Appraisal and regulation of the ship energy performance

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Abstract. The ship may be viewed as a living environment associated with two industrial environments, one corresponding to the transport industry and other one to the processing, services, or other specific type of industry developed aboard. Each environment has its own energy system and changes energy with the other two. Nowadays, the appraisal and regulation of the ship energy performance is based on the Energy Efficiency Design Index (EEDI). Its definition covers the three mentioned systems, without distinction between them. This paper addresses the assessment and regulation of the ship energy performance, bearing in mind that, by far, the main purpose is to increase the level of performance by selecting, from the available measures of performance improvement, those that are the most effective. The paper highlights the EEDI shortcomings, explaining that they appear mainly due to the fact that this index covers a couple of energy systems that are far too different (though these energy systems are intimately interpenetrated).

1. Introduction

The shipping sector has emitted 1.015 million tonnes of CO2 in 2007, corresponding to 3.3% of the global emissions. Of this, international shipping has emitted 870 million tonnes or about 2.7% of the global total in 2007 [1]. The propulsion power and energy conversion on-board installation – namely the ship’s energy conversion system – is the main contributor to the overall emission footprint, cost effectiveness, and energy performance of a vessel.

Anticipated climate changes on the international agenda require reducing the global CO2 emissions in order to achieve stabilization at 2 °C of mean global temperature increase. The existing and impending stringent environmental legislations could be very strong drivers for growing the sustainability regarding the environmental footprint and energy performance of the vessels.

Energy policy is among the fastest, highest impacting, and most cost-effective ways of reducing greenhouse gases (GHG) emissions. Over the years, the European Union has introduced a number of directives, regulations [2, 3], and initiatives to encourage and support Member States, regional authorities, individuals and so on to increase the energy performance in the different sectors, including buildings, transport, and products.

In the figure 1, the energy forms and energy demands on board ships are suggested [4]. Energy systems of the ship must be autonomous and it includes the entire chain of energy production,
distribution and use. Energy production is necessary for moving vessel and for meet other needs that are required shipboard (electricity, heat and cooling) depending on the destination of the ship. Prime mover or main engine converts the chemical energy of the fuel as primary energy source to kinetic energy for ship moving. The propulsion power is result of the kinetic energy which is dissipated to the sea, overcoming the ship’s resistance. Some ships have on main engine shaft, one electrical generator called shaft generator which supply electricity on board ship. Moreover, to satisfy all electricity need, all ships have auxiliary engines which drives electrical generators.

![Figure 1. Energy forms and demands on board ships [4].](image)

Besides electricity and mechanical power for propulsion, the heat is required for ships. It is produced by ship boiler resulting from combustion (including the exhaust gases from the main propulsion), nuclear reaction, or thermal effect of electric current, and is transferred to the water. The water is heated, evaporated, and converted into saturated steam and if the continuous heating process, the steam produced is over-heated steam. The steam consumption on board depends on the type and class of ship. In naval practice, the ship boilers fall into two categories: fuel boiler, which use heat energy produced by burning a quantity of oil, and exhaust-gas boiler, using heat energy accumulated by the exhaust gas resulted from the main engine. In the first case, fuel boiler only works when the ship is stationary, whereas during the voyage the ship has a sufficient amount of steam to supply all consumers on board. For ships which have main boiler, donkey boiler operates continuously since these vessels do not have other sources of steam.

On the other hand, two terms – namely the ‘energy savings’ and ‘energy efficiency’ - are used (often with little precision or accuracy) to express the performance in the area of energy policy. The definitions, provided in the Energy Efficiency Directive (EED), establish a clear relation between the two terms, as follows:

- Article 2.4 defines energy efficiency as “the ratio of output of performance, service, goods, or energy to input of energy “.
- Article 2.5 on the other hand defines energy savings as “an amount of saved energy determined by measuring and/or estimating consumption before and after implementation of an energy efficiency improvement measure, whilst ensuring normalization for external conditions that affect energy consumption”. Specifically, energy saving is defined as the result of energy efficiency improvements. Savings are measured as the difference in energy consumption before and after the efficiency improvements.

As conclusion, the ship it may view as a living environment associated with two industrial environments, one corresponding to the transport industry and other one to the processing, services, or other specific type of industry developed aboard. Each environment has own energy system and changes energy with the other two.

