IMO Train the Trainer (TTT) Course

on

Energy Efficient Ship Operation

Module 2 – Ship Energy Efficiency Regulations and Related Guidelines

I M O

ACKNOWLEDGEMENTS

The "Train the Trainer" course presented herein is based on material originally developed by WMU in 2013 under contract for the IMO. This current edition represents a major upgrade of the training package by Dr Zabi Bazari of Energy and Emissions Solutions, UK (EnEmSol) under contract for the IMO.

IMO wishes to express its sincere appreciation for WMU and EnEmSol expert assistance

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MODULE 2
Ship Energy Efficiency Regulations and Related Guidelines

Module Aims and Objectives

This Module aims to provide an overview of IMO's energy efficiency regulations for ships and related guidelines. It describes Chapter 4 of MARPOL Annex VI in detail and then specifically explains the EEDI (Energy Efficiency Design Index), SEEMP (Ship Energy Efficiency Management Plan) and EEOI (Energy Efficiency Operational Indicator) in detail using their relevant IMO guidelines.

Upon completion of this module, you should be able to:

- Name and explain energy efficiency related MARPOL Annex VI regulations;
- Describe the concept of Attained EEDI, Required EEDI, reference lines, and reduction factors and how they are related to each other;
- Calculate Attained EEDI and Required EEDI using ship data;
- Describe the main aspects of EEDI survey and verification and relevant processes and organizations involved;
- Describe the main features of a SEEMP according to relevant guidelines;
- Calculate EEOI using relevant data for a ship; and
- Identify related guidelines and why they have been developed and their usage.

To support your learning process, a list of references and IMO guidelines are provided as references. Referring to them will allow you to go deeper in areas that may be of most interest to you.

The material presented herein is current at the time of preparations of this document. Because of the evolving nature of regulations, technologies and future studies in area of MARPOL Annex VI and in particular energy efficiency of ships, some aspects may require updating over time.

The views expressed in this document are purely those of the author(s) and may not in any circumstances be regarded as stating an official position of the organizations involved or named in this document.

This document is subject to change by the IMO.

Dr Zabi Bazari, EnEmSol, January 2016

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1. Introduction

1.1 Introduction

Figure 1.1 shows the IMO activities that led to the adoption of Chapter 4 of MARPOL Annex VI on energy efficiency regulations for ships. This Figure and full chronological account of relevant IMO activities have been described in detail in Module 1 (see **Module 1**, **Section 6.5**) and thus will not be further addressed here. Instead this whole Module is devoted to describing details of the resultant IMO regulations and guidelines.

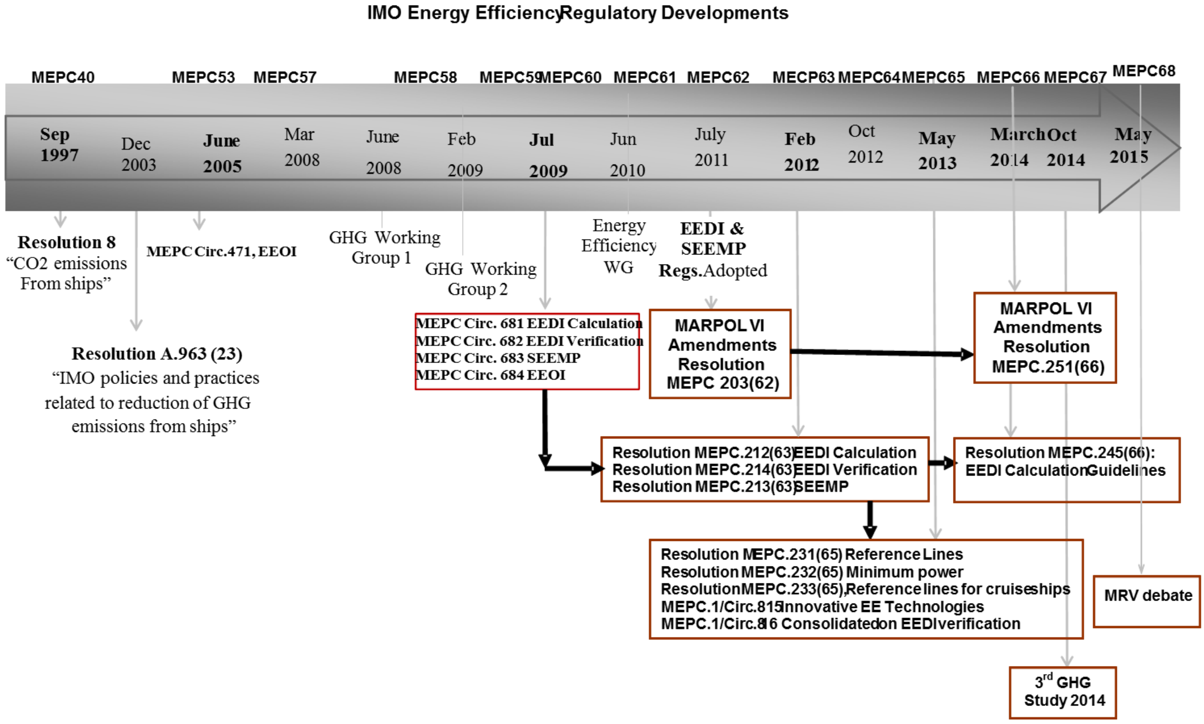


Figure 1.1: IMO GHG control related activities in chronoligal order

Chapter 4 of MARPOL Annex VI introduces two mandatory mechanisms as energy efficiency standard for ships; with the main objective of reducing international shipping's GHG emissions via improved ship design and operations. These regulatory mechanisms are:

- Energy Efficiency Design Index (EEDI), for new ships
- Ship Energy Efficiency Management Plan (SEEMP), for all ships.

The EEDI is an index that indicates the energy efficiency of a ship in terms of gCO_2 (generated) / tonne.mile (cargo carried); calculated for a specific reference ship operational condition. The intention is that by imposing limits on this index, IMO will be able to drive ship technologies to more energy efficient ones over time. EEDI is thus a goal-based technical standard that is applicable to new ships. Ship designers and builders are free to choose the technologies to satisfy the EEDI requirements in a specific ship design. Overtime, the EEDI level will reduce; this gradually leading to more energy efficient ships.

On the other hand, SEEMP is a management tool and establishes a mechanism for ship operators to improve the energy efficiency of a ship during its operation lifecycle. It works according to planning, implementation, monitoring and review of a number of energy efficiency measures within a continuous improvement management cycle.

Additionally, IMO has adopted a voluntary scheme for calculation of Energy Efficiency Operational Indicator (EEOI) with the main objective of its future use as a monitoring performance indicator in shipping, most likely in relation to SEEMP. **Figure 1.2** shows the concept of how the above instruments will work with each other to cover both ship design and ship operation.

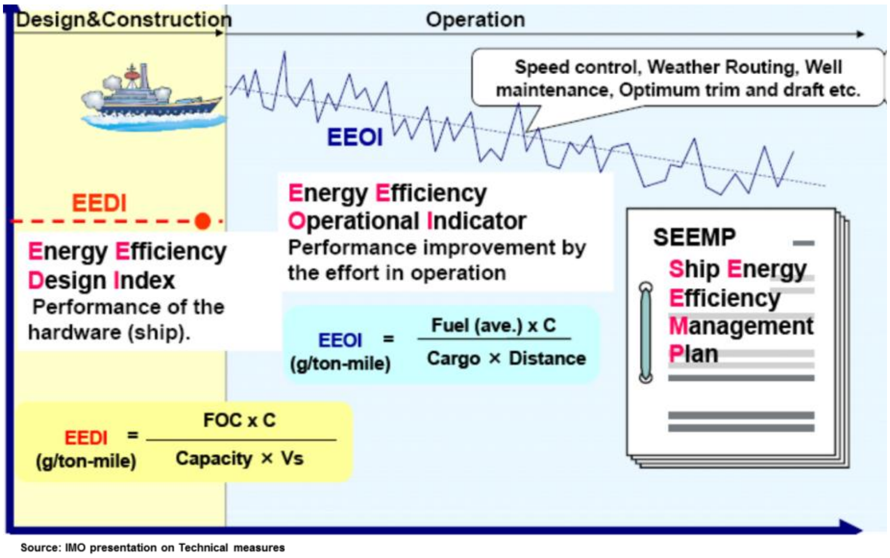


Figure 1.2: Main components of the IMO energy efficiency regulations

In this Section, the regulatory framework will be described by giving details of related changes to MARPOL Annex VI. These include changes to existing regulations as a result of energy efficiency and then new regulations that are specifically for energy efficiency.

1.2 Changes to existing MARPOL Annex VI regulations

Following a significant debate at IMO on ship energy efficiency regulations, new major amendments to MARPOL Annex VI were adopted in July 2011 [MEPC Resolution 203(62)]. As a result (1) Some of the existing regulations were updated and (2) a set of new regulations were added.

Table 1.1 summarizes the existing regulations in Chapters 1 and 2 of MARPOL Annex VI and the ones that were changed (in red color) to accommodate the energy efficiency regulations.

Resolution MEPC.176(58)	Resolutions MEPC.203(62) & MEPC251 (66), …..
Chapter I Reg. 1 Application Reg. 2 Definitions Reg. 3 Exceptions and Exemptions Reg. 4 Equivalents	Chapter I Reg. 1 Application Reg. 2 Definitions Reg. 3 Exceptions and Exemptions Reg. 4 Equivalents
Chapter II Reg. 5 Surveys Reg. 6 Issue or endorsement of a Certificate Reg. 7 Issue of a Certificate by another Party Reg. 8 Form of Certificate Reg. 9 Duration and Validity of Certificate Reg. 10 Port State Control on Operational Requirements Reg. 11 Detection of Violations and Enforcements	Chapter II Reg. 5 Surveys Reg. 6 Issue or endorsement of a Certificate Reg. 7 Issue of a Certificate by another Party Reg. 8 Form of Certificate Reg. 9 Duration and Validity of Certificate Reg. 10 Port State Control on Operational Requirements Reg. 11 Detection of Violations and Enforcements

Table 1.1 – Existing regulations and those amended shown in red

A summary of the changes are given below:

Regulation 2: The amendments mainly include definitions for "new ship" as applicable to various phases of EEDI regulations, "major conversion" and "ship types" for which EEDI regulations apply. Since EEDI only applies to new ships and those ships that undergo major conversions beyond 1 January 2013, the exact definition of the above terms were required. Additionally, terms such as "Attained EEDI" and "Required EEDI" have been defined.

Regulation 5: The requirement for surveys including an initial survey for newly built ships, a full or partial survey in case of a major conversion of existing ships, survey for SEEMP to verify its existence on board ship, etc. are specified in this regulation. This regulation states that EEDI survey and verification shall be carried out according to relevant IMO guidelines (see **Section 4** for full details).

Regulations 7 and 8: The changes to these regulations deal with energy efficiency certification, making it mandatory for ships to have an International Energy Efficiency (IEE) Certificate; also emphasizing the responsibility of flag State Administration.

> "An International Energy Efficiency Certificate for the ship shall be issued after a survey in accordance with the provisions of regulation 5.4 to any ship of 400 gross tonnage and above, before that ship may engage in voyages to ports or offshore terminals under the jurisdiction of other Parties.
>
> The certificate shall be issued or endorsed either by the Administration or any organization duly authorized by it. In every case, the Administration assumes full responsibility for the certificate." [MEPC Resolution 203(62)]

Regulations 9: This regulation defines the validity aspects of the IEE certificate. It will be valid for the life of the ship unless otherwise invalidated by a major conversion or change of flag or ship withdrawal from service.

> "The International Energy Efficiency Certificate shall be valid throughout the life of the ship subject to the provisions of paragraph below:
>
> An International Energy Efficiency Certificate issued under this Annex shall cease to be valid in any of the following cases if the ship is withdrawn from service or if a new certificate is issued following major conversion of the ship; or upon transfer of the ship to the flag of another State......." [MEPC Resolution 203(62)]

Regulation 10: This regulation specifies the requirement for Port State Control (PSC) for energy efficiency. Accordingly, the IEE certificate is the starting point for any PSC inspection.

> "In relation to chapter 4, any port State inspection shall be limited to verifying, when appropriate, that there is a valid International Energy Efficiency Certificate on board, in accordance with article 5 of the MARPOL Convention." [MEPC Resolution 203(62)]

2. Chapter 4 of MARPOL Annex VI

2.1 Overview

As a result of energy efficiency debate at the IMO and subsequent agreements, a new Chapter 4 was added to MARPOL Annex VI. **Table 2.1** shows (in red) the list of added new regulations.

