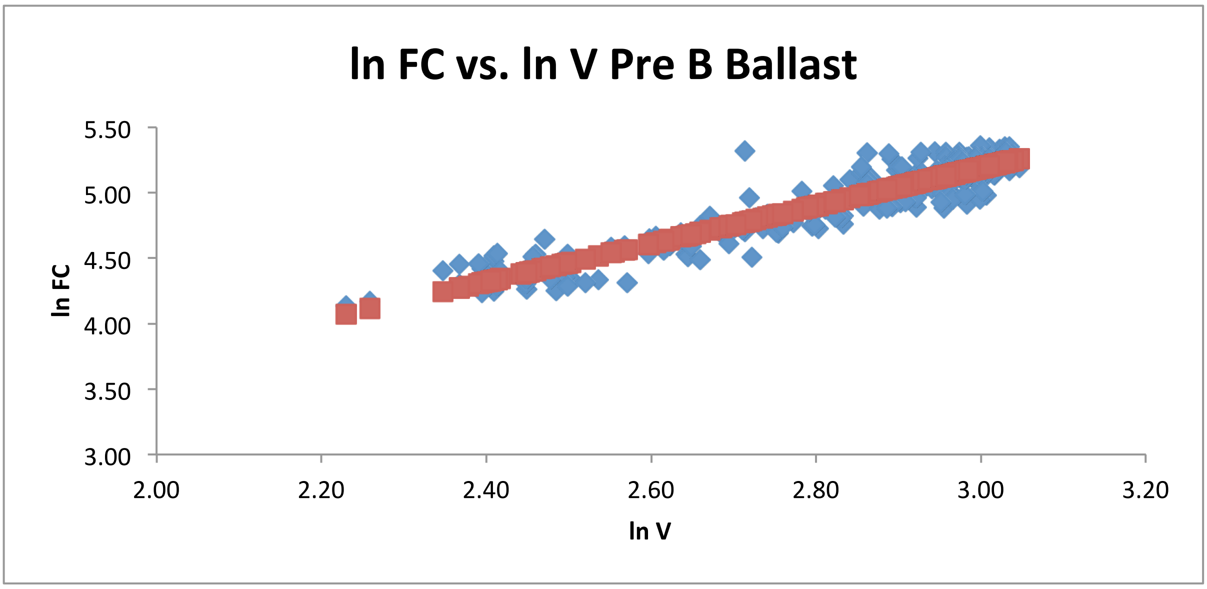


Once again, the trend line (green) practically coincides with the x-axis, as in the Ballast data subset. And, as noted before, there are strong short term trends in the residuals.

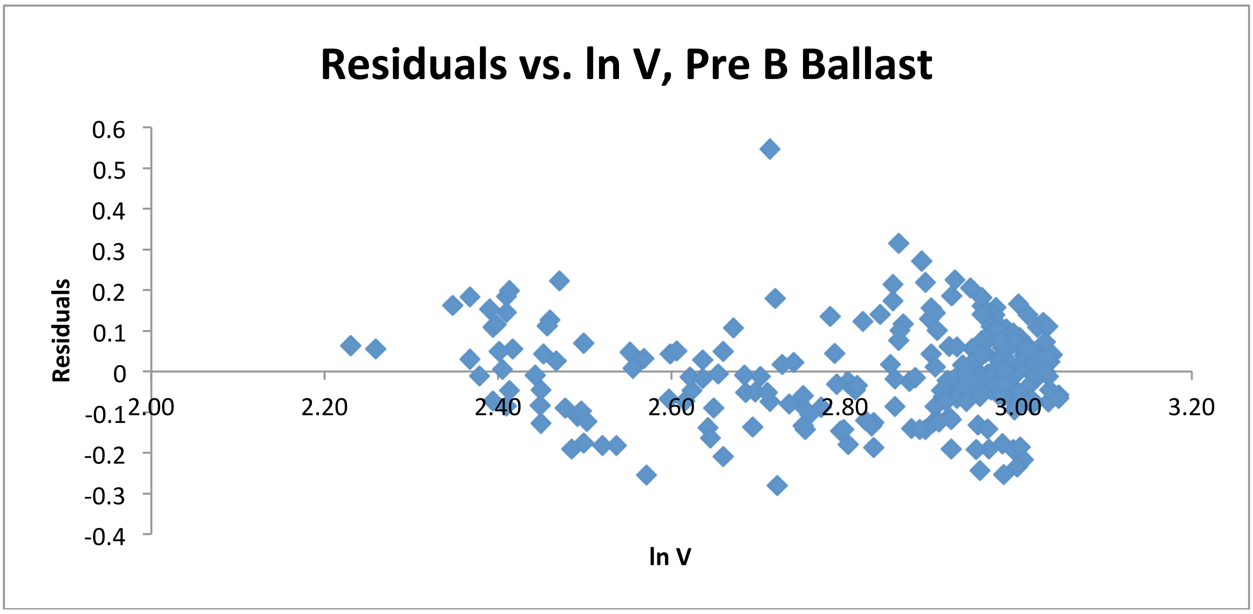
Ship 2. LNG Carrier, LNG.1

Data Set: Pre-B Ballast. (Note that "Pre-B" is the data set for one docking cycle, following "Pre-A". The "B" here does not mean "ballast". Hence "ballast" is spelt out in full, to avoid confusion.)

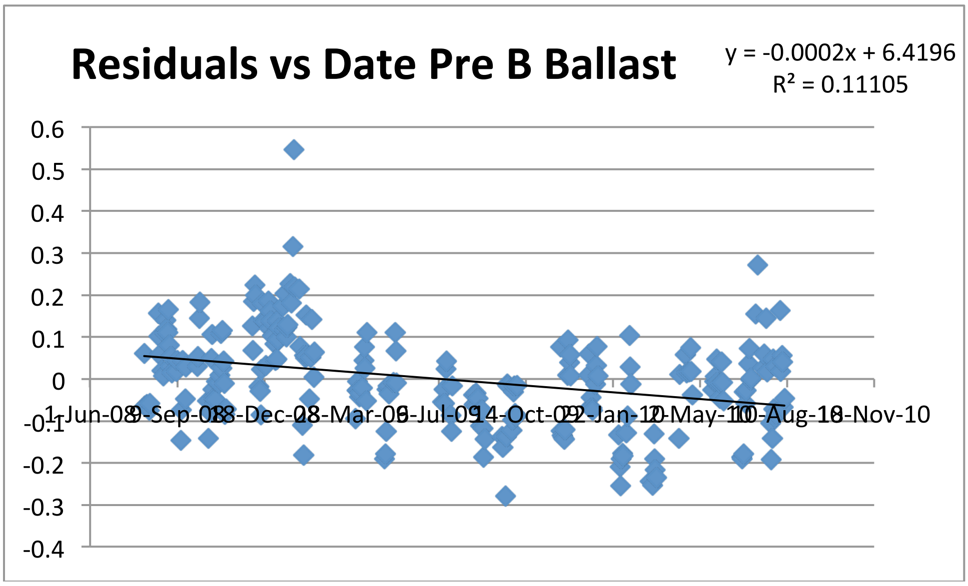
A plot of ln FC vs. Ln V for this data subset is shown below.



There are no major no outliers. The red dots are values "predicted" by the regression coefficients for each value of ln V in the data set. The line joining these dots would be the regression trend line.



The residuals show no apparent relation to ln V. Moreover, they appear to be symmetrically distributed above and below the x axis, indicating the absence of any pattern.