The purpose of this paper is to highlight the shortcomings of both the EEDI definition and the regulations regarding the implementation of this index, as well as to propose a new approach through
which these shortcomings could be diminished. As a result, the next section presents the gaps of the
current appraisal and regulation system, and how they affect the qualitative attributes of the system,
namely the relevance, sensitivity, precision, sustainability, and coherence. Further, the third section
presents a new approach of the appraisal and regulation system, which aims to diminish the
shortcomings. The numerical example given in the fourth section highlights the benefits of the new
approach. Finally, the conclusions are summarised in the fifth section.

2. Criticism of the current appraisal and regulation system

The current system [5, 6] is based on the following features:

a) Energy Efficiency Design Index (EEDI), which quantifies the amount of carbon dioxide that a ship
emits in relation to the goods transported. The actual EEDI of a vessel is called the “attained
EEDI” and is calculated based on guidelines published by IMO. The result must be below the limit
(“required EEDI”) prescribed in MARPOL.

b) International Energy Efficiency Certificate (IEEC), which is to be issued at the vessel’s initial
survey, and provides that the EEDI has been verified (for applicable vessels) and the SEEMP is on
board.

c) Ship Energy Efficiency Management Plan (SEEMP), having as main purpose to lay down a
mechanism for a company and/or a ship to improve the energy efficiency of a ship’s operation. All
ships must have a SEEMP on board before the issuance of the first IEEC. The SEEMP is not
subject to approval or verification by the Administration.

d) Energy Management Systems (ISO 50001: 2011), which is an ISO standard that establishes a
framework for a company’s energy management system. It follows along similar lines to
Environmental Management Systems (ISO 14001).

The EEDI index is a fundamental element for the actual system. This index measures a certain
attribute of the ship, namely its level of aggressiveness over the environment, measured through the
quantity of CO2 emitted. The index is designed so that, by regulating the maximum value allowed, the
aggression is limited.

The attained EEDI is calculated on the base of the technical design parameters and standard
conditions of operation, and provides specific figure for an individual ship design, expressed in grams
of CO2 per ship’s capacity-mile. That can be illustrated by its definition formula, for instance those
given by-Germanischer Lloyd [7]:

\[
\text{Attained EEDI} = \frac{\sum P \cdot SFC \cdot C_F}{f_i \cdot \text{Capacity} \cdot V_{\text{ref}} \cdot f_w}
\]  

(1)

where: P- power, C_F - conversion between fuel and CO2, SFC - specific fuel consumption, f_i - capacity
factor, f_w - non-dimensional coefficient indicating the decrease of speed in representative sea
conditions of wave height, frequency and wind speed, V_{\text{ref}} - reference speed, and Capacity - a
consistent set of 75 % main engine power and the corresponding speed when the ship is carrying its
full capacity in calm weather.

The numerator of this fraction includes the amount emissions of main engine, auxiliary engine and
shaft generator/motor, minus emission savings from innovative technologies.

The required EEDI is the maximum allowable value of the attained EEDI and is given by the
following equation:

\[
\text{Attained EEDI} \leq \text{Required EEDI} = (1-X /100) \times \text{baseline value}
\]  

(2)

where X is the reduction factor of the required EEDI, compared to the EEDI baseline value.
The baseline values shall be calculated as follows:

\[
\text{Baseline value} = a \cdot b^{-c}
\]  

(3)
Where: \(a\), \(b\), and \(c\) are the parameters given for the different ship types. The baseline value is defined by a diagram which is mathematically defined.

The shortcomings of the current appraisal and regulation system are presented below:

a) The name of the index is inappropriate as energy efficiency is a variable defined as a ratio between output of performance, service, goods, or energy to input of energy. Though it has the same naming, the EEDI is referring to the ratio between the quantity of \(\text{CO}_2\) emitted and the transport work. The measurement unit for the EEDI is grams of \(\text{CO}_2\)/tonne nm. More to it, the actual name defies intuition as the increase in the ship’s efficiency is highlighted by the decrease in the index value.

b) The definition of the index is inappropriate for the following reasons:
   - The quantity of \(\text{CO}_2\) that forms the numerator of the ratio is referring to both the energy used for ship propulsion and all the onboard users of energy, regardless of their energy consuming activity, while the denominator of the ratio contains only a certain measure that evaluates the transport activity, namely the transport work (defined as multiplication between the ship’s capacity and speed). Indeed, the energy used for propulsion and the transport work are directly correlated, and consequently they can define an attribute. But the other consumers are referring to other activities that are not correlated to the transport work, for instance, loading and unloading the ship is correlated to the ships capacity, crew accommodation is correlated with time, regardless of the fact that the ship is moving or not, transported goods maintenance is correlated with the quantity and type of good and with the travel time. As a result, according to the actual definition, the numerator and denominator of the index are insufficiently correlated. This is affecting the relevance of the index.
   - The components forming the numerator have far too different values so that some of them are insignificant to the others. For instance, the power of the main engine is dozens of times higher than the sum of all the other. Thus, the modification of certain components leads to very small modifications of the index value. This is affecting the sensitivity of the index.
   - Moreover, it appears that the effect of the component modifications has comparable values to the effect of the appreciation errors of the variables value. This is affecting the precision of the index (namely the precision with which the index is measuring the effect of the modifications).

c) The regulation regarding the index baseline is inappropriate for the following reasons:
   - The baseline is referring to the level of \(\text{CO}_2\) emissions of the ship and does not take into account the fact that, even though the EEDI is under the baseline level, the global emission can surpass the actual level through the increase in the number of ships under exploitation. This is affecting the sustainability of the index.
   - The baseline for ships is not in agreement with the baseline for the similar terrestrial constructions, sustaining the same type of activity (transport, residential, or industrial). This is affecting the coherence of the index.

3. The proposed approach
From our perspective, the appraisal should first of all pinpoint the effect of the measures to reduce the \(\text{CO}_2\) emissions, therefore helping the target groups to compare the possible solutions and highlight the most efficient. The target groups of the regulations are the designers / builders, owners and operators of ships. The index should sustain the procedures that the target groups applied for identification and application of the most efficient solutions.

Moreover, the appraisal should be coherent with the methodology applied in the other fields where the \(\text{CO}_2\) emissions are considered the attribute reflecting the level of aggression over the environment.

On the other hand, the index should be regarded as any measurement instrument, intended for the evaluation (through measurement or calculation) of certain variables (in this case, the variable is the specific quantity of \(\text{CO}_2\) emitted as a consequence of an activity). For this reason it has the same qualitative attributes as any measurement instrument and particularly, the relevance of the measured value, sensitivity to small variations of the variable value, precision of repeated measurement of the
same value, sustainability in time (linked to the fact that the index leads to the same conclusion, though the measurement conditions have evolved in time), and finally coherence with other similar instruments (respectively, the indexes used in similar fields).

The regulations should oblige the target groups to modify the adopted solutions, both in design and in exploitation of the ships, in order for the value of the index to decrease.

To materialize this vision we propose the following:

Firstly, the name of the index should be Energy Impact Design Index (EIDI) as the index points out the unwanted environmental impact of the used energy for developing a certain useful activity and not the quantity of energy used (as the name Energy Efficiency Design Index suggests). This way, the intuition is not “aggressed” as for a good use of energy, the “Energy Efficiency” is high and the “Energy Impact” is low.

Secondly, we propose that both the index and the baseline to be vectors with three components called naval component, residential component, and industrial component. Thus, the index will have the naval EEDI component, residential EEDI component and industrial EEDI component. Similarly, the baseline will have the naval baseline component, residential baseline component and industrial baseline component. Each component, either of the index or of the baseline, is defined by a calculation formula and through standard conditions in which the values of the variables from the calculation formula are evaluated.

In what the calculation formula is concerned, the components of the index would therefore be defined as follows:

- Naval EIDI is the ratio between CO₂ amount and the transport work (the last being expressed as multiplication between capacity and speed).
- Residential EIDI is the ratio between CO₂ amount and the residential work (the last being expressed as multiplication between total floor area and time).
- Industrial EIDI is the ratio between CO₂ amount and the industrial work (the last being expressed specifically for the onboard industrial activity undergone).

