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Proposed Inland Oil Tanker Design in Bangladesh Focusing CO₂ Emission Reduction Based on Revised EEDI Parameters

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Abstract: Though inland ships account for a small portion of the total global CO₂ emissions from shipping, from the individual country's economic and environmental perspective, this is very important. To reduce CO₂ emissions from sea-going ships by increasing energy efficiency, the International Maritime Organization (IMO) adopted a generalized Energy Efficiency Design Index (EEDI) in 2011. However, due to the variation in environmental, geographic and economic conditions, a generalized EEDI cannot be established in a similar fashion to that established by IMO. Shallow and restricted water effects, different fuel qualities (to reduce operational cost), increase in engine power requirements, reduction in carrying capacity, cargo availability, etc. make the EEDI by IMO inadequate for inland waterways. Therefore, an EEDI formulation based on revised parameters has been proposed for the inland ships in Bangladesh. This paper focuses on the possibility of CO₂ emissions reduction from inland oil tankers in Bangladesh by implementing the revised EEDI formulation (henceforth denoted as EEDI_{INLAND}). A sensitivity analysis was performed for the different ship design parameters of those oil tankers. Based on the analysis, suggestions were made on how to design inland oil tankers in Bangladesh using the revised EEDI formulation for reducing CO₂ from the current level without any major cost involvement. Keeping the same speed and capacity, the vessels were redesigned based on those suggestions. The Computational Fluid Dynamics (CFD) analysis of those redesigned vessels using 'Shipflow' showed a reduction in CO₂ emissions through increasing EEDI_{INLAND} by 7.54–13.65%.

Keywords: EEDI; EEDI_{INLAND}; inland oil tanker; CO₂ emission; energy efficiency; MEPC

1. Introduction

Inland Waterborne Transport (IWT) has contributed to the development of mature economies over many centuries and created many bridges between nations [1]. It helps the developing country to achieve several of the Millennium Development Goals (MDGs), especially MDG 7 (Ensure Environmental Sustainability) and MDG 8 (Develop a Global Partnership for Development). To ensure the environmental goals of MDGs, and with particular regard to the IMO's efforts to reduce or limit GHG emissions from ships (as mandated under the Kyoto Protocol) [2], the IMO established the Energy Efficiency Design Index (EEDI) to reduce the CO₂ emissions at the design stage from sea-going ships [3]. However, studies on environmental sustainability and reduction of Green House Gas (GHG) from inland shipping have been somewhat limited, despite many studies having been reported on sea-going ships [4].

The EEDI formulation adopted by the IMO to increase the energy efficiency of sea-going ships has been successful so far [5]. However, the IMO does not have any guidelines for inland ships in

the EEDI regulations yet. The absence of appropriate energy and emissions benchmarks for Inland Waterway Self-Propelled ships is a large impediment to performance improvements of inland ships [6]. Inland ships, in general, require more power at the same speed than open water/sea-going ships of similar type [7]. Figure 1 shows the CO₂ emissions per transport unit (tonne-km), presenting different freight transport modes (Road, Rail, Maritime and Inland Shipping) over the period of 1995 to 2011 in Europe [8]. CE Delft (an independent research and consultancy organization, based in The Netherlands) found CO₂ emissions per tonne-km for inland and short-sea shipping to be 38 and 15, respectively [9], whereas, the Logistics Research Centre, Heriot-Watt University, presented the same as 20 and 8.4, respectively [10]. In all cases, on average it is shown that the CO₂ emissions per tonne-km for inland shipping is more than double that of sea-going ships.

Figure 1. Specific CO₂ emissions per tonne-km and per mode of transport in Europe. The graph is an intellectual property of the Commission of the European Union [8].

Although inland shipping accounts for only 9% of the total CO₂ emissions of global shipping [11], attempts to reduce CO₂ from its current level can be very important for individual countries from an economic and environmental perspective.

By definition, the EEDI quantifies the transport work for estimating the amount of CO₂ emissions by sea-going ships [12]. However, inland waterways are a complex and diverse sector involving a wide variety of vessels operating for a multitude of purposes [13]. In general, inland ships require more power at the same speed in comparison to open water/sea-going ships of similar type. The main reasons for this are:

- Shallow water effect drops the speed;
- Ship design is mostly governed by the river width and depth;
- Choice of length, breadth, draft, and propeller diameter of the ship is not free as in open sea ship design.
- Less dense river water lowers the capacity at the same draft in comparison to a sea-going ship, which has huge impact on EEDI calculation.

These unfavorable conditions increase the CO₂ emissions of inland vessels, especially for poorly designed ships. Restrictions on inland navigation will vary from country to country because of the differences in geographical conditions. As a result, a generalized EEDI like for sea-going ships is not

possible. This problem has been addressed by the authors in their previous study [12]. Incorporating the speed drop due to shallow water effect and other necessary required changes, a set of revised EEDI parameters (denoted as EEDI_{INLAND}) for inland ships in Bangladesh was proposed by Hasan and Karim [12]. Like EEDI by IMO, the EEDI_{INLAND} also quantifies CO₂ emissions per tonne-nautical mile considering the influential factors of inland ships in Bangladesh.

This study focuses on the possibility of reducing CO₂ emissions based on the revised EEDI_{INLAND} [12] for inland ships in Bangladesh. Major effort has been given to ship design improvements in order to reduce CO₂ emissions and increase the energy efficiency of ships.

EEDI_{INLAND} was implemented on 102 existing inland oil tankers in Bangladesh, and the results are presented.

Since EEDI is simply the ratio of ‘Environmental Cost (CO₂ emission)’ to the ‘Benefit to the Society (Cargo carried at a certain speed)’, which involves the total input and output of a ship including ship design parameters [14], hull forms can be made more efficient by modifying the main ratios between the ship’s length, beam, draught and coefficients, while keeping the cargo-carrying capacity unchanged. In this study, a set of suggestions is also provided for modifying the main ship design ratio and coefficient, focusing on the reduction of EEDI_{INLAND} value (i.e., CO₂ emission) by improving inland oil tanker ship design for Bangladesh. A sensitivity analysis that involves ship design parameters was implemented on all 102 oil tankers under consideration. It was found in this research that a slender ship hull design emits less CO₂ in comparison with a bulky one. Kristensen [15], Scott and Wright [16], Lindstad et al. [17] and Lindstad [18] have also shown in their studies how slender ship hull design reduces drag and significantly lowers the power requirements and fuel consumption.

Sensitivity analysis had allowed this study to identify the ship design parameters with the highest influence on ship design (focusing EEDI_{INLAND}). Thus, in this research, a set of suggestions is proposed based on the sensitivity analysis. These suggestions are used to redesign the existing inland oil tankers in Bangladesh. The EEDI_{INLAND} value and the total resistance of the parent and redesigned ships based on the suggestions from the sensitivity analysis were analyzed using the commercial CFD software called ‘Shipflow’ [19]. For fair comparison of existing and redesigned ship, capacity and service speed were kept the same as the existing one.