Resolution MEPC.176(58)	Resolution MEPC.203(62)
Chapter Ⅲ Reg. 12 Ozone Depleting Substances Reg. 13 Nitrogen Oxides(NOx) Reg. 14 Sulphur Oxides(SOx) and Particular Matter Reg. 15 Volatile Organic Compounds (VOCs) Reg. 16 Shipboard Incineration Reg. 17 Reception Facilities Reg. 18 Fuel Oil Availability and Quality	Chapter Ⅲ Reg. 12 Ozone Depleting Substances Reg. 13 Nitrogen Oxides(NOx) Reg. 14 Sulphur Oxides(SOx) and Particular Matter Reg. 15 Volatile Organic Compounds(VOCs) Reg. 16 Shipboard Incineration Reg. 17 Reception Facilities Reg. 18 Fuel Oil Availability and Quality
	Chapter Ⅳ **Reg. 19 Application** **Reg. 20 Attained EEDI** **Reg. 21 Required EEDI** **Reg. 22 SEEMP** **Reg. 23 Promotion of technical co-operation and transfer of technology relating to the improvement of energy efficiency of ships**
Appendix Ⅰ~Ⅵ	Appendix Ⅰ~Ⅵ **Appendix Ⅷ Form of International Energy Efficiency(IEE) Certificate**

Table 2.1 Newly added regulations (marked red) for energy efficiency of ships

In this section, a short description of the main aspects of these regulations is provided. Further details on the subject can be found in relevant publications by IMO in particular the IMO book on MARPOL Annex VI [IMO MARPOL Annex VI, 2013].

2.2 Regulation 19 - Application

This regulation specifies the domain of application of the energy efficiency regulations. Accordingly, Chapter 4 of MARPOL Annex VI applies to all ships of 400 gross tonnage and above that are engaged in international waters. It gives limited power to Administrations to waive the requirements for EEDI for a new ship up to a delivery date of 1 July 2019; subject to informing the IMO and other Parties to MARPOL Annex VI of this decision.

The "waiver" clause came about due to significant discussions at MEPC and stressing that some ships may not be able to comply with IMO requirements whilst considered as good design ships. It is important that waiver applied to specific ships and not the whole of flag State fleet. So far, there has been no need for Administrations to use this option.

2.3 Regulation 20 – Attained EEDI

This regulation deals with the Attained EEDI and specifies the need for its calculation and verification. Attained EEDI is the actual EEDI of a ship as calculated using EEDI formula (see **Section 3**). According to this regulation:

- The Attained EEDI must be calculated for each new ship, each new ship when undergoes a major conversion, or existing ships that undergo so many changes as according to judgment by Administration can be considered as a new ship.
- The Attained EEDI is only applicable to a large number of ship types but not all ships. For example, fishing vessels are not required to have an Attain EEDI.
- The Attained EEDI must be calculated taking into account relevant IMO guidelines (see **Section 3** for details).
- The Attained EEDI must be accompanied by an "EEDI Technical File" that contains the information necessary for the calculation of the attained EEDI and that shows the process of calculation.
- The Attained EEDI must be verified, based on the EEDI Technical File, either by the Administration or by any organization duly authorized by it (see **Section 4** on details of verification).

As indicated, some ship types (e.g. fishing vessels) are not yet part of the EEDI regulations. Specifically, the following list provides the ship types that are currently required to comply with Attained EEDI regulation.

- Bulk carrier
- Gas carrier (none LNG carriers)
- Tanker
- Container ship
- General cargo ship
- Refrigerated cargo ship
- Combination carrier
- Ro-Ro cargo ships (vehicle carrier)
- Ro-Ro cargo ships
- Ro-Ro Passenger ship
- LNG carrier
- Cruise passenger ships (having non-conventional propulsion)

Also, specific ship types such as those with turbine propulsion (with the exception of LNG ships) are also excluded.

2.4 Regulation 21 – Required EEDI

This regulation specifies the methodology for calculation of the Required EEDI and all relevant details. The Required EEDI is the regulatory limit for EEDI and its calculation involves use of "reference lines" and "reduction factors".

The basic concepts included in this regulation are:

- **Reference line***:* A baseline EEDI for each ship type, representing reference EEDI as a function of ship size.
- **Reduction factor***:* This represents the percentage points for EEDI reduction relative to the reference line, as mandated by regulation for future years. This factor is used to tighten the EEDI regulations in phases over time by increasing its value.

- **Cut-off levels***:* Smaller size vessels are excluded from having a Required EEDI for some technical reasons. Thus, the regulatory text specifies the size limits. This size limit is referred to as cut off levels.
- **Implementation phases***:* the EEDI will be implemented in phases. Currently, it is in phase 1 that runs from year 2015 to 2019. Phase 2 will run from year 2020 to 2024 and phase 3 is from year 2025 onwards.

Figure 2.1 shows the above concepts in diagrammatic format.

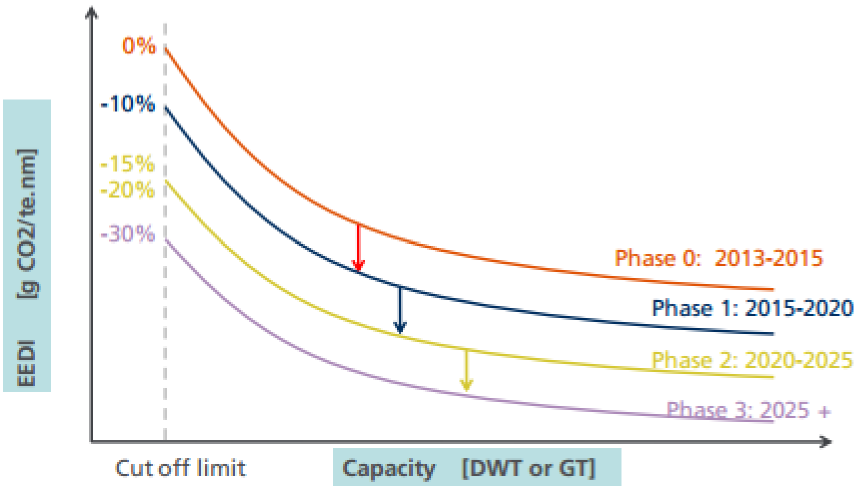


Figure 2.1: Concept of Required EEDI, reduction factor, cut off limits and EEDI phases

2.4.1 EEDI Reference line

This is a baseline EEDI for each ship type, representing reference EEDI as a function of ship size (see graph for Phase 0 in **Figure 2.1**). The reference lines are developed by the IMO using data from a large number of existing ships and analyzing these data as is shown in **Figure 2.2**.

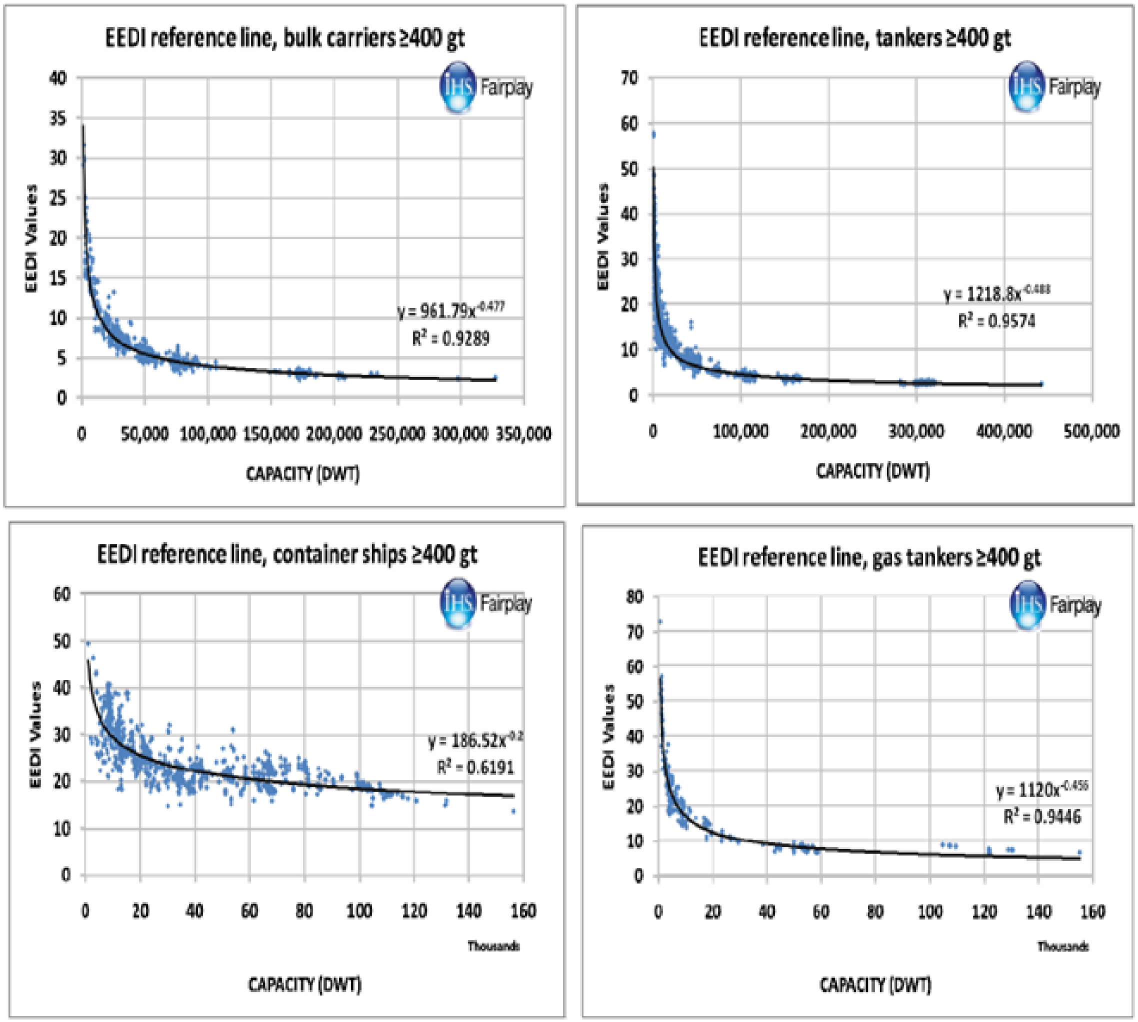


Figure 2.2: EEDI Reference Lines as developed by the IMO using techniques in Resolution MEPC.231(65)

Full details of how reference lines are developed including sources of data, data quality checks, number of ships selected and year of build, ship sizes, etc. are fully described in relevant IMO guidelines [see Resolution MEPC.231(65) and Resolution MEPC.233(65)]. As indicated, the above reference lines are produced through regression analysis of a large number of data and the resultant regression equation is shown on each diagram. These regression equations are then embodied in Regulation 21 in the form of a formula:

$$\textit{Reference EEDI} = a * b^{-c}$$

Parameters a, b and c for some of the ship types are given in **Table 2.2**.

Ship type defined in regulation 2	a	b	c
2.25 Bulk carrier	961.79	DWT of the ship	0.477
2.26 Gas carrier	1120.00	DWT of the ship	0.456
2.27 Tanker	1218.80	DWT of the ship	0.488
2.28 Container ship	174.22	DWT of the ship	0.201
2.29 General cargo ship	107.48	DWT of the ship	0.216
2.30 Refrigerated cargo carrier	227.01	DWT of the ship	0.244
2.31 Combination carrier	1219.00	DWT of the ship	0.488

2.33	Ro-ro cargo ship (vehicle carrier)	$(DWT/GT)^{-0.7} \cdot 780.36$ where DWT/GT<0.3 1812.63 where DWT/GT≥0.3	DWT of the ship	0.471
2.34	Ro-ro cargo ship	1405.15	DWT of the ship	0.498
2.35	Ro-ro passenger ship	752.16	DWT of the ship	0.381
2.38	LNG carrier	2253.7	DWT of the ship	0.474
2.39	Cruise passenger ship having non-conventional propulsion	170.84	GT of the ship	0.214

Table 2.2: Parameters for determination of EEDI Reference value [Resolutions MEPC.203(62) and MEPC.251(66)]

2.4.2 EEDI reduction factor (X)

This represents the percentage points for EEDI reduction relative to reference line, as mandated by regulation for future years. The value of "reduction factor" is decided by the IMO and is recorded in Regulation 21. This is shown in **Table 2.3**.

Ship Type	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Jan 2025 and onwards
Bulk carrier	20,000 DWT and above	0	10	20	30
	10,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Gas carrier	10,000 DWT and above	0	10	20	30
	2,000 – 10,000 DWT	n/a	0-10*	0-20*	0-30*
Tanker	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Container ship	15,000 DWT and above	0	10	20	30
	10,000 – 15,000 DWT	n/a	0-10*	0-20*	0-30*
General Cargo ships	15,000 DWT and above	0	10	15	30
	3,000 – 15,000 DWT	n/a	0-10*	0-15*	0-30*
Refrigerated cargo carrier	5,000 DWT and above	0	10	15	30
	3,000 – 5,000 DWT	n/a	0-10*	0-15*	0-30*
Combination carrier	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
LNG carrier***	10,000 DWT and above	n/a	10**	20	30
Ro-ro cargo ship (vehicle carrier)***	10,000 DWT and above	n/a	5**	15	30
Ro-ro cargo ship***	2,000 DWT and above	n/a	5**	20	30
	1,000 – 2,000 DWT	n/a	0-5*,**	0-20*	0-30*
Ro-ro passenger ship***	1000 DWT and above	n/a	5**	20	30
	250 – 1,000 DWT	n/a	0-5*,**	0-20*	0-30*
Cruise passenger ship*** having non-conventional propulsion	85,000 GT and above	n/a	5**	20	30
	25,000 – 85,000 GT	n/a	0-5*,**	0-20*	0-30*

Note: n/a means that no required EEDI applies.