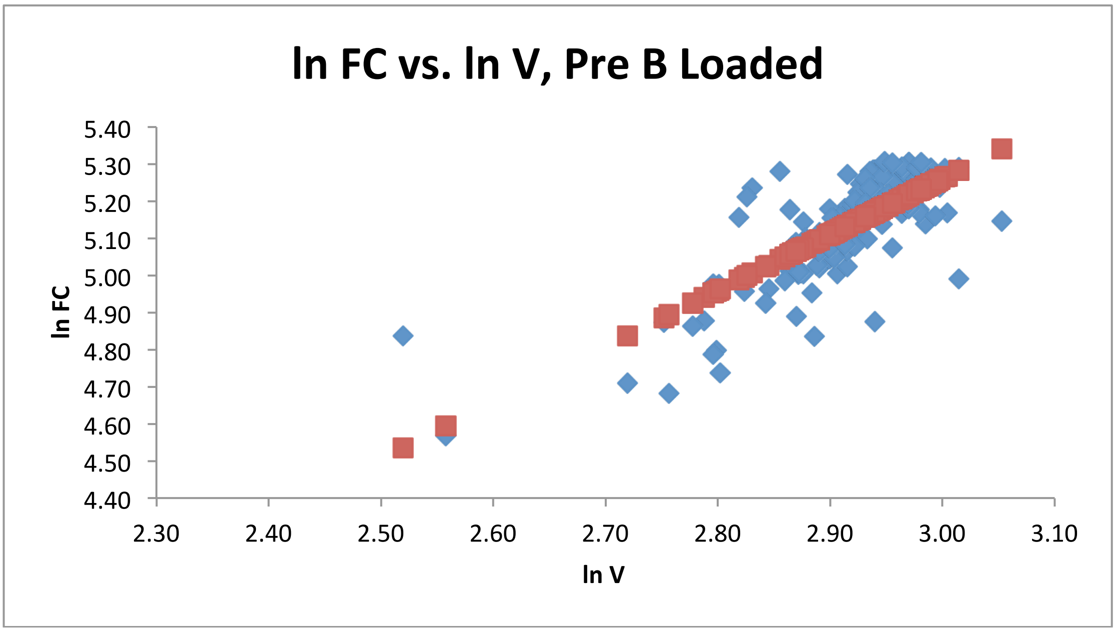
In this case, the long-term trend line has a small negative slope, suggesting that fuel consumption decreased over time. There is no physical basis for a negative slope. Any specific energy saving measure would lead to an abrupt reduction in fuel use following the date of the measure. No such pattern can be seen in the data.

Once again, there are short-term trend, of successive days, not explained.

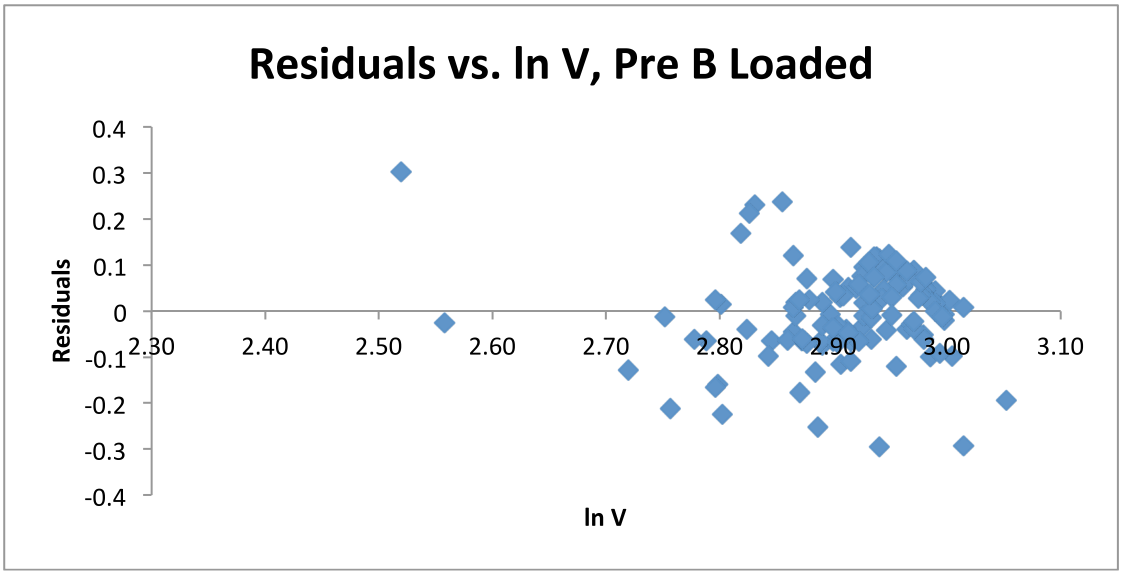
Ship 2. LNG Carrier, LNG.1

Data Set: Pre-B Loaded.

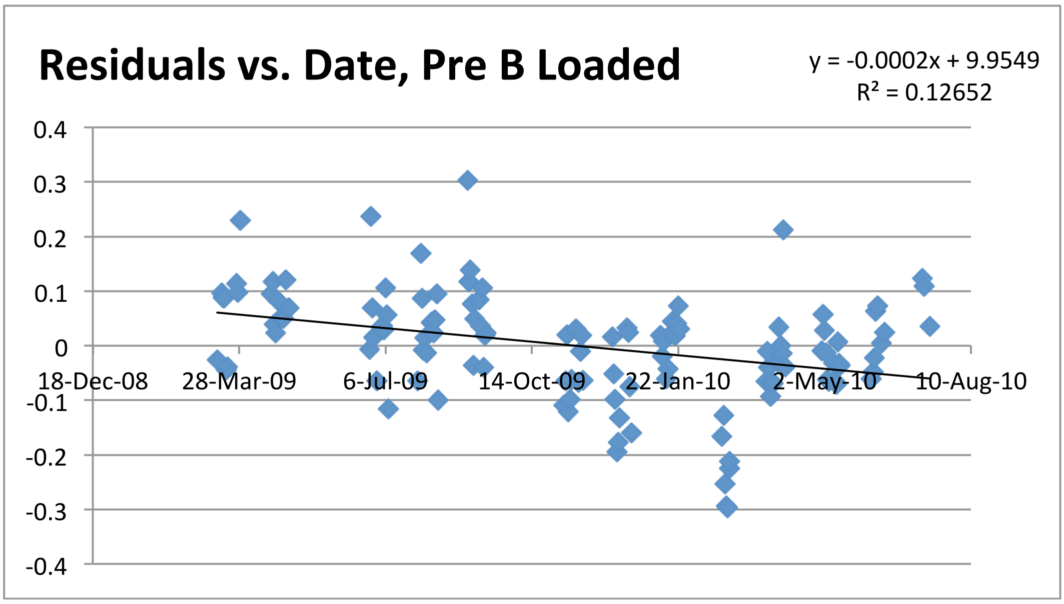
The corresponding figures for the "Loaded" subset of "Pre B" are shown below.



There are two data points for lower ln V compared to the rest. However, they are not removed from the analysis.



Residuals as a function of ln V show no pattern, though the dispersion in the negative values appears to be slightly higher.