2. Brief Description of EEDI by IMO

EEDI in its simplest form can be expressed as follows [20]:

$$\begin{aligned}
 EEDI &= \frac{\text{CO}_2 \text{ Emission}}{\text{Transport Work}} \\
 &= \frac{\text{Power} \times \text{Specific Fuel Consumption} \times \text{CO}_2 \text{ Conversion factor}}{\text{Factors} \times \text{Capacity} \times \text{Speed}} \\
 &= \frac{\text{Emission from Main Engine} + \text{Emission from Auxiliary Engine} + \text{Emission for running shaft motor} - \text{Efficient Tech. Reduction}}{\text{Different factors} \times \text{Capacity} \times \text{Reference Speed}} \\
 &= \frac{\left(\prod_{j=1}^n f_j \right) \left(\sum_{i=1}^{nME} P_{ME(i)} \times C_{FME(i)} \times SFC_{ME(i)} \right) + (P_{AE} \times C_{FAE} \times SFC_{AE}) + \left(\prod_{j=1}^n f_j \sum_{i=1}^{nPTI} P_{PTI(i)} \times C_{FAE} \times SFC_{AE} \right)}{\left(\sum_{i=1}^{neff} f_{eff(i)} \times P_{AEff(i)} \times C_{FAE} \times SFC_{AE} \right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \times P_{eff(i)} \times C_{FME} \times SFC_{ME} \right)} \quad (1) \\
 &= \frac{f_i \times f_c \times f_l \times f_W \times \text{Capacity} \times V_{REF}}{f_i \times f_c \times f_l \times f_W \times \text{Capacity} \times V_{REF}} \\
 &= \frac{\text{kW} \times \frac{\text{g}_{fuel}}{\text{kWh}} \times \frac{\text{g}_{CO_2}}{\text{g}_{fuel}}}{\text{Tonne} \times \frac{\text{nautical mile}}{\text{hour}}} \\
 &= \frac{\text{g}_{CO_2}}{\text{Tonne} \times \text{nautical mile}}
 \end{aligned}$$

Equation (1) of EEDI contains different constants and coefficients that are briefly described in Table 1. Table 1 is the summary of the Marine Environment Protection Committee (MEPC) resolution by the IMO on EEDI [20].

Table 1. Description of different parameters of EED by the IMO [20].

Parameter	Description
f_j	Correction factor to account for ship specific design elements (e.g., ice classed ships, shuttle tankers)
P_{ME}	75% of the main engine MCR (Maximum Continuous Rating) in kW
C_{FME} and C_{FAE}	Non-dimensional conversion factor for main engine between fuel consumption measured in gram and CO ₂ emissions also measured in gram on carbon content. ME and AE stands for main and auxiliary engine, accordingly.
SFC_{ME}	Certified Specific Fuel Consumption of main engine in g/kWh
P_{AE}	Auxiliary Engine Power
SFC_{AE}	Certified Specific Fuel Consumption of main engine in g/kWh
$PPT_{(i)}$	75% of rated power consumption of shaft motor
$f_{eff(i)}$	Availability factor of innovative energy efficiency technology
$P_{AEff(i)}$	Auxiliary power reduction due to innovative electrical energy efficient technology
$P_{eff(i)}$	Output of innovative mechanical energy efficient technology for propulsion at 75% main engine power
f_i	Correction factor to account for ship specific design elements. (For e.g., ice classed ships, shuttle tankers)
f_c	Cubic capacity correction factor (for chemical tankers and gas carriers)
f_l	Factor for oil tanker ships equipped with cranes and other cargo related gear to compensate in a loss of deadweight of the ship
Capacity	Oil Tanker: Computed as a function of dead weight (DWT), as indicated in 2.3 and 2.4 of MEPC 245(66) "2014 Guidelines on the calculation of the Attained EEDI for new ships"
f_w	Non-dimensional coefficient indicating the decrease of speed in representative sea condition of wave height, wave frequency and wind speed
V_{ref}	Ship speed in nautical miles per hour at P_{ME}

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3. EEDI_{INLAND} Parameters for Inland Ships in Bangladesh

The IMO established EEDI for sea-going ships in 2011 [3]. Later, it was amended in 2018 with some important updates [20]. For new regulations, these types of amendments are quite normal. Vladimir, Ančić and Šestan [21] also proposed updating the existing baseline formulation for sea-going ships with new Ultra Large Container Ship (ULCS) data available in the IHS Fairplay database. Similarly, for inland ships in Bangladesh, necessary modifications of the original EEDI formulation of the IMO were proposed by the authors [12]. The required changes are presented in Table 2.

Table 2. Comparison of EEDI parameters as defined by the IMO and revised for Bangladesh.

Serial.	EEDI Parameter	Defined by IMO [20]	Reason for the Revision [12]	EEDI _{INLAND} Parameters
1	P_{ME}	75% of the main engine MCR in kW	Investigation showed that the average MCR for the inland oil tankers in Bangladesh is 60%, considering shallow water and other economic effects	60% of the main engine MCR in kW
2	V_{REF}	Ship speed in nautical miles per hour at P_{ME} (at 75% MCR)	As per the definition of the IMO, speed at P_{ME} is the V_{REF} . Moreover, speed drop due to the shallow water effect must be incorporated.	Ship speed in knot at P_{ME} (60% MCR)
3	Capacity	Computed as a function of dead weight	Because of the availability of cargo and poor ship design, 85% of the total dead weight is considered to be 'capacity' for inland oil tankers in Bangladesh.	85% of the total design dead weight.
4	Diesel oil Carbon Content	Grade: ISO 8217 Carbon Content: 0.87441	Bangladesh government-owned fuel oil distribution company supplies the same quality fuel. However, mixing impurities at the user end change the actual carbon content. Fuel testing by Hasan and Karim [12] showed that the average carbon content of fuel used for inland ships in Bangladesh was 0.76.	0.76 as per the test result.
5	C_F (non-dimensional CO ₂ conversion factor)	$C_F(IMO)$: Carbon Content in the fuel $\times$ (Molecular weight of CO ₂ /Molecular weight of Carbon) = $0.8744 \times (44/12)$ = 3.206 gm CO ₂ /gm fuel	As per the new carbon content value.	C_F (Inland ships in Bangladesh): Carbon Content in the fuel $\times$ (Molecular weight of CO ₂ /Molecular weight of Carbon) = $0.76 \times (44/12)$ = 2.787 gm CO ₂ /gm fuel

As presented in Table 2, P_{ME} (the power at MCR of the main engine) and V_{REF} (reference ship speed) are related to each other, since V_{REF} is the speed at the specified P_{ME} . In general, sea-going vessels move at a continuous engine RPM for longer periods, which is on an average 75% of MCR. However, for inland ships, it is very difficult to maintain a continuous engine RPM for longer periods, primarily because of the shallow water, and inland waterway traffic. The shallow water effect is defined as any effect of the river/channel bottom or bank on the ship's hull. The lower the river depth/Ship draft is, the higher the effect. This effect decreases ship speed at the same engine power. As investigated by Hasan and Karim [12], the average MCR for inland oil tankers in Bangladesh is 60%.