* Reduction factor to be linearly interpolated between the two values dependent upon ship size. The lower value of the reduction factor is to be applied to the smaller ship size.

** Phase 1 commences for those ships on 1 September 2015.

*** Reduction factor applies to those ships delivered on or after 1 September 2019, as defined in paragraph 43 of regulation 2.

Table 2.2: EEDI reduction factors, cut off limits and implementation phases [Resolutions MEPC.203(62) and MEPC.251(66)]

2.4.3 Required EEDI calculation formula

Using the above concept, the following equations show the way Required EEDI is calculated for a ship. First, for each ship a "reference EEDI" is calculated using the below equation:

$$\textit{Reference EEDI} = a * b^{-c} \quad (1)$$

Where:

b: Ship capacity
a and c: Constants agreed for each ship type and included in the regulation.
Reference EEDI: Reference value for EEDI.

The next step is to establish the reduction factor (X) for the ship. This is dependent on year of ship built and is specified within the regulation (see **Table 2.3**). Having established the Reference EEDI and X, the Required EEDI is calculated from the following equation:

$$\textit{Required EEDI} = (1 - X/100) * (\textit{Reference EEDI}) \quad (2)$$

Where:

X: Reduction rate; agreed and included in Regulation.
Required EEDI: The regulatory limit of the ship's EEDI, which the actual EEDI must not exceed.

The Required EEDI applies only to ships named in column 1 and the ship sizes specified in column 2 of **Table 2.2**. For these ships, regulation 22 stipulates that Attained EEDI must always be less than or equal to Required EEDI:

$$\textit{Attained EEDI} \leq \textit{Required EEDI} \quad (3)$$

Where:

Attained EEDI: The actual EEDI of the ship, as calculated by the shipyard and verified by a recognized organization.

This regulation additionally stipulates the following:

- "If the design of a ship allows it to fall into more than one of the above ship type definitions, the required EEDI for the ship shall be the most stringent (the lowest) required EEDI".
- "For each ship to which this regulation applies, the installed propulsion power shall not be less than the propulsion power needed to maintain the maneuverability of the ship under adverse conditions as defined in the guidelines to be developed by the Organization". The related guidelines are briefly introduced in **Section 4.8**.
- "At the beginning of Phase 1 and at the midpoint of Phase 2, the IMO shall review the status of technological developments and, if proven necessary, amend the time periods, the EEDI reference line parameters for relevant ship types and reduction rates set out in this regulation". This review process is currently underway at the IMO.

2.5 Regulation 22 - SEEMP

Regulation 22 is on SEEMP and states:

> "1 Each ship shall keep on board a ship specific Ship Energy Efficiency Management Plan (SEEMP). This may form part of the ship's Safety Management System (SMS).
>
> 2 The SEEMP shall be developed taking into account guidelines adopted by the Organization." [MEPC Resolution 203(62)]

Accordingly:

- Each ship more than 400 GT that is involved in international voyages should have a SEEMP on board.
- There is no specific reference to a need for review and verification of a SEEMP's content. However, its existence on board must be verified.
- The SEEMP should be developed according to IMO guidelines.

Section 5 provides a full description of relevant IMO guidelines on SEEMP development and best practice.

2.6 Regulation 23 – Technical cooperation and technology transfer

This regulation was developed at the request of developing countries following a significant debate at IMO MEPC on role of various countries on GHG reduction efforts as well as the technological and financial difficulties that developing countries may face as a result of energy efficiency regulations. This regulation entitled "Promotion of technical co-operation and transfer of technology relating to the improvement of energy efficiency of ships". It stipulates that:

> "1 Administrations shall, in co-operation with the Organization[1] and other international bodies, promote and provide, as appropriate, support directly or through the Organization to States, especially developing States, that request technical assistance.
>
> 2 The Administration of a Party[2] shall co-operate actively with other Parties, subject to its national laws, regulations and policies, to promote the development and transfer of technology and exchange of information to States which request technical assistance, particularly developing States, in respect of the implementation of measures to fulfill the requirements of chapter 4 of this annex, in particular regulations 19.4 to 19.6.". [MEPC Resolution 203(62)]

In support of the implementation of the above regulation, IMO MEPC approved a new Resolution MEPC.229(65). This Resolution provides a framework for the promotion and facilitation of capacity building, technical cooperation, and technology transfer to support the developing countries in the implementation of the EEDI and the SEEMP. As part of this, the Ad Hoc Expert Working Group on Facilitation of Transfer of Technology for Ships (AHEWG-TT) was set up and IMO supported relevant meetings and work items as has been fully described in **Module 1, Section 6.8**. Additionally, IMO has carried out a significant amount of capacity building activities and implementing relevant project in this area as was fully described in **Module 1, Section 6.8**.

[1] Organisation in IMO documents refers to IMO itself.
[2] A Party refers to a country who has ratified MARPOL Annex VI.

3. EEDI calculation

3.1 Concept of EEDI

The Attained EEDI is the actual value of EEDI for a ship and represents the amount of CO_2 generated by a ship while doing one tonne-mile of transport work. In simple term, it may be represented by equation (1):

$$EEDI = \frac{CO_2\ emission}{transport\ work} \quad = \quad EEDI = \frac{\text{Engine power x SFC x } C_F}{\text{DWT x speed}} \ (gCO_2/\text{ton-mile}) \qquad \textbf{(1)}$$

It is argued that EEDI represents the ratio of a ship's "cost to society" in the form of its CO_2 emissions, divided by its "benefit to the society" represented by the transport work done by the ship as shown in (1). The above concept then translated into a more vigorous calculation method as represented by EEDI formula in equation (2) to account for diversity of ship types, ship sizes, alternative propulsion technologies, alternative fuels and future renewable technologies.

3.2 EEDI formula

Attained EEDI is calculated using the "EEDI formula" as shown below:

$$\frac{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}*\right) + \left(\left(\prod_{j=1}^{n} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}**\right)}{f_i \cdot f_c \cdot Capacity \cdot f_w \cdot V_{ref}} \qquad \textbf{(2)}$$

Figure 3.1 shows the main terms of the formula indicating that all relevant ship technologies will influence the EEDI level.

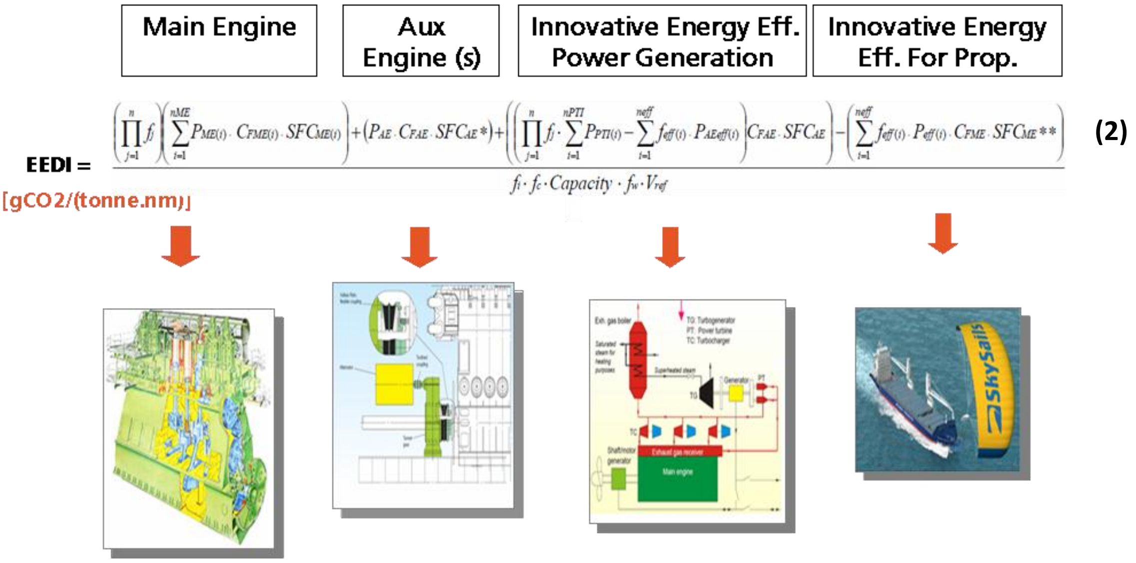


Figure 3.1: Main terms in EEDI formula

The items that primarily influence EEDI are:

- Main engine and energy needed for propulsion; this represented by the first term in the nominator of the formula.
- Auxiliary power requirements of the ship; this is represented by the second term in the nominator.

- Any innovative power (electric) generation devices on board such as electricity from waste heat recovery or solar power. These are represented by the third term in the nominator.
- Innovative technologies that provide mechanical power for ship propulsion such as wind power (sails, kites, etc.). This is the last term in the nominator.
- In the denominator of the formula, ship capacity and ship speed are represented that together gives the value of transport work.

Figure 3.2 shows the scope of ship systems that are represented in equation (2). The items contained within the red dashed-line box are included in EEDI formula while everything outside the box is excluded.

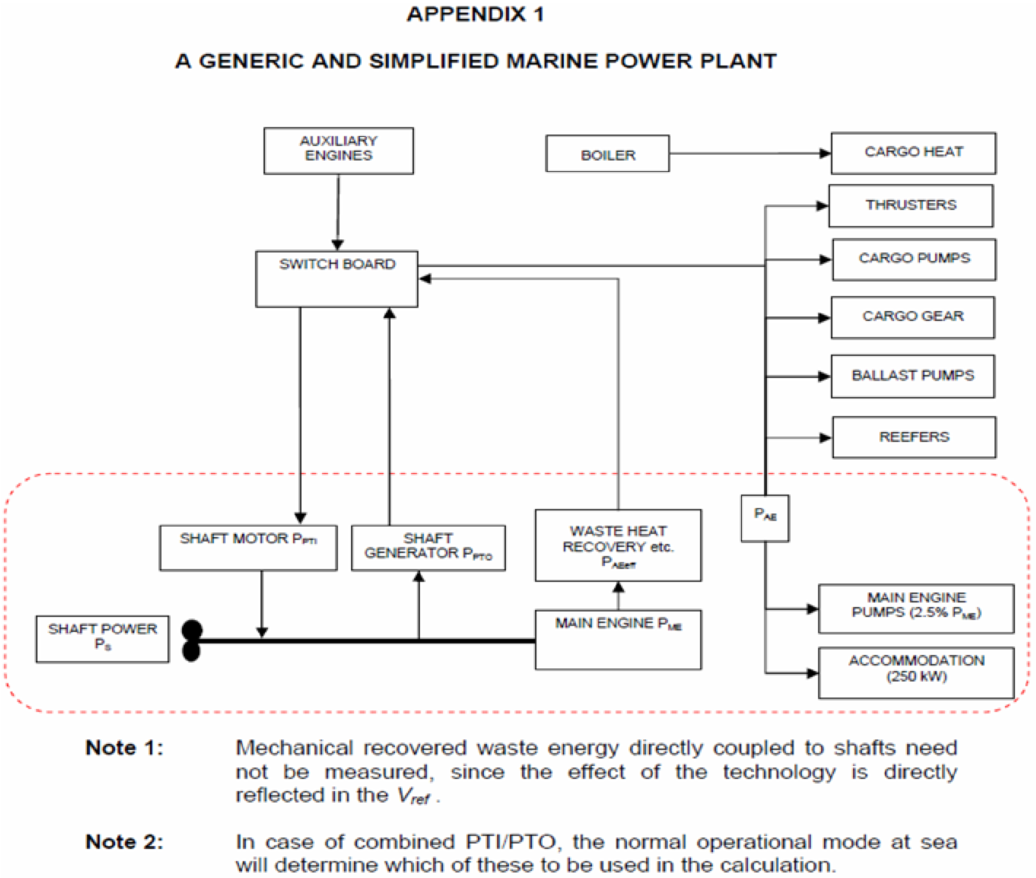


Figure 3.2: Scope of ship systems included in EEDI formula [Resolution MEPC.245(66)]

As a general rule:

- All the cargo-related energy uses on-board are outside the scope of the EEDI calculations (not included in the formula).
- Auxiliary boilers are also excluded from the formula; assuming that under normal sea-going conditions, boilers will not be operating.

Therefore, electricity needed for cargo pumps, cargo handling equipment, ship thrusters, etc. are out of scope of EEDI calculations.

3.3 Terms in the EEDI formula

Various terms in equation (2) are fully defined in the relevant IMO guidelines [Resolution MEPC.245(66)], a summary of which is given in **Table 3.1**.

