Chapter 3
The Energy Efficiency Design Index (EEDI)

Maria Polakis, Panos Zachariadis, and Jan Otto de Kat

Abstract Thus far the only regulatory measure to reduce greenhouse gases (GHGs) from ships is the adoption of the Energy Efficiency Design Index (EEDI) by the IMO in 2011. This chapter will go over the rationale behind EEDI and the important factors that influence compliance of a vessel's Attained EEDI with the regulatory limit of ship-type specific reference lines (Required EEDI) set by the IMO. This chapter will also go over related concepts and requirements, such as the Ship Energy Efficiency Management Plan (SEEMP) and the Energy Efficiency Operational Indicator (EEOI). Concerns around possible implications directly linked or relevant to the EEDI framework will be outlined, including EEDI vs minimum propulsion power. The Existing Vessel Design Index (EVDI) rating of RightShip will also be presented. Last but not least, a discussion of the weaknesses of EEDI will be provided.

Abbreviations

AER	Annual Efficiency Ratio
AHEWG-TT	Ad Hoc Expert Working Group on Facilitation of Transfer of Technology for Ships
BIMCO	Baltic and International Maritime Council
CO_2	Carbon dioxide
CSI	Clean Shipping Index
DCS	Data Collection System
DWT	Deadweight
EEDI	Energy Efficiency Design Index

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EEOI	Energy Efficiency Operational Indicator
EIAPP	Engine International Air Pollution Prevention
ETS	Emission trading system
EVDI	Existing Vessel Design Index
FORS	Fuel Oil Reduction Strategy
FPSO	Floating production storage and offloading
FSU	Floating storage unit
GHG	Greenhouse gas
GT	Gross tonnage
IACS	International Association of Classification Societies
IEE	International Energy Efficiency
IMO	International Maritime Organization
ISO	International Organization for Standardization
ITTC	International Towing Tank Conference
LNG	Liquefied natural gas
MARPOL	The International Convention for the Prevention of Pollution from Ships
MCR	Maximum continuous rating
MEPC	Marine Environment Protection Committee
MPP	Minimum propulsion power
PP	Propulsion power
PSC	Port State Control
RO	Recognized organization
SEEMP	Ship Energy Efficiency Management Plan
SFOC	Specific fuel oil consumption
SMS	Safety management system
VLCC	Very large crude carrier

1 Introduction

For the past decade, energy regulations and global demand for reducing international shipping's greenhouse gas (GHG) emissions have progressively stimulated innovation and targeted technology readiness of all components influencing the performance of a ship from its design phase.

The Energy Efficiency Design Index (EEDI) was established as part of the International Maritime Organization's (IMO) strategy to reduce carbon dioxide (CO_2) emissions from shipping and provides a benchmark for comparing the energy efficiency of vessels, while setting a minimum required level of efficiency for different ship type and size segments.

The EEDI was the first legally binding climate change treaty to be adopted since the Kyoto Protocol and made mandatory for new ships at the 62nd session of IMO's Marine Environment Protection Committee (MEPC 62) with the adoption of amendments to MARPOL Annex VI, IMO (2011a). Following this breakthrough, the IMO MEPC, at its 63rd session of March 2012, adopted four important guidelines, IMO (2012a, b, c, d) aimed at assisting the implementation of the mandatory regulations on Energy Efficiency for Ships formally introduced into Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL).

The EEDI for new ships aims at promoting the use of more energy-efficient (less polluting) equipment and engines. The EEDI requires a minimum energy efficiency level per capacity mile (e.g., tonne mile) for different ship type and size segments. From 1 January 2013, following an initial 2-year Phase 0 when new ship design will need to meet the reference level for their ship type, the level is to be tightened incrementally by 10% every 5 years. Therefore, regulations on EEDI are intended to stimulate continued innovation and technical development of all the components influencing the fuel efficiency of a ship from its design phase.

The EEDI is a non-prescriptive, performance-based mechanism that leaves the choice of technologies to use in a specific ship design to the industry. As long as the required energy efficiency level is attained, ship designers and builders are free to use the most cost-efficient solutions for the ship to comply with the regulations. EEDI is thus a goal-based technical standard intended to encourage improvements in ship design and to promote the use of less polluting equipment and engines.

The EEDI provides a specific numerical figure for an individual ship design, expressed in grams of CO_2 per ship's capacity mile (the smaller the EEDI, the more energy efficient is the ship's design) and is calculated by the formula below which is based on the technical design parameters for a given ship:

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

Starting on 1 January 2013, an initial 2-year "Phase 0" required new ship designs to meet the reference level for their specific ship type. From that point on, new designs are required to become progressively more efficient in three more "phases" reaching a 30% reduction between 2025 and 2030 for applicable ship types.

The rest of this chapter is organized as follows: Sect. 2 provides an overview of the EEDI regulations. Section 3 outlines the details of the EEDI calculation formula. Section 4 describes the EEDI survey and verification process. Section 5 describes the minimum propulsion power requirements under EEDI Regulation 21. Section 6 discusses weaknesses of EEDI. Finally Section 7 includes suggestions on way forward for improvement of EEDI.

2 Overview of EEDI Regulations: MARPOL Annex VI

The primary changes that the new energy regulations brought to MARPOL Annex VI can be categorized as follows:

- Amendments to existing regulations as a result of energy efficiency
- Introduction of new regulations specifically for energy efficiency

2.1 Amendments to Existing Regulations

A summary of the changes are briefly described here and also shown in Table 3.1.

Regulation 2 Introduction of definitions for "new ship" that are applicable to various Phases of EEDI regulations, "major conversion," "conventional/non-conventional propulsion," 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 "new ship" and "major conversion" terms were required, see IMO (2014a). Additionally, terms such as "Attained EEDI" and "Required EEDI" were defined.

Regulation 5 Requirements were specified for surveys including an initial survey for newly built ships, a full or partial survey in case of a major conversion of existing ships, a survey for a Ship Energy Efficiency Management Plan (SEEMP) to verify

Table 3.1 Existing regulations/amended regulations shown in red

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

Source: IMO (2015e)

its existence on board ship, etc. Regulation 5 states that EEDI survey and verification shall be carried out according to relevant IMO guidelines.

Regulations 7 and 8 The changes to these regulations deal with energy efficiency certification. For ships subject to EEDI regulations, an International Energy Efficiency (IEE) Certificate was made mandatory. The responsibility of the Flag Administration was also emphasized:

> 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. IMO (2011a)

Regulation 9 The validity aspects of the IEE Certificate were defined. The IEE Certificate has been determined to 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 IEE Certificate shall be valid throughout the life of the ship subject to the provisions of paragraph below:

> An IEE 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 . . . . . . IMO (2011a)

Regulation 10 This regulation specifies how compliance with the EEDI requirements is verified by Port State Control Authorities and defines the extent of the inspection scheme. At present stage, as described in MEPC Resolution 203(62), a Port State Control (PSC) inspection would be limited to verifying that a valid IEE Certificate exists on board the vessel files.

2.2 Introduction of New Regulations: Chapter 4

The introduction of EEDI regulations came following a series of discussions at the IMO MEPC sessions. The committee in July 2011 at its 62nd session reached a consensus to add a new Chapter 4 to MARPOL Annex VI, covering the new requirements exclusively. The consensus though was not general as a group of member states primarily consisting of developing countries were strongly opposed to the agreement.

Table 3.2 shows an outline of the newly introduced regulations.

A short description of the main aspects of these new regulations is provided below.

Regulation 19 Regulation 19 specifies the domain of application of the energy efficiency regulations. Chapter 4 of MARPOL Annex VI applies to all ships of 400 gross tonnage (GT) and above that are engaged in international voyages. It gives

Table 3.2 Newly introduced 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**

Source: IMO (2015e)

limited power to Administrations to waive the requirements for EEDI for a new ship contracted before 1 January 2017 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, stressing that some ships may not be able to comply with IMO requirements while considered as good design ships. According to IMO sources, there has been no need for Administrations to use this option.

Regulation 20 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. According to Regulation 20:

- Attained EEDI must be calculated for each new ship, each new ship that undergoes a major conversion, or existing ships that undergo so many changes that according to the Administration’s judgment are 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 Attained EEDI.
- The Attained EEDI must be calculated taking into account relevant IMO guidelines.
- 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 B.3 on details of verification).

The following ship types are currently required to comply with the Attained EEDI regulation:

1. Bulk carrier
2. Gas carrier
3. Tanker
4. Containership
5. General cargo ship
6. Refrigerated cargo ship
7. Combination carrier
8. Passenger ship
9. Ro-Ro cargo ship (vehicle carrier)
10. Ro-Ro cargo ship
11. Ro-Ro passenger ship
12. LNG carrier
13. Cruise passenger ship

The definitions of the 13 ship types are described in Regulation 2 of MARPOL ANNEX VI and presented cumulatively in Table 3.3 below:

Of these ship types, EEDI is only applicable to ships with conventional propulsion, i.e., engines that are either direct drive or geared. However, EEDI would not apply to ships not propelled by mechanical means, including floating production storage and offloading assets (FPSO), floating storage units (FSU), and drilling rigs, regardless of their propulsion. Cruise ships however are subject to EEDI regulations when fitted with nonconventional propulsion (such as diesel-electric propulsion, turbine propulsion, or hybrid propulsion systems). Liquefied natural gas (LNG) carriers need to comply when fitted with either conventional or nonconventional propulsion.

Some vessel types are not defined in the regulations. If these types do not fall under 1 of the 13 mandatory vessel types, then it is not mandatory for them to comply with Regulation 20 or Regulation 21.o.

EEDI regulations do not apply to cargo ships with ice-breaking capability but do apply to ice-strengthened ships.

Regulation 21 Regulation 21 provides the requirement and guidelines for calculating the Required EEDI and verifying that a vessel's Attained EEDI is less than the Required EEDI. The Required EEDI is the regulatory limit for EEDI, and its calculation is dependent on a reference line value and a reduction factor.

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 (DWT). The reference line is a regression, i.e., a mathematical distribution of data representing the average efficiency for ships built between years 1999 and 2009. Reference lines have been developed for each individual ship type

Table 3.3 Definition of each type of ship defined in Regulation 2 of MARPOL ANNEX VI, Chap. 4

Reg.	Ship type	Definition
2.25	Bulk carrier	A ship which is intended primarily to carry dry cargo in bulk, including such types as ore carriers as defined in SOLAS Chap. XII, Regulation 1 but excluding combination carriers
2.26	Gas carrier	A cargo ship, other than an LNG carrier as defined in paragraph 38 of this regulation, constructed or adapted and used for the carriage in bulk of any liquefied gas
2.27	Tanker	An oil tanker as defined m MARPOL Annex I, Regulation 1 or a chemical tanker or an NLS tanker as defined in MARPOL Annex II, Regulation 1
2.28	Container ship	A ship designed exclusively for the carriage of containers in holds and on deck
2.29	General cargo ship	A ship with a multi-deck or single deck hull designed primarily for the carriage of general cargo This definition excludes specialized dry cargo ships, which are not included in the calculation of reference lines for general cargo ships, namely, livestock carrier, barge carrier, heavy load carrier, yacht carrier, and nuclear fuel carrier
2.30	Refrigerated cargo carrier	A ship designed exclusively for the carriage of refrigerated cargoes in holds
2.31	Combination carrier	A ship designed to load 100% deadweight with both liquid and dry cargo in bulk
2.32	Passenger ship	A ship which carries more than 12 passengers
2.33	Ro-ro cargo ship (vehicle carrier)	A multi-deck roll-on-roll-off cargo ship designed for the carriage of empty cars and trucks
2.34	Ro-ro cargo ship	A ship designed for the carriage of roll-on-roll-off cargo transportation units
2.35	Ro-ro passenger ship	A passenger ship with roll-on-roll-off cargo spaces
2.38	LNG carrier	A cargo ship constructed or adapted and used for the carriage in bulk of liquefied natural gas (LNG)
2.39	Cruise passenger ship	A passenger ship not having a cargo deck, designed exclusively for commercial transportation of passengers in overnight accommodations on a sea voyage

Source: ClassNK (2015)

and relate the EEDI value to the vessel's size (deadweight, DWT or gross tonnage, GT). 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 the relevant IMO guidelines, IMO (2013a) and IMO (2013c). Example reference lines developed by the IMO for four indicative vessel types are shown in Fig. 3.1.

The regression equations for each ship type are embodied in Regulation 21 in the form of a formula:

$$\text{Reference EEDI} = a \times b^{-c}$$

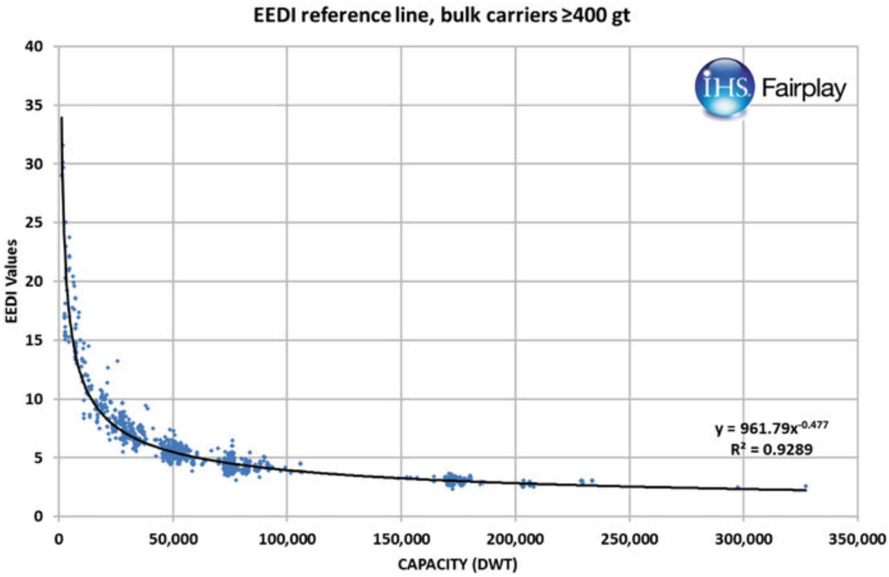

Fig. 3.1 EEDI reference line for bulk carrier developed by the IMO (IMO 2013a, b, c, d, e). (Source: IMO 2015e)

Table 3.4 Parameters for determination of reference line values for the different ship types

Ship type		Reference line
Bulk carrier		$961.79 \times DWT^{-0.477}$
Gas carrier		$1120.00 \times DWT^{-0.456}$
Tanker		$1218.80 \times DWT^{0.488}$
Container ship		$174.22 \times DWT^{-0.201}$
General cargo ship		$107.48 \times DWT^{-0.216}$
Refrigerated cargo carrier		$227.01 \times DWT^{-0.244}$
Combination carrier		$1219.00 \times DWT^{-0.488}$
Ro-ro cargo ship (vehicle carrier)	DWT/GT < 0.3	$((DWT/GT)^{-0.7} \times 780.36) \times DWT^{-0.471}$
	DWT/GT ≥ 0.3	$1812.63 \times DWT^{-0.471}$
Ro-ro cargo ship		$1405.15 \times DWT^{-0.498}$
Ro-ro passenger ship		$752.16 \times DWT^{-0.381}$
LNG carrier		$2253.7 \times DWT^{-0.474}$
Cruise passenger ship having nonconventional propulsion		$170.84 \times GT^{-0.214}$

Source: ClassNK (2015)

Parameters *a*, *b*, and *c* for some of the ship types are given in Table 3.4.

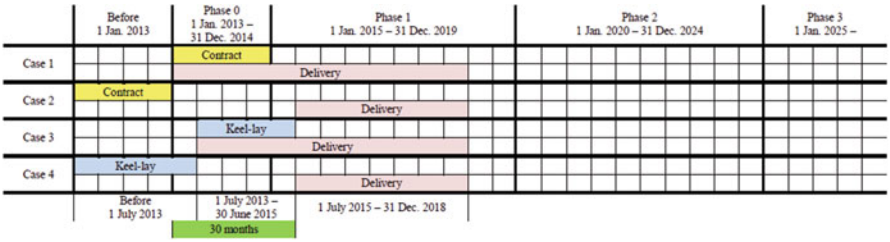

Fig. 3.2 Required EEDI of Phase 0. (Source: ClassNK 2015)

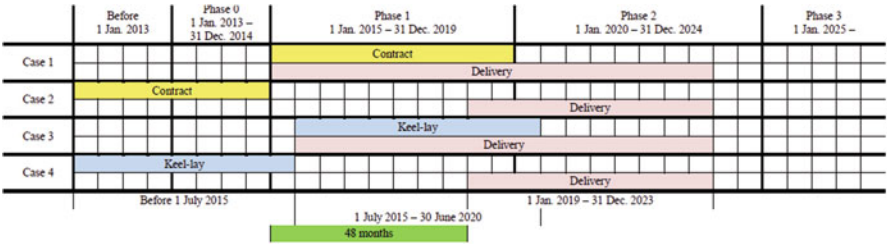

Fig. 3.3 Required EEDI of Phase 1. (Source: ClassNK 2015)

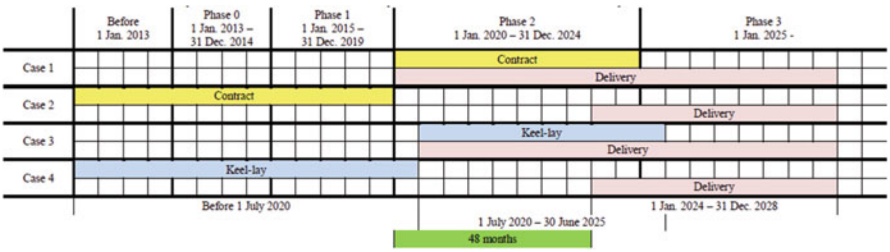

Fig. 3.4 Required EEDI of Phase 2. (Source: ClassNK 2015)

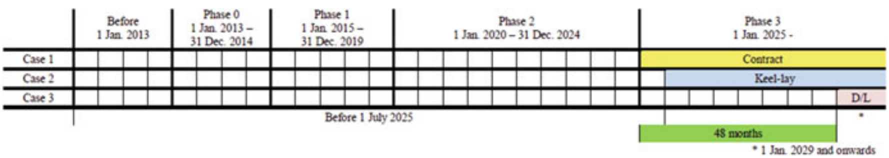

Fig. 3.5 Required EEDI of Phase 3. (Source: ClassNK 2015)

Implementation Phases Required EEDI will be implemented in phases. Currently, it is in Phase 1 that runs from the year 2015 to 2019. Phase 2 will run from the year 2020 to 2024 and Phase 3 starts from the year 2025 onward. Below, the general implementation dates for each of the phases are described and shown in Figs. 3.2, 3.3, 3.4, and 3.5.

Phase 0 (2013–2014) The Required EEDI of Phase 0 is applied to the following new ship:

1. For which the building contract is placed in Phase 0 and the delivery is before 1 January 2019
2. The building contract of which is placed before Phase 0, the delivery is on or after 1 July 2015 and before 1 January 2019, or in the absence of a building contract
3. The keel of which is laid or which is at a similar stage of construction on or after 1 July 2013 and before 1 July 2015 and the delivery is before 1 January 2019
4. The keel of which is laid or which is at a similar stage of construction before 1 July 2013 and the delivery is on or after 1 July 2015 and before 1 January 2019

Phase 1 (2015–2019) The Required EEDI of Phase 1 is applied to the following new ship:

1. For which the building contract is placed in Phase 1 and the delivery is before 1 January 2024
2. The building contract of which is placed before Phase 1, the delivery is on or after 1 January 2019 and before 1 January 2024, or in the absence of a building contract
3. The keel of which is laid or which is at a similar stage of construction on or after 1 July 2015 and before 1 July 2020 and the delivery is before 1 January 2024
4. The keel of which is laid or which is at a similar stage of construction before 1 July 2015 and the delivery is on or after 1 January 2019 and before 1 January 2024

Phase 2 (2020–2024) The Required EEDI of Phase 2 is applied to the following new ship:

1. For which the building contract is placed in Phase 2 and the delivery is before 1 January 2029
2. The building contract of which is placed before Phase 2, the delivery is on or after 1 January 2024 and before 1 January 2029, or in the absence of a building contract
3. The keel of which is laid or which is at a similar stage of construction on or after 1 July 2020 and before 1 July 2025 and the delivery is before 1 January 2029
4. The keel of which is laid or which is at a similar stage of construction before 1 July 2020 and the delivery is on or after 1 January 2024 and before 1 January 2029

Phase 3 (2025+) The Required EEDI of Phase 3 is applied to the following new ship:

1. For which the building contract is placed on or after 1 January 2025.
2. In the absence of a building contract, the keel of which is laid or which is at a similar stage of construction on or after 1 July 2025.
3. The delivery of which is on or after 1 January 2029.

Table 3.5 Implementation phases for bulk carrier, gas carrier, tanker, container ship, general cargo ship, refrigerated cargo carrier, and combination carrier

Delivery \ Contract	Before 1 Jan. 2013	1 Jan. 2013 – 31 Dec. 2014	1 Jan. 2015 – 31 Dec. 2019	1 Jan. 2020 – 31 Dec. 2024	1 Jan. 2025 -
Before 1 July 2015	n/a	Phase 0	Phase 1		
1 July 2015 - 31 Dec. 2018	Phase 0	Phase 0	Phase 1		
1 Jan. 2019 - 31 Dec. 2023	Phase 1	Phase 1	Phase 1	Phase 2	
1 Jan. 2024 - 31 Dec. 2028	Phase 2	Phase 2	Phase 2	Phase 2	Phase 3
1 Jan. 2029 -	Phase 3	Phase 3	Phase 3	Phase 3	Phase 3

Source: ClassNK (2015)

Table 3.6 Implementation phases for Ro-Ro cargo ship (vehicle), Ro-Ro cargo ship, Ro-Ro passenger ship, LNG carrier, and Cruise passenger ship

Delivery \ Contract	Before 1 Jan. 2013	1 Jan. 2013 – 31 Aug. 2015	1 Sep. 2015 – 31 Dec. 2019	1 Jan. 2020 – 31 Dec. 2024	1 Jan. 2025 -
Before 1 July 2015	n/a	n/a			
1 July 2015 - 31 Aug. 2019	n/a	n/a	Phase 1		
1 Sep. 2019 - 31 Dec. 2023	Phase 1	Phase 1	Phase 1	Phase 2	
1 Jan. 2024 - 31 Dec. 2028	Phase 2	Phase 2	Phase 2	Phase 2	Phase 3
1 Jan. 2029 -	Phase 3	Phase 3	Phase 3	Phase 3	Phase 3

Source: ClassNK (2015)

Summary Tables 3.5 and 3.6 also provide the implementation phases *per ship type* by combination of contract and delivery dates.

Reduction Factor This is a phase in percentage value *X* for EEDI reduction relative to the reference line. Reduction factors *X* are dependent on the vessel's type, deadweight, contract and delivery dates and use a structured approach to tighten EEDI regulations over time.

Table 3.7 Reduction factors (in percentage) for the EEDI relative to the EEDI reference line

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 onward
Bulk carrier	20,000 DWT and above	0	10	20	30
	10,000–20,000 DWT	n/a	0–10[a]	0–20[a]	0–30[a]
Gas carrier	10,000 DWT and above	0	10	20	30
	2000–10,000 DWT	n/a	0–10[a]	0–20[a]	0–30[a]
Tanker	20,000 DWT and above	0	10	20	30
	4000–20,000 DWT	n/a	0–10[a]	0–20[a]	0–30[a]
Container ship	15,000 DWT and above	0	10	20	30
	10,000–15,000 DWT	n/a	0–10[a]	0–20[a]	0–30[a]
General Cargo ships	15,000 DWT and above	0	10	15	30
	3000–15,000 DWT	n/a	0–10[a]	0–15[a]	0–30[a]
Refrigerated cargo carrier	5000 DWT and above	0	10	15	30
	3000–5000 DWT	n/a	0–10[a]	0–15[a]	0–30[a]
Combination carrier	20,000 DWT and above	0	10	20	30
	4000–20,000 DWT	n/a	0–10[a]	0–20[a]	0–30[a]
LNG carrier[c]	10,000 DWT and above	n/a	10[b]	20	30
Ro-ro cargo ship (vehicle carrier)[c]	10,000 DWT and above	n/a	5[b]	15	30
Ro-ro cargo ship[c]	2000 DWT and above	n/a	5[b]	20	30
	1000–2000 DWT	n/a	0–5[a, b]	0–20[a]	0–30[a]
Ro-ro passenger ship[c]	1000 DWT and above	n/a	5[b]	20	30
	250–1000 DWT	n/a	0–5[a, b]	0–20[a]	0–30[a]
Cruise passenger ship[c] having nonconventional propulsion	85,000 GT and above	n/a	5[b]	20	30
	25,000–85,000 GT	n/a	0–5[a, b]	0–20[a]	0–30[a]

Source: ClassNk (2015)
n/a means that no Required EEDI applies
[a]Where a range is given, the lower value is for the lower deadweight segments. The reduction factor increases linearly as the deadweight increases
[b]Phase 1 commences for those ships contracted on 1 September 2015
[c]Reduction factor applies to those ships delivered on or after 1 September 2019, as defined in paragraph 43 of Regulation 2

Reduction factor values have been decided by the IMO and documented in Regulation 21 as shown in Table 3.7.

Figure 3.6 shows a graphic demonstration of the relation between implementation phases and reduction factors.

Cut-Off Levels Smaller size vessels are excluded from having a Required EEDI under certain technical justifications. The size limits are referred to as cut-off levels

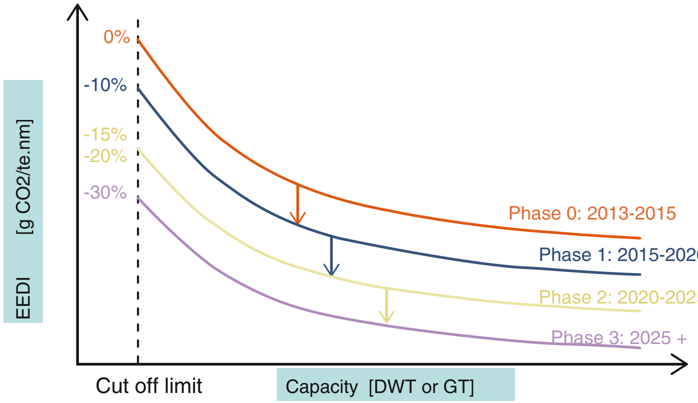

Fig. 3.6 Concept of Required EEDI, reduction factor, cut-off limits, and EEDI phases. (Source: IMO 2015e)

and specified in the regulatory text per vessel type. Cut-off levels are shown in above Table 3.7.

Required EEDI Calculation Formula Using the concepts described above, the following equations show the way Required EEDI is calculated for a ship. As mentioned earlier, for each ship a "Reference EEDI" is calculated using the below equation:

$$\text{Reference EEDI} = a \times b^{-c}$$

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 3.7). Having established the Reference EEDI and X, the Required EEDI is calculated from the following equation:

$$\text{Required EEDI} = \left(1 - \frac{X}{100}\right) \times \text{Reference line value} = \left(1 - \frac{X}{100}\right) \times a(\text{Capacity})^{-c}$$

The Required EEDI applies only to ships defined in column 1 and the ship sizes specified in column 2 of Table 3.7. For these ships, Regulation 21 states that the Attained EEDI must always be less than or equal to Required EEDI:

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

where Attained EEDI: The actual EEDI of the ship, as calculated by the shipyard and verified by a recognized organization (RO)

Note: Regulation 21 does not apply to passenger ships even though vessels falling into this ship type definition are required to have an Attained EEDI calculated and verified subject to Regulation 20.

Regulation 21 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 interim guidelines are introduced in Sect. 6.
- The reference lines and the reduction factors are subject to change. The IMO built two mandatory periods into the regulations when the MEPC would review the status of the currently available technologies and, if necessary, amend the reference lines and reduction factors. The first period was at the beginning of Phase 1, around January 2015, and the second period is midpoint to Phase 2.

Most Recent Developments The IMO MEPC at its 70th session agreed to retain the current reduction rates, time periods, and EEDI reference line parameters in the Phase 2 requirements for ship types other than Ro-Ro cargo and Ro-Ro passenger ships.

For Ro-Ro cargo and Ro-Ro passenger ships, the IMO MEPC adopted amendments concerning the new parameters from Phase 2 that increase the reference line by 20% and introduce a DWT threshold value for larger Ro-Ro cargo ships of 17,000 DWT and Ro-Ro passenger ships of 10,000 DWT, IMO (2018).

A thorough review of EEDI Phase 3 requirements, their early implementation, and of the possibility of establishing a Phase 4 is currently underway. The IMO MEPC has agreed that the review should be finalized in time for adoption of the necessary amendments to MARPOL Annex VI with a view to early implementation of Phase 3 and, if agreed, introduction of Phase 4 as soon as possible.

Regulation 22 The Ship Energy Efficiency Management Plan (SEEMP) is an operational measure that establishes a mechanism to improve the energy efficiency of a ship in a cost-effective manner through the following key steps: planning, implementation, monitoring, self-evaluation, and improvement.

The SEEMP provides an approach for shipping companies to manage ship and fleet efficiency performance over time using, for example, the Energy Efficiency Operational Indicator (EEOI) as a monitoring tool.

The EEOI can be enhanced by applying best practices for fuel-efficient operations as well as deploying latest technological devices for existing vessels. The introduction of initiatives, such as slow steaming, weather routing, antifouling, and trim optimization, can lead to a reduction in fuel consumption for existing vessels as well as contribute to an improvement of ship life cycle environmental performance.

Regulation 22 of MARPOL Annex VI requires that as of 1 January 2013, each ship that is subject to energy regulations 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). The SEEMP shall be developed taking into account guidelines adopted by the organization, IMO (2011a).

There are two parts to a SEEMP. Part I provides a possible approach for monitoring ship and fleet efficiency performance over time and some options to be considered when seeking to optimize the performance of the ship. Part II of SEEMP provides the ship-specific methodologies to collect, aggregate, and report ship data with regard to annual fuel oil consumption, distance traveled, hours underway, and other data required by Regulation 22A of MARPOL Annex VI.

Amendments to MARPOL Annex VI under Regulation 22 entered into force on 1 March 2018 to introduce the IMO Data Collection System (DCS) for fuel oil consumption of ships. Beginning January 1, 2019, vessels of 5000 GT and above are required to have a documented plan in place in view of monitoring CO2 emissions.

IMO DCS regulations require companies to update their existing Ship Energy Efficiency Management Plan (SEEMP) to document the methodology that will be used to collect the required data and the processes that will be used to report the data to the ship's Administration for verification, IMO (2016b, 2017).

In summary:

1. Each ship more than 400 GT that is involved in international voyages should have a SEEMP on board.
2. 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.
3. Currently, the IMO has issued technical guidelines in the form of a basic framework for SEEMP development and implementation. Ship owners and operators should use the IMO guidelines as a basis to develop a vessel's SEEMP, but it is up to them to further identify the appropriate energy KPIs that will stimulate future efficient operational practices.
4. ISO 50001 for Energy Management Systems, which is considered one step beyond SEEMP, is also available to the industry helping companies to improve their energy performance, maximize energy efficiency, and reduce fuel consumption. ISO 50001 requires that energy baselines are established and changes in energy performance are measured against them.

Regulation 23 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 is entitled "Promotion of technical cooperation and transfer of technology relating to the improvement of energy efficiency of ships." It stipulates that:

- Administrations shall, in co-operation with the Organization1 and other international bodies, promote and provide, as appropriate, support directly or through the Organization to States, especially developing States that request technical assistance.
- The Administration of a Party2 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 19.4–19.6. IMO (2011a)

In support of the implementation of the above regulation, IMO MEPC approved a new guideline, IMO (2013d). This document 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. Additionally, IMO has carried out a significant amount of capacity building activities and implemented relevant project in this area.

3 EEDI Calculation

3.1 The EEDI Calculation Formula

The Attained EEDI provides a specific figure for an individual ship, expressed in grams of carbon dioxide (CO_2) per ship's capacity mile (the smaller the EEDI, the more energy efficient the ship design) and is calculated by a formula based on the technical design parameters for a given ship. A simplified form of the EEDI formula is shown below:

$$\text{EEDI} = \frac{\text{Engine power} \times \text{SFC} \times \text{CF}}{\text{DWT} \times \text{speed}}$$

All terms of the EEDI formula are described in detail in Table 3.8.

At first glance a ship's EEDI appears to be a strong incentive to improve the design efficiency of new ships as an indication of a cost/benefit ratio to society in the form of CO_2 emissions. To adapt the formula to a comprehensive calculation method that represents the diverse ship types, propulsion system configurations, fuel systems, and potential energy efficiency technologies, the formula was expanded to its current form:

$$\frac{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{n\mathrm{ME}} P_{\mathrm{ME}(i)} \cdot C_{\mathrm{FME}(i)} \cdot \mathrm{SFC}_{\mathrm{ME}(i)}\right) + \left(P_{\mathrm{AE}} \cdot C_{\mathrm{FAE}} \cdot \mathrm{SFC}_{\mathrm{AE}}\right) + \left(\left(\prod_{j=1}^{n} f_j \cdot \sum_{i=1}^{n\mathrm{PTI}} P_{\mathrm{PTI}(i)} - \sum_{i=1}^{n\mathrm{eff}} f_{\mathrm{eff}(i)} \cdot P_{\mathrm{AEeff}(i)}\right) C_{\mathrm{FAE}} \cdot \mathrm{SFC}_{\mathrm{AE}}\right) - \left(\sum_{i=1}^{n\mathrm{eff}} f_{\mathrm{eff}(i)} \cdot P_{\mathrm{eff}(i)} \cdot C_{\mathrm{FME}} \cdot \mathrm{SFC}_{\mathrm{ME}}\right)}{f_i \cdot f_c \cdot f_l \cdot \mathrm{Capacity} \cdot f_w \cdot V_{\mathrm{ref}}}$$

Table 3.8 Terms of the EEDI formula

V_{ref}	V_{ref} is the ship's speed measured in knots, in deep water for EEDI loading condition using $\sum_{i+1}^{nME} P_{ME(i)} + \sum P_{PTI(i),Shaft}$ as propulsion shaft power (generally 75% MCR)
	$\sum P_{PTI(i),Shaft} = \sum (0.75 \cdot P_{SM,\ max\ (i)} \cdot \eta_{PTI(i)})_*$
	$P_{SM,\ max\ (i)}$: rated power consumption of each shaft motor measured in kW (if installed)
	$\eta_{PTI(i)}$: efficiency of each shaft motor
	When power to the propulsor is limited by verified technical means, 75% (*) of the limited propulsion power is used to determine V_{ref}
	(*) For steam turbine propulsion systems, 0.75 to be replaced by 0.83
	V_{ref} is subject to the following conditions:
	Deepwater operation
	Calm weather including no wind and waves
	Loading condition corresponding to the capacity
	Total shaft propulsion power at corresponding value of PME
Capacity	*Capacity* for EEDI loading condition is measured in MT and shall be:
	DWT at maximum summer load draft as certified in the vessel's stability booklet approved by the Administration for bulk carriers, tankers, gas carriers, LNG carriers, Ro-Ro cargo ships (vehicle carriers), Ro-Ro cargo ships, Ro-Ro passenger ships, general cargo ships, refrigerated cargo carrier, and combination carriers
	70% DWT for containerships. Draft at 70% DWT may account for a specific trim provided that speed/power curves have been established by dedicated model tests at 70% deadweight and same trim
	Gross tonnage (GT) for passenger ships and cruise passenger ships
$P_{ME(i)}$	$P_{ME(i)}$ is 75% of the engines maximum continuous rating (MCR) for each main engine (*i*), measured in kW
	For LNG carriers with diesel-electric propulsion, $P_{ME(i)}$ is calculated as:
	$P_{ME(i)} = 0.83 \times MPP_{Motor}/\eta_i$ where,
	$MPP_{Motor(i)}$ is the rated output of motor per certified document
	$\eta_i = 91.3\%$
	$\eta_i = \eta_{gen} \cdot \eta_{transf} \cdot \eta_{cov} \cdot \eta_{motor}$ (weighted average)
	For LNG carriers with steam turbine propulsion, $P_{ME(i)}$ is to be taken:
	$P_{MEi} = 0.83 \times MCR_{Steam\ Turbine}$
P_{PTO}	In case shaft generator(s) are installed, $P_{PTO(i)}$ is 75% of the rated electrical output power measured in kW of each shaft generator: $P_{PTO(i)}$: $0.75 \times MCR_{PTO(i)}$*
	For calculation of the effect of the shaft generators, two options are available:
	Option 1:
	$\sum_{i+1}^{nME} P_{ME(i)} = 0.75 \times \left(\sum MCR_{ME(i)} - \sum P_{PTO(i)}\right)$
	Maximum allowable deduction for calculation $0.75 \times \sum P_{PTO(i)} \leq P_{AE}$
	Option 2:
	$\sum P_{ME(i)} = 75\%$ of limited power
	Applicable *only* if installed main engine power is limited by verified technical means
	*In case shaft generators are fitted to steam turbine, 0.75 to be replaced by 0.83

(continued)

Table 3.8 (continued)

P_{PTI}	If shaft motors are installed, $P_{PTI(i)}$ is 75% of the rated power consumption of each shaft motor, measured in kW, divided by the weighted average efficiency of the generators:
	$\sum P_{PTI(i)} = \frac{\sum(0.75 \cdot P_{SM,max(i)})}{\eta_{\overline{Gen}}} (*)$
	$\eta_{\overline{Gen}}$ = weighted average efficiency of generator(s)
	$P_{SM,\ max\ (i)}$: rated power consumption of each shaft motor measured in kW
	*In case shaft motors are fitted to steam turbine, 0.75 to be replaced by 0.83
P_{AE}	P_{AE} is the required auxiliary engine power to supply normal maximum sea load and includes necessary power for propulsion machinery/systems and accommodation
	For ships with total propulsion power of 10,000 kW or above:
	$P_{AE(\sum MCR_{ME(i)} \geq 10{,}000\ kW)} = \left[0.025 \times \left(\sum_{i=1}^{nME} MCR_{ME(i)} + \frac{\sum_{i=1}^{nPTI} P_{PTI(i)}}{0.75}\right)\right] + 250$
	For ships with total propulsion power below 10,000 kW:
	$P_{AE(\sum MCR_{ME(i)} < 10{,}000\ kW)} = \left[0.05 \times \left(\sum_{i=1}^{nME} MCR_{ME(i)} + \frac{\sum_{i=1}^{nPTI} P_{PTI(i)}}{0.75}\right)\right]$
	P_{AE} calculations have specific rules for LNG carriers with re-liquefaction plant or compressors to supply boil of gas BOG to the engines refer to IMO (2014c)
	For cases where calculated P_{AE} is significantly different from actual P_{AE}, the ship Electric Power Table (EPT) should be used to estimate P_{AE}
C_F	C_F is the nondimensional conversion factor between fuel consumption and CO_2 emission. The value of C_F corresponds to the fuel used when determining the SFC listed in the NOx Technical File. C_F shall be determined separately for main engine(s) C_{FME} and auxiliary engine(s) C_{FAE}
SFC	Certified-specific fuel consumption, g/kWh, for main engine(s) SFC_{ME} and auxiliary engine(s) SFC_{AE} obtained from NOx Technical File
	SFC for steam turbine installations should be calculated by manufacturer and verified by ABS
	For those engines with power output below 130 kW, which do not have a test report included in a NOx Technical File, the SFC specified by the manufacturer and endorsed by a competent authority should be used
	For LNG-driven engines for which SFC is measured in kJ/kWh, the SFC value is to be converted to g/kWh using the standard lower calorific value of the LNG (48,000 kJ/kg), referring to the 2006 IPCC Guidelines
f_w	Weather factor, f_w, accounts for a decrease in speed in representative sea conditions of wave height, wave frequency, and wind speed and determined as follows
	$f_w = 1.0$ for the Attained EEDI calculated under Regulations 20 and 21 of MARPOL Annex VI
	$f_w \neq 1.0$ is applicable only to vessels that consistently operate in rough weather on their trade
	Attained EEDI calculated based on $f_w \neq 1.0$ is to be referred to as "Attained $EEDI_{weather}$"
	f_w can be determined using either of the two methods:
	Ship-specific simulation of performance in representative sea conditions following IMO (2012e)
	Standard f_w table/curves, expressed as a function of capacity, for bulk carriers, tankers, and containers provided in IMO (2012e)
	f_w and Attained $EEDI_{weather}$ are to be listed in the EEDI Technical File if calculated

(continued)

Table 3.8 (continued)

$f_{\text{eff(i)}}$	$f_{\text{eff}(i)}$ is the availability factor for innovative energy efficiency technology
	$f_{\text{eff}(i)} = 1.0$ for waste heat recovery systems. Other technologies may have $f_{\text{eff}(i)}$ factors less than 1.0 as their output may only be available intermittently. Refer to IMO (2013e)
f_j	f_j is the power correction factor and is applicable to:
	Ice-classed ships
	Shuttle tankers with propulsion redundancy (80,000–160,000 DWT)
	Ro-Ro ships, all types
	General cargo ships
	For detailed information on how f_j is assigned to each of the above categories, refer to IMO (2014c)
f_i	f_i is the capacity correction factor applicable as:
	$f_{i\text{VSE}}$ for ship-specific voluntary structural enhancements
	$f_{i\text{CSR}}$ for ships built in accordance with the Common Structural Rules (CSR) and assigned the class notation CSR
	$f_{i\text{ICE}}$ for ice-strengthened ships
	$f_i = 1.0$ for all other ship types
	For detailed information on how f_{i} is assigned to each of the above categories, refer to IMO (2014c)
f_{C}	f_c is the cubic capacity correction factor. It is applicable to chemical carriers, gas carriers which carry LNG, with direct diesel propulsion systems, and Ro-Ro passenger ships having a DWT/GT ratio of less than 0.25 where DWT is the capacity and GT is in accordance with tonnage measurement conventions
	f_c should not be applied to LNG carriers that fall into the ship definition of Regulation 2.38 of MARPOL Annex VI
	$f_c = 1.0$ for all other ship types
f_{l}	*f_l is the crane and cargo gear correction factor for general cargo ships*
	f_l compensates for a loss of deadweight of the ship due to cranes and cargo gear
	$f_l = f_{\text{cranes}} \cdot f_{\text{sideloader}} \cdot f_{\text{roro}}$
	$f_{\text{l}} = 1.0$ for all other ship types

Figure 3.7 explains how each of the terms included in the EEDI formula affects the vessel's Attained EEDI.

The items that primarily influence EEDI are:

- Installed main engine power and energy needed for propulsion; this is represented by the first term in the numerator of the formula.
- Auxiliary power requirements of the ship; this is represented by the second term in the nominator.
- Innovative electrical technologies on board such as electricity from waste heat recovery or solar power. These are represented by the third term in the nominator.
- Innovative mechanical technologies that provide power for ship propulsion such as wind power (sails, kites, etc.). This is the last term in the nominator.
- Ship capacity and ship speed are represented in the denominator. Their product represents the value of transport work.

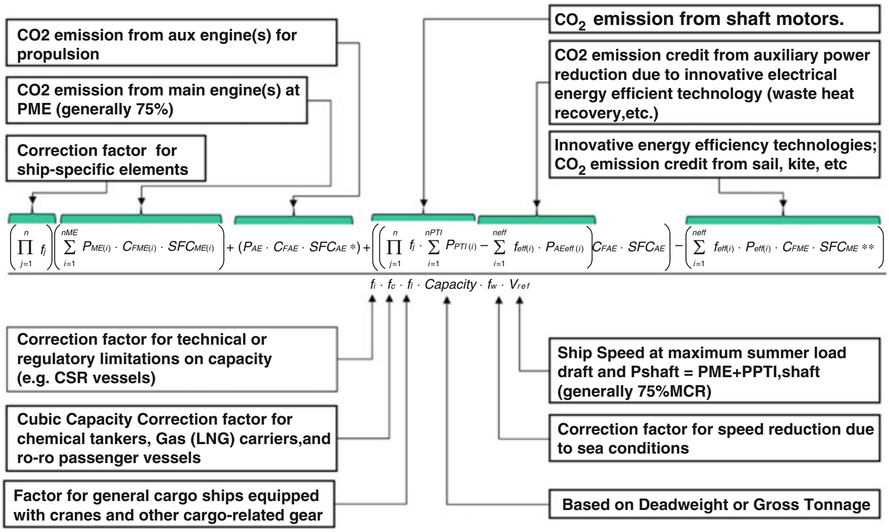

Fig. 3.7 The EEDI calculation formula input parameters

For the majority of ships for which EEDI data have been reported to the IMO and made publically available, several of the parameters in this formula are taken as 0 or 1. More specifically:

1. Correction factor $f_j = 1$ as it represents ship-specific design elements of ice class vessels, Ro-Ro ships, general cargo, or shuttle tankers with propulsion redundancy.
2. Availability factor $f_{\mathrm{eff}} = 0$ as reported innovative technologies are currently limited to numbered waste heat recovery system installations for electrical power generation. It should be pointed out here that the effect of more common energy-saving devices (e.g., pre-swirl stators, rudder bulbs) cannot be separated from the overall performance of the vessel and is accounted for in the EEDI reference speed (V_{ref}) during model tests and speed trials.
3. Correction factor $f_l = 1$ as this is only applicable to general cargo vessels.
4. Correction factor $f_w = 1$ as the weather factor f_w demonstrates the reduction of ship speed in representative sea conditions of wave height, wave frequency, and wind speed (e.g., Beaufort Scale 6). IMO Guidelines on f_w calculation are for now only interim.

Therefore the EEDI formula simplifies to the equation shown below:

$$\frac{\left(\sum_{i=1}^{n\mathrm{ME}} P_{\mathrm{ME}(i)} \cdot C_{\mathrm{FME}(i)} \cdot \mathrm{SFC}_{\mathrm{ME}(i)}\right) + \left(P_{\mathrm{AE}} \cdot C_{\mathrm{FAE}} \cdot \mathrm{SFC}_{\mathrm{AE}}\right)}{f_i \cdot f_c \cdot \mathrm{Capacity} \cdot V_{\mathrm{ref}}}$$

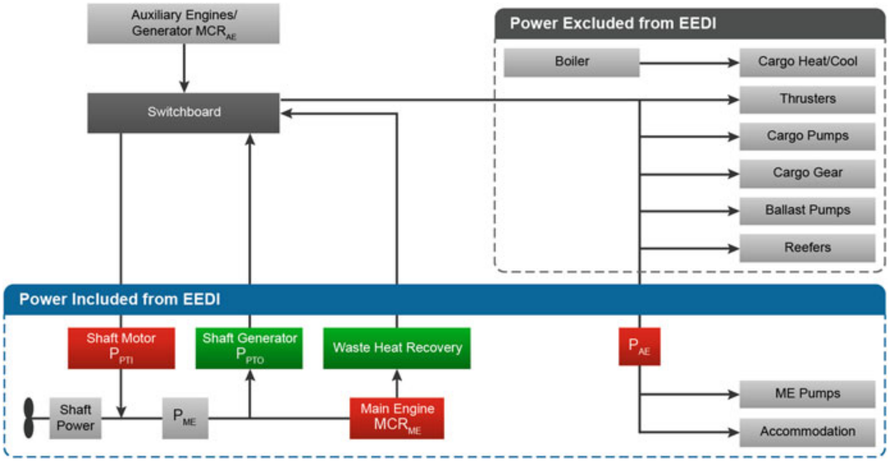

Fig. 3.8 Power included in EEDI calculation – example graph

Figure 3.8 gives a simplified outline of the vessel's power plant in order to demonstrate which machinery components are taken into account in the EEDI calculation.

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. is out of scope of EEDI calculations.

3.2 *Terms in the EEDI Formula*

Table 3.8 gives a cumulative summary description of all the terms used in the EEDI calculation and how these shall be applied according to IMO guidelines, IMO (2014c).

3.3 *EEDI Technical File*

For verification, implementation, and enforcement purposes by Flag Administrations and Port States, all the relevant terms used in the EEDI calculation and their values are required to be recorded in the "EEDI Technical File" along with the calculation methodology applied 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. The "EEDI Technical File" needs to be kept on board and forms a supplement to International Energy Efficiency Certificate (see Sect. 5).

The IMO in its EEDI survey and verification guidelines IMO (2014b) has provided a sample "EEDI Technical File." A similar example is also given in the Procedural Requirement 38 of the International Association of Classification Societies (2016) and attached Industry Guidelines, IMO (2015d). The examples identified are non-exhaustive but provide comprehensive guidance on the use of all data necessary for verification purposes including all the terms defined in Table 3.8 that need to be recorded in the EEDI Technical File.

4 EEDI Survey and Verification

EEDI verification is conducted on behalf of the vessel's Flag Administration by recognized organizations (ROs) according to "2014 Guidelines on survey and certification of the Energy Efficiency Design Index (EEDI)," IMO (2014b). For vessel's equipped with innovative energy efficiency technologies, guidance is provided in the "2013 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the Attained EEDI," IMO (2013e).

EEDI Verification is performed at two separate stages:

- Preliminary stage
- Final stage

Verification at the preliminary stage is done during the ship's initial design and pre-construction period. Final verification is carried out after construction following the vessel's sea trials and prior to delivery. 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 certain constraints applicable to the execution and witnessing of tank (model) tests, speed-power scaling methods, as well as standardized approaches used for sea trial correction hold room for further review and improvement.

Figure 3.9 shows the overall process diagram for EEDI verification.

4.1 Preliminary Verification

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

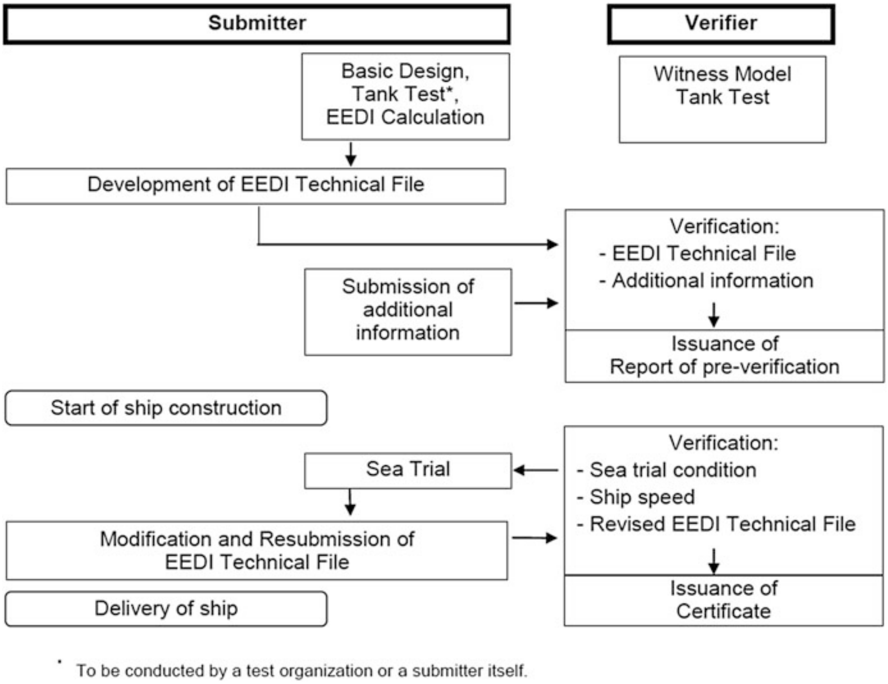

Fig. 3.9 The EEDI verification process (Source: IMO 2014b)

- An application for an initial survey.
- Preliminary “EEDI Technical File” containing the necessary information.
- Relevant background documents and information.

The EEDI Technical File should be developed by the submitter (ship designer or shipyard) and must include of all the data required.

Additional background documents and information necessary for the verifier include but are not limited to:

- Model Test Report complete with towing tank test results and full-scale tabulated power/speed predictions for below two (2) loading conditions:

  I. EEDI loading condition is based on maximum summer load line draft as certified in the approved Stability Booklet and applies for different vessel types as follows:

     Capacity is 100% DWT for bulk carriers, tankers, gas carriers, LNG carriers, Ro-Ro cargo ships (vehicle carriers), Ro-Ro cargo ships, Ro-Ro passenger ships, general cargo ships, refrigerated cargo carrier, and combination carriers.

     Capacity is 70% DWT for containerships.

     Capacity is gross tonnage for passenger ships and cruise passenger ships.

II. Intended sea trial condition (vessel loading condition during sea trials if different from EEDI loading condition, which is required for final verification of EEDI)

- 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.
- Calculation process of the ship reference speed.
- Reasons for exempting a tank test, if applicable.
- Copy of the NOx Technical File and documented summary of the SFC correction for each type of engine with copy of engines' (Engine International Air Pollution Prevention) EIAPP certificate.
- Electric Power Table (if P_{AE} is significantly different from the value computed using the formula defined in the IMO Calculation Guidelines)
- 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 CF calculation purposes.

The most important element of preliminary verification is the ship's model tank test. According to the IMO guidelines IMO (2014b):

> 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, the International Towing Tank Conference (ITTC) quality system should be taken into account. Model tank test should be witnessed by the verifier.

4.2 Final Verification

At the final EEDI verification stage, the submitter shall prepare a dedicated sea trial plan in accordance with the International Organization for Standardization ISO 15016:2015 guidelines. The sea trial plan will be the guiding document during the execution of the ship's commissioning trials. Adherence to the process ensures that the ship's final speed-power curve and EEDI reference speed, $V_{ref,}$ are determined accurately; this is an essential step of the final EEDI verification.

Afterward, all relevant parameters of the EEDI calculation will be revisited and verified. Aspects that need to be considered for sea trail are elaborated further here using the IMO guidelines IMO (2014b).

4.3 Calculation and Verification of Innovative Technologies

The verification of innovative energy efficiency technologies is an involved process and is fully documented in the guidelines, IMO (2013e). This is an interim guidance document and will evolve over time as experience is gained as a result of future use of these 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.

4.4 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 categories (B) and (C) are categorized to two subcategories (categories (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); 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 PAEeff.
  - Category (C-1): Technologies which can be used at all times during the operation (e.g., waste heat recovery); 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 3.9 Number of double runs for EEDI trials based on current correction method

Current correction	Power setting	Lead vessel	Sister vessel
Mean of means	Below EEDI	2	1
	Around EEDI	2	1
	Above EEDI	2	1
Iterative method	Below EEDI	1	1
	Around EEDI	2	1
	Above EEDI	1	1

4.5 Sea Trials: Observation

In order to ensure accurate EEDI calculation, sea trial conditions should be set close to the "EEDI Condition," if possible. As mentioned earlier, the vessel's sea trial plan should be submitted to the verifier for approval and confirmation that the conditions and processes described follow the ISO 15016:2015 guidelines. EEDI trial requirements include but are not limited to the following:

Ship's actual Displacement measured prior commencement of speed power trials shall be less than 2% of required displacement as derived from dedicated model tests.

The power settings and number of double runs for EEDI speed-power trials are based on the current correction method to be applied and whether the vessel trialed is a lead ship or sister ship:

- Power settings should be distributed within the range from 65%MCR to 100%MCR.
- Number of double runs for Lead and Sister vessels depends on agreed current correction method (Table 3.9).

Each double run shall be conducted heading into and following the dominant wave direction over the same ground area. Duration of each speed run shall be at least 10 min at steady-state ship state.

Speed-power trials should be conducted soon after launching and/or with the hull and propeller clean.

Trial location and heading of forward/return runs shall be consistent for all double runs of the progressive speed trial. Changes in heading (e.g., reversal of forward/return run direction) are not recommended. Recorded parameters may provide inaccuracies in speed trial analysis results (ISO 15016:2015).

The speed-power trials shall be conducted in a location free of hindrance by small boats and commercial traffic where the environmental conditions are expected to be constant with limited wind, waves, and current.

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 parameters shown in Tables 3.10 and 3.11 are measured and recorded as accurately as possible.

Table 3.10 Parameters measured and recorded prior to speed trials

Measure	Device	Unit
Water density	Salinity sensor, conductivity density Temperature (CDT) sensor	kg/m^3
Water temperature	Thermometer, CDT sensor	°C
Air temperature	Thermometer	°C
Air pressure	Barometer	hPa, mb
Torsion meter zero setting	Torsion meter with calibrated torque sensor or strain gauges	kNm
Trial area	Geographical position (Lat-Long) by DGPS	dddd-mm
Vertical position of anemometer	General arrangement plan of the ship	m
Drafts	Physical observation and/or calibrated draft gauges	m

Table 3.11 Parameters measured and recorded during speed trials

Measure	Device	Unit
Ship track	DGPS	Lat../Long, deg
Speed over ground	DGPS	Knots
Shaft torque	Torsion meter with strain gauges or torque sensor	kNm
Shaft power	Calculated from torque and RPM	kW
Shaft RPM	Pickup, optical sensor, ship revs counter	RPM
Propeller pitch	Bridge replicator	Deg or m
Time	GPS time, stopwatch	s
Water depth	Ship echo sounder and nautical charts	m
Ship heading	Gyro compass or DGPS	deg
Relative wind	Anemometer	m/s, deg
Bow acceleration (STAWAVE-1)	Acceleration meter	m/s^2
Wave height, period and direction	Radar scanner, wave buoy (minimum of three observers)	m, deg
Drafts	Observation, draft gauges	m

4.6 *Speed Trial Analysis*

The main output of the speed trial will be the actual measured ship speed-power curve and its corrected/extrapolated equivalent for the EEDI Condition. A large number of vessels are trialed at ballast condition, for example, bulk carriers and containerships. The speed-power curve representing the actual performance of the vessel at the trial loading condition is derived by analysis calculations that involve the application of a number of corrections related mainly to the prevailing weather and sea state during the course of trials. Once the analysis of the corrected speed-power curve for the trial loading condition is determined, a conversion is done to EEDI loading condition.

The speed trial analysis shall follow the requirements described in ITTC (2017) and ISO (2015).

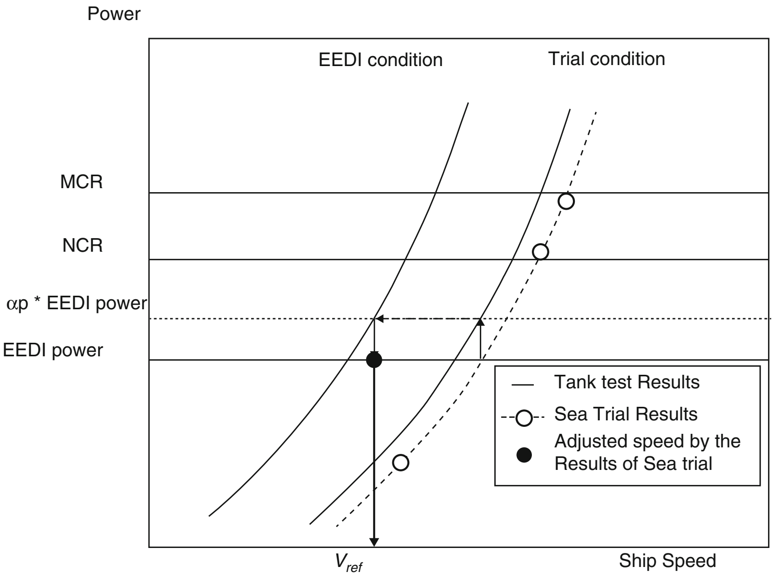

Fig. 3.10 Example scheme of conversion from trial condition to EEDI condition at EEDI power. (Source: IMO 2014b)

The speed adjustment and correction from ballast condition to EEDI condition plays an important role in an accurate estimation of EEDI. An example of a simplified method of the speed adjustment is given in Fig. 3.10 as is included in IMO EEDI survey and verification guidelines, IMO (2014b).

The EEDI reference speed, 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 are also carried out at both drafts: 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 αP is V_{ref}.

The verifier is required to ensure that the sea trial analysis and conversion to EEDI loading condition are done accurately. The collected shipboard data along with a detailed analysis including intermediate results and providing the vessel's EEDI reference speed V_{ref} should be submitted to the verifier.

4.7 Verification of the Attained EEDI for Major Conversions

"Major Conversion" means a conversion of a ship:

- Which substantially alters the dimensions, carrying capacity, or engine power of the ship.

- Which changes the type of the ship.
- The intent of which in the opinion of the Administration is substantially to prolong the life of the ship.
- Which otherwise so alters the ship that, if it were a new ship, it would become subject to relevant provisions of the present Convention not applicable to it as an existing ship.
- Which substantially alters the energy efficiency of the ship and includes any modifications that could cause the ship to exceed the applicable required EEDI.

In case of a major conversion, the owner or shipyard 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 including but 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

4.8 EEDI Verification: Scope of Activities

The scope of verification activities may be summarized separately for the preliminary and final stages in the lists below:

Preliminary stage:

- 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 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 organization 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 EEDI loading conditions.
- Issue a preliminary verification report inclusive, possibly in the form of a preliminary statement of compliance.

Final stage:

- Review the sea trial plan to check that the test procedure complies with the requirements of the IMO guidelines. It should be noted that the IMO guidelines have endorsed the use of the ISO 15016:2015 standard for all ships trialed after September 2015.
- Survey the vessel to ascertain the ship principle and machinery characteristics conform with those in the EEDI Technical File.
- Attend the sea trial and record 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 the ISO 15016:2015 standard.
- Perform independent speed trial analysis to verify reference ship speed V_{ref}, and confirm the conversion of the speed-power curve to the EEDI loading condition.
- Verify revised EEDI calculation inputs and results.
- Confirm that the vessel's Attained EEDI is less than the required regulatory limit.
- Review the revised EEDI Technical File, if applicable.
- Complete relevant parts of the Record of Construction and endorse.

4.9 International Energy Efficiency (IEE) Certificate and Its Supplements

Following the final EEDI verification, an IEE Certificate is issued, and a Record of Construction for Energy Efficiency will be attached to the certificate. The IEE Certificate has no expiry date, since it will be valid throughout the life of the ship, except in cases where the certificate is rewritten or reissued.

The following two documents are considered as supplements to the IEE Certificate:

- EEDI Technical file
- SEEMP

As specifically stated in MARPOL Annex VI Chapter 4, Port State inspections 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.

5 Interim Guidelines for Determining Minimum Propulsion Power (MPP) to Maintain the Maneuverability of Ships in Adverse Conditions

One of the most effective ways of reducing a ship's EEDI is by reducing the ship's design speed by selection of a smaller main engine or main propulsion motor.

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. To ensure safe maneuvering in adverse conditions, a requirement was introduced within the EEDI regulations (Regulation 21.5, Chapter 4 of MARPOL Annex VI):

> 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.

IACS was tasked to develop guidelines for determining minimum propulsion power to enable safe maneuvering. The studies conducted by the IACS working groups served as a basis for the "2013 Interim Guidelines," IMO (2013b), which were further updated in 2015 by IMO (2015a, b).

The IMO guidelines 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 satisfies these minimum requirements.

The guidelines currently apply to:

- Tankers
- Bulk carriers
- Combination carriers

Investigation showed that the above ship types are most critical with respect to the sufficiency of power for maneuverability in adverse conditions. Views have been expressed by IMO member states that further consideration for other ship types should be done at a later stage.

The applicability of the guidelines from a capacity perspective is currently limited to ships of 20,000 DWT and above. The main reason behind this restriction is that a systematic evaluation of the required standard environmental conditions for ships with deadweight less than 20,000 DWT has not been completed yet. Ongoing studies in the IMO are addressing the issue for these ships, and a solid proposal is envisaged for the future.

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

Assessment Level 1: Minimum Power Lines Assessment A simple approach that involves calculation of the minimum power from a specific line as a function of ship DWT, based on engine power data from already built ships. 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:

$$\text{Minimum Power Line Value } [\text{MCR, kW}] = a \times (\text{DWT}) + b$$

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

It should be noted here that the maximum summer load condition (corresponding to the EEDI condition) has been identified as the "most severe" when estimating required propulsion power in adverse conditions.

Heavy ballast loading condition has been also examined, but the required propulsion power under heavy ballast is typically less than that under full-load conditions.

Furthermore, the normal ballast condition is generally not critical because ship masters generally change from the normal ballast condition to the heavy ballast condition based on weather forecast IMO (2015b).

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 Level 2 assessment requires the determination of added resistance of waves by model tests in regular waves; empirical formulae are also referenced albeit not directly specified. To address this challenge, in-depth research was initiated by the EU research project SHOPERA (Energy Efficient Safe SHip OPERAtion) and Japan's JASNAOE research project.

As mentioned above, at IMO MEPC 68, the two assessment levels of the 2013 Interim Guidelines were thoroughly reviewed. It was agreed that the alternative approaches introduced, using inputs from ongoing research projects, could warrant further consideration. The strengthening of existing Level 1 assessment criteria was agreed as a tentative measure and adopted by the IMO MEPC, IMO (2015b).

More specifically, the technical justifications and appropriateness of the formulas embodied in the Level 2 assessment were examined by the Committee in order to confirm whether the current approach correctly evaluates maneuverability and adverse weather conditions and ensures safety.

Because the Level 2 Assessment has not been finalized to date, Level 1 was revised (strengthened) by Resolution IMO (2015b). Figure 3.11 is a sample graph showing old and new Level 1 for bulk carriers.

Discussions in the IMO for Level 2 are currently ongoing. The research project conclusions were examined by the member states at MEPC 71 but considered not mature enough to revise the interim guidelines for calculation of minimum propulsion power.

The IMO MEPC at its 72nd session agreed to extend the 2013 Interim Guidelines to EEDI Phase 2 and requested government states and participating bodies to continue discussions on the matter in an effort to further develop the revision to the guidelines in the upcoming sessions.

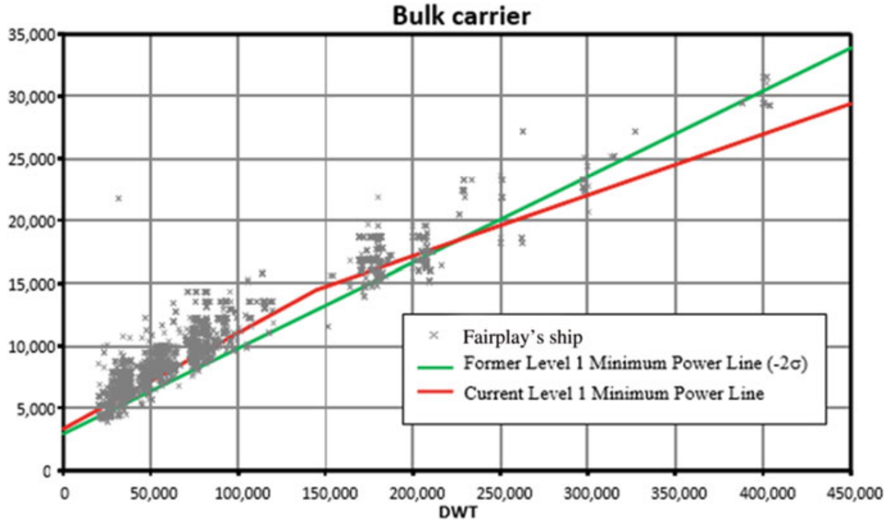

Fig. 3.11 Comparison of former and current Level 1 minimum power lines. (Source: Author's Private Archive)

6 Weaknesses of EEDI

The intent of EEDI is of course to push ship designers and shipyards to design more energy-efficient ships. It has been said that the most effective energy-saving devices are well-designed hull lines, creating the least possible hydrodynamic resistance and a good propulsion coefficient.

EEDI is thus a design index attempting to capture this philosophy, while at the same time giving a measure of how much CO2 is produced under some standard conditions per transport capacity. In simpler terms, EEDI is a measure of the penalty that society pays to enjoy the benefit of goods transportation. Obviously therefore, society wishes a smallest possible index.

At the same time, and in spite of the above intention, EEDI exhibits some weaknesses, which are described below.

6.1 It Is Easy to Comply with the Required EEDI Simply by Reducing the Design Speed, Without Reducing Ship's Resistance or Increasing Its Efficiency

Every ship must comply with the regulation:

$$\text{Attained (actual ship's) EEDI} \le \text{Required EEDI}$$

"Attained EEDI" grows as a function of speed to the square power (V^2) or even more (and for fast ships V^3 or higher), while "Required EEDI" is a fixed number (from the baselines depending on ship's deadweight). The implication is obvious: Reduce the ship speed (power), and you can reach the Required EEDI.

This weakness was realized early on during the development of the formula and baselines at IMO, and there were calls from few member states (e.g., Greece) to correct it. A solution was proposed by Greece (IMO 2011b) which would make it harder to comply just by reducing speed and thus force designers to refine the ship's hull lines, use better propellers, etc. The proposal was to include speed in the "Required EEDI" so that both sides of the above inequality drop as speed drops. However, the proposal was not accepted; for a more detailed discussion, see Psaraftis (2018).

6.2 Compliance with EEDI Requirements, by Reducing Speed, Leads to Safety Concerns (Possible Underpowering)

Previous IMO Work While fast ships (e.g., containerships) have plenty of room to reduce their design speed safely, slow-speed ships (tankers and bulk carriers) do not. Reducing speed is the direct result of reducing installed power (to lower the Attained EEDI). Early on, concerns were expressed by ship operators that such ships may not have sufficient power to maneuver in adverse weather, leading IMO to examine the issue and publish guidelines on minimum propulsion power (MPP), as described in Sect. 5 of this chapter.

We will simply reiterate here that despite many years of examination and two large projects (SHOPERA and JASNAOE), the MPP Level 2 assessment has not been finalized, while there has been ongoing debate of what constitutes "adverse weather" (Beaufort 7, 8, 9 or 10?). The results from the projects suggest that when high Beaufort numbers are applied, the required power is unrealistically high (much higher than pre-EEDI ships), which is not in line with actual experience (typical pre-EEDI ships have not shown serious adverse weather performance concerns in Beaufort 9 or 10). Thus the project partners proposed Beaufort 7 or 8 as "adverse," with ship operators claiming that this is a relatively mild weather condition. Further adjustment of Level 2 assessment is required to produce results in line with experience.

For the time being, shipyards and operators rely on the MPP Level 1 assessment, which simply is a straight-line regression at the lower ends of pre-EEDI installed powers for various ship sizes.

Further IMO Work After setting the IMO GHG reduction targets in April of 2018 at MEPC 72, there are already calls for various measures in order to achieve the set reduction targets. Among those measures considered "ripe" for fast application is to further strengthen the EEDI requirements. The proposals include to bring the application date of Phase 3 forward and to introduce a more stringent Phase 4 for certain ship types. For slow-speed ships, this might exacerbate the safety concerns, especially for the larger DWT segments (see further below). Even with the current requirements, large-size tankers and bulk carriers cannot easily be made to comply with Phase 3, and if their power drops to the point of compliance, they will have issues even in Beaufort 8. It is recognized that IMO must finalize the minimum power requirements before enacting more stringent EEDI requirements for slow-speed ships.

Proposals have been submitted by certain Flag Administrations (IMO 2015c) to install a proper (safe) size engine, according to this minimum required power, and use a torque limiter at the propeller shaft so the ship operates normally at the EEDI required reduced power. In case of bad weather, the chief engineer can hit the limiter's by-pass button to have all the power available to him. This proposal has been disputed by IMO member states on grounds that it constitutes a dual NOx certification.

Greece has submitted several times, IMO (2011c, 2015c) that the problem is being looked at from a wrong perspective. Instead of setting a minimum power requirement, a minimum required speed (at sea trials) should be set. Speed is a better performance measure than installed power. This way, both safety and better efficiency of future designs could be achieved since, among others, full bodied ships will require large, thirstier engines to achieve the minimum speed than well-designed (slimmer) ships. With a minimum power requirement, there might be no further incentive for the designer to improve a given hull, since in any case he must install the required power. Of course, a minimum power (instead of speed) requirement does not guarantee that this power will be sufficient on a poorly designed ship.

6.3 The Required EEDI Baselines (or Reference Lines) Were Oversimplified

It was decided early on to use one regression line for each ship type and for all ship sizes in the category. As can be seen from Fig. 3.1 of this Chapter, however, smaller-size ships (data points) weigh much more on the regression than larger ships, simply due to the fewer number of larger ships. The result is that, whereas the line is appropriate for the smaller ships, it might penalize the larger ships. This is more profound for tankers and bulkers.

Once the reference lines were set, it became evident that most existing large ships such as very large crude carriers (VLCC), capesizes, etc. fall about 10% above the baseline, i.e., these ships had to drop their EEDI 10% more than other ships, in all EEDI phases going forward. This is part of the reason they are not expected to easily comply with Phase 3 (along with the related power safety issues). This was acknowledged by IMO at the time; however, drawing power lines for each different ship size would be very time-consuming. It was suggested then that a special adjustment "factor" would apply for these ships to be set during a future reviewed period. To date such a factor has not been discussed. However, given that shipyards and owners are now facing the issue, it is expected to be discussed again in view of the calls for strengthening EEDI further.

6.4 "Attained EEDI Weather" Provides a Truer Picture of Efficiency

EEDI is quite a theoretical index, being a snapshot of ship's performance at a rarely used draft (maximum) and in ideal sea conditions (no wind and no waves). As a result, ships with similar EEDI's may have very different performance in real sea conditions. The industry has fresh memories of very full bow ship designs (to increase displacement/deadweight), which at sea trials performed well but which, in real sea conditions of Beaufort 3 or 4, exhibited reduced speed capability and increased fuel consumption compared to similar designs or EEDIs with a more slender bow.

A truer picture of a ship's actual performance could be reflected in the EEDI if the weather coefficient (f_w) was actually used (currently the f_w in the EEDI formula is taken as 1.0), where $f_w = Vw/V_{\mathrm{ref}}$. The weather coefficient f_w is a measure of the drop in ship speed at 75% MCR in weather conditions of Beaufort 6. A typical range for f_w for slow-speed ships (bulk carriers and tankers) is 0.80–0.95, which in itself is an indication of the extreme variation in design efficiency that is not captured in the EEDI (obviously a ship losing less speed – i.e., with $f_w = 0.95$ – is the more efficient.) Each ship design has its own f_w which can be determined experimentally by model tests. IMO (2012e) provides guidelines for the calculation of f_w as well as typical values. Experimental values included in said IMO circular show that, for same deadweight ships, the f_w can vary widely. For example, for 300,000 dwt tankers, f_w ranges from 0.83 to 0.94. Obviously the 0.94 design is far more efficient than the 0.83, dropping only 6% in speed from Beaufort 0 to Beaufort 6, versus 17% for the less efficient design. Since this speed drop is at the fixed power of 75% MCR, it is a direct measure of the efficiency of the ship's hull lines (especially bow shape) (Fig. 3.12).

Including actual f_w in the EEDI formula, resulting in "Attained EEDI weather," would provide a more realistic picture of the ship's efficiency in real operating conditions. At present, both ships in our example may have identical EEDI's, but their actual performance will be very different. Furthermore, the "less efficient" ship, due to smaller engine, may even have a better "Attained EEDI" than the more efficient ship but, in reality, may emit much more CO_2 when operating at the same speed. It has been observed in the past that, due to the large speed drop, such poor designs tend to increase their operating horsepower output to partially recover the loss and thus achieve a more "competitive" speed, thus operating at 90% MCR or more, which increases the engine's specific fuel oil consumption exponentially.

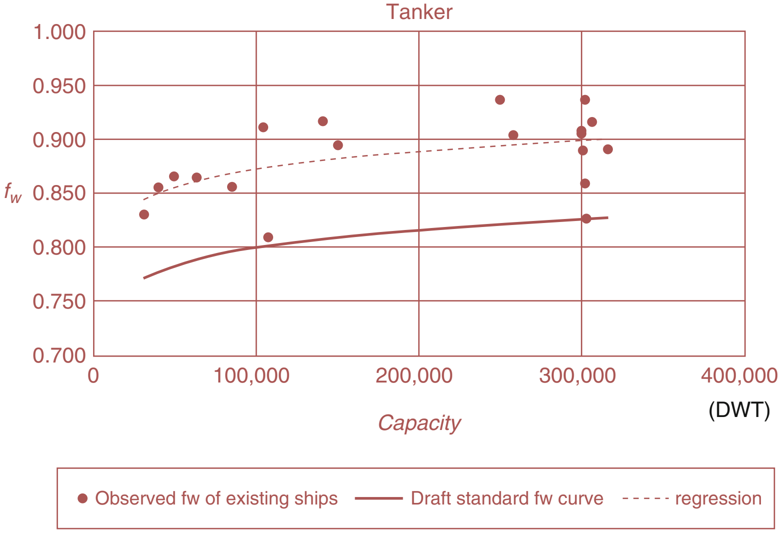

Fig. 3.12 Standard f_w curve for tanker. (Source: IMO 2012e)

Obviously then, f_w and "Attained EEDI weather" are crucial pieces of information of a ship's real efficiency.