Hasan and Karim [12] also found that in many cases, poorly/faultily designed oil tankers fail to carry their full load (when loaded fully to the forward hold, these tankers trim to the bow). Sometimes, higher hold volume than the required dead weight leaves empty spaces in the hold when loaded. In addition to this, the availability of cargo is another issue. On average, 85% of cargo is available, as determined by Hasan and Karim [12]. Therefore, 85% of the dead weight is suggested as the value of 'Capacity' in $EEDI_{INLAND}$ for oil tankers in Bangladesh.

Quality of fuel is another important issue for Bangladesh. The IMO-defined EEDI formulation uses standard carbon content of different types of fuel [20]. However, it was observed by Hasan and Karim that quality of fuel used in the inland ships in Bangladesh varied at the user end, mainly because of mixing impurities. Ekanen and Bucknall [22] also observed a similar issue for LNG carriers, where it was shown that the Green House Gas (GHG) index value could potentially rise by up to 115% when considering unburnt methane emission.

4. Methodology for Reducing CO₂ Emissions from Inland Oil Tankers Based on $EEDI_{INLAND}$

The methodology for reducing CO₂ emissions from inland oil tankers based on $EEDI_{INLAND}$ is as follows:

- The $EEDI_{INLAND}$ parameters as explained in Section 3 are implemented on 102 inland oil tankers in Bangladesh.
- All results are further divided into three groups. Each group is again subdivided into the ship design principal particulars, such as length/Beam, Beam/Draft, Dead Weight (DWT)/Displacement, ship speed, Froude number, block coefficient and finally the calculated value of $EEDI_{INLAND}$.
- This subdivision allows us to identify the ranges of ship parameters for efficiently and poor-performing ships in each group.
- A sensitivity analysis is carried out that provides a clear picture of the ship design particulars that have higher influence on $EEDI_{INLAND}$. This analysis leads us to a set of suggestions aimed at achieving efficient ship design parameters.
- To verify these suggestions, an existing ship design from each group is selected for CFD analysis.
- The same vessel is remodeled based on the provided suggestions. The parent and remodeled design are analyzed by the commercial CFD software 'Shipflow' (Manufacturer: 'Flowtech International AB', Gothengurg, Sweden) [19]. The CFD results are presented for comparison to validate the suggestions provided by the sensitivity analysis.
- Since the reduction of the $EEDI_{INLAND}$ value implies the reduction of CO₂ emissions per tonne-nautical mile, environmental benefit will be achieved.

5. Implementing Revised EEDI Parameters on Inland Oil Tankers in Bangladesh

The revised EEDI formulation was implemented on 102 inland oil tankers in Bangladesh (shown in Appendix A). The results were further divided into following groups, based on their length and EEDI values.

- 'Group-1' consists of ships having a length below 51.00 m.
- 'Group-2' consists of ships having a length ranging between 51.00 and 61.00 m.
- 'Group-3' consists of ships having a length above 61.00 m.

The groups were determined in such way that a good number of vessels was available for analysis in each group. A sample calculation based on the revised EEDI parameters on an oil tanker in Bangladesh is shown in Table 3. Table 3 also shows the calculation of EEDI as defined by the IMO for a comparison with the modified EEDI.

Table 3. Calculated values of different EEDI parameters of inland oil tankers in Bangladesh.

Vessel's Basic Parameters: Length: 64 m, Breadth: 11 m, Draft: 3.5 m, Block Coefficient: 0.70			
EEDI Components	Unit	EEDI by IMO	EEDI _{INLAND}
Installed Engine Power	Kilowatt (kW)	448	448
P_{ME}	Kilowatt (kW)	336	270
MCR	% of installed power	75%	60%
Main Engine RPM	% of maximum engine RPM	91.30%	80%
Increase in required power due to Shallow water effect	% of required open water power	0%	20%
C_{FME}	gm CO ₂ /gm fuel	3.206	2.787
SFC_{ME}	gm CO ₂ /gm fuel	196	190
P_{AE}	Kilowatt (kW)	22	22
C_{FAE}	gm CO ₂ /gm fuel	3.206	2.787
SFC_{AE}	gm CO ₂ /gm fuel	210	205
$P_{PT(i)}, P_{AEff(i)}, P_{eff(i)}$	Kilowatt (kW)	0	0
$f_{eff(i)}, f_j, f_i, f_c, f_l, f_w$	Non dimensional	1	1
Capacity	Tonne	1206 (100% DWT)	1025 (85% of DWT)
V_{REF}	Knot	9.5	8.5
EEDI	gm CO ₂ /tonne-nautical mile	19.71	17.87

A total number of 23 oil tankers were analyzed under group-1, and the results are presented in Table 4 in the form of ranges. The preliminary ship design parameters, such as Length/Beam, Beam/Draft, Dead Weight (DWT)/Displacement ratios, Ship speed, Froude number, Block coefficient and finally EEDI_{INLAND} values, are presented. To support the sensitivity analysis, those values of ship design parameters were further divided into well-performing and poor-performing vessels, in order to better understand the ranges of ship design parameters.

The same procedure was followed for group-2 (a total of 39 oil tankers) and group-3 (a total of 40 oil tankers), and the results are presented in Tables 5 and 6. All the minimum and maximum values in Tables 4–6 are based on EEDI_{INLAND} value. Values of EEDI as per IMO directives were also calculated and are presented in Tables 4–6.

The value of EEDI by the IMO is approximately 8–11% less than the EEDI_{INLAND}, on average. This reflects the effects of shallow water, speed drop and the capacity of the ship.

Table 4. Ship design particulars of oil tanker from Group-1.

Ship Design Particulars	Vessel Length Up to 51.00 m			Vessel Length Up to 51.00 m		
	Well Performing Vessel's Ranges ($EEDI_{INLAND} < 31.00$)			Poor Performing Vessel's Ranges ($EEDI_{INLAND} > 31.00$)		
	Min	Max	Average	Min	Max	Average
Length/Beam	4.47	5.90	4.80	4.00	5.62	4.82
Beam/Draft	2.44	5.56	3.92	2.38	5.93	3.88
DWT/Displacement	0.59	0.76	0.67	0.53	0.69	0.63
Ship Speed (Knot)	7.50	9.00	8.58	6.50	9.00	8.15
Froude Number (F_N)	0.18	0.22	0.206	0.18	0.26	0.2173
Block Coefficient (C_B)	0.73	0.79	0.76	0.68	0.78	0.75
$EEDI_{INLAND}$	25.70	30.07	28.09	31.89	49.46	35.44
$EEDI_{IMO}$	23.08	28.10	25.77	29.95	46.66	32.72

Table 5. Ship design particulars of oil tanker from Group-2.