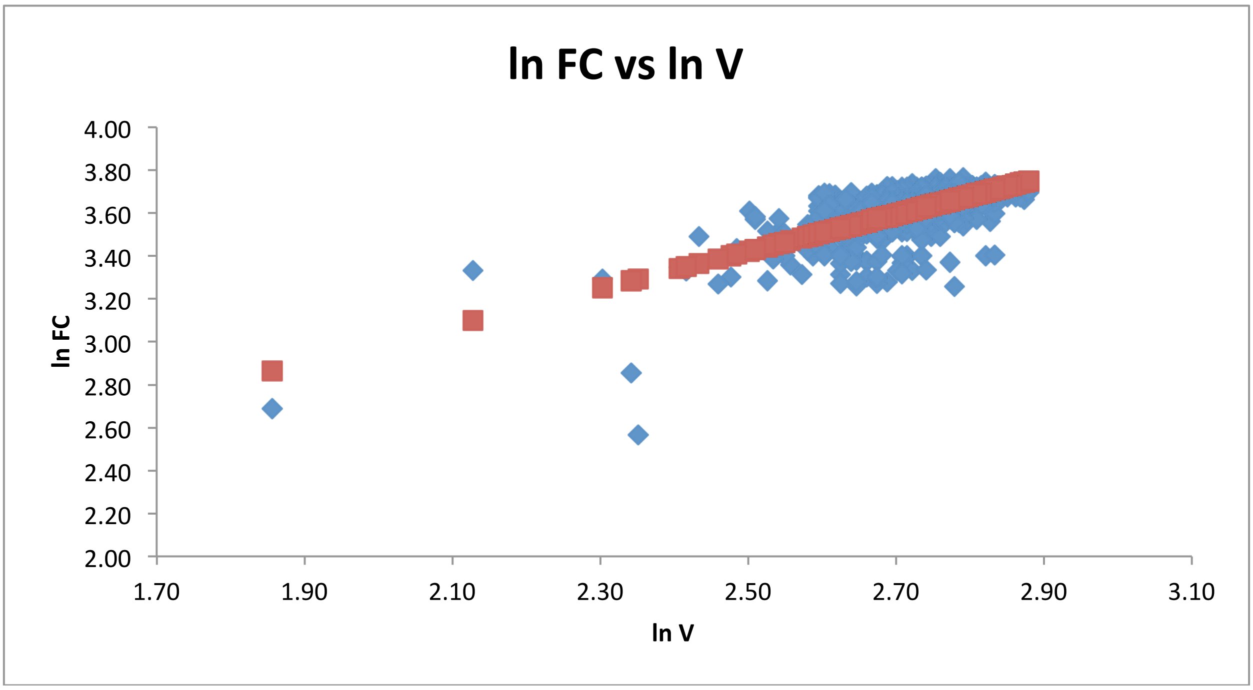
Residuals against date show a downward trend over time, as in the "Ballast" subset, with no apparent explanation.

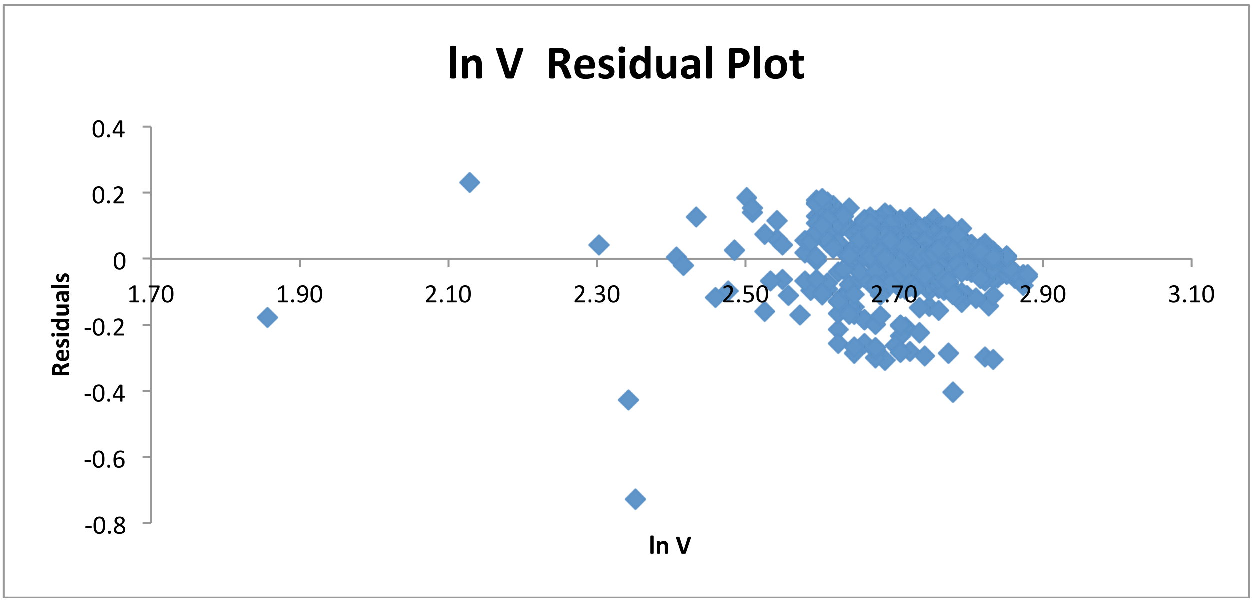
Short-term trends are strong, as before.

Ship 3. Roll-on, Roll-off ferry, Ro-Ro.1

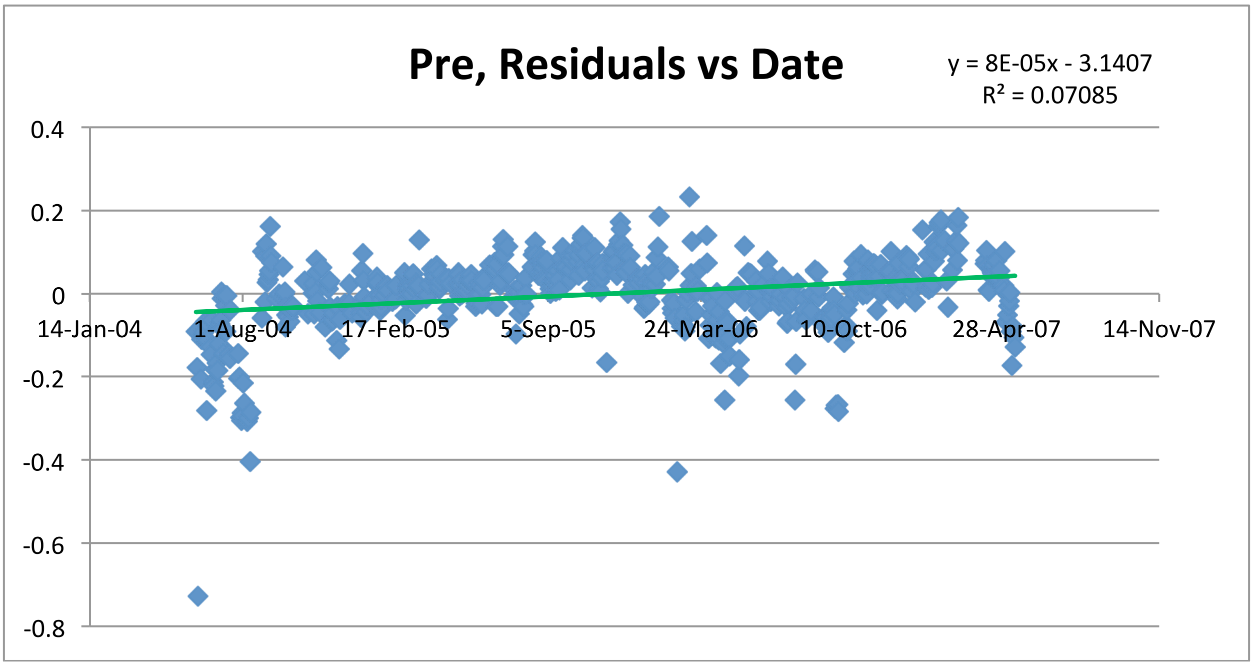
Data set: Pre.

