Development of Energy Efficiency Design Index for Inland Vessels of Bangladesh

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Development of Energy Efficiency Design Index for Inland Vessels of Bangladesh

By

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Certificate of Approval

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ABSTRACT

According to IMO, ships engaged in international trade in 1996 contributed about 1.8% of the total world's CO_2 emissions which is approximated as 2.7% in 2007 and this percentage could go two or three times higher by 2050 if present trend continues. In order to reduce CO_2 emission, Marine Environment Protection Committee (MEPC) at its 62nd session adopted resolution MEPC.203(62) (MEPC, 2011a) which includes amendments to MARPOL Annex VI. It introduces new chapter which intends to improve energy efficiency for ships through a set of technical performance standards. The amendments, which entered into force on 1st January 2013, require that every ship has to comply with the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). The EEDI is mandatory for all new ships and SEEMP for all ships of 400 GT and above engaged in the international shipping. Several attempts have been made to establish a reliable tool for seagoing vessels with respect to energy efficiency that can be found in various papers & reports. At the same time, many countries around the world are trying to develop some benchmarks for their inland shipping that could be used for assessment of the energy efficiency of inland waterway vessels. In Bangladesh, there are more than 10,000 different types of ship plying all the year round, but performance of these ships in terms of CO_2 emission is not known and regulations related to the energy efficiency for inland waterway ships still does not exist. This is why this thesis attempts to assess and develop EEDI for inland vessels of Bangladesh.

To assess the present situation of inland class vessels in terms of EEDI, a database has been developed. Using the database, EEDI references lines for different types of inland vessels of Bangladesh have been established. Then the validation of the EEDI reference lines have been done and compared with other countries EEDI reference lines for inland vessels. The impact of design parameters on EEDI for different types of inland vessels of Bangladesh has been evaluated and the present status of existing inland vessels in terms of EEDI has been investigated. Furthermore, sensitivity analysis of inland vessels of Bangladesh has been performed in terms of EEDI considering socio-economic and technical factors in Bangladesh. The results indicate that most of the existing vessels do not meet the current EEDI baseline and so new guideline will be soon necessary for achieving EEDI compliance. Finally some recommendations have been proposed for assessment of the energy efficiency of different types of ship during design stage and trial/ performance test stage so that it can be helpful for Regulatory Authority to introduce some tools for EEDI for the inland shipping in Bangladesh in near future.

Nomenclature

Abbreviations	Description
C_F	Carbon emissions factor (tCO_2/tFuel)
DWT	Deadweight (t)
P_{AE}	Auxiliary engine power (KW)
P_{ME}	Main engine power (KW)
P_{PTO}	Shaft Generator power (KW)
R^2	Coefficient of determination
P_{PTI}	Shaft Motor power (KW)
SFC	Specific fuel consumption (g/kWh)
Fi	Capacity factor
Vref	Reference speed (knot)
Fw	Weather factor
GT	Gross tonnage
Fc	Cubic capacity correction factor
R_F	Frictional resistance
R_{APP}	Resistance of appendages
R_W	Wave making resistance
R_A	Model ship correlation resistance

R_B	Additional pressure resistance of bulbous bow
R_{TR}	Additional pressure resistance of immersed transom stern
IMO	International Maritime Organization
EEOI	Energy Efficiency Operational Index
BIMCO	Baltic and International Maritime Council
EIAPP	Engine International Air Pollution Prevention
EEDI	Energy Efficiency Design Index

Chapter-1

Introduction

1.1 Background

International shipping plays a vital role in the facilitation of world trade as the most cost effective and energy efficient mode of mass transport, making a significant contribution to global prosperity in both developing and developed countries. According to IMO, ships engaged in international trade in 1996 contributed about 1.8% of the total world's CO_2 emissions which is approximated as 2.7% in 2007 and this percentage could go two or three times higher by 2050 if present trend continues [1]. In order to control this CO_2 emission from shipping, the ship Energy Efficiency Design Index (EEDI) has been formulated by the IMO Marine Environment Protection Committee (MEPC) as a measure of the CO_2 emission performance. The basic formulation of EEDI is based on the ratio of total CO_2 emission per tonne.mile. The amount of CO_2 emission depends upon fuel consumption and fuel consumption depends upon the total power requirement which means the EEDI formulation eventually has certain impact on ship design parameters which are closely related to the economic performance of the ship. New ships (building contract as from 1st of January 2013 and the delivery of which is on or after 1 July 2015.) will have to meet a required Energy Efficiency Design Index (EEDI). In addition, all ships, new and existing, are required to keep on board a ship-specific Ship Energy Efficiency Management Plan (SEEMP) which may form part of the ship's Safety Management System (SMS). The SEEMP shall be developed taking into account guidelines developed by IMO. The regulations apply to all ships of 400 gross tonnages and above and are expected to enter into force on 1 January 2013[2].

Although Energy Efficiency Design Index (EEDI) is primarily developed as one of the greenhouse emissions reduction measures, it can also be regarded as an indicator of energy efficiency of a ship and ship propulsion. 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 would be free to use the most cost-efficient solutions for the ship to comply with the regulations. Engine emissions are more or less directly related to engine power engaged for achieving desired ship speed. In spite of the fact that ships are generally very efficient transport vehicles, there is still significant potential for further improvements of their efficiency even by applying existing technologies, as for instance more efficient engines and propulsion systems, improved hull designs, increasing their size etc.