In what the standard conditions are concerned, the following key ideas should be considered:

- The three energy systems exchange energy between them. Nonetheless, the standard conditions will correspond to the situation in which there is no exchange of energy. This decision has a double motivation. The first motivation is that the energy exchange is not permanent but only occasional, for limited term. For each of the three energy systems there are situations in which they have to function independently. Sizing the system components is achieved through design and is based on the standard condition of independent functioning. The second motivation refers to the fact that the index characterises the energy system by itself and not by the occasions in which it functions.
- The components of the baseline are defined separately from one another. The naval baseline is defined according to the current methodology, while the industrial and residential baselines are defined according to the methodologies applied to similar terrestrial constructions.

Thirdly, we propose that the actual regulations should foresee the obligation to periodically weighting the current baselines with the percentage of increase in global volumes of the shipping transport activities so that the quantity of CO₂ emitted into the atmosphere is decreased at a global level, even though the volume of this activity increases.

Numerical example

This example is for Anchor Handling Tug Supply vessels (AHTS) [8] that is capable of operations in the harshest environments. AHTS vessels mainly perform anchor handling duties and towage of offshore drilling units and floating production units. As AHTS vessels generally have free deck area, and some of them have tanks below deck, they can also carry cargo and bulk.

a) According to the current system, the index EEDI have only one component:

\[
EEDI=((P_{me} \times CF_{me} \times SCF_{me})+(P_{ae} \times CF_{me} \times SCF_{me}))/DWT \times Vref = 21.43 \text{ gCO}_2/\text{t nm}
\]

for:

- Capacity = 700+4,580 t; Speed = 17 knots; MCR_{me} = 6,000kW; P_{me}= 0.75 \times (MCR_{me}) = 4,500kW; P_{ae}=(0.025 \times MCR_{me})+250kW = 400kW; Vref = 17 knots; CF_{me} = 3.206 \text{ gCO}_2/\text{g-fuel}.
CF_{ae} = 3.206 \text{ gCO}_2/\text{g-fuel}; \text{ SFC}_{me} = 190 \text{ g/kWh}; \text{ SFC}_{ae} = 215 \text{ g/kWh}.

As in other examples, different structures of energy system lead to the modification of the EEDI value with just a few percent.

b) According to the proposed system, the index EIDI have the following three components:

1. \text{EIDI}_{\text{naval}} = (P_{me} \times \text{SFC}_{me} \times \text{CF}_{me})/\text{DWT} \times \text{Vref} = 19.47 \text{ gCO}_2/\text{t nm}

2. \text{EIDI}_{\text{accomodation}} = \text{CO}_2/\text{surface} = 63.19 \text{ kgCO}_2/\text{m}^2\text{year}, \text{ for: } P = 394.6\text{ kW}; \text{ Time} = 2,190\text{ h}; \text{ Energy} = 864,182\text{ kWh}; \text{ Surface} = 9,429\text{ m}^2; \text{ EPC} = 91.65 \text{ kWh/m}^2\text{corresponding to the B energetic class}; \text{ CO}_2 (\text{calculated by using [9]} \text{is} \ 595,898 \text{ kg/year}.

3. \text{EIDI}_{\text{industrial}} = (P_{me} \times \text{SFC}_{me} \times \text{CF}_{me})/\text{Brake Power} = 4500 \times 3.206 \times 190/19,000 = 144.27 \text{ gCO}_2/\text{kWh}

By its components, the proposed index highlights areas where are real possibilities to improve the energy performance.

4. Conclusions

A strategy for ship energy efficiency is welcome, but regulation only monitors fuel consumption instead of directly reducing it, and covers only CO2 and not air pollutants like SO2 or NOx.

A simple analogy with eco-design directive or energy performance of buildings indicates lack of ecological labelling of ships. All ship type is possible in the future, to use the cleaner fuel (gas fuel or hydrogen fuel) and is expected to achieve the green ship by using efficiency of renewable technologies. The use of renewable energy technologies in ship is not a usual practice yet. Even if the market can offer adequate technology, neither clears mandatory actions, nor provisions stimulating the increase of renewable energy use in especially hydrogen technology for new ships. The path towards a greener marine future and sustainable shipping involves the more widespread use of wind, solar and electric power to help propel and power vessels of all sizes.

Finally, the current appraisal and regulation system 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 level of energy impact is attained, the ship designers and builders are free to use the most cost-efficient solutions for the ship to comply with the regulations.

References

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