Term	Unit	Brief description
Capacity	[Tonne]	Ship capacity in deadweight or gross tonnage at summer load line draught (for container ships, 70% of deadweight applies).
C_{FAE}	[gCO_2/gfuel]	Carbon factor for fuel for auxiliary engines.
C_{FME}	[gCO_2/gfuel]	Carbon factor for fuel for main engines.
f_{eff}	[-]	Correction factor for availability of innovative technologies.
f_i	[-]	Correction factor for capacity of ships with technical/regulatory elements that influence ship capacity.
f_c	[-]	Correction factor for capacity of ships with alternative cargo types that impact the deadweight-capacity relationship (e.g. LNG ships in gas carrier segment).
f_j	[-]	Correction factor for ship specific design features (e.g. ice-class ships).
f_w	[-]	Correction factor for speed reduction due to representative sea conditions.
n_{eff}	[-]	Number of innovative technologies.
n_{ME}	[-]	Number of main engines.
n_{PTI}	[-]	Number of power take-in systems (e.g. shaft motors).
P_{ME}	[kW]	Ship propulsion power that is 75% of main engine Maximum Continuous Rating (MCR) or shaft motor (where applicable); also taking into account the shaft generator. This will be influenced by alternative propulsion configurations.
P_{AE}	[kW]	Ship auxiliary power requirements at normal sea going conditions.
P_{AEeff}	[kW]	Auxiliary power reduction due to use of innovative electric power generation technologies.
P_{eff}	[kW]	75% of installed power for each innovative technology that contributes to ship propulsion.
P_{PTI}	[kW]	75% of installed power for each power take-in system (e.g. propulsion shaft motors).
SFC_{AE}	[g/kWh]	Specific fuel consumption for auxiliary engines as per NOx certification values.
SFC_{ME}	[g/kWh]	Specific fuel consumption for main engines as per NOx certification values.
V_{ref}	[knots]	Reference ship speed attained at propulsion power equal to P_{ME} and under clam sea and deep water operation at summer load line draught.

Table 3.1: Parameters for EEDI formula

More details of the important parameters are given below:

- **SFC (Specific Fuel Consumption):** The specific fuel consumption (SFC) is for engines and represents their fuel efficiency (fuel used) in g/kWh. The value for SFC is determined from the results recorded in the engine's NOx Technical File; determined as part of the engine NOx certification. The SFC for main engine is generally taken at 75% load and for auxiliary engines is generally taken at 50% load.
- **C_F (Carbon Factor):** This factor specifies the amount of CO_2 generated per unit mass of fuel used. **Table xx** provides the standard value for marine fuels. The type of fuel used for the NOx Certification test (to be taken from NOx Technical File) should be used to determine the value of the C_F conversion factor.

Type of fuel	Reference	Carbon content	C_F (t-CO_2/t-Fuel)
1 Diesel/Gas Oil	ISO 8217 Grades DMX through DMB	0.8744	3.206
2 Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.8594	3.151
3 Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.8493	3.114
4 Liquefied Petroleum Gas (LPG)	Propane	0.8182	3.000
	Butane	0.8264	3.030
5 Liquefied Natural Gas (LNG)		0.7500	2.750
6 Methanol		0.3750	1.375
7 Ethanol		0.5217	1.913

Table 3.2: Standard values of CF for marine fuels [Resolution MEPC.245(66)]

- **Capacity:** The Capacity of the ship is the deadweight or gross tonnage based on summer load line draught. The calculation of the deadweight is based on the lightweight of the ship, and the displacement at the summer load line draught. At the design stage, for EEDI preliminary verification (see **Section 4**), the lightweight and the displacement may be calculated using the provisional ship's stability documentation. For containerships, capacity is taken as 70% of the capacity at summer load line draught.

- **Power (propulsion – P_{ME})) :** The term "P" for power is used in different places in the formula for main engine, auxiliary power (electrical), shaft motor, shaft generator, renewable energy devices, etc. Power for shaft propulsion P_{ME}, generally is calculated at 75% MCR (Maximum Continuous Rating) of the main engine. Depending on various options of the propulsion line (shaft generator, shaft motor, limited power, etc.) different formulas are used for this purpose. For details, refer to the IMO guidelines (e.g. Resolution MEPC.245(66)).

- **Power (auxiliary – P_{AE})**: For auxiliary power (electrical), also different formulation to calculate the auxiliary power applies. P_{AE} generally includes the power consumed by the main engine pumps, navigational systems and equipment as well as accommodation but excludes other power used not for propulsion machinery/systems, e.g. thrusters, cargo pumps, cargo gear, ballast pumps, maintaining cargo, e.g. reefers and cargo hold fans (see also **Figure 3.2**). In the IMO guidelines [Resolution MEPC.245(66)], there are specific formulas for calculation of P_{AE}. It should be noted that P_{AE} is not linked to the actual installed power of ship auxiliary engines.

- **Reference Speed (V_{ref}):** The reference speed V_{ref} is the ship speed as measured and verified during sea trials and corrected to the following conditions:
  - Deep water operation
  - Calm weather including no wind and waves
  - Loading condition corresponding to the Capacity
  - Total shaft propulsion power at corresponding value of P_{ME}

- **Weather factor f_w:** f_w is a non-dimensional coefficient indicating the decrease of speed in representative sea conditions of wave height, wave frequency and wind speed (e.g. Beaufort Scale 6), and is taken as 1.0 for the calculation of the Attained EEDI. Efforts are underway to define how this factor can be estimated for various ships but effort so far has not led to any agreed solution.

- **Ship design related correction factors that influence propulsion power f_j:** There are a host of correction factors that are used to differentiate ships of same type and size if their basic design requirements are different. For example a tanker with ice-class as against same tanker without ice-class will have a correction factor to cater for their design differences. Design related correction factor f_j for the following ships are specified (see relevant IMO guidelines [Resolution MEPC.245(66)] for calculation process, formula and values); otherwise it is 1.0:

- Ice-classed ships
- Shuttle tankers with propulsion redundancy (80,000~160,000 DWT)
- Ro-Ro ships, all types
- General cargo ships

- **Design factor that impact ship Capacity f_i:** These are a set of correction factors that are used to differentiate ships of same type and size if their cargo capacity is influenced by design or type of cargo. For example a tanker with ice-class as against same tanker without ice-class will have a smaller capacity that needs to be taken into account. Other examples are when an owner decides to voluntarily strengthen the ship structure via use of thicker still plates or when a ship is classed according to Common Structural Rules. Capacity related correction factors are (for details of calculation of each, see Resolution MEPC.245(66) and relevant formulas for each factor below):
  - Ice-class capacity factor f_i: This is the factor used for ice-class ships.
  - Voluntary Structural Enhancement f_{iVSE}: For a ship with voluntary structural enhancement, the f_{iVSE} factor is to be computed according to according to formulation provided in the IMO guidelines.
  - Common Structural Rules f_{iCSR}: For bulk carriers and oil tankers built in accordance with the Common Structural Rules and assigned the class notation CSR, the f_{iCSR} factor is to be computed according to formulation provided in the IMO guidelines.

- **Cubic capacity correction factor f_c:** This refers to correction factors that are used to differentiate various types of cargos. Except in the cases listed below, the value of the fc factor is 1.0.
  - For a number of chemical tankers as defined under MARPOL Annex II, the f_c factor is to be computed according to formulation provided in the IMO guidelines [Resolution MEPC.245(66)].
  - For gas carriers as defined in certain regulation of IGC Code[3] having direct diesel driven propulsion. In such cases, the f_c factor is computed according to formulation provided in the IMO guidelines [Resolution MEPC.245(66)].

3.4 EEDI Condition

It is important to note that EEDI is calculated for a single ship's operating condition. This single operating condition is referred to as "EEDI Condition". The EEDI Condition is as follows:

- Draught: Summer load line draught.
- Capacity: Deadweight (or gross tonnage for passenger ships, etc.) for the above draught (container ship will be 70% value).
- Weather condition: Calm with no wind and no waves.

[3] International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk

- Propulsion shaft power: 75% of main engine MCR (conventional ships) with some amendments for shaft motor or shaft generator or shaft-limited power cases, where applicable.
- Reference speed (V_{ref}): Is the ship speed when measured/estimated under the above conditions.

To calculate EEDI, all the measurements and data used should be corrected to the above conditions.

3.5 EEDI Technical File

Calculation of Attained EEDI involves the determination / measurement / calculation of all the terms as identified in **Table 3.1** and their verification. Also, determination of Required EEDI is done via formulations provided in **Section 2.4**.

For verification purposes and subsequent implementation and enforcement purposes by flag and port States, it is a requirement that all the relevant terms and their values shall be recorded in an "EEDI Technical File" (see **Section 2.3**) and then submitted to the verifiers (normally Recognized Organization on behalf of flag State) that will carry out the certification on behalf of flag Administration. Also, the "EEDI Technical File" needs to be kept on board and forms a supplement to International Energy Efficiency Certificate.

IMO in its EEDI survey and verification guidelines [Resolution MEPC.254(67)] have provided a sample "EEDI Technical File". This sample indicates that all data necessary for verification purposes including all the terms defined in **Section 3.3** need to be recorded in this technical file.

4. EEDI Survey and Verification

4.1 Overview

EEDI verification is carried out by flag Administration (and most likely on their behalf by the by the ROs[4]), using corresponding data and documents and observing the ship's model tank tests and ship's commissioning sea trials. Full details of the EEDI verification are described in the relevant IMO Guidelines [Resolution MEPC.254(67)]. Accordingly, the EEDI verification takes place in two stages:

- **Pre-verification**
- **Final verification**

Pre-verification is done at the ship's design stage whereas final verification is carried out after construction and as part of the ship's commissioning sea trials; at the end of ship construction. Relevant ship design data, tank test data and speed trial data will be subject to scrutiny and verification by ROs. The aforementioned IMO guidelines on EEDI verification are developed to ensure consistency of verification, although some important issues such as speed-power scaling methods and unified approach for correction of the measured data has yet to be harmonised as part of industry practices. A document entitled "industry guidelines" has been developed by the main players for this purpose [Industry Guidelines (2015)].

Figure 4.1 shows the overall process diagram for EEDI verification.

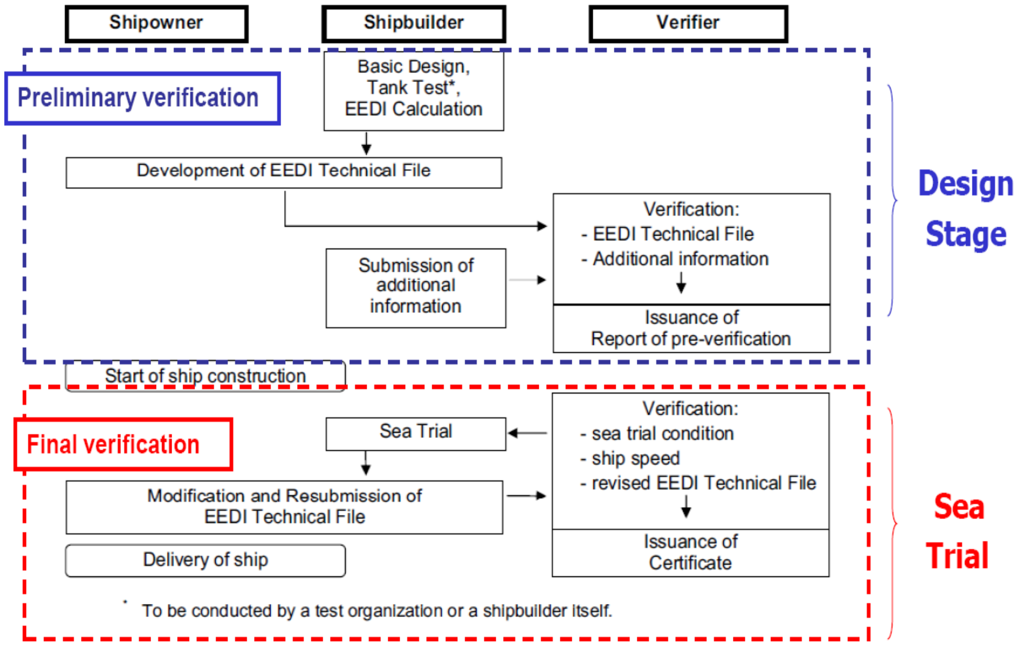


Figure 4.1: EEDI verification process

4.2 Preliminary verification

For the preliminary verification at the design stage, the following should be submitted to the verifier:

- An application for an initial survey.
- An "EEDI Technical File" containing the necessary information.
- Other relevant background documents and information.

[4] Class Societies will mainly act as ROs for this purpose.

The EEDI Technical File should be developed by the submitter (normally ship designer at this stage) inclusive of all the data required. The content of an EEDI Technical File was discussed in **Section 3.5** and will include all the required data for EEDI calculations.

In addition to the EEDI Technical File, the verifier may request additional information. Additional information that the verifier may request includes but not limited to:

- Description of the tank test facility including test equipment and calibrations.
- Lines of the model and the actual ship for the verification of the similarity of model and actual ship.
- Lightweight of the ship and displacement table for the verification of the deadweight. This may require submission of available ship stability data for verification purposes.
- Detailed report of the tank test; this should include at least the tank test results at sea trial condition and extrapolated values to the EEDI condition.
- Calculation process of the ship reference speed.
- Copy of the NOx Technical File and documented summary of the SFC correction for each type of engine with copy of engines' EIAPP certificate.
- Reasons for exempting a tank test, if applicable.
- Other specific data for specific ships: For example for ships using gas as primary fuel, the verifier may request data on gas fuel and liquid fuel tank arrangement and capacities for C_F calculation purposes.

The most important element of preliminary verification is the ship's model tank test. According to IMO guidelines [Resolution MEPC.254(67)]:

> "The speed power curve used for the preliminary verification at the design stage should be based on reliable results of tank test. A tank test for an individual ship may be omitted based on technical justifications such as availability of the results of tank tests for ships of the same type. In addition, omission of tank tests is acceptable for a ship for which sea trials will be carried under the "EEDI Condition"[5], upon agreement of the ship-owner and shipbuilder and with approval of the verifier. For ensuring the quality of tank tests, ITTC (International Towing Tank Conference) quality system should be taken into account. Model tank test should be witnessed by the verifier."