Ship Design Particulars	Vessel Length 51.00–61.00 m			Vessel Length 51.00–61.00 m		
	Well Performing Vessel's Ranges ($EEDI_{INLAND} < 26.00$)			Poor Performing Vessel's Ranges ($EEDI_{INLAND} > 26.00$)		
	Min	Max	Average	Min	Max	Average
Length/Beam	4.82	6.03	5.25	4.82	6.37	5.28
Beam/Draft	1.80	6.11	3.15	2.45	6.11	4.11
DWT/Displacement	0.57	0.77	0.67	0.57	0.68	0.64
Ship Speed (Knot)	8.00	9.00	8.71	8.00	10.00	8.75
Froude Number (F_N)	0.17	0.21	0.190	0.17	0.21	0.193
Block Coefficient (C_B)	0.65	0.79	0.77	0.64	0.79	0.75
$EEDI_{INLAND}$	21.94	25.65	23.95	26.18	32.79	29.07
$EEDI_{IMO}$	19.56	24.01	21.42	23.90	30.93	26.48

Table 6. Ship design particulars of oil tanker from Group-3.

Ship Design Particulars	Vessel Length above 61 m			Vessel Length above 61 m		
	Well Performing Vessel's Ranges ($EEDI_{INLAND} < 24.00$)			Poor Performing Vessel's Ranges ($EEDI_{INLAND} > 24.00$)		
	Min	Max	Average	Min	Max	Average
Length/Beam	5.29	6.87	5.81	5.50	6.73	6.21
Beam/Draft	2.46	3.30	2.94	2.14	2.90	2.65
DWT/Displacement	0.58	0.70	0.628	0.58	0.67	0.6313
Ship Speed (Knot)	9.00	10.00	9.40	9.00	12.00	9.92
Froude Number (F_N)	0.17	0.20	0.19	0.19	0.26	0.20
Block Coefficient (C_B)	0.68	0.79	0.75	0.65	0.78	0.72
$EEDI_{INLAND}$	20.91	23.96	22.86	24.05	27.11	25.29
$EEDI_{IMO}$	18.64	21.36	20.38	21.44	24.17	22.54

6. Sensitivity Analysis

A ‘Sensitivity Analysis’ can be defined as the impact of the independent variables of a system or mathematical model under a given set of assumptions. In other words, this analysis is a study that determines the variables that have the greatest amount of control over the output.

As observed in Tables 4–6, the Length/Beam (L_{WL}/B) of the well-performing vessels was lower (for Table 4, it is very close) than that of poor-performing ships. As most ships sailing in shallow water have low Froude numbers, the frictional resistance dominates the total resistance [23]. Thus, a reduction of the wetted surface area is preferable to lower the total resistance of the ship. However, reduction of wetted surface area will also lower the internal volume of a ship, resulting a drop of dead weight capacity from the original. For better $EEDI_{INLAND}$, higher carrying capacity is always desirable. For this reason, in order to improve a vessel’s design in light of $EEDI_{INLAND}$, focus should be given to the reduction of wave resistance. Wave resistance will drop as a result of making the ship slender. To make a ship slender, L_{WL}/B should be higher, which can be achieved by increasing the length.

Though the block coefficients of the well-performing vessels have higher values than those of the poor-performing oil tankers, lowering the block coefficient will make the ship slender. Thus, wave resistance will be decreased.

Thus, increasing L_{WL}/B ratio and lowering the block coefficient will make the ship more efficient in waves. However, the stability criteria of the ship will not allow the L_{WL}/B ratio to be increased by lowering the breadth to a great extent. If any of the above processes decrease the ship’s dead weight capacity, it should be compensated by increasing the draft of the ship. Higher draft will ensure the required displacement by lowering the Beam/Draft ratio. However, this option has to be chosen carefully for inland ships because of the draft limitations.

Reason for Altering the Decision Rather Than the Table

It seems very unusual that although the existing well-performing oil tankers in Bangladesh have lower L_{WL}/B ratio and higher block coefficients, the design suggestions that will make those inland tankers more energy efficient in light of $EEDI$ are the opposite. Following Tables 7 and 8 will help to understand this paradox, where the sensitivities of individual ship design parameters were investigated for fixed and variable block coefficients. The 2nd rows of Tables 7 and 8 show the original design parameters and in the 3rd row, the length is increased by 5%.

In the case of the fixed block coefficient of Table 7, to compensate the change in displacement due to the increase in length, breadth and draft were reduced. Increase in length resulted in an increase in surface area by 2.4%, which also increased the frictional resistance by 1.7%. However, the gain in wave resistance because of the increase in L_{WL}/B ratio was 13.53%, and the overall decreases in resistance and $EEDI_{INLAND}$ were 2.43% and 2.33%, respectively.

Table 7. Sensitivity analysis example for fixed block coefficient (0.7), speed (10 knot) and displacement (945 tonne).

	L_{WL} (m)	B (m)	T (m)	Surface Area (m ²)	Frictional Resistance, R_F (kN)	Wave Resistance, R_W (kN)	Total Resistance, R_T (kN)	$EEDI_{INLAND}$
Parent	50.00	9.00	3.00	581.01	14.71	6.43	32.56	30.28
Length (L_{WL})	52.50	8.78	2.93	594.93 (+2.40%)	14.96 (+1.70%)	5.56 (−13.53%)	31.77 (−2.43%)	29.57 (−2.33%)
Breadth (B)	48.80	9.45	2.93	577.71 (−0.57%)	14.67 (−0.27%)	6.96 (+8.24%)	33.32 (+2.33%)	31.02 (+2.46%)
Draft (T)	48.80	8.78	3.15	571.42 (−1.65%)	14.51 (−1.36%)	6.83 (+6.22%)	32.70 (+0.43%)	30.35 (+0.22%)

Table 8. Sensitivity analysis example for fixed speed (10 knot) and displacement (945 tonne) but variable block coefficient.

	L _{WL} (m)	B (m)	T (m)	C _B	Surface Area (m ²)	Frictional Resistance, R _F (kN)	Wave Resistance, R _W (kN)	Total Resistance, R _T (kN)	EEDI _{INLAND}
Parent	50.00	9.00	3.00	0.70	581.01	14.71	6.43	32.56	30.28
Length (L _{WL})	52.50	9.00	3.00	0.67	592.01 (+1.89%)	14.89 (+1.22%)	4.55 (−29.24%)	30.45 (−6.48%)	28.74 (−5.07%)
Breadth (B)	50.00	9.45	3.00	0.67	580.45 (−0.10%)	14.69 (−0.14%)	5.25 (−18.35%)	31.23 (−4.08%)	29.49 (−2.62%)
Draft (T)	50.00	9.00	3.15	0.67	576.30 (−0.81%)	14.59 (−0.82%)	5.20 (−19.13%)	30.86 (−5.22%)	29.07 (−3.98%)

The 4th row of Table 7 shows a similar change, but this time breadth increased by 5%. By lowering length and draft, displacement was kept the same. Increasing the breadth and lowering the length and L_{WL}/B ratio lowered the frictional resistance by 0.27%; however, the wave resistance went up by 8.24%. Overall, total resistance and EEDI_{INLAND} increased by 2.33% and 2.46%, respectively. A similar procedure was followed in the 5th row for draft, where draft increased by 5%. In all cases of Table 7, lowering the length increased EEDI_{INLAND} value, because this change made the ship blunt and inefficient through waves.

Table 8 also presents a similar sensitivity analysis; however, this time it is for a variable block coefficient. In this case, the increase of individual particulars was compensated by lowering the block coefficient. For each case presented in Table 8, EEDI_{INLAND} values decreased. However, the increase in L_{WL} reduced EEDI_{INLAND} the most, as in this case, although there was a 1.22% increase in frictional resistance, the reduction in wave resistance was the highest (29.24%). Overall, there was a 6.48% reduction in resistance and a 5.07% reduction in EEDI_{INLAND}.

Every case presented in Tables 7 and 8 proves that, in order to reduce CO₂ emissions by reducing EEDI_{INLAND} value, slender ships give better results. A ship's efficiency is the combined hydrodynamic performance of all her design particulars and EEDI incorporates the social benefit (transportation of cargo) with ship's hydrodynamic performance. For this reason, when CO₂ emissions are reduced by increasing the ship's energy efficiency with a focus on EEDI_{INLAND}, the amount of cargo carried at a certain speed is a very important factor. If the procedure for any ship hull resistance improvement decreases the capacity of the ship, EEDI_{INLAND} value will increase. For example, Tables 4–6 show that the ranges of L_{WL}/B ratio are comparatively lower for vessels that lie in the efficient range. Further attempts to increase energy efficiency should start by lowering the L_{WL}/B ratio. This can be done either by decreasing the length or increasing breadth, or by doing both. Lowering the length will decrease the overall ship capacity, which will increase the EEDI_{INLAND} value. This can be compensated either by increasing breadth or the block coefficient or by doing both. However, this compensation will make the ship fuller and bulkier, which will increase the wave resistance at a given speed. This increase in wave resistance will increase the power requirement, and thus increase the value of EEDI_{INLAND}.

Based on the sensitivity analysis and discussion, the following design suggestions as presented in Table 9, can be implemented on the inland oil tankers in Bangladesh to improve the performance in light of EEDI.

Table 9. Ship design suggestions based on sensitivity analysis.

Ship Design Particulars	Ship Design Improvement Suggestion
Water Line Length (L_{WL})	Length of the vessel should be the minimum possible that meets the required displacement and surface area. The prime reason behind this decision is that an increase of ship length will increase the surface area of the ship, which will eventually increase the frictional resistance.
Length/Breadth (L_{WL}/B)	Increasing L/B ratio is recommended. This will make the ship slender, which will decrease wave resistance. However, it should be done by decreasing the breadth and fulfilling all types of stability criteria.
B/T	Decreasing B/T ratio is recommended. This should be done by lowering breadth and/or increasing draft. This will also increase L_{WL}/B , helping in the reduction of wave resistance. For inland ships, because of the draft restriction, the maximum achievable draft should be used to achieve the required displacement.
DWT/Displacement	High DWT/Displacement is desirable. Higher dead weight capacity for a fixed displacement will increase the value of the denominator, which will decrease EEDI. On the other hand, a decrease in displacement for a fixed dead weight capacity will result in a lower surface area. As a result, frictional resistance will be decreased and the main engine power required will be less. This will decrease the numerator of the EEDI equation, which will decrease $EEDI_{INLAND}$.
Block Coefficient (C_B)	A lower C_B will ensure a sharp ship hull, which is preferable for a ship to have low resistance. However, this coefficient is connected with displacement of the hull and the carrying capacity. Therefore, minimum C_B to achieve the desired displacement is recommended.
Ship Speed (V) and Froude number (F_N)	Having a low Froude number is recommended. As minimum length is recommended in order to have lower surface area, lowering the speed would be the best solution to reduce Froude Number and EEDI. It should be noted that, in the EEDI equation, speed is in the denominator. Lowering the speed should increase EEDI. However, since the required power increases by roughly the cube of the variation in speed [24], reduction in speed reduces the power requirement (the numerator of the EEDI equation) and EEDI to a great extent.

7. CFD Analysis of Improved Vessel Based on Suggestion from Sensitivity Analysis

As discussed above, individual ship design parameters have individual impacts on EEDI. This means that changing the ship design particulars and ratio have both negative and positive impacts on EEDI value. The prime reason for this is that EEDI actually calculates the ‘Benefit to the Society’ and the ‘Environmental Cost’.

Therefore, selection of initial ship design parameters based on the suggestion provided from the sensitivity analysis (Table 9) should go under a holistic impact analysis on $EEDI_{INLAND}$. In holistic impact analysis, all suggestions provided in Table 9 to improve $EEDI_{INLAND}$ will be implemented in an existing ship design. This will find the best ship design with the lowest $EEDI_{INLAND}$. In the following Sections 7.1–7.3, a holistic approach is implemented on one of the best performing ships from each group. Later, parent and improved design performance are examined using CFD.

7.1. CFD Analysis of Improved Vessel of Group-1 Based on Suggestion from Sensitivity Analysis

As shown in Table 10, the L_{WL}/B ratio of a vessel under Group-1 increased by 12.03%. This was achieved by increasing length by 10.60% and decreasing breadth by 1.28%. This change resulted in an increase in surface area by 3.32%, which increased frictional resistance by 8.05%. However, increase in the length and decrease in the block coefficient by 16.63% made the ship slender. As a result, wave resistance decreased by 21.88%, and the overall decreases in resistance and EEDI are 7.95% and 13.65%, respectively.

Figures 2–4 present the free surface wave, wave height and the pressure coefficient distribution, respectively. Parent and improved hull results are presented side by side for visual comparison. In the improved hull, overall, there was a 7.95% decrease in resistance and a 13.65% decrease in EEDI value. Figures 2–4 also reflect this result, as the range of values of the figures is decreased.

Table 10. Comparison between parent and improved oil tanker under Group-1.

	Parent Design	Improved Design	Change (%)
Water line length, L_{WL} (meter)	49.73	55	10.60%
Moulded Breadth, B (meter)	10.13	10	−1.28%
L_{WL}/B	4.91	5.5	12.03%
Loaded Draft, T(meter)	3.04	3.34	9.87%
B/T	3.33	2.99	−10.15%
Block Coefficient, C_B	0.72	0.6	−16.63%
Displacement (Tonne)	1102	1102	0.0%
Dead Weight (Tonne)	733	733	0.0%
Speed (Knot)	09	09	0.0%
Froude Number, F_N	0.21	0.2	−4.91%
EEDI _{INLAND} (gram/tonne.mile)	23.04	19.89	−13.65%
Surface Area, S (m^2)	625.69	646.44	3.32%
Frictional Resistance Coefficient, C_F	0.00168	0.00181	8.05%
Wave Resistance Coefficient, C_W	0.00147	0.00115	−21.88%
Total Resistance Coefficient, C_T	0.00406	0.00374	−7.95%

(a) **(b)****Figure 2.** Free surface wave of vessel from Group-1. (a) Parent hull and (b) improved hull.

(a)

(b)

Figure 3. Wave height along hull of vessel from Group-1. (a) Parent hull and (b) improved hull.

(a)

Figure 4. Cont.

Figure 4. Pressure distribution and potential flow streamlines of vessel from Group-1. (a) Parent hull and (b) improved hull.

CFD software calculation also shows that the viscous pressure resistance coefficient decreased in the improved hull, which is presented below in Table 11.

Table 11. Comparison of viscous pressure resistance coefficient for parent and improved Hull.

Group of Vessel	Viscous Pressure Resistance Coefficient, Parent Hull	Viscous Pressure Resistance Coefficient, Improved Hull	Improvement
Group-1	0.0009157	0.000779	15%

7.2. CFD Analysis of Improved Vessel of Group-2 Based on Suggestion from Sensitivity Analysis

As shown in Table 12, the L_{WL}/B ratio of a vessel under Group-2 increased by 14.35%. This was achieved by increasing length by 6.04% and decreasing breadth by 7.27%. This change resulted in an increase in surface area by 1.31%, which increased frictional resistance by 4.78%. However, the increase in the length and the decrease in the block coefficient by 8.5% made the ship slender. As a result, wave resistance decreased by 30.68%, and the overall decreases in resistance and EEDI are 11.67% and 12.12%, respectively.

Figures 5–7, present the free surface wave, wave height and pressure coefficient distribution, respectively. Parent and improved hull results are presented side by side for visual comparison. In the improved hull, overall, there was an 11.67% decrease in resistance and a 12.12% decrease in EEDI. Figures 5–7 also reflect this result, as the range of values in the figures is decreased.

Table 12. Comparison between parent and improved oil tanker under Group-2.

	Parent Design	Improved Design	Change (%)
Water line length, L_{WL} (meter)	53	56.2	6.04%
Moulded Breadth, B (meter)	11	10.2	−7.27%
L_{WL}/B	4.82	5.51	14.35%
Loaded Draft, T(meter)	1.8	2	11.11%
B/T	6.11	5.1	−16.55%
Block Coefficient, C_B	0.765	0.7	−8.50%
Displacement (Tonne)	1102	802	0.00%
Dead Weight (Tonne)	530	530	0.00%
Speed (Knot)	08	08	0.00%
Froude Number, F_N	0.18	0.175	−2.89%
EEDI _{INLAND} (gram/tonne.mile)	32.79	28.81	−12.12%
Surface Area, S (m^2)	618.54	626.63	1.31%
Frictional Resistance Coefficient, C_F	0.00184	0.00193	4.78%
Wave Resistance Coefficient, C_W	0.00164	0.00114	−30.68%
Total Resistance Coefficient, C_T	4.04×10^{-3}	0.00357	−11.67%

(a)

(b)

Figure 5. Free surface wave of vessel from Group-2. (a) Parent hull and (b) improved hull.

(a)

(b)

Figure 6. Wave height along hull of vessel from Group-2. (a) Parent hull and (b) improved hull.

(a)

Figure 7. Cont.

(b)

Figure 7. Pressure distribution and potential flow streamlines of vessel from Group-2. (a) Parent hull and (b) improved hull.

CFD software calculation also shows that the viscous pressure resistance coefficient is reduced in the improved hull, which is presented below in Table 13.

Table 13. Comparison of viscous pressure resistance coefficient for parent and improved Hull.

Group of Vessel	Viscous Pressure Resistance Coefficient, Parent Hull	Viscous Pressure Resistance Coefficient, Improved Hull	Improvement
Group-2	0.0005507	0.0004962	10%

7.3. CFD Analysis of Improved Vessel of Group-3 Based on Suggestion from Sensitivity Analysis

Table 14 shows an increase in the L_{WL}/B ratio of a vessel from Group-3 by 9.70%. It was achieved by increasing length by 5.73% and decreasing breadth by 3.61%. This change gave an increase in surface area by 1.87%, which increased frictional resistance by 1.83%. However, increase in the length and decrease in the block coefficient by 1.87% made the ship slender. As a result, wave resistance decreased by 5.6%, and the overall decreases in resistance and EEDI are 5.56% and 7.54%, respectively.

Figures 8–10 present the free surface wave, wave height and the pressure coefficient distribution, respectively. Parent and improved hull results are presented side by side for the visual comparison. In the improved hull, overall, there was a 5.56% decrease in resistance and a 7.54% decrease in EEDI. Figures 8–10 also reflect this result, as the range of values of the figures is decreased. Viscous pressure resistance coefficient is decreased in the improved hull, as presented below in Table 15.

CFD software calculation also shows that the viscous pressure resistance coefficient is reduced in the improved hull, which is presented below in Table 15.

Table 14. Comparison between parent and improved oil tanker under Group-3.

	Parent Design	Improved Design	Change (%)
Water line length, L_{WL} (meter)	73.77	78	5.73%
Moulded Breadth, B (meter)	12.45	12	−3.61%
L_{WL}/B	5.93	6.5	9.70%
Loaded Draft, T (meter)	4	4	0.00%
B/T	3.11	3	−3.61%
Block Coefficient, C_B	0.75	0.736	−1.87%
Displacement (Tonne)	2762	2762	0.00%
Dead Weight (Tonne)	1934	1934	0.00%
Speed (Knot)	09	09	0.00%
Froude Number, F_N	0.172	0.167	−2.75%
$EEDI_{INLAND}$ (gram/tonne.mile)	16.19	14.97	−7.54%
Surface Area, S (m^2)	1183.09	1205.24	1.87%
Frictional Resistance Coefficient, C_F	0.00161	0.00164	1.83%
Wave Resistance Coefficient, C_W	0.00085	0.00081	−5.60%
Total Resistance Coefficient, C_T	0.00293	0.00277	−5.56%

Table 15. Comparison of viscous pressure resistance coefficient for parent and improved hull.

Group of Vessel	Viscous Pressure Resistance Coefficient, Parent Hull	Viscous Pressure Resistance Coefficient, Improved Hull	Improvement
Group-3	0.0004399	0.0003559	19%

(a)

Figure 8. Cont.

(b)

Figure 8. Free surface wave of vessel from Group-3. (a) Parent hull and (b) improved hull.

(a)

(b)

Figure 9. Wave height along hull of vessel from Group-3. (a) Parent hull and (b) improved hull.

Figure 10. Pressure distribution and potential flow streamlines of vessel from Group-3. (a) Parent hull and (b) improved hull.

8. Conclusions and Recommendation

Though inland shipping accounts for a small portion on the total CO₂ emissions of global shipping, the attempt to reduce CO₂ from current level can be very important for individual countries from an environmental perspective and an economic point of view [25]. The prime objective of this research was to assess the possibility of reducing CO₂ emissions from inland oil tankers in Bangladesh without any major cost involvement. The research proved that EEDI_{INLAND} value can be reduced by 7.54–13.65% simply by readjusting ship design parameters in light of EEDI_{INLAND}. CO₂ will be reduced proportionally.

The final outcome for a commercial vessel is to carry a certain amount of goods (or passengers) at a certain speed. When a ship is well designed to carry more goods without sacrificing speed or without increasing the construction cost, it may be considered an efficient design, as long as she does not consume more fuel. The engine burns fuel and transmits the power to the shaft, and finally, the propeller delivers the energy in the form of thrust. This thrust needs to be enough to push the ship hull, overcoming the resistance. This resistance of ships depends on many factors and involves practically all types of ship design parameters. Some of those design parameters are very sensitive to ship hull resistance. For example, reduction of underwater surface area will reduce frictional resistance drastically, which is the dominant part of the total resistance for lower Froude number vessels. Since the underwater surface area depends upon the ship's principal particulars, reduction of underwater surface area will involve those particulars. However, any kind of improvement of resistance cannot reduce the carrying capacity, as this would eventually increase EEDI_{INLAND} value. For this reason, in this research, the ship design improvement suggestions based on the sensitivity analysis considered a holistic approach that focused on the reduction of EEDI_{INLAND} value.

The suggestions provided as a result of the sensitivity analysis were verified by Computational Fluid Dynamics software. As a result, the suggestions of this research can be implemented practically to reduce CO₂ emissions from their current state.

It should be understood that, for fair comparison, dead weight, speed and DWT/Displacement were kept the same for both the parent and the improved vessel. Only the principal particulars were adjusted based on the sensitivity analysis. Simple adjustment of those principal particulars improved the hydrodynamic performance of the vessel, therefore reducing the total resistance coefficient. More reduction of EEDI_{INLAND} is possible with improved hull form, propeller design and other improved efficiency enhancement measures. The possibility of reducing CO₂ by more than 10% simply by adjusting the principal particulars of the ship will not increase the construction cost of the ship. In fact, the ship's first cost should decrease, as the main engine power requirement will decrease because of the redesign.

Another important aspect is the economic impact on the individual country. It is a fact that the total CO₂ emissions from the inland shipping accounts for a very small portion of global CO₂ emissions. However, from an individual country's perspective, the economic impact is considerably high. Since this research has proved that it is possible to reduce CO₂ emissions by 7.54–13.65% with respect to their current rate in Bangladesh, a large quantity of fuel will be saved per trip. This will have a market impact as well, because, without any exception, reduction in carrying cost will reduce the commodity price as well. Implementation of this rule will not increase the construction cost of the ship, but will decrease the operational cost to large extent, in addition to the direct environmental benefits.

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Appendix A

Table A1. EEDI_{INLAND} of the well-performing oil tankers in Bangladesh, Group-1 ($L_{WL} < 51$ m).

L_{WL} (m)	B (m)	T (m)	Capacity (Tonne)	Speed (knot)	C_B	EEDI _{INLAND}	EEDI By IMO
40.82	9.13	2.39	529	0.78	8.50	27.86	25.56
45.00	10.00	1.90	473	0.75	7.50	29.78	28.10
45.00	10.00	2.30	583	0.75	8.00	27.40	25.13
45.00	10.00	2.80	602	0.73	9.00	28.55	26.19
47.00	10.00	2.80	685	0.78	9.00	29.43	27.00
47.20	8.00	3.28	616	0.75	8.50	29.92	26.67
47.37	10.00	2.00	446	0.75	8.00	30.07	27.59
48.11	9.95	2.92	787	0.78	9.00	26.80	24.59
48.79	10.03	2.97	814	0.79	9.00	25.70	23.58
49.73	10.13	2.82	734	0.78	9.00	26.03	23.88
49.95	10.00	2.65	726	0.75	9.00	28.39	26.05
50.90	10.25	3.13	902	0.75	9.00	25.89	23.08
45.00	10.00	1.80	372	0.78	8.00	29.32	27.65

Table A2. EEDI_{INLAND} of the poor-performing oil tankers in Bangladesh, Group-1 ($L_{WL} < 51$ m).

L_{WL} (m)	B (m)	T (m)	Capacity (Tonne)	Speed (knot)	C_B	EEDI _{INLAND}	EEDI By IMO
17.30	4.32	1.20	43	0.75	6.50	49.46	46.66
32.00	6.86	2.60	254	0.68	8.50	36.41	33.40
37.65	6.70	2.64	281	0.75	8.00	33.70	30.92
37.76	7.62	2.72	340	0.75	8.00	34.73	31.86
38.40	7.62	3.20	477	0.75	9.00	34.13	30.42
40.10	7.94	2.36	353	0.75	8.50	34.45	31.61
41.84	9.46	2.04	382	0.78	8.00	32.65	29.95
49.50	10.00	2.00	510	0.77	8.50	33.21	30.47
50.67	10.68	1.80	463	0.75	8.00	31.89	30.08
50.67	10.68	1.80	507	0.75	8.50	33.74	31.82

Table A3. EEDI_{INLAND} of the well-performing oil tankers in Bangladesh, Group-2 (L_{WL} 51–60 m).

L_{WL} (m)	B (m)	T (m)	Capacity (Tonne)	Speed (knot)	C_B	EEDI _{INLAND}	EEDI By IMO
51.67	10.33	3.19	935	9.00	0.78	25.65	22.87
52.92	10.46	3.29	990	9.00	0.79	23.59	21.03
53.00	11.00	1.80	604	8.00	0.75	25.46	24.01
54.50	10.62	3.41	1063	9.00	0.79	23.97	21.37
55.45	10.72	3.48	1108	9.00	0.79	24.56	21.90
55.68	10.74	3.50	1120	9.00	0.79	25.37	22.62

Table A3. Cont.

L _{WL} (m)	B (m)	T (m)	Capacity (Tonne)	Speed (knot)	C _B	EEDI _{INLAND}	EEDI By IMO
55.80	10.76	3.51	1125	9.00	0.79	22.81	20.33
56.03	10.78	3.53	1137	9.00	0.78	24.40	21.76
56.03	10.78	3.53	1137	9.00	0.78	25.28	22.54
56.72	10.85	3.58	1171	9.00	0.79	22.57	20.12
57.06	10.88	3.61	1188	9.00	0.79	22.48	20.04
57.29	10.91	3.63	1200	9.00	0.79	22.42	19.99
57.40	10.92	3.64	1205	9.00	0.79	23.20	20.69
57.97	10.97	3.68	1234	8.00	0.79	24.76	22.08
58.52	11.03	3.72	1263	9.00	0.75	24.62	21.95
58.30	11.01	3.71	1251	8.00	0.79	24.68	22.00
58.41	11.02	3.72	1257	8.50	0.75	24.65	21.98
59.30	11.11	3.79	1303	9.00	0.79	21.94	19.56
60.25	10.00	4.00	895	8.00	0.65	24.02	21.41
60.51	11.22	3.88	1369	8.50	0.79	24.13	21.51
60.80	11.25	3.91	1385	8.00	0.75	22.38	19.95

Table A4. EEDI_{INLAND} of the poor-performing oil tankers in Bangladesh, Group-2 (L_{WL} 51–60 m).

L _{WL} (m)	B (m)	T (m)	Capacity (Tonne)	Speed (knot)	C _B	EEDI _{INLAND}	EEDI By IMO
53.00	11.00	2.80	766	9.00	0.76	29.06	26.66
53.75	11.00	1.80	566	8.00	0.75	28.09	26.50
53.75	11.00	2.00	633	8.50	0.75	31.98	29.34
53.00	11.00	2.00	624	8.00	0.75	26.18	24.02
53.00	11.00	2.50	766	9.00	0.78	29.66	27.21
53.75	11.00	2.00	640	8.50	0.75	32.04	29.39
53.00	11.00	2.40	721	8.50	0.75	27.77	25.48
53.00	11.00	1.80	531	8.00	0.77	32.79	30.93
55.00	9.80	4.00	1039	8.00	0.77	27.75	24.74
56.00	10.00	4.00	994	9.50	0.73	27.34	24.37
56.00	10.01	3.94	895	9.50	0.71	28.85	25.72
56.15	10.79	3.54	1142	9.00	0.75	27.09	24.15
57.18	10.90	3.62	1194	9.00	0.79	26.80	23.90
57.24	10.00	2.20	593	8.50	0.76	30.30	27.80
57.24	10.00	1.80	549	8.00	0.77	31.36	29.58
60.86	9.56	3.15	763	10.00	0.64	29.99	26.74
60.16	10.00	4.00	1061	10.00	0.74	27.35	24.38
58.19	11.00	3.40	1059	8.50	0.76	28.81	25.68

Table A5. EEDI_{INLAND} of the well-performing oil tankers in Bangladesh, Group-3 ($L_{WL} > 60$ m).

L_{WL} (m)	B (m)	T (m)	Capacity (Tonne)	Speed (knot)	C_B	EEDI _{INLAND}	EEDI By IMO
61.75	11.34	3.98	1438	9.00	0.75	22.16	19.76
58.10	10.99	3.69	1241	9.50	0.75	23.86	21.28
70.80	12.50	4.00	1706	9.50	0.78	23.96	21.36
70.80	12.50	4.00	1706	9.50	0.78	23.96	21.36
70.80	12.50	4.00	1706	9.50	0.78	23.96	21.36
70.80	12.50	4.00	1706	9.50	0.78	23.96	21.36
63.00	11.50	4.00	1360	9.50	0.74	22.49	20.05
68.00	11.80	4.00	1513	9.50	0.76	21.87	19.50
68.50	11.85	4.00	1594	9.50	0.79	22.39	19.96
70.80	12.50	4.00	1706	9.50	0.78	23.96	21.36
68.78	12.40	4.00	1615	9.50	0.75	21.51	19.17
73.10	11.90	4.25	1785	9.00	0.76	23.02	20.52
73.80	12.20	3.70	1445	9.50	0.69	20.91	18.64
73.77	12.45	4.00	1934	10.00	0.75	21.77	19.41
71.13	12.50	4.26	1666	10.00	0.69	23.89	21.29
67.68	11.90	4.30	1568	9.00	0.76	22.16	19.76
70.06	10.20	4.15	1314	9.50	0.68	23.86	21.27
67.68	11.90	4.10	1488	9.00	0.76	23.32	20.79
69.48	11.40	4.40	1548	9.00	0.76	22.44	20.00
73.17	11.90	4.30	1712	9.50	0.76	23.67	21.10
66.20	11.00	4.00	1447	9.00	0.77	20.94	18.67

Table A6. EEDI_{INLAND} of the poor-performing oil tankers in Bangladesh, Group-3 ($L_{WL} > 60$ m).

L_{WL} (m)	B (m)	T (m)	Capacity (Tonne)	Speed (knot)	C_B	EEDI _{INLAND}	EEDI By IMO
62.00	10.10	4.00	1149	10.00	0.72	25.75	22.95
63.10	11.47	4.00	1515	9.50	0.77	25.32	22.57
63.80	10.10	4.00	1115	9.50	0.71	25.21	22.48
63.80	10.10	4.00	1115	9.50	0.71	25.21	22.48
63.80	10.10	4.00	1155	10.00	0.71	26.66	23.77
63.80	10.10	3.50	877	9.50	0.67	27.11	24.17
64.55	11.00	4.00	1277	10.00	0.71	26.13	23.29
64.80	10.40	4.00	1107	10.00	0.65	24.41	21.76
65.32	10.00	4.00	1086	10.00	0.66	24.65	21.97
67.08	11.90	4.30	1588	10.00	0.76	24.52	21.86
58.00	9.61	4.50	1207	12.00	0.78	26.73	23.83
65.00	11.48	4.00	1517	9.50	0.77	25.31	22.56
70.06	11.40	4.68	1572	10.00	0.68	24.48	21.83

Table A6. Cont.

LWL (m)	B (m)	T (m)	Capacity (Tonne)	Speed (knot)	C _B	EEDI _{INLAND}	EEDI By IMO
73.00	11.20	4.00	1591	10.00	0.75	24.05	21.44
74.00	11.00	4.00	1540	10.00	0.74	24.98	22.27
74.00	11.00	4.00	1540	10.00	0.74	24.98	22.27
74.00	11.00	4.00	1540	10.00	0.74	24.98	22.27
62.90	10.00	4.00	1176	9.00	0.70	25.80	23.01
67.50	11.21	3.87	1360	10.00	0.75	24.17	21.55

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