Related distortion: Ships with larger engines, having lower actual (in real operating conditions) fuel consumption at same speed and deadweight, will have higher (worse) EEDI than otherwise identical standard ships.

Some owners install larger engines on a shipyard's standard design (e.g., one extra cylinder) in order to be able to operate at the optimum specific fuel oil consumption (SFOC) point of 70–75% MCR in real weather conditions of Beaufort 4–5, instead of 75% MCR at the calm conditions of EEDI. Thus they are able to achieve V_{ref} (or the design speed[1]) in real weather conditions, whereas a typical EEDI ship would need to operate at much higher MCR than 75% to achieve the same speed. The larger-engine ship has a higher (worse) EEDI, typically by about 15%, yet for the same speed and draft, it might save typically 7–7.5% in fuel consumption. This is a direct contradiction of the EEDI premise and could easily be alleviated by using "EEDI weather."

[1]Practically V_{ref} is approximately equal to a typical shipbuilding contract's "design speed." V_{ref} is speed at maximum deadweight (70% DWT for container vessels), at 75% MCR but with no sea margin. Design speed is speed at the reduced design draft, typically at 85% MCR but with 15% sea margin.

6.5 Operational Indices (EEOI, EVDI, etc.) Can Be Meaningless

For real CO_2 reductions, ship performance in real operating conditions should be evaluated. Several “Operational Efficiency Indices” have been devised, but unfortunately none has proven effective in capturing a ship’s true operating efficiency. This is because of (a) the inaccuracy of data in the databases used for some indices and mostly (b) the unpredictable and unavoidable effect of bad weather (slower speed – high fuel consumption) and (c) penalization of ballast voyages (consuming fuel without carrying cargo).

The most commonly referred to “operational” index is the Energy Efficiency Operational Indicator (EEOI), with a formula very similar to that of EEDI, but instead of DWT in the denominator, actual amount of cargo carried is used. Also, total CO_2 emitted at the actual voyage speed (not V_{ref} at 75% MCR) is estimated.

The official position on EEOI of the Baltic and International Maritime Council (BIMCO), the largest shipping association with members controlling 65% of the world’s tonnage, is as follows: “Operational efficiency indices, such as the IMO Energy Efficiency Operational Indicator (EEOI), are overly simplistic or even misleading on an individual ship basis and therefore irrelevant, and should not be considered for regulatory purposes. Also, such indices could be wrongly perceived as valid selection criteria when assessing the efficiency of a ship prior to chartering.”[2]

As BIMCO correctly advises, there are several problems with EEOI, rendering it an unreliable indicator of efficiency. First, the effect of bad weather, where a ship increases fuel consumption to keep a certain speed, penalizes the EEOI value. Secondly, a voyage with less than maximum cargo, and more so zero cargo (on ballast), heavily worsens the EEOI value. Some owners add the fuel consumption from the preceding ballast voyage to the subsequent laden voyage and in this way account for the total fuel consumption to carry a certain amount of cargo per voyage.

Penalizing the value of EEOI for a ship in ballast (empty of cargo) proceeding to a port to load its cargo implies that a ship in ballast condition is not producing a benefit to society. In analogy, this is similar to assuming that an empty ambulance rushing to an accident scene to pick up the injured also does not produce a benefit to society.

Apart from these issues, the EEOI is not really connected to the efforts of the ship operator to operate his ship as efficiently as possible. Bad weather and ballast voyages are mostly out of the control of the operator, and their effect on EEOI may be much larger than any best practices applied by the ship owner (e.g., course optimization, frequent hull and propeller cleaning, etc.) Figure 3.13 shows that even for ships on dedicated (identical) voyages for years, a plot of EEOI rolling average

[2]Statement on BIMCO’s web site (https://www.bimco.org/about-us-and-our-members/bimco-statements/04-greenhouse-gases-ghg-emissions, accessed 2 July 2018).

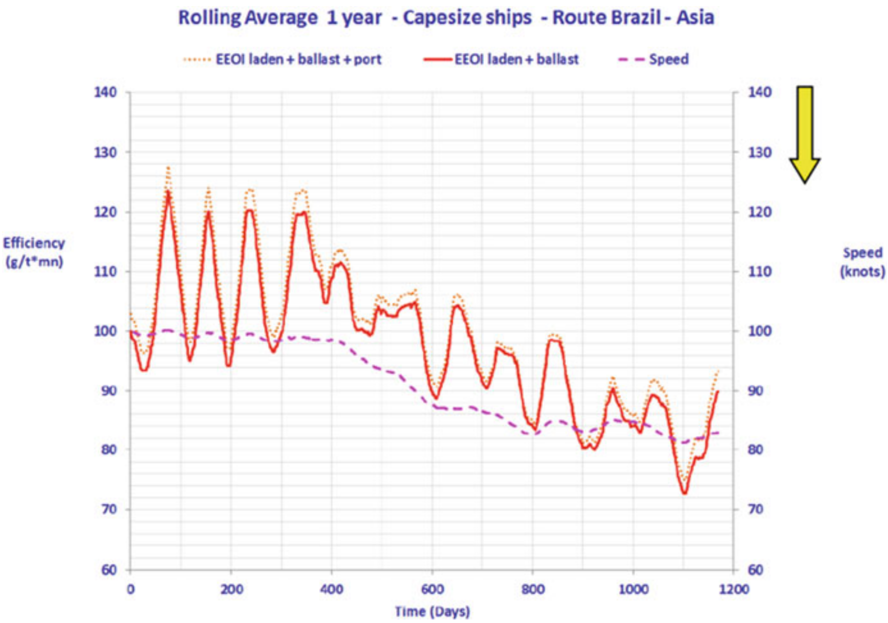

Fig. 3.13 Rolling average EEOI for capesize ships. (Source: IMO 2016a)

(each daily plot being the average value of the previous 365 daily EEOIs) shows no convergence. A most efficient ship with the most prudent operator may have a good EEOI one year and a bad EEOI the next, thanks to the whims of nature and the markets. Several companies, initially using EEOI as an efficiency indicator in their SEEMPs, have since abandoned it for other more targeted individual KPIs, suitable to the specific ship and its trade.

Several other proposed "operational" efficiency indices are more or less variations of EEOI. These include the Annual Efficiency Ratio (AER) proposed by Japan, the Fuel Oil Reduction Strategy (FORS) proposed by Germany, and others. These suffer from similar randomness and non-convergence issues, while several general ship energy efficiency indices used by some ports (for instance, the Clean Shipping Index (CSI), the Environmental Ship Index (ESI), etc.) use the EEOI in evaluating the portion of the ship's CO_2 footprint. Nevertheless, the desire for such indices stems from a desire to give a simple operational "efficiency" rating to each ship and compare it to an average value (e.g., EEOI baselines). That could be appropriate provided the ship index (e.g., EEOI) and the baselines (collection of various EEOIs from similar ship types) had a meaningful connection with ships' actual energy efficiency. So far, no simple index has been found to truly represent real operational efficiency.

Yet another "operational" index used for CO_2 efficiency evaluation is the EVDI (Existing Vessel Design Index), originated by the shipping rating service "Right-Ship." It has the same formula as the simplified EEDI formula, using data for each ship as they appear in public and proprietary databases. Such data have shown to be fraught with errors and inaccuracies, without independent verification of the accuracy of the data. In IMO (2013a, b, c) it was reported that even identical sister ships that were built by the same yard in the same period as part of a series program have EEDIs varying between 8% and 10%, the sole reason being different entries for the design speed recorded in the fleet databases. Such inaccuracies in the data also translate into EVDI, whose scope is broader than EEDI's. Of course, there is no standard % MCR for the reported speed, nor can there be any verification of the supplied data for EVDI. RightShip advises that any ship operator may provide to them corrected or more accurate data for their ship. Practically, however, ships with initially favorable published EVDIs, which may have been calculated from such inaccurate data, would have little incentive to provide "correct" data to RightShip. Lastly, a ship may have a very good EVDI, calculated with accurate or inaccurate data, but may be imprudently operated and still be registered with a favorable energy efficiency rating. Even if the vessel is prudently operated, it is clear that a better EEDI (EVDI) does not necessarily mean an efficient ship in actual operation (see above).

7 Way Ahead: Can EEDI Be Improved?

Despite the weaknesses identified above, we cannot and should not dismiss the usefulness of EEDI, if only for its intention of trying to push designers to design more efficient ships. To achieve CO_2 reductions in actual operation, EEDI must be linked more closely with the operation of ships in real weather conditions. Some studies suggest that the effectiveness of EEDI in improving efficiency so far might be quite small, on the order of 3% according to (Smith et al. 2016). While this may be because EEDI is a theoretical design index, it does increase awareness of energy efficiency. However, when optimizing a ship for maximum overall fuel efficiency, this cannot be achieved simply by minimizing the EEDI. As described in Chap. 2 of this book, to minimize fuel consumption (and hence CO_2 emissions), as part of a proper design process, the hull lines and propulsion system should be evaluated for a set of realistic draft and speed conditions, which are representative for the operational profile of the ship. The EEDI should thus be considered as a design constraint rather than an optimization objective.

What matters also is how the ship performs in real seas of, e.g., Beaufort 4–5, and some prudent owners require model tests in such simulated conditions (seakeeping tests). More and more shipyards care and design their ships for more realistic conditions, simply because owners want to know their future ships' actual projected performance and fuel consumption, in various loaded conditions and various speeds. As stated in the previous section, "EEDI weather" would be a big step forward albeit it still relates to the one condition of maximum draft and speed of 75% MCR. For a complete ship energy evaluation, a matrix of data should be used providing the fuel consumption and CO_2 emissions for various speeds and drafts of a typical operational profile.

It is a small wonder then that exactly that has been used for decades by charterers to choose the most efficient ship from those available to them for hire, i.e., they use a matrix that, as a minimum, includes the charter party owner-guaranteed speeds and fuel consumption figures in laden and ballast conditions, at full speed and slow speed, up to a weather condition of Beaufort 4, without paying much attention to index ratings (EEDI, EVDI, etc.) for the ships under evaluation, which are considered mostly unreliable.

To be more representative of operational conditions, the EEDI could be transformed with the use of f_w, however, at various drafts and speeds, toward a more meaningful index reflective of the real ship efficiency, not only as theoretically designed but also in actual operation.

Based on the above, it is preferable in our opinion that instead of trying to devise elusive "operational" indices which attempt to rate how efficiently an operator operates his ship, the ship should be designed to be most efficient at actual operating conditions. This is done in all other industries (e.g., we don't rate how efficiently a driver drives his car but how the car performs by design at predetermined conditions and cycles). Thus, a next step for EEDI should be to connect it to the expected operational conditions instead of searching for elusive operators' "operational" indices.

Disclaimer The views and opinions expressed in this chapter are those of the authors and do not necessarily reflect the position or views of American Bureau of Shipping or organizations that the authors belong to.

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