EEDI of IMO has given main focus on ocean going ships. On the other hand, inland waterway ships often navigate through populated areas (as opposed to the ocean-going ships), their footprint, energy efficiency and similar environmental attributes will soon become very important. In Bangladesh, due to geographical advantages, waterways are the cheapest mode of transport for transporting passengers and cargoes. Although, there are more than 10,000 different types of ship plying all the year round in Bangladesh, but performance of these ships in terms CO_2 emission is not known and any regulations related to the energy efficiency for inland waterway ships still does not exist. Several attempts have made to establish a reliable tool for seagoing vessels with respect to energy efficiency that can be found in various papers & reports but there are no suggested benchmarks that could be used for assessment of the energy efficiency of inland waterway vessels for Bangladesh. Keeping this scenario in mind, this research attempts to review the present status of inland vessels in terms of CO_2 emission, analyze the results and propose some reliable tool for benchmarking energy efficiency and carbon emission index of different types of vessels considering existing socio-economic and technical factors in Bangladesh.

1.2 Development of different environmental indexes and emission control measures by IMO and International Classification Societies

1.2.1 Present Status of IMO

IMO has been working on emission control from shipping as a mandate to the Kyoto Protocol. In the 62nd MEPC meeting, mandatory measures to reduce emissions of greenhouse gases (GHGs) from international shipping were adopted by parties to MARPOL Annex VI, which is the first ever mandatory global greenhouse gas reduction regime for an international maritime industry sector.

A new provision allows Administrations to delay the enforcement of these amendments by up to 4 years. This means that ships built under the flag of such Administrations would not be bound to have EEDI certification (i.e. International Energy Efficiency Certificate) if their building contract is dated before 1 January 2017. Each Administration giving such waivers needs to inform the IMO. Parties to MARPOL Annex VI have agreed to allow ships with such waivers to call to their ports.

IMO, through the MEPC has agreed on a work plan to continue the work on energy efficiency measures for ships, to include the development of the EEDI framework for ship types and sizes, and propulsion systems, not covered by the current EEDI requirements and the development of EEDI and SEEMP-related guidelines.

The Regulation has a set of initial values for the required EEDI which are individualized for each ship type through a reference line. The reference line of each ship type will also give the value of the required EEDI for each ship's size. Finally, the Regulation includes a step–by-step phase-in scheme for reduction of the required EEDI values as described in Table 1.

The Regulation requires assessment that the installed propulsion power shall not be less than the propulsion power needed to maintain the manoeuvrability of the ship under adverse conditions as defined in the guidelines to be developed by IMO.

The Regulation also provides that, at the beginning of Phase 1 of the phase-in, the IMO shall review the status of technological developments and, if proven necessary, adjust the time periods and reduction rates set out for Phases 2 and 3.The first phase CO_2 reduction level in grams of CO_2 per tonne mile is set to 10 per cent which will be strengthened every five years to keep up with technological developments of new efficiency and reduction measures. This means that the EEDI will require ships built between 2015 and 2019 to improve their efficiency by 10 per cent, rising to 20 per cent for those built between 2020 and 2024 and 30 per cent for ships delivered after 2024. These reductions are calculated from a baseline which represents the average efficiency for ships built between 2000 and 2010.

***Table1**. Phase in scheme for reduction of required EEDI for different ship types[1]*

Ship Type	Size (DWT)	Phase 0 1 Jan 2013–31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020–31 Dec 2024	Phase 3 1 Jan 2025–and onwards
Bulk Carrier	≥20000	0	10	20	30
	10,000-20,000	n/a	0-10*	0-20*	0-30*
Gas tanker	≥10000	0	10	20	30
	2,000 – 10,000	n/a	0-10*	0-20*	0-30*
Tanker	≥20000	0	10	20	30
	4,000 – 20,000	n/a	0-10*	0-20*	0-30*
Container ship	≥15000	0	10	20	30
	10,000–15,000	n/a	0-10*	0-20*	0-30*
General Cargo ships	≥15000	0	10	15	30
	3,000 – 15,000	n/a	0-10*	0-15*	0-30*
Refrigerated cargo carrier	≥5000	0	10	15	30
	3,000 – 5,000	n/a	0-10*	0-15*	0-30*
Combination carrier	≥20000	0	10	20	30
	4,000 – 20,000	n/a	0-10*	0-20*	0-30*

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

With regard to tankers, the Regulation applies to tankers of 4,000 dwt and above. The Regulation will not apply to ships which have diesel-electric propulsion, turbine propulsion or hybrid propulsion systems until such time as the method of

calculation of the attained EEDI for each of these categories of ships is established in the guidelines for the method of calculation of the attained EEDI for new ships, and the EEDI reference lines for these categories of ships have been established.
As reported, it was agreed to hold another MEPC Working Group inter sessional meeting to finalize all the associated guidelines for these new amendments to MARPOL Annex VI which are:

- Draft Guidelines on the method of calculation of the Energy Efficiency Design Index (EEDI) for new ships;
- Draft Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP);
- Draft Guidelines on Survey and Certification of the EEDI;
- Draft interim Guidelines for determining minimum propulsion power and speed to enable safe manoeuvring in adverse weather conditions;
- Identify the necessity of other Guidelines or supporting documents for technical and operational measures;
- