Consideration of Energy Efficiency Operational Index evaluation

C Faitar¹ A T Nedelcu² N Buzbuch³ L C Stan⁴ D E Juganaru⁵
¹³⁴⁵ Maritime University of Constanta, 104 Mircea cel Batran Street, Constanta, Romania
² Mircea cel Bătrân Naval Academy, 1 Fulgerului Street, Constanta, Romania

Abstract. The Energy Efficiency Operational Indicator (EEOI) is a monitoring tool for managing ship and fleet efficiency performance over time. The EEOI enables operators to measure the fuel efficiency of a ship in operation and to gauge the effect of any changes in operation, e.g. improved voyage planning and more frequent propeller cleaning, or the introduction of technical measures such as waste heat recovery systems or a new propeller. The EEDI index implies a minimum acceptable level in terms of ship energy efficiency, quantified by CO₂ emissions and relative to freight and transport distance. Supported values will be reduced depending on the implementation phases. It expects the implementation of this index to drive the deployment of innovative shipboard technologies to influence their energy efficiency. The values of the reduction factors have a decreasing trend during the implementation periods, reaching a minimum of 30% reduction of the pollutant emissions in the years 2025 compared to the levels before the implementation of this index. EEDI has been conceived as the largest and most powerful segments of the maritime industry.

1. Introduction
In order to facilitate the successful implementation on board ships from the operational point of view of the EEDI reduction requirements and implicitly of the current levels of NOx, was developed the concept of SEEMP - Ship Energy Efficiency Management Plan. This management plan establishes a mechanism for ship owners and their teams to improve the efficiency of systems onboard ships. SEEMP allows the development of an energy efficiency monitoring system on board ships over time using indices such as EEOI (Energy Efficiency Operational Index). The implementation of this instrument forces both shipowners and their operators to consider operational procedures and refurbishment of vessels at any stage of their operating cycle.

Following studies carried out at the IMO level, it was found that the correct implementation of the efficiency index would lead to a significant decrease in NOx emissions from activities in the Maritime Industry.
2. EEOI evaluation for ship diesel engine propulsion system

Consider that the ship is equipped with the engine which has an actual specific fuel consumption $SFC = 171 \text{ g/kWh}$ and the conversion factor $C_f = 3.1144$.

For the calculation of the index we apply the formula below:

$$EEOI = \frac{PM_E \cdot C_f \cdot SFC}{V_{\text{ref}} \cdot \Delta} \left[ \frac{tCO2}{t \times \text{mile}} \right]$$

where:
- $PM_E = 40282.91 \text{ kW}$ - main engine power for the speed of 17 knots;
- $PAE = 1500 \text{ kW}$ - auxiliary engine power;
- $SFC = 171 \text{ g/kWh}$ - specific fuel consumption;
- $V_{\text{ref}} = 17 \text{ Nd}$ - ship speed from 0 to 20 knots;
- $\Delta = 105700 \text{ dwt}$ - ship capacity in tonnes;
- $C_f = 3.1144$ - conversion factor.

The index for the speed 0 - 17 knots range was calculated and the values were obtained in table 1.

| Ship speed [Nd] | Propulsion power [kW] | EEOI    |
|----------------|-----------------------|---------|
| 0              | 0                     | 0       |
| 1              | 17.7970313            | 7.647319108 |
| 2              | 35.5940626            | 3.868494132 |
| 3              | 150.5321878           | 2.772032114 |
| 4              | 265.470313            | 2.223801105 |
| 5              | 541.7549193           | 2.057449196 |
| 6              | 872.2150176           | 1.992041191 |
| 7              | 1340.933566           | 2.044836327 |
| 8              | 2077.838828           | 2.253337787 |
| Speed [knots] | EEOI |
|---------------|------|
| 0             | 1    |
| 1             | 2    |
| 2             | 3    |
| 3             | 4    |
| 4             | 5    |
| 5             | 6    |
| 6             | 7    |
| 7             | 8    |
| 8             | 9    |
| 9             | 2.531433583 |
| 10            | 2.906162742 |
| 11            | 3.462162646 |
| 12            | 4.179880393 |
| 13            | 5.193892891 |
| 14            | 6.491353301 |
| 15            | 7.861924824 |
| 16            | 9.869449017 |
| 17            | 12.38355498 |

Figure 2. EEOI vs speed for diesel engine propulsion

3. EEOI evaluation for ship dual fuel engine propulsion system

In the case of LNG ship has a dual fuel engine which has an actual specific gaseous consumption of $SFC = 158 \text{ g/kWh}$, have a conversion factor of $C_f = 2,3358$. For the calculation of the index we apply the formula below:

$$EEOI = \frac{(P_{ME} \cdot C_f \cdot SFC) + (P_{AE} \cdot C_f \cdot SFC)}{V_{ref} \cdot \Delta} [\text{tCO2/t x mile}]$$

unde:
- $P_{ME}$ – main engine power for design speed in konts;
- $P_{AE} = 1500 \text{ kW}$ - auxiliary engines power;
- $SFC = 158 \text{ g/kWh}$ - specific fuel consumption;
- $V_{ref} = 17 \text{ N}d$ - ship speed from 0-20 knots;
- $\Delta=105700 \text{ dwt} –$ ship capacity in tonnes;
- $C_f = 2,3358$ - conversion factor.

The index for the speed 0 - 17 knots range was calculated and the values were obtained in table 2.
Table 2. EEOI values for dual fuel propulsion

| Ship speed [Nd] | Propulsion power [kW] | EEOI     |
|-----------------|------------------------|----------|
| 0               | 0                      | 0        |
| 1               | 17.7970313             | 5.299457978 |
| 2               | 35.5940626             | 2.680798565 |
| 3               | 150.5321878            | 1.920969623 |
| 4               | 265.470313             | 1.541055151 |
| 5               | 541.7549193            | 1.425776197 |
| 6               | 872.2150176            | 1.380449597 |
| 7               | 1340.933566            | 1.4170357 |
| 8               | 2077.838828            | 1.561523554 |
| 9               | 3021.822733            | 1.754239062 |
| 10              | 4267.988912            | 2.01391795 |
| 11              | 6058.656993            | 2.399217974 |
| 12              | 8455.190772            | 2.896583781 |
| 13              | 11901.11172            | 3.599276652 |
| 14              | 16537.14384            | 4.498393954 |
| 15              | 21905.86156            | 5.448175975 |
| 16              | 29841.32672            | 6.83935502  |
| 17              | 40282.91584            | 8.581586344 |

Figure 3. EEOI vs speed for dual fuel engine
4. EEOI evaluation for diesel – electric dual fuel propulsion system

In the case of LNG ship has a diesel – electric dual fuel propulsion which has an actual specific gaseous consumption of $SFC = 165 \text{ g/kWh}$, have the conversion factor of $C_f = 2.3358$. 

For the calculation of the index we apply the formula below:

$$EEOI = \frac{(P_{ME} \cdot C_f \cdot SFC) + (P_{AE} \cdot C_f \cdot SFC)}{V_{ref} \cdot \Delta} [tCO_2/t \times \text{mile}]$$

unde:
- $P_{ME}$ - engine power for design speed in konts;
- $P_{AE} = 1500 \text{ kW}$ - auxiliary engines power;
- $SFC = 158 \text{ g/kWh}$ - specific fuel consumption;
- $V_{ref} = 17 \text{ Nd}$ - ship speed from 0-20 knots;
- $\Delta=105700 \text{ dwt}$ – ship capacity in tonnes;
- $C_f = 2.3358$ - conversion factor.

The index for the speed 0 - 17 knots range was calculated and the values were obtained in table 3.

| Ship speed [Nd] | Propulsion power [kW] | EEOI          |
|----------------|-----------------------|---------------|
| 0              | 0                     | 0             |
| 1              | 17.7970313            | 5.534244091  |
| 2              | 35.5940626            | 2.799568121  |
| 3              | 150.5321878           | 2.006075872  |
| 4              | 265.470313            | 1.609329747  |
| 5              | 541.7549193           | 1.488943497  |
| 6              | 872.2150176           | 1.441608756  |
| 7              | 1340.933566           | 1.479815763  |
| 8              | 2077.838828           | 1.630704978  |
| 9              | 3021.822733           | 1.831958514  |
| 10             | 4267.988912           | 2.10314409   |
| 11             | 6058.656993           | 2.505512441  |
| 12             | 8455.190772           | 3.024913442  |
| 13             | 11901.11172           | 3.758738276  |
| 14             | 16537.14384           | 4.697689889  |
| 15             | 21905.86156           | 5.68955086   |
| 16             | 29841.32672           | 7.14236442   |
| 17             | 40282.91584           | 8.961783208  |
5. EEOI evaluation for gas turbine propulsion system

In the case of LNG ship has a gas turbine propulsion system which has an actual gaseous $SFC = 188 \text{ g/kWh}$, have the conversion factor of $C_f = 2.779$.

For the calculation of the index we apply the formula below:

$$EEOI = \frac{(P_{ME} \cdot C_f \cdot SFC) + (P_{AE} \cdot C_f \cdot SFC)}{v_{ref} \cdot \Delta} \text{ [tCO2/t x mile]}$$

unde:

- $P_{ME}$ - engine power for design speed in konts;
- $P_{AE} = 1500 \text{ kW}$ - auxiliary engines power;
- $SFC = 188 \text{ g/kWh}$ - specific fuel consumption;
- $v_{ref} = $ ship speed from 0-20 knots;
- $\Delta = 105700 \text{ dwt}$ - ship capacity in tonnes;
- $C_f = 2.779$ - conversion factor.

The index for the speed 0 - 17 knots range was calculated and the values were obtained in table 4.

| Ship speed [Nd] | Propulsion power [kW] | EEOI       |
|----------------|-----------------------|------------|
| 0              | 0                     | 0          |
| 1              | 17.7970313            | 7.502139022|
| 2              | 35.5940626            | 3.795052929|
| 3              | 150.5321878           | 2.719406631|
| 4              | 265.470313            | 2.181583481|
| 5              | 541.7549193           | 2.018389671|
|   | EEOI       | Speed [knots] |
|---|-----------|---------------|
| 6 | 872.2150176 | 1.9542234     |
| 7 | 1340.933566 | 2.00601625    |
| 8 | 2077.838828  | 2.21059427    |
| 9 | 3021.822733  | 2.48337529    |
| 10| 4267.988912  | 2.85090864    |
| 11| 6058.656993  | 3.39643542    |
| 12| 8455.190772  | 4.100527696   |
| 13| 11901.11172  | 5.095289732   |
| 14| 16537.14384  | 6.36811858    |
| 15| 21905.86156  | 7.712670568   |
| 16| 29841.32672  | 9.682083034   |
| 17| 40282.91584  | 12.1484601    |

Figure 5. EEOI vs speed for gas turbine propulsion

Figure 6. EEOI comparison
6. Conclusions

The graphs for the variation of the energy efficiency index for the diesel and gaseous fuel consumption are presented in the following. Compared to the current level of CO\textsubscript{2} emissions, a reduction in fuel consumption and CO\textsubscript{2} emissions between 13\% and 23\% is expected by 2020 and 2030. It is noted that the measures envisaged for the SEEMP implementation (especially operational measures) will begin to feel its medium-term effect (2020), while technological approaches will have long-term effects (2030-2050) as the world fleet will be upgraded and as new technologies are adopted. However, considering the development trends of the world fleet, on the one hand, and trends in the development and deployment of new technologies on board ships, on the other hand, there will be no decrease in the level of emissions and an absolute value but a decrease in the level of emissions compared to the level that would have been achieved without the implementation of these measures.

References

[1] Faitar, C.; Considerații teoretice și practice de optimizare a exploatarii sistemelor energetice la un VLCC de 305000 tdw, License Degree, Constanța, 2017; p.113-121;
[2] Faitar, C.; Concepte de modernizare energetică a unui VLCC de 305000 t.d.w. Calculul și proiectarea sistemelor energetice auxiliare, Master’s Degree, Constanța, 2017; p.89-113;
[3] Faităr, C.; Novac, I.; A new approach on the upgrade of energetic system based on green energy. A complex comparative analysis of the EEDI and EEOI, ModTech International Conference Modern Technologies in Industrial Engineering 15-18 June 2016, Ramada Hotel, Iasi, Romania. (http://iopscience.iop.org/1757-899X/145/4/042014);
[4] Dobref, V., Popa, I., Popov, P., Scurtu, I.C., Unmanned Surface Vessel for Marine Data Acquisition, (2018) IOP Conference Series: Earth and Environmental Science, 172 (1), art. no. 012034, DOI 10.1088/1755-1315/172/1/012034
[5] Scurtu, I.C., Manufacturing and design of the offshore structure Froude scale model related to basin restrictions, (2015) IOP Conference Series: Materials Science and Engineering, 95 (1), art. no. 012068, DOI: 10.1088/1755-1315/95/1/012068
[6] Scurtu, I.C., Clinci, C., Popa, A., Water interference effect on ship due to square shaped object shielding, (2018) IOP Conference Series: Earth and Environmental Science, 172 (1), art. no. 012030, DOI: 10.1088/1755-1315/172/1/012030
[7] Faitar, C.; Novac, I. Basic aspects and contributions to the optimization of energy systems exploitation of a super tanker ship, ModTech International Conference Modern Technologies in Industrial Engineering 14-17 June 2017, Sibiu, Romania;