4.3 Final Verification

Sea trails and verification of ship's speed-power curve is an essential element of the final verification. As part of the final verification, all relevant aspects of EEDI calculation will be re-visited and verified. Aspects that need to be considered for sea trail are elaborated further here using the relevant IMO guidelines [Resolution MEPC.254(67)]

4.3.1 Sea trials - Observation

In order to ensure accurate EEDI calculation, sea trial conditions should be set close to the "EEDI Condition", if possible. As part of sea trail verification and prior to the sea trial, the following documents should be submitted to the verifier:

- Trial plan and test procedure: Description of the test procedure to be used for the speed trial, with number of speed points to be measured and indication of PTO/PTI to be in operation, testing area and method, etc.

[5] See **Section 3**

- The final displacement table and the measured lightweight, or a copy of the survey report of deadweight. Final stability file including lightweight of the ship and displacement table based on the results of the inclining test or the lightweight check. This will form the basis for verification of Capacity.
- A copy of engines' "NOx Technical File" as necessary.

The test procedure should include, as a minimum, descriptions of all necessary items to be measured and corresponding measurement methods. The verifier should attend the sea trial and confirm the following:

- Propulsion and power supply system.
- Particulars of the engines, and other relevant items described in the EEDI Technical File.
- Draught and trim: Should be confirmed by the draught measurements taken prior to the sea trial.
- Sea conditions: should be measured in accordance with ITTC Recommended Procedure 7.5-04-01-01.1 Speed and Power Trials Part 1; 2014 or ISO 15016:2015 [MEPC.261(68)].
- Ship speed: should be measured in accordance with ITTC Recommended Procedure 7.5-04-01-01.1 Speed and Power Trials Part 1; 2014 or ISO 15016:2015, and at more than two points of which range includes the power of the main engine as specified in paragraph 2.5 of the EEDI Calculation Guidelines [MEPC.261(68)].
- Shaft power of the main engine: Should be measured by shaft power meter or a method which the engine manufacturer recommends and the verifier approves.
- Results of on-board simplified measurement method of SFC: Only if on-board measurements are used for the calculation of SFC of an engine, copy of the measurements and documented calculation of the SFC correction will need to be provided.

4.3.2 Speed Trial: Ship speed-power curve

The main output of the speed trial will be the actual measured ship speed-power curve and its corrected/extrapolated equivalent for the EEDI Conditions. As most of the ships are normally tested under ballast conditions, the speed trial to EEDI Condition need to be developed through a number of corrections not only for sea and weather conditions but also extrapolated from ballast condition to EEDI loading condition (summer load line draught).

The required corrections for sea and weather conditions will need to be based on ITTC Recommended Procedure 7.5-04-01-01.2 Speed and Power Trials Part 2; 2014 or ISO 15016:2015 standard. The speed adjustment and correction from ballast condition to EEDI Condition plays and important role in an accurate estimation of EEDI. An example of a simplified method of the speed adjustment is given in **Figure 4.2** as is included in IMO EEDI survey and verification guidelines.

Accordingly, V_{ref} is obtained from the results of the sea trials at trial condition using the speed-power curves predicted by the tank tests. The tank tests shall be carried out at both draughts: trial condition corresponding to that of the speed-power trials and EEDI condition. For trial conditions the power ratio α_P between model test prediction and sea trial result is calculated for constant ship speed. Ship speed from model test prediction for EEDI condition at EEDI power multiplied with α_P is V_{ref}.

$$\alpha_P = \frac{P_{Trial,P}}{P_{Trial,S}}$$

where

$P_{Trial,P}$: power at trial condition predicted by the tank tests,

$P_{Trial,S}$: power at trial condition obtained by the S/P trials,

α_P : power ratio

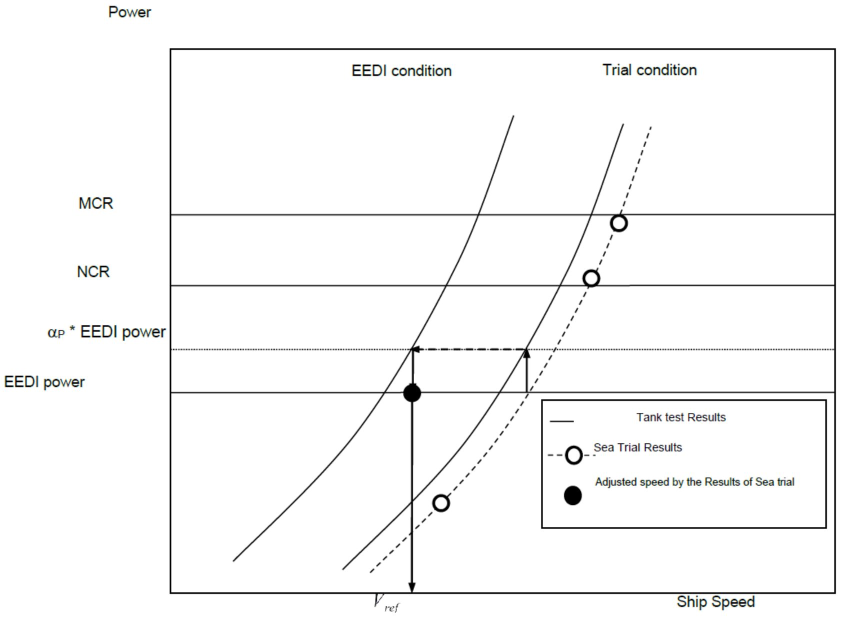


Figure 4.2: A scheme of conversion from trial condition to EEDI condition

The verifier is required to ensure that both correction and extrapolation of data to EEDI condition is done correctly and accurately. For this purpose, it is required that the full report of sea trials with detailed computation of the corrections allowing determination of the reference speed V_{ref} to be supplied to the verifier.

Additionally and to ensure consistency and accuracy, the submitter should compare the power curves obtained as a result of the sea trial and the estimated power curves at the design stage. In case of differences, the attained EEDI should be recalculated.

4.4 Verification of the Attained EEDI for major conversions

In case of a major conversion, the ship-owner should submit to a verifier an application for an Additional Survey with the EEDI Technical File duly revised based on the conversion made and other relevant background documents.

The background documents should include at least but are not limited to:

- Documents explaining details of the conversion.
- EEDI parameters changed after the conversion.
- Reasons for other changes made in the EEDI Technical File.
- Calculated value of the attained EEDI, with the calculation summary for each value of the calculation parameters and the calculation process.

The verifier normally will make sure that as a result of the “major conversion”, EEDI has not increased. In case of such an increase, the verifier will define the scope for sea trails, if any, and other activities to ensure compliance with regulation.

4.5 Verifier scope of activities

Based on what described in previous sections, the scope of verification activieis may be listed as below.

For preliminary verification, scope of the verifier work includes the following:

- Review the EEDI Technical File, check that all the input parameters are documented and justified and check that the possible omission of a tank test has been properly justified.
- Check that the ITTC procedures and quality system are implemented by the organization conducting the ship model tank tests. The verifier would possibly audit the quality management system of the towing tank if previous experience is insufficiently demonstrated.
- Witness the tank tests according to a test plan initially agreed between the submitter and the verifier.
- Check that the work done by the tank test organisation is consistent with the ITTC recommendations. In particular, the verifier will check that the power speed curves at full scale are determined in a consistent way between test condition and and fully loaded conditions.
- Issue a pre-verification report inclusive, possibly in the form of a preminary statement of compliance.

For final verification, scope of the verifier work includes the following:

- Examine the programme of the sea trial to check that the test procedure and in particular that the number of speed measurement points comply with the requirements of the IMO guidelines.
- Perform a survey to ascertain the ship principle and machinery characteristics to conform with those in the EEDI Technical File.
- Attend the sea trial and notes the main parameters to be used for the final calculation of the EEDI as discussed before.
- Review the sea trial report provided by the submitter and check that the measured power and speed have been corrected according to ITTC Recommended Procedure 7.5-04-01-01.2 Speed and Power Trials Part 2; 2014 or ISO 15016:2015 standard.
- Adjust the reference ship speed V_{ref} according to the simplified method and checks that the difference between the value provided by the submitter and the one computed by the simplified method don’t exceed the threshold value. If the threshold is exceeded, request and review a complete justification from the submitter.
- Review the revised EEDI Technical File, if applicable.
- Complete relevant parts of the Record of Construction and endorse.

4.6 SEEMP verification

The verification of SEEMP is only limited to checking if a SEEMP is on board. As indicated in **Section 2.5**, there is no need for verification of a SEEMP content to establish if it complies with relevant IMO guidelines. It is worth noting that this is the case at this point in time and may change in the future.

Upon verification of existence of SEEMP on board, relevant part of the Record of Construction will be completed.

4.7 International Energy Efficiency (IEE) Certificate and its supplements

Upon a successful verification and EEDI and SEEMP, where applicable, the following sets of documents will be issued to the ship by the verifier:

- An IEE Certificate
- A Record of Construction for Energy Efficiency will be attached to the certificate

Additionally, the following two documents that has already been used as part of verification are considered as supplements to the IEE certificate:

- EEDI Technical file
- SEEMP

The "Record of Construction" is a checklist that contains the checkboxes with regard to availability of the following information:

- Particular of ship
- Propulsion system details
- Attained EEDI
- Required EEDI
- SEEMP
- EEDI Technical File
- Endorsement that confirms that data are correct.

The verifier will endorse the "Record of Construction" to confirm that the above details have been checked and verified. For samples of "EEDI Technical File" refer to reference [Resolution MEPC.254(67)] and for format of IEE Certificate and the Record of Construction for Energy Efficiency refer to Annex VIII of MARPOL Annex VI.

According to IMO regulations [MEPC 203(62)]:

> "Upon successful verification of EEDI (for new ships) and verification of the existence of a SEEMP on-board for all ships, an IEE Certificate will be issued to the ship. The Certificate shall be issued or endorsed either by the Administration or any organization duly authorized by it. The IEE Certificate shall be drawn up in a form corresponding to the model given in Chapter 4 of MARPOL Annex VI."

As indicated before, IEE Certification will have the following specifics:

- The IEE Certificate will be valid throughout the life of the ship unless:
  - If the ship is withdrawn from service; or
  - If a new certificate is issued following major conversion of the ship; or
  - Upon transfer of the ship to the flag of another State.
- In relation to Chapter 4, any port State inspection shall be limited to verifying, when appropriate, that there is a valid IEE Certificate on board, in accordance with Article 5 of the MARPOL Convention.

4.8 Other related Guidelines

There are a number of additional guidelines that need to be used / consulted while conducting either the EEDI calculations or verification. These Guidelines include the following:

- **Resolution MEPC.232(65):** 2013 Interim Guidelines for determining minimum propulsion power to maintain the manoeuvrability (as amended by resolutions MEPC.255(67) and MEPC.262(68)).
- **MEPC.1/Circ.815:** 2013 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI for ships in adverse conditions.

A short description of the above guidelines follows.

4.8.1 Interim guidelines for minimum power

Introduction

One of the most effective ways of reducing a ship's EEDI is to choose a smaller main engine or main propulsion motor for the ship, thus reduce the ship's design speed. Within IMO a debate took place on how far speed reduction could be used for EEDI reduction? As a result, it was decided that there is a need to limit the use of this method of EEDI reduction so that it does not lead to unsafe and underpowered ships that may lose maneuvering capability under adverse weather condition. These guidelines effectively define a methodology for estimating the minimum propulsion power for each ship for safe maneuvering, thus ensuring that choice of the main propulsion engines/motors that satisfies these minimum requirements.

Accordingly, the purpose of the guidelines is to assist Administrations and ROs in verifying that ships, complying with EEDI, have sufficient installed propulsion power to maintain the maneuverability in adverse conditions [Resolution MEPC.232(65), as amended by resolutions MEPC.255(67) and MEPC.262(68)]. The guidelines currently apply to:

- Tankers
- Bulk carriers
- Combination carriers

Assessment methods

The methodologies proposed for estimating the minimum power are based on two assessment levels or methods that are briefly described.

Assessment Level 1 – Minimum power lines assessment: This is a simple approach and involves calculation of the minimum power from a specific line as a function of ship deadweight. For this purpose, the verifier should check if the ship has an installed power not less than the minimum power defined by the line represented by the following equation:

Minimum Power Line Value [MCR, kW] = *a*(DWT) + b*

Where "a" and "b" are constants and vary with ship type and given in the guidelines. As can be seen, this is a very simple approach.

Assessment Level 2 – Simplified assessment: This is a more mathematically involved method of assessment. The assessment procedure consists of two steps:

- Step 1: Definition of the required advance speed in head wind and waves, ensuring course-keeping in all wave and wind directions.
- Step 2: Assessment whether the installed power is sufficient to achieve the above required advance speed.

The required ship advance speed through the water in head wind and waves is decided first. Then relevant calculation formulas are used to determine the required power to achieve this advance speed. For details of relevant mathematics and equations, refer to IMO guidelines [Resolution MEPC.232(65), as amended by resolutions MEPC.255(67) and MEPC.262(68)].