This type of ship does not have separate loaded and ballast operation, so there are no subsets to the "Pre" data set. Hence a single set of Pre data are analyzed and shown below.





Residuals show no patterns as a function of ln V.

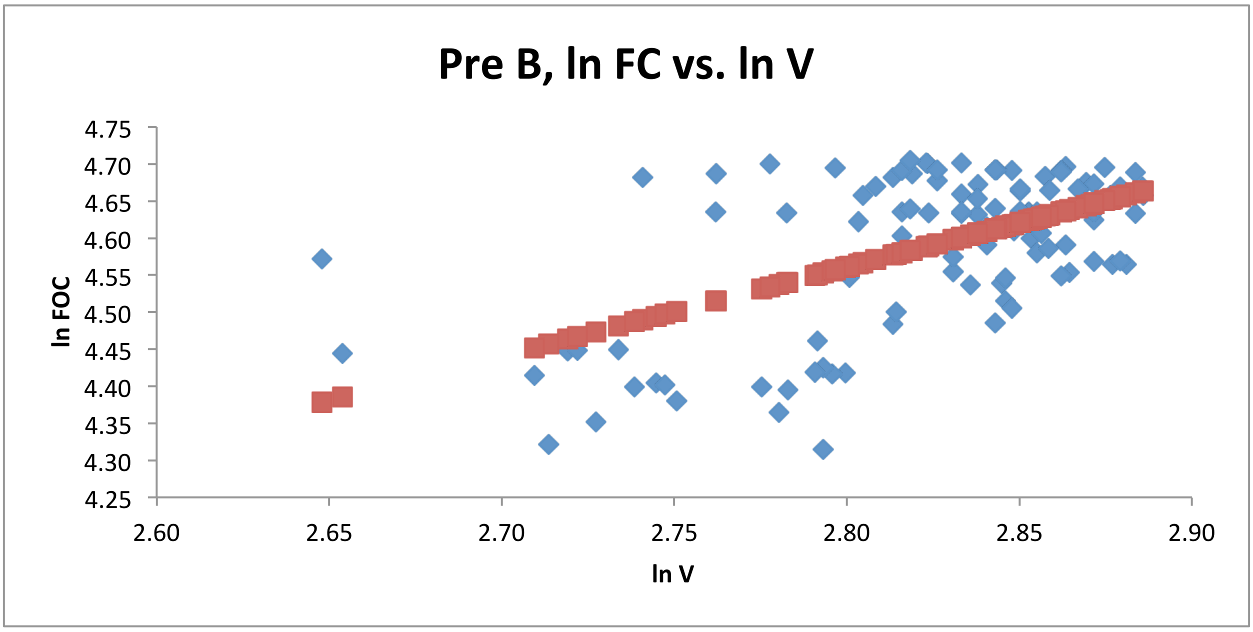


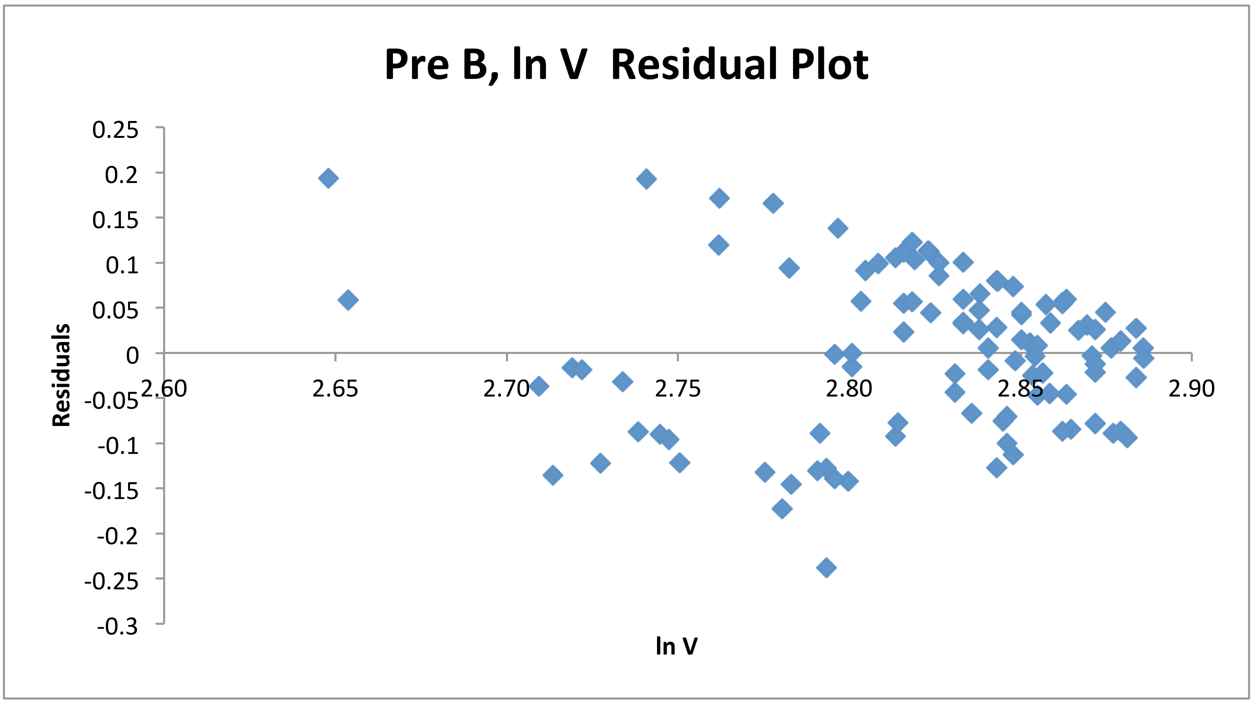
Residuals versus Date show a slight increasing trend over the years, as indicated by the green trend line. Looking closer, there may have been a decrease in early 2006, with increasing trend lines before and after.