4.8.2 Draft Guidelines for innovative energy efficiency technologies

Introduction

The purpose of this guidance is to assist manufacturers, shipbuilders, ship-owners, verifiers and other interested parties related to Energy Efficiency Design Index (EEDI) of ships to treat innovative energy efficiency technologies for calculation and verification of the attained EEDI [MEPC.1/Circ.815].

As indicated, the guidance document is in its preliminary stage and as such as time progresses:

- The guidance should be reviewed for the inclusion of new innovative technologies not yet covered by the guidance.
- The guidance also should be reviewed, after accumulating the experiences of each innovative technology, in order to make it more robust and effective, using the feedback from actual operating data.

Categorization of technologies

Innovative energy efficiency technologies are allocated to category (A), (B) and (C), depending on their characteristics and the way they influence the EEDI formula. Furthermore, innovative energy efficiency technologies of category (B) and (C) are categorized to two sub-categories (category (B-1) and (B-2), and (C-1) and (C-2), respectively).

- ***Category (A)***: Technologies that directly influence and shift the ship speed-power curve, which results in the change of combination of Propulsion Power (*PP)* and V_{ref}. For example, such technologies at constant V_{ref} can lead to a reduction of *PP;* or for a constant *PP* they could lead to an increased V_{ref}. All technologies that directly impact the ship hydrodynamics could have such impacts.

- ***Category (B)***: Technologies that reduce the *PP*, at a V_{ref}, but do not generate electricity. The saved energy is counted as P_{eff} .
    - ***Category (B-1)***: Technologies which can be used at all times during the operation (e.g. hull air lubrication) and thus the availability factor (f_{eff}) should be treated as 1.00.
    - ***Category (B-2)***: Technologies which can be used at their full output only under limited conditions and periods (e.g. wind power). The setting of availability factor (f_{eff}) should be less than 1.00.
- ***Category (C):*** Technologies that generate electricity. The saved energy is counted as P_{AEeff}
    - ***Category (C-1)***: Technologies which can be used at all times during the operation (e.g. waste heat recovery) and thus the availability factor (f_{eff}) should be treated as 1.00.
    - ***Category (C-2)***: Technologies which can be used at their full output only under limited condition (e.g. solar power). The setting of availability factor (f_{eff}) should be less than 1.00.

Table 4.1 shows the current categories of technologies and typical examples.

Innovative Energy Efficiency Technologies					
Reduction of Main Engine Power				Reduction of Auxiliary Power	
Category A	*Category B-1*	*Category B-2*		*Category C-1*	*Category C-2*
Cannot be separated from overall performance of the vessel	Can be treated separately from the overall performance of the vessel			Effective at all time	Depending on ambient environment
	$f_{eff}=1$	$f_{eff}<1$		$f_{eff}=1$	$f_{eff}<1$
– low friction coating – bare optimization – rudder resistance – propeller design	– hull air lubrication system (air cavity via air injection to reduce ship resistance) (can be switched off)	– wind assistance (sails, Flettner-Rotors, kites)		– waste heat recovery system (exhaust gas heat recovery and conversion to electric power)	– photovoltaic cells

Table 4.1: Innovative energy efficiency technologies categories [MEPC.1/Circ.815]

The way each category influences the EEDI is schematically shown in **Figure 4.3**. For example, "solar power" and "waste heat recovery" for power generation are category C and influence via the term shown by arrow as shown. Wind power is a category B and is influencing the last term in the nominator. Category A mainly influences the speed power curve thus P_{ME} and V_{ref}.

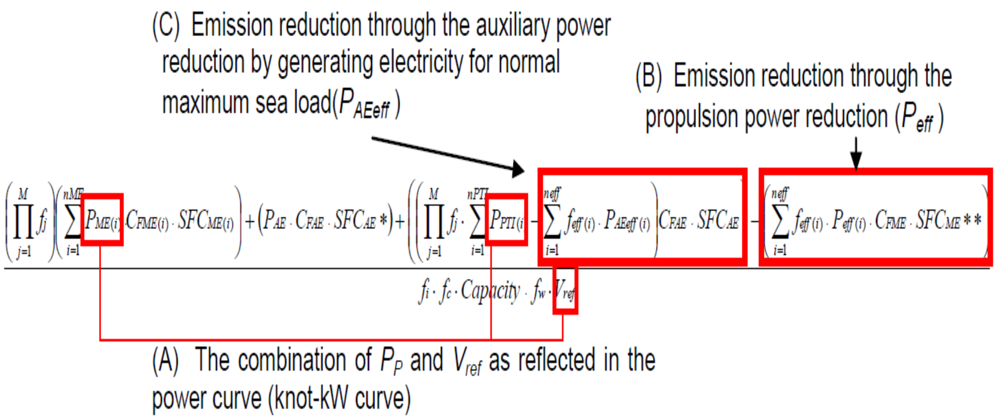
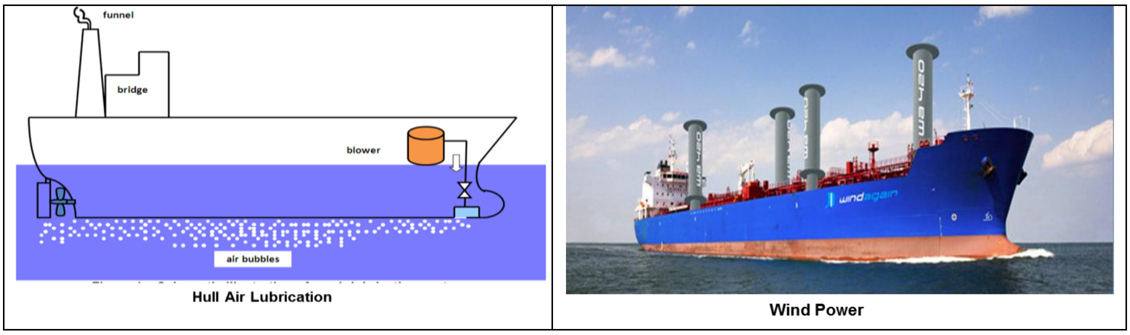


Figure 4.3: The way various categories influences the EEDI [MEPC.1/Circ.815]

The technologies that are currently covered in the guidelines are shown schematically in **Figure 4.4**.



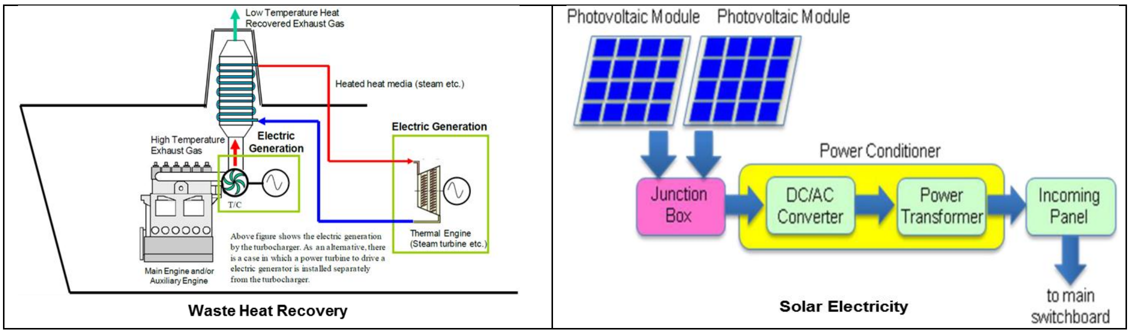


Figure 4.4: Technologies currently covered under the innovative technology guidelines [MEPC.1/Circ.815]

Calculation and verification of innovative technologies

The evaluation of the benefit of innovative technologies on EEDI is to be carried out in conjunction with the hull form and propulsion system with which it is intended to be used. Results of model tests or sea trials of the innovative technology in conjunction with different hull forms or propulsion systems may or may not be applicable. An outline of calculation and verification aspects is given here. Full details can be found in the relevant guidelines [MEPC.1/Circ.815].

Category A: Innovative energy efficiency technologies in category (A) affect *PP* and/or V_{ref} and their effects cannot be measured in isolation. Therefore, these effects should not be calculated nor certified in isolation but should be treated as part of the vessel's EEDI calculation and verification as described before using EEDI calculation guidelines and EEDI survey and verification guidelines.

Category B: The effects of innovative energy technologies in category (B) are expressed as P_{eff} which would be directly used together with f_{eff} in the EEDI formula. The calculation and verification of the above two parameters are described in Annex 1 of the guidelines (see **Figure 4.5**).

Category C: The effects of innovative energy technologies in category (C) are expressed as P_{AEeff} *and* f_{eff} which would be directly used in the EEDI formula. The details of calculation and verification of the above two parameters are detailed in Annex 2 of the guidelines **Figure 4.5**.

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Figure 4.5: Content of guidelines for calculation and verification of innovative technologies

The verification of innovative energy efficiency technologies is an involved process and is fully documented in MEPC.1/Circ.815. This is an interim guidance document and will evolve over time as experience is gained as a result of future use of these technologies.

5. Ship Energy Efficiency Management Plan (SEEMP) Development

According to MARPOL Annex VI Regulation 22, it is a requirement for ships of more than 400 GT operating internationally, to have a SEEMP on board from 1st January 2013. The SEEMP should be developed taking into account the relevant IMO guidelines. Existing ships will receive an IEE Certificate when the existence of SEEMP on-board is verified. This will happen at the 1st intermediate or renewal survey of the vessel after 1 January 2013, whichever is the first. It is expected that all the existing ships by now have gone through this process and possess an IEE certificate.

IMO has adopted guidelines for the development of SEEMP (Resolution MEPC.213(63)); from which most of the main features of a SEEMP are described in this section. According to IMO guidelines, the SEEMP establishes a mechanism for shipping companies to improve the energy efficiency of their ships operations. The SEEMP also provides an approach for monitoring of a ship efficiency performance over time. The SEEMP urges the ship owner and operator, that at each stage of the operation of the ship, to review and consider operational practices and technology upgrade to optimize the energy efficiency performance of a ship.

SEEMP development should follow the IMO guidelines. In this section, the main aspects of a SEEMP are discussed with a view to understand the regulatory requirements and best practice. The content of this section is mainly developed using the IMO guidelines [Resolution MEPC.213(63)]. The aim of this section is to cover the SEEMP regulatory requirements, practical aspects of SEEMP planning and development. The SEEMP implementation or best practice aspects are not included herein. Such topics are further covered in **Module 6** that deals with ship energy management systems.

5.1 SEEMP purposes

The purpose of a SEEMP is to establish a mechanism for a company and/or a ship to improve the energy efficiency of the ship during its operation. Preferably, the ship-specific SEEMP is linked to a broader corporate energy management system of the company that owns, operates or controls the ship. The ship-specific SEEMP is needed since no two shipping companies or ship-owners are the same, and that ships operate under a wide range of different conditions including geographical and commercial.

Many companies normally have an environmental management system (EMS) in place under ISO 14001[6] which contains procedures for selecting the best measures for particular vessels and then setting objectives for the measurement of relevant parameters, along with relevant control and feedback features. Monitoring of operational environmental efficiency should therefore be treated as an integral element of broader company environmental management systems. In addition, many companies already develop, implement and maintain a Safety Management System[7]. In such cases, the SEEMP may form part of the ship's Safety Management System.

The SEEMP is intended to be a management tool to assist a company in managing the on-going environmental performance of its vessels and as such, it is recommended that a company develops procedures for implementing the SEEMP in a manner which limits any on-board administrative burden to the minimum necessary.

[6] Also company's may have ISO 50001 on "energy management system" that could be directly linked to SEEMP.
[7] "Safety Management System" means a structured and documented system enabling company personnel to implement effectively the company's safety and environmental protection policy, as defined in *the* International Safety Management Code.

5.2 SEEMP framework

The SEEMP should be developed as a ship-specific plan by the ship-owner, operator or any other party concerned, e.g., charterer. The SEEMP seeks to improve a ship's energy efficiency through four steps:

- Planning;
- Implementation;
- Monitoring; and
- Self-evaluation and improvement.

These are shown in **Figure 5.1**. These stages are similar to PDCA (Plan-Do-Check-Act) stages of any other management system and the continuous improvement cycle.

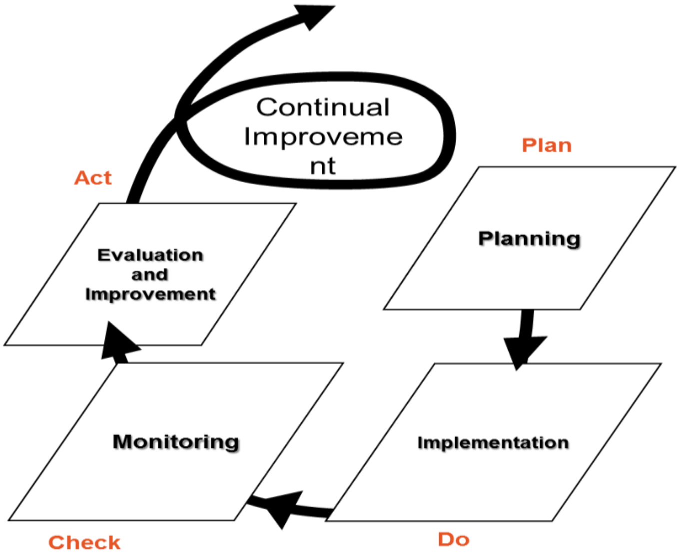

Figure 5.1: SEEMP continuous improvement concept

The PDCA components play a critical role in the continuous cycle to improve ship energy management. With each iteration of the cycle, some elements of the SEEMP will necessarily change while others may remain as before. The above components are further described in the following sections.