Ship 4. Very Large Crude Carrier, VLCC.1

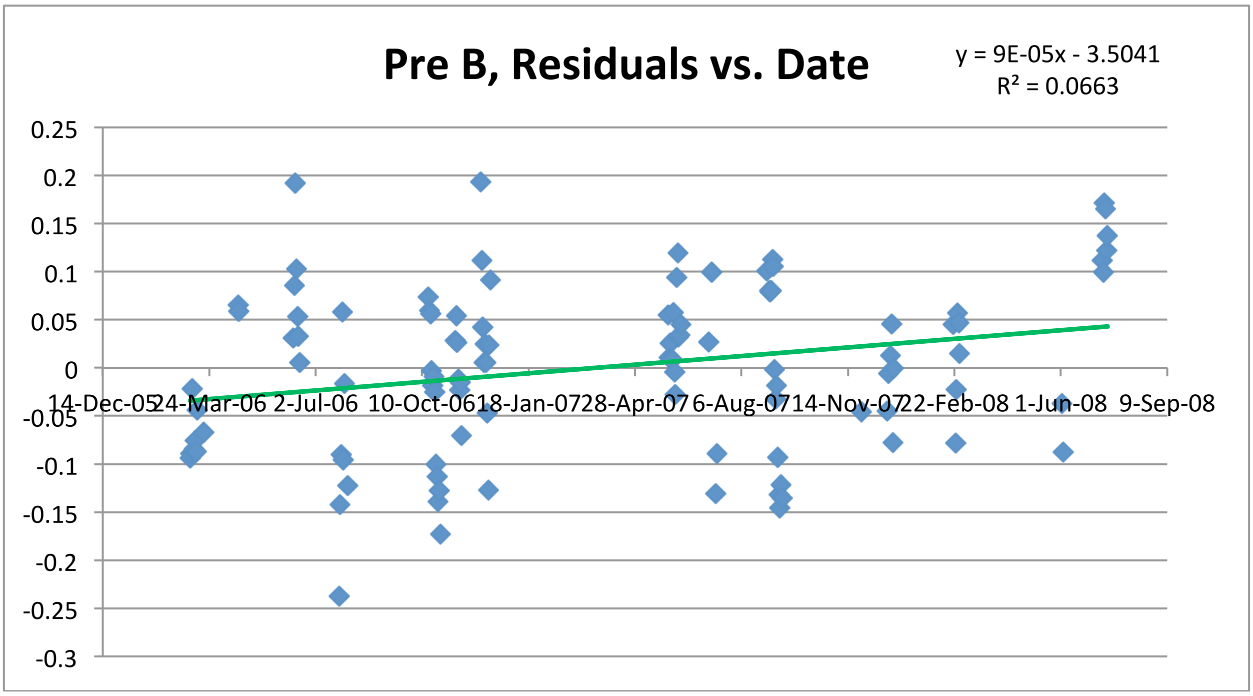
The "Pre" data set is divided into "Pre B" (ballast) and "Pre L" (loaded) subsets, and analyzed in turn below.

Data set: Pre B



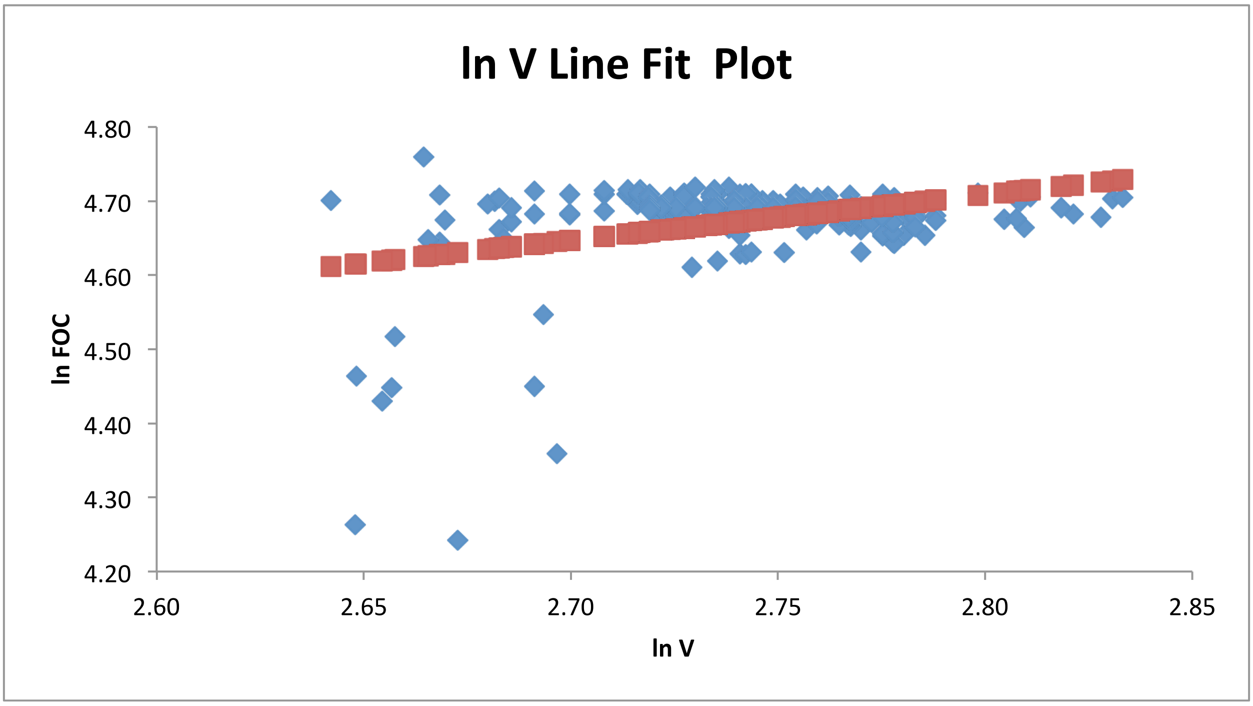


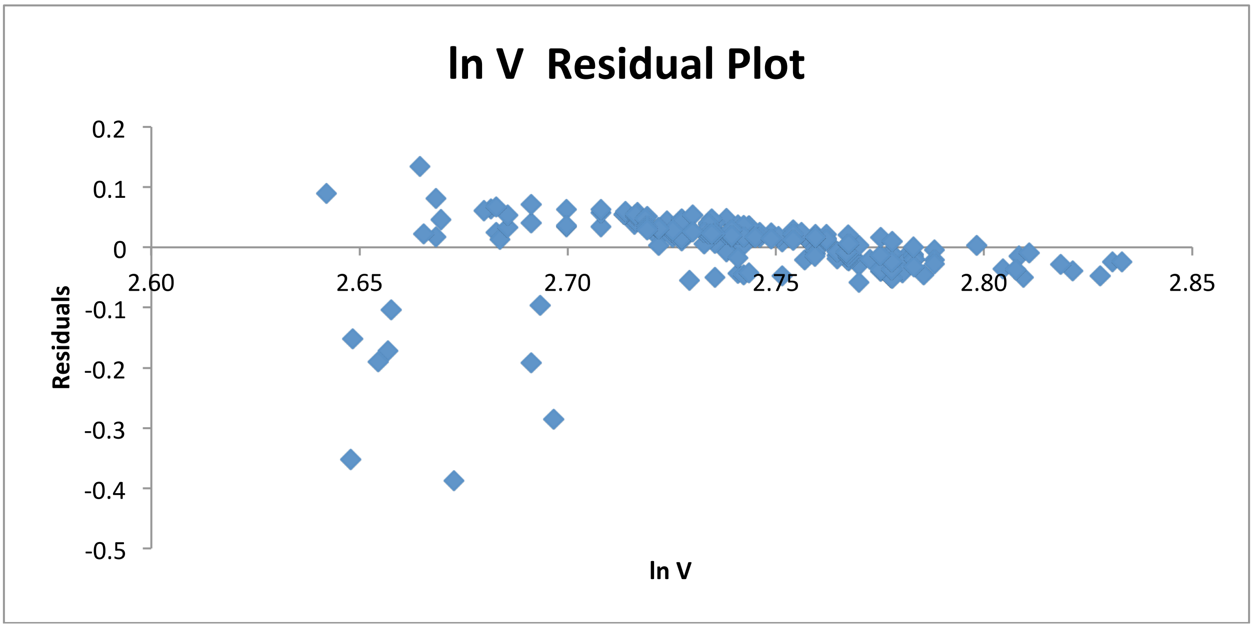
While the residuals are evenly balanced around zero, there is a pattern indicating negative values in the range of ln V from about 2.7 to 2.75, with more positive values to the right.

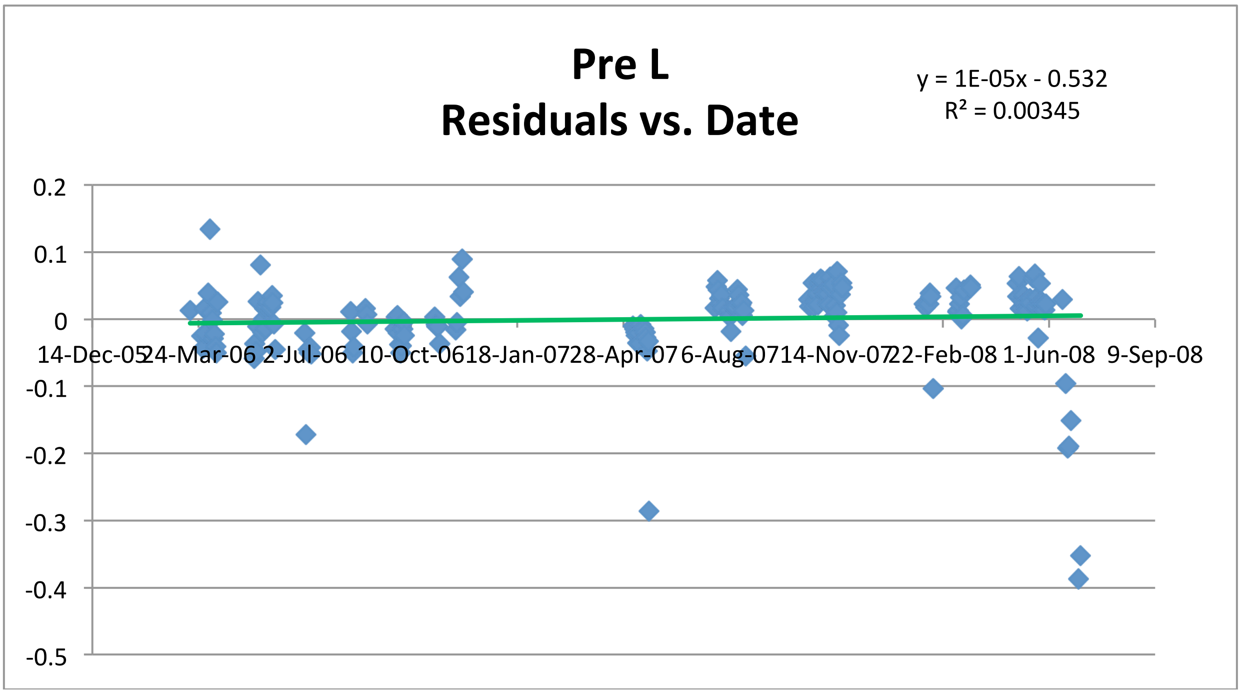


The residuals show a slowly increasing long term trend, with trend line shown in green.

Ship 4. Very Large Crude Carrier, VLCC.1
Data set: Pre L







The long term trend line (green) coincides with the horizontal axis. However, there are a number of negative points at the right which appears to be masking a small increasing trend. Note that the Pre B subset showed an increasing trend over time.

Note on long term and short-term trends

For the ships analyzed, including the four for which results are presented above, long-term trends in the Pre data are small, if they exist at all. In some cases, the trend in residuals is increasing slightly over time, which is physically reasonable in the sense of deterioration of ship performance over time. In other cases, the residuals are gradually decreasing over time, which does not have any obvious physical explanations. An abrupt reduction in residuals would suggest an energy efficiency improvement, but this is suggested only in one of the data subsets analyzed (Ro-Ro.1). Given that these long term trends may exist, the Pre period for determining the regression coefficients should be as long as possible, preferably covering the entire docking cycle prior to the application of the advanced hull coating. Any trend is likely to cause distortions in estimates of fuel savings if short periods of Post data are considered. However, over the entire docking cycle corresponding to the Post period, which is also the crediting period proposed in this methodology, there would be no net effect of any long term trend on estimates of fuel savings and emissions reduction.

Strong short term trends were noted in all ships, often covering a set of consecutive days. These trends reduce the ability to predict fuel savings accurately for any given day in the Post period. However, the purpose of the model is not to predict day-by-day variations in fuel consumption or savings, but savings over extended periods of time in the Post period. Therefore, while the methodology proposes the model as a Basic Model, and invite project developers to improve predictability with more elaborate models, it is important to note that short term trends do not affect fuel savings, since they would cancel out over the medium term.

In general, the analysis of residuals presented above appears to support the model. The coefficients estimated by the regression analysis, for each of these ships are discussed below.

Ship 1. Pure Car Carrier, PCC.1

Pre-3 Ballast

Adjusted R Square	0.113
Standard error	0.052

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	2.865	0.188	15.251	1.78E-31
ln V	0.282	0.065	4.346	2.66E-05

Pre 3 Loaded

Adjusted R Square	0.0076
Standard Error	0.050

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	3.303	0.211	15.662	3.63E-41
ln V	0.135	0.073	1.841	0.0666

Ship 2. LNG Carrier, LNG.1

Pre-B Ballast

Adjusted R Square	0.846
Standard Error	0.114

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.662	0.117	5.636	4.86E-08
ln V	1.511	0.041	36.464	7.53E-100

Pre-B Loaded

Adjusted R Square	0.594
Standard Error	0.098

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.733	0.323	2.268	0.0251
ln V	1.509	0.111	13.617	1.87E-26

Ship 3. Roll-on, Roll-off ferry, Ro-Ro.1

Data set: Pre.

Adjusted R Square	0.433
Standard Error	0.092

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1.260	0.110	11.452	1.36E-27
ln V	0.865	0.040	21.412	6.22E-76

Ship 4. Very Large Crude Carrier, VLCC.1

Pre Ballast

Adjusted R Square	0.317
Standard Error	0.086

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1.202	0.480	2.501	0.01395
ln V	1.200	0.170	7.047	2.06E-10

Pre Loaded

Adjusted R Square	0.115
Standard Error	0.063

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	2.988	0.342	8.744	1.66E-15
ln V	0.614	0.125	4.931	1.87E-06

By looking at all the regression results, the following observations are made:

1. Some of the R^2 values are quite low, e.g. for PCC.1, the values are 0.113 and 0.0076, for ballast and loaded conditions, respectively. Yet for these two cases, the standard errors (residuals) are the lowest. A low R^2 represents a weak dependence on ln V, which is confirmed by the fact that the coefficients of the ln V term are very low, 0.282 and 0.135 respectively. Yet the residuals around the best fit line are the smallest for this ship. At the other extreme is the ballast case of LNG.1 with a relatively high adjusted R^2 of 0.846. Yet the standard error is about twice as large, 0.114. The standard error is a better determination of the accuracy of the model prediction.
2. All the coefficients for the ln V term are considerably below 3. Recall that if fuel consumption scaled as the cube of ship speed, this value would be 3. The values range from 0.113 for PCC.1 (Loaded) to 1.51 for LNG.1 (both cases). This confirms the finding that a cubic dependence appeared not to be correct. A low value of the coefficient does not mean that hydrodynamic theory is erroneous, but merely that over the relatively narrow range of speeds where these ships operate, the relationship does not appear to be cubic.
3. The accuracy of estimate of the individual coefficients (both the intercept and slope of the regression line) are given by the standard errors shown next to each estimation. Since the standard error and the coefficient itself have the same dimension, a non dimensional indicator of the accuracy of the estimate is the ratio coefficient/standard error, called t-stat, where a *high* t-stat indicates that the coefficient is well determined. Another indicator is the p-value where a *small*

value indicates more accuracy.[9] The t-values vary from 1.84 (PCC.1 Loaded) to 36.46 (LNG.1 Ballast). In the first case, the coefficient is not well determined, while in the latter case it is very well defined.