Figure 5.2 provides more detailed aspects of each stage of the cycle. Further description of each stage of the SEEMP cycle follows with reference to **Figures 5.1** and **5.2**.

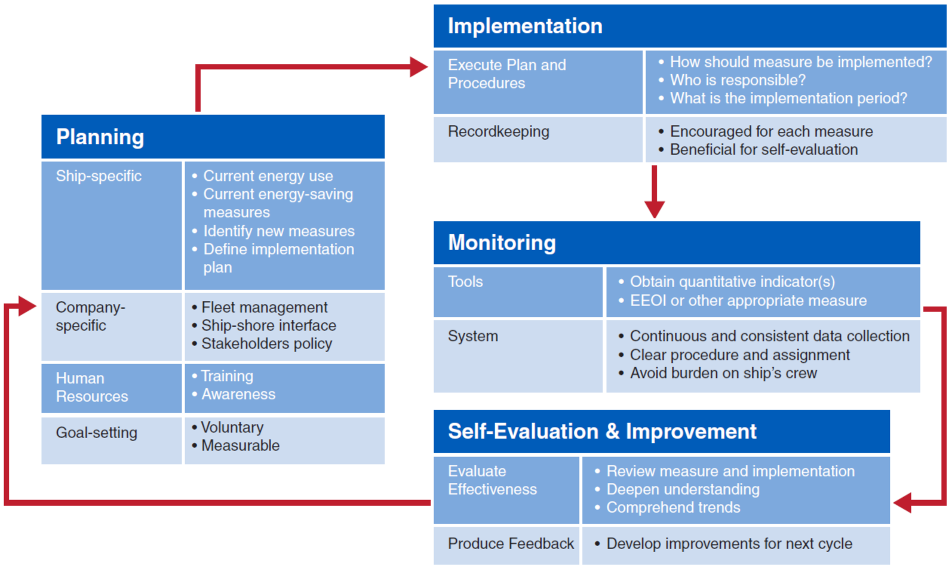

Figure 5.2: SEEMP as a 4-step ship energy management [ABS]

5.3 Planning

Planning is the most crucial stage of a SEEMP development. It involves activities such as determination of both:

- The current status of ship energy usage; and
- The expected improvements.

Based on the above and via using further energy reviews or audits, a set of Energy Efficiency Measures (EEMs) are identified and documented as part of the planning phase. The SEEMP planning activities do not stop at identification of EEMs but includes dealing with all aspects of planning for implementation, monitoring and self-assessment of the identified EEMs. Therefore, planning part for ship energy management and SEEMP is crucial and it is essential to devote sufficient time to planning.

5.3.1 Identification of ship's EEM

The first step in energy management planning is to identify the EEMs for improving the energy efficiency of a ship. It is important to note that there are a variety of options to improve a ship's efficiency; that the best EEMs for a ship to improve efficiency differs to a great extent for various ship types, cargoes, routes and other factors, As such, it is recommended that the specific EEMs for each ship needs to be defined.

To do this, there will be a need for carrying out activities such as energy audits or energy reviews[8] for the corresponding ship. SEEMP should be adjusted to the characteristics and needs of individual companies and ships, thus each ship will have its own ship-specific plan.

5.3.2 Goal Setting

According to IMO guidelines, goal setting for SEEMP is voluntary and there is no need for announcement to public nor are they subject to external inspection. Purpose of goal setting is to increase commitment to improving energy efficiency; thus the IMO guidelines encourage companies to set goals.

The goal should be measurable and easy to understand. It can take any form such as "annual fuel consumption", "EEOI targets" or other items.

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[8] For energy audit and review techniques, refer to **Module 5**.

On importance of goal setting, the following may be mentioned:

- Although IMO has made goal setting voluntary, a company with quantitative goals for their ship's energy efficiency would show more determination in this area.
- A goal will be a measureable indicator and will be used to evaluate if the set objectives are met.
- Many good quality companies already have quantitative goals for their ship energy management; primarily at corporate levels.
- Despite difficulty of goal setting at ship level, it is important that ways for making sure that the continuous improvement is actually taking place could be evaluated.
- Current IMO debates on data collection for ships and future likely MRV (see **Module 1**) is likely to deal with these aspects in the future. As such, SEEMP related regulatory framework is likely to be enhanced in the future.

5.3.3 Managing the stakeholders

The improvement of energy efficiency of a ship does not necessarily depend on ship operator/owner only. A number of stakeholders are involved as shown in **Figure 5.3**. These are:

- Port authorities who are in charge of port management and thus ships' use of ports and related delays and so on.
- Cargo owner and charterer that have ultimate authority for ship itinerary and commercial activities of the ship.
- Ship owner could be different from operator/manager and thus will impact ship operational efficiency via decision making on ship technical improvements and relevant investments.

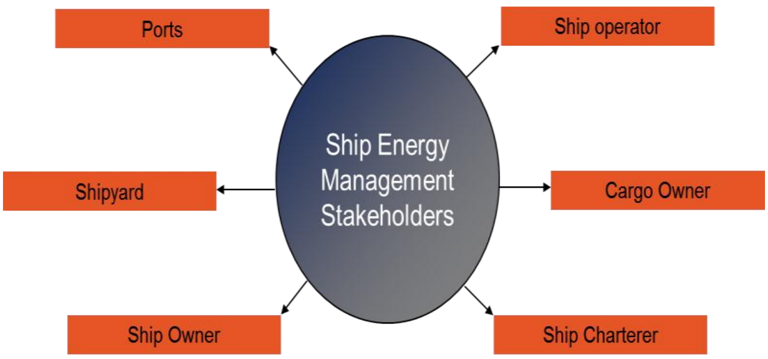

Figure 5.3: Ship energy management stakeholders

More coordination between stakeholders is more rewarding and to do this, the company should do the coordination rather than the ship. Therefore, IMO recommends that a company should also establish a "company energy management plan" to manage its fleet and ensures stakeholders' coordination. This will also reduce the work burden on ship-board staff.

On importance of company-level energy management plan/system, the following may be mentioned:

- The overall ship energy efficiency is highly impacted by many industry stakeholders who have influence on the way the ship is commercially operated.
- Main stakeholders are ship owner, ship operator/manager/ports, regulatory authorities, charterer, cargo owner and so on.

- Management of the above stakeholder to ensure good ship operation and loading profile is essential.
- Without effective stakeholders' management, most of potential energy saving opportunities will not be realized.
- The above could be realized as part of a "company energy management plan" as advocated by the IMO or a "company energy management system" as advocated by ISO 50001. For further details on this, refer to **Module 5**.

5.3.4 Human resources development

According to IMO guidelines, raising awareness and providing necessary training for personnel both on shore and on board are an important element. Such human resource development is encouraged and should be considered as an important component of planning as well as a critical element of implementation.

Additionally, the company should implement procedures, which limit any onboard administrative burden. The company management should define and communicate the companies' values and aspirations and detail how the company intends to achieve the objectives of their energy policy including the identification of roles and responsibilities, the setting of targets and monitoring performance.

5.4 Implementation

Two areas are of importance as far as planning for implementation is concerned:

- Establishment of an implementation system; and
- Record keeping.

Establishment of implementation system: A system for implementation of the selected EEMs needs to be defined via developing the procedures, tasks and assigning roles and responsibilities. The SEEMP should describe how each measure should be implemented and who the responsible person(s) is. The implementation period (start and end dates) of each selected measure should be indicated. The development of such a system can be considered as a part of planning, and therefore may be completed at the planning stage.

Record keeping: According to IMO guidelines, the planned EEMs should be carried out in accordance with the predetermined implementation system. Record-keeping for the implementation of each EEM is beneficial for self-evaluation and should be encouraged.

On the importance of implementation system and record keeping, it can be mentioned that:

- Without proper implementation of EEMs, the energy management objectives could not be completed.
- Assignment of responsibilities for various EEMs together with implementation process and schedules are important indicators that EEMs implementation is managed properly.
- Record keeping is important for not only monitoring purposes but also for use during self-assessment and the next planning phase of continuous improvement cycle.

5.5 Monitoring

In a SEEMP, the monitoring aspects also need to be clarified at the planning phase. Consistent data collection is the foundation for monitoring. To allow for meaningful and consistent monitoring, the monitoring system, including the procedures for collecting data and the assignment of responsible personnel, should be developed. The development of such a system can be considered as a part of planning, and therefore should be completed at the planning stage.

To avoid unnecessary administrative burdens on ships' staff, monitoring should be carried out as far as possible by shore staff, utilizing data obtained from existing ship-board log books and data systems. In this monitoring context, the ship’s EEOI that is introduced in **Section 6** may be advocated as the primary monitoring tool to ensure that the energy management cycle provides expected outcomes.

On the importance of monitoring, the following may be mentioned:

- Monitoring is an essential element of any management cycle. It is well known that “if one cannot measure, one cannot manage”. This applies to energy management system as well.
- Monitoring to a large extent relies on data collection and data analysis over long term. Thus establishment of a data collection and analysis system is an essential part of any monitoring system.
- To effectively analyse and make conclusions, a set of Key Performance Indicators (KPIs) need to be defined for quantitative assessment of the gathered data. As indicated, the KPIs could relate to overall ship performance (such as EEOI) or developed for each EEM.
- Data collection and analysis, performing internal audits, energy reviews, benchmarking, etc. and so on forms the backbone of any good monitoring system.

5.6 Self-evaluation and Improvement

Self-evaluation and improvement is the final phase of the management cycle (see **Figures 5.1** and **5.2**). It should produce meaningful feedback for planning stage of the next improvement cycle.

The purpose of self-evaluation is to evaluate the effectiveness of the planned measures and of their implementation. For this process, procedures for self-evaluation of ship energy management should be developed. Furthermore, self-evaluation should be implemented periodically by using data collected through monitoring.

On importance of self-evaluation and target setting for future improvements, the following may be mentioned:

- Self-evaluation and improvement is the responsibility of the management team.
- The closer this “management team” is to top management of the company, the more effective will be their decisions; thus is indicative of more corporate management engagement.
- Developing an energy policy, setting quantitative goals and committing investment in energy efficiency technologies and operations are main indications of the top management commitment.
- Results of the self-evaluation form the basis for planning of the next improvement cycle.
- Self-evaluation is normally done periodically for example annually or bi-annually.

5.7 SEEMP Format

IMO guidelines [Resolution MEPC.213(63)] provide a sample template for development of the SEEMP as shown in **Figure 4.3**.

A SAMPLE FORM OF A SHIP EFFICIENCY ENERGY MANAGEMENT PLAN

Name of Vessel:		GT:	
Vessel Type:		Capacity:	

Date of Development:		Developed by:	
Implementation Period:	From: Until:	Implemented by:	
Planned Date of Next Evaluation:			

1 MEASURES

Energy Efficiency Measures	Implementation (including the starting date)	Responsible Personnel
Weather Routeing	<Example> Contracted with [Service providers] to use their weather routeing system and start using on-trial basis as of 1 July 2012.	<Example> The master is responsible for selecting the optimum route based on the information provided by [Service providers].
Speed Optimization	While the design speed (85% MCR) is 19.0 kt, the maximum speed is set at 17.0 kt as of 1 July 2012.	The master is responsible for keeping the ship's speed. The log-book entry should be checked every day.

2 MONITORING

Description of monitoring tools

3 GOAL

Measurable goals

4 EVALUATION

Procedures of evaluation

Figure 5.4: Sample SEEMP template from IMO guidelines

Accordingly, the SEEMP will, as a minimum, include the following elements:

- Ship identification details
- Energy Efficiency Measures and how they should be implemented, responsible persons and timeline
- Monitoring aspects
- Goals (optional)
- Evaluation aspects.

There are already typically developed SEEMPs in public domain. An example is given in Reference [OCIMF 2011] for a tanker.

6. Energy Efficiency Operational Indicator (EEOI)

6.1 Introduction

As explained earlier (see **Module 1**), EEOI is one element of the IMO regulatory framework that is intended to act as an "energy efficiency performance indicator" during the operational phase of the ship and be used to monitor overall ship energy efficiency performance. IMO Guidelines "MEPC.1/Circ.684"[9] provide the methodology and basis for EEOI development and calculations. In this section, extracts of these Guidelines are provided in order to further understand the EEOI purpose and method of calculation. Additionally, information will be provided on the experience so far in the use of EEOI.

The purpose of EEOI, according to IMO guidelines, is to establish a consistent approach for measuring a ship's energy efficiency for each voyage or over a certain period of time. The EEOI is expected to assist ship-owners and ship operators in the evaluation of the operational performance of their fleet. It is hoped that it will enable the monitoring of individual ships in operation and thereby the results of any changes made to the ship or its operation. In fact The EEOI is advocated to be used as a monitoring tool in the SEEMP as discussed in **Section 3**.