4. The coefficients vary substantially from one case to another. The poor determination is in part since there are two explanatory variables, and the data are clustered far from the origin. Thus a line with a high slope and small intercept and another with a low slope and high intercept could go through the data cluster equally well, especially when the data points are close together and far from the origin. The latter is to be expected since a ship in full voyage is not likely to vary its speed a great deal.

In synthesis, the analysis suggests that the regressions appear to be reasonable in terms of the standard error of the residuals. Moreover, despite the range of estimates of slope and intercept the regression may be expected to provide reasonable estimates for data within the cluster. This may be confirmed by applying this model to estimate fuel savings, as explained below.

It is important to note that the regression coefficients were obtained over relatively small ranges of values of speed (as independent variable). The coefficients are not expected to be valid outside this range. Hence applying these coefficients to estimate fuel consumption outside the range of speeds can lead to erroneous results, as seen below.

Using the regression coefficients to estimate fuel savings

The regression coefficients allow an estimation of the two parameters, 'n' and 'a' as defined in Eq. (A.6).

Once 'n' and 'a' are available from the Pre-period, a baseline fuel consumption for the ship for a given Post period can be determined by the following equation:

$$BFC = a \times V^n \qquad \text{(A.9)}$$

A % fuel savings is given by:

$$\% \, FS = \frac{BFC - FC}{BFC} \times 100 \qquad \text{(A.10)}$$

Where FC is the actual fuel consumption in the Post period.

The calculation can be undertaken in two ways, (i) adjusting average data on fuel consumption rate for the Post period, by the average speed over the entire period, or (2) adjusting the data daily to determine savings on a daily basis, and summing the daily savings over the Post period.

Both approaches were applied to a number of ships where Pre and Post data were available. These included the four ships discussed earlier. The results are shown in the tables below.

[9] The p-value and the F-value are determined by the t-distribution and the F-distribution respectively.

Ship: PCC.1	Ballast	Loaded
Baseline FC (for average Post speed using Pre regression coeffs)	38.88	39.62
Post FC (actual average)	34.18	33.48
Savings, %, by average values over entire period	12.1%	15.5%
Savings, %, by summing daily savings over Post period	13.6%	18.3%

Ship: LNG.1	Ballast	Loaded
Baseline FC (for average Post speed using Pre regression coeffs)	171.23	169.96
Post FC (actual average)	163.12	154.63
Savings, % by average values over entire period	4.7%	9.0%
Savings, %, by summing daily savings over Post period	4.9%	9.2%

Ship: Ro-Ro.1	Combined
Baseline FC (for average Post speed using Pre regression coeffs)	39.19
Post FC (actual average)	35.56
Savings, %, by average values over entire period	9.3%
Savings, %, by summing daily savings over Post period	9.2%

Ship: VLCC.1	Ballast	Loaded
Baseline FC (for average Post speed using Pre regression coeffs)	92.09	108.80
Post FC (actual average)	81.87	102.47
Savings, %, average over entire period	11.1%	5.8%
Savings, %, by summing daily savings over Post period	11.2%	5.8%

Looking at these four tables, the following observations are made:

1. All savings estimates are positive, with % values varying from 4.7% to 18.3% (PCC.1 Loaded). The latter case is an anomaly commented later.
2. The savings estimates applying the Eqs. (A.9) and (A.10) to average values over the period generally give similar results to summing daily savings over the period, with differences for PCC.1.
3. Looking closer at the data for PCC.1 (Loaded) in the Post period, one finds a number of days where ship speed is substantially below typical values in other days, and in the Pre period. During the Pre period, the speed varied from 15.5 to 19.6 knots. In the Post period, the speed varied from 6.5 to 19.2 knots. Specifically, there was one day with 6.5 knots and another with 8 knots. Clearly these values are way outside the range of validity of the regression, and led to large "savings" for these days, which translated into large savings, summing over days. Applying the average speed over the entire Post period (16.32 knots), the savings estimate (15.5%) was not so affected as in the estimate summing over individual days (18.3%). *Hence, the regression coefficients should be applied only over the range of speed values in the Pre data set*.
4. Savings % for the same ship in loaded and ballast conditions varied somewhat. Note, however, that the ballast data set is smaller, so that savings in the loaded condition has a higher weight in determining overall savings.

It is concluded that this model meets the four validity conditions identified earlier:

a) The model chosen is *statistically valid*, verified through an analysis of residuals, and relatively low standard error of residuals.

b) The fuel consumption values are reasonably *consistent* with fuel consumption estimates using the regression generally (3 out of the 4 cases) indicating higher values under loaded compared to ballast operation.
c) The fuel savings estimates are *reasonable* since positive % fuel savings similar for the different ships are obtained, though the values show a certain amount of variation from one ship to another, and also for the same ship in loaded and ballast operation. Savings vary from about 5% (LNG.1 Ballast) to about 18% (PCC.1 Loaded).
d) The model is simple insofar as fuel consumption is explained by a single explanatory variable, ship speed and two coefficients obtained by regression. This has been referred to as the Basic Model, subject to future improvement.

Model validity with respect to changes in ship speed

Recall that each regression model is only valid over the range of ship speeds over which data were analyzed. Therefore, the regression model should not be applied to predict baseline fuel consumption for days in the Post period where the speed is outside the range of speeds over which the model is valid. Anomalous days for the Post period of the PCC.1 ship above were noted above, where speeds were considerably below the valid range. Ship operators may increase ship speed as a “rebound effect” following the application of the advanced hull coating. Thus, a part or all of the fuel savings may be “taken back” by operating the ship at a higher speed. Therefore, for any days in the Post period, where the ship speed is above the valid range, fuel savings should not be counted towards the total for the Post period.

On the other hand, if the ship speed is lower, then there is no “rebound effect”: ship operators are not “taking back” fuel savings. However, fuel savings cannot be accurately estimated by the regression coefficients, which were determined over, and are valid for, a certain range of ship speeds. Therefore for days when the speed is lower than the range, these days should be eliminated from the summation to determine emissions reduction.

Appendix B

Beaufort Scale

Beaufort number	Description	Wind speed	Wave height	Sea conditions
0	Calm	< 1 km/h < 1 mph < 1 knots < 0.3 m/s	0 m	Flat.
1	Light air	1.1–5.5 km/h 1–3 mph 1–2 knots 0.3–1.5 m/s	0–0.2 m	Ripples without crests.
2	Light breeze	5.6–11 km/h 4–7 mph 3–6 knots 1.6–3.4 m/s	0.2–0.5 m	Small wavelets. Crests of glassy appearance, not breaking
3	Gentle breeze	12–19 km/h 8–12 mph 7–10 knots 3.4–5.4 m/s	0.5–1 m	Large wavelets. Crests begin to break; scattered whitecaps
4	Moderate breeze	20–28 km/h 13–17 mph 11–15 knots 5.5–7.9 m/s	1–2 m	Small waves with breaking crests. Fairly frequent whitecaps.
5	Fresh breeze	29–38 km/h 18–24 mph 16–20 knots 8.0–10.7 m/s	2–3 m	Moderate waves of some length. Many whitecaps. Small amounts of spray.
6	Strong breeze	39–49 km/h 25–30 mph 21–26 knots 10.8–13.8 m/s	3–4 m	Long waves begin to form. White foam crests are very frequent. Some airborne spray is present.
7	High wind, Moderate gale, Near gale	50–61 km/h 31–38 mph 27–33 knots 13.9–17.1 m/s	4–5.5 m	Sea heaps up. Some foam from breaking waves is blown into streaks along wind direction. Moderate amounts of airborne spray.
8	Gale, Fresh gale	62–74 km/h 39–46 mph 34–40 knots 17.2–20.7 m/s	5.5–7.5 m	Moderately high waves with breaking crests forming spindrift. Well-marked streaks of foam are blown along wind direction. Considerable airborne spray.
9	Strong gale	75–88 km/h 47–54 mph 41–47 knots 20.8–24.4 m/s	7–10 m	High waves whose crests sometimes roll over. Dense foam is blown along wind direction. Large amounts of airborne spray may begin to reduce visibility.
10	Storm Whole gale	89–102 km/h 55–63 mph 48–55 knots 24.5–28.4 m/s	9–12.5 m	Very high waves with overhanging crests. Large patches of foam from wave crests give the sea a white appearance. Considerable tumbling of waves with heavy impact. Large amounts of airborne spray reduce visibility.
11	Violent storm	103–117 km/h 64–72 mph 56–63 knots 28.5–32.6 m/s	11.5–16 m	Exceptionally high waves. Very large patches of foam, driven before the wind, cover much of the sea surface. Very large amounts of airborne spray severely reduce visibility.
12	Hurricane-force	≥ 118 km/h ≥ 73 mph ≥ 64 knots ≥ 32.7 m/s	≥ 14 m	Huge waves. Sea is completely white with foam and spray. Air is filled with driving spray, greatly reducing visibility.

Appendix C

The following is extracted from the website of the International Maritime Organization[10]

Copied text is shown in italics.

SOx and particulate matter emission controls apply to all fuel oil, as defined in regulation 2.9, combustion equipment and devices onboard and therefore include both main and all auxiliary engines together with items such boilers and inert gas generators. These controls divide between those applicable inside Emission Control Areas (ECA) established to limit the emission of SOx and particulate matter and those applicable outside such areas and are primarily achieved by limiting the maximum sulphur content of the fuel oils as loaded, bunkered, and subsequently used onboard.

[Table showing changes in regulations over time deleted]

The ECA established are:

1. *Baltic Sea area – as defined in Annex I of MARPOL (SOx only);*
2. *North Sea area – as defined in Annex V of MARPOL (SOx only);*
3. *North American area (expected to enter into effect 1 August 2012) – as defined in Appendix VII of Annex VI of MARPOL (SOx, NOx and PM); and*
4. *United States Caribbean Sea area (expected to enter into effect 1 January 2014) – as defined in Appendix VII of Annex VI of MARPOL (SOx, NOx and PM).*

Most ships which operate both outside and inside these ECA will therefore operate on different fuel oils in order to comply with the respective limits. In such cases, prior to entry into the ECA, it is required to have fully changed-over to using the ECA compliant fuel oil, regulation 14.6, and to have onboard implemented written procedures as to how this is to be undertaken. Similarly change-over from using the ECA compliant fuel oil is not to commence until after exiting the ECA. At each change-over it is required that the quantities of the ECA compliant fuel oils onboard are recorded, together with the date, time and position of the ship when either completing the change-over prior to entry or commencing change-over after exit from such areas. These records are to be made in a logbook as prescribed by the ship's flag State, in the absence of any specific requirement in this regard the record could be made, for example, in the ship's Annex I Oil Record Book.

The first level of control in this respect is therefore on the actual sulphur content of the fuel oils as bunkered. This value is to be stated by the fuel oil supplier on the bunker delivery note and hence this, together with other related aspects, is directly linked to the fuel oil quality requirements as covered under regulation 18 – see below. Thereafter it is for the ship's crew to ensure, in respect of the ECA compliant fuel oils, that through avoiding loading into otherwise part filled storage, settling or service tanks, or in the course of transfer operations, that such fuel oils do not become mixed with other, higher sulphur content fuel oils, so that the fuel oil as actually used within an ECA exceeds the applicable limit.

Consequently, regulation 14 provides both the limit values and the means to comply. However, there are other means by which equivalent levels of SOx and particulate matter emission control, both outside and inside ECA, could be achieved. These may be divided into methods termed primary (in which the formation of the pollutant is avoided) or secondary (in which the pollutant is formed but subsequently removed to some degree prior to discharge of the exhaust gas stream to the atmosphere). Regulation 4.1 allows for the application of such methods subject to approval by the Administration. In approving such

[10] http://www.imo.org/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Sulphur-oxides-(SOx)-–-Regulation-14.aspx

equivalents an Administration should take into account any relevant guidelines. As of October 2010 there are no guidelines in respect of any primary methods (which could encompass, for example, onboard blending of liquid fuel oils or dual fuel (gas / liquid) use). In terms of secondary control methods, guidelines (MEPC.184(59)) have been adopted for exhaust gas cleaning systems which operate by water washing the exhaust gas stream prior to discharge to the atmosphere, in using such arrangements there would be no constraint on the sulphur content of the fuel oils as bunkered other than that given the system's certification.

Appendix D

Energy efficiency measures applicable to existing ships

On July 15, 2011, the International Maritime Organization adopted mandatory energy efficiency measures to be applicable to all new ships of 400 gross tonnage and above. These regulations are expected to enter into force on 1 January 2013.[11] However, note that the IMO rules do not include hull coatings as an energy saving measure. Therefore, even if ships contracted after 1/1/2013 or delivered after 1/1/2015 use conventional antifouling coatings and are subsequently converted to the advanced coating at the next docking, they would still be eligible for consideration in this methodology.

The International Maritime Organization (IMO) conducted the Second IMO GHG Study in 2009 (Buhaug et al., 2009). Appendix 2 of the report deals with "Emission reduction technology options".

Most of the measures are only applicable to new ships at the design stage. Operational improvements are listed starting in p. 195, and include:

(a) Fleet composition and selection of ships;

(b) Speed reduction;

(c) Hull coatings,

(d) De-rating engines;

(e) Engine upgrades;

(f) Propeller maintenance and upgrades; and

(g) Other upgrades (speed-control pumps and fans and the substitution of steam with electricity for powering cargo pumps).

Item (a) is clearly not an option for a given ship.

Item (b) is speed reduction, and any effect of speed reduction would be taken into consideration in the methodology, since speed is the main determinant of fuel consumption.

Item (c) is clearly the project activity.

Items (d, e, and f) comprise potentially major energy efficiency measures. If they are undertaken at the same time as the application of the advanced hull coating, the ship would not qualify for carbon credits. In case such upgrades are undertaken during the docking cycle following the application of the advanced coating, either (i) all subsequent fuel savings will not count towards carbon credits or (ii) statistical evidence should indicate that these upgrades did not reduce fuel consumption, as would be indicated by a sudden drop in fuel consumption. This would be clearly visible in the graphs that are part of the data analysis procedure included in this methodology, as described later.

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[11] Mandatory energy efficiency measures for international shipping adopted at IMO environment meeting. Marine Environment Protection Committee (MEPC) – 62nd session: 11 to 15 July 2011 http://www.imo.org/MediaCentre/PressBriefings/Pages/42-mepc-ghg.aspx

Item (g) is not related to ship propulsion and therefore these energy savings will not be included in fuel consumption or energy savings, according to this methodology.