EEOI, similar to EEDI, represents the amount of CO_2 emissions from a ship per unit of cargo-mile transport service (with a unit of gCO_2/tonne.mile). However as against the EEDI that is defined for one operating point of a ship, EEOI represents the actual CO_2 emission from combustion of all types of fuels on board a ship during each voyage, which is calculated by multiplying total fuel consumption for each type of fuel (distillate fuel, refined fuel or LNG, etc.) with the respective carbon factor of each fuel. The performed transport work is calculated by multiplying the actual mass of cargo (tonnes, number of TEU/cars, or number of passengers) and the corresponding actual distance in nautical mile travelled by the vessel.

At this stage, IMO has developed the EEOI to encourage ship-owners and ship operators to use it on a voluntary basis and to collect information on the outcome and experiences in applying it. So far, the feedback received on effectiveness of EEOI as a monitoring tool has been mixed.

The rest of this section is taken mostly from IMO Guidelines [MEPC.1/Circ.684] with some textual adjustments. The main aim of the section is to become familiar with the IMO guidelines and how EEOI is calculated.

6.2 Background and objectives

The EEOI guidelines can be used to establish a consistent approach for the voluntary use of an EEOI, which will assist ship-owners, ship operators and parties concerned in the evaluation of the performance of their fleet with regard to CO_2 emissions. As the amount of CO_2 emitted from a ship is directly related to its actual fuel consumption, the EEOI can also provide useful information on a ship's performance with regard to its operational fuel efficiency.

The objective of the IMO guidelines is to provide the users with assistance in the process of establishing a mechanism to achieve the limitation or reduction of GHG emissions from ships in operation. The EEOI guidelines are intended to provide an example of a calculation method which could be used as an objective, performance-based approach to monitor the efficiency of a ship's operation.

The EEOI Guidelines are recommendatory in nature and present a possible use of an operational indicator. However, ship-owners, ship operators and parties concerned may implement either the

[9] IMO, Marine Environment Protection Committee, *Guidelines for Voluntary Use of the Ship Energy Efficiency Operational Indicator,* MEPC.1/Circ.684, 2009. This is currently a voluntary guideline and not mandatory.

IMO guidelines or an equivalent method in their environmental management systems and consider adoption of the principles therein when developing plans for performance monitoring.

6.3 Basic definitions

To help with consistent estimation of EEOI, the following definitions are provided in the EEOI guidelines:

Fuel consumption: *Fuel consumption* is defined as all fuels consumed at sea and in port or for a voyage or period in question (e.g., a day), by main, auxiliary engines, boilers and incinerators.

Distance sailed: *Distance sailed* means the actual distance sailed in nautical miles (deck log-book data) for the voyage or period in question.

Ship and cargo types: The EEOI guidelines are applicable for all ships performing transport work. The types of cargo are generic and include but not limited to: all gas, liquid and solid bulk cargo, general cargo, containerized cargo, heavy lifts, frozen and chilled goods, timber and forest products, cargo carried on freight vehicles, cars and freight vehicles on Ro-Ro ferries and passengers (for passenger and Ro-Ro passenger ships).

Cargo mass carried or work done: In general, *cargo mass carried or work done* is expressed as follows:

- For dry cargo carriers, liquid tankers, gas tankers, ro-ro cargo ships and general cargo ships, metric tonnes (t) of the cargo carried should be used;
- For containerships carrying solely containers, number of containers (TEU) or metric tons (t) of the total mass of cargo and containers should be used;
- For ships carrying a combination of containers and other cargoes, a TEU mass of 10 t could be applied for loaded TEUs and 2 t for empty TEUs; and
- For passenger ships, including ro-ro passenger ships, number of passengers or gross tonnes of the ship should be used;

In some particular cases, work done can be expressed as follows:

- For car ferries and car carriers, number of car units or occupied lane metres;
- For containerships, number of TEUs (empty or full); etc.

It should be generally noted that for specific cases, the choice of cargo definition should fit the purpose of energy management and may vary from one company to the other.

Voyage: *Voyage* generally means the period between a departure from a port to the departure from the next port. Alternative definitions of a voyage could also be acceptable.

Consistent implementation of the above definitions in a company is essential for subsequent benchmarking of energy performance indicators such as EEOI across the fleet.

6.4 Establishing the EEOI

Calculation formula

The basic expression for EEOI for a voyage is defined as:

$$EEOI = \frac{\sum_j FC_j \times C_{Fj}}{m_{cargo} \times D} \qquad (1)$$

The guidelines allow averaging of EEOI over a number of voyages. Where the average of the indicator for a period or for a number of voyages is obtained, the EEOI is calculated as:

$$AverageEEOI = \frac{\sum_i \sum_j (FC_{ij} \times C_{Fj})}{\sum_i (m_{cargo,i} \times D)} \qquad (2)$$

Where:

- j is the fuel type;
- i is the voyage number;
- FC_{ij} is the mass of consumed fuel j at voyage i;
- C_{Fj} is the fuel mass to CO_2 mass conversion factor for fuel j;
- m_{cargo} is cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships; and
- D is the distance in nautical miles corresponding to the cargo carried or work done.

The unit of EEOI depends on the measurement of cargo carried or work done, e.g., tonnes CO_2/(tonnes·nautical miles), tonnes CO_2/(TEU·nautical miles), tonnes CO_2/(person·nautical miles), etc. It should be noted that Equation (2) does not give a simple average of EEOI among the number of voyages; thus simple averaging of the voyages' EEOI must be avoided. Instead, for using the average value as a performance indicator, calculation of rolling average is used.

Rolling average

Rolling average, when used, can be calculated in a suitable time period, for example one year or a number of voyages, for example six or ten voyages, which are agreed as statistically relevant to the initial averaging period. The rolling average EEOI is then calculated for this period or number of voyages by Equation (2) above using the following technique.

For a series of voyages (e.g. for 20 voyages), the first element of the rolling average (e.g. for a subset of 4 voyages) is obtained by taking the average of the initial number of voyages (e.g. initial 4). Then the subset is modified by "shifting forward"; that is, excluding the first voyage in the previous subset (e.g. voyage 1) and including the next voyage (e.g. voyage 5). This new subset number two will give the second rolling average element. This process continues until all voyages are covered.

Data sources

Primary data sources selected could be the ship's log-book (bridge log-book, engine log-book, deck log-book and other official records). It is important that sufficient information is collected on the ship with regard to fuel type and quantity, distance travelled and cargo type so that a realistic assessment can be generated.

Amount and type of fuel used (bunker delivery notes or other sources) and distance travelled (according to the ship's log-book or other sources) need to be documented by the ship on a consistent basis. The whole process may be automated if possible.

Fuel mass to CO_2 mass conversion factors (C_F)

C_F is a non-dimensional conversion factor between fuel consumption and CO_2 emissions produced. It is used in EEOI formula; see Equations (1) and (2). The value of C_F according to IMO guidelines is given in **Table 6.1**.

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

Table 6.1: Carbon factor of marine fuels

Data collection template

For a voyage or period (e.g., a day), data on fuel consumption/cargo carried and distance sailed in a continuous sailing pattern could be collected as shown in the reporting sheet below, **Table 6.2**.

Name and type of ship						
Voyage or day (i)	Fuel consumption at sea and in port in tonnes				Voyage or time period data	
	Fuel type ( )	Fuel type ( )	Fuel type ( )	…	Cargo (m) (tonnes or units)	Distance (D) (NM)
1						
2						
3						
4						

Note: For voyages with m_{cagro}=0, it is still necessary to include the fuel used during this voyage in the summation above the line.

Table 6.2:- EEOI data reporting sheet (template) [MEPC.1/Circ.684]

The above template is from IMO guidelines; however alternative templates may be used for the purpose if required.

6.5 Further aspects

Main calculation steps

The EEOI should be a representative value of the energy efficiency of the ship operation over a consistent period which represents the overall trading pattern of the vessel. In order to establish the EEOI, the following main steps will generally be needed:

- Define the period for which the EEOI is calculated[10]
- Define data sources for data collection
- Collect data
- Convert data to appropriate format; and finally
- Calculate EEOI.

Data recording and documentation procedures

Ideally, the data recording method used should be uniform so that information can be easily collated and analysed to facilitate the extraction of the required information. The collection of data from ships should include the distance travelled, the quantity and type of fuel used, and all fuel information that may affect the amount of carbon dioxide emitted.

Monitoring and verification

Documented procedures to monitor and measure, on a regular basis, should be developed and maintained. It is important that the source of figures established are properly recorded, the basis on which figures have been calculated and any decisions on difficult or grey areas of data. This will provide assistance on areas for improvement and be helpful for any later analysis.

Ship and shore responsibility

Based on IMO guidelines and in order to avoid unnecessary administrative burdens on ships' staff, it is recommended that monitoring of an EEOI should be carried out by shore staff, utilizing data obtained from existing required records such as the official and engineering log-books and oil record books, etc. The necessary data could be obtained during internal audits under the ISM Code, routine visits by superintendents, etc.

[10] Ballast voyages, as well as voyages which are not used for transport of cargo, such as voyage for docking service, should also be included. Voyages for the purpose of securing the safety of a ship or saving life at sea should be excluded.

7. References and further reading

1. MEPC.1/Circ.684, "Guidelines for voluntary use of the ship EEOI", MEPC.1/Circ.684, 17 August 2009.
2. Resolution MEPC.203(62) "Amendments to the Annex of the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978" relating thereto (Inclusion of regulations on energy efficiency for ships in MARPOL Annex VI), IMO MEPC, adopted 15 July 2011.
3. Resolution MEPC.212(63): "2012 Guidelines on the Method of Calculation of the Attained EEDI for new ships", Adopted by IMO MEPC on 2 March 2012.
4. Resolution MEPC.213(63), "2012 Guidelines for the development of a ship energy efficiency management plan (SEEMP)" IMO MEPC, Adopted on 2 March 2012.
5. Resolution MEPC.214(63): "2012 Guidelines on Survey and Certification of the EEDI", IMO MEPC, adopted on 2 March 2012.
6. Resolution MEPC.231(65): 2013 Guidelines for calculation of reference lines for use with the energy efficiency design index (EEDI), adopted in 2013.
7. Resolution MEPC.232(65): 2013 Interim Guidelines for determining minimum propulsion power to maintain the manoeuvrability.
8. Resolution MEPC.233(65): 2013 Guidelines for calculation of reference lines for use with the Energy Efficiency Design Index (EEDI) for cruise passenger ships having non-conventional propulsion.
9. ABS "Ship Energy Efficiency Measures, Status and Guidance", http://ww2.eagle.org/content/dam/eagle/publications/2013/Energy%20Efficiency.pdf, cited September 2015.
10. IMO MARPOL Annex VI, 2013, "MARPOL Annex VI and NTC 2008 with Guidelines for Implementation, 2013 Edition, IMO.
11. Resolution MEPC.229(65), "Promotion of Technical Co-Operation and Transfer of Technology Relating to the Improvement of Energy Efficiency of Ships", Adopted on 17 May 2013.
12. MEPC.1/Circ.795.rev1 Unified Interpretations to MARPOL Annex VI (2014).
13. MEPC.1/Circ.815: 2013 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI for ships in adverse conditions.
14. Resolution MEPC.254(67): 2014 Guidelines on Survey and Certification of EEDI (one amendments made in MEPC 68).
15. Resolution MEPC.245(66): 2014 Guidelines on the method of calculation of the Attained Energy Efficiency Design Index (EEDI) for new ships, adopted 4 April 2014.
16. Resolution MEPC.251(66): Amendments to MARPOL Annex VI and the NOX Technical Code 2008 (Changes to Regs. 2, 13, 19, 20 and 21 and …. and certification of dual-fuel engines under the NOX Technical Code 2008), Adopted on 4 April 2014.
17. Resolution MEPC.245(66): 2014 Guidelines on the Method of Calculation of the Attained EEDI for new ships, Adopted on 2 March 2012.
18. Industry Guidelines (2015): 2015 Industry guidelines on calculation and verification of Energy Efficiency Design Index, MEPC 68 / INF.30.

19. OCIMF "Example of a Ship Energy Efficiency Management Plan", Submission to IMO, MEPC 62/INF.10, 8 April 2011.

20. Resolution MEPC.260(68) , Amendments to the 2011 Guidelines Addressing Additional Aspects to the Nox Technical Code 2008 with Regard to Particular Requirements Related to Marine Diesel Engines Fitted with Selective Catalytic Reduction (SCR) Systems (Resolution MEPC.198(62)), adopted on 15 May 2015.

21. Resolution MEPC.259(68), 2015 Guidelines for Exhaust Gas Cleaning Systems, adopted on 15 May 2015.

22. Resolution MEPC.261(68), "Amendments to the 2014 Guidelines on Survey and Certification of the Energy Efficiency Design Index (EEDI)", (Resolution MEPC.254(67)), adopted on 15 May 2015.

23. Resolution MEPC.262(68), "Amendments to the 2013 Interim Guidelines for

24. Determining Minimum Propulsion Power to Maintain the Manoeuvrability of Ships in Adverse Conditions", (Resolution MEPC.232(65), as amended by Resolution MEPC.255(67)), adopted on 15 May 2015.

25. Resolution MEPC.263(68), "Amendments to the 2014 Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships, (Resolution MEPC.245(66)), adopted on 15 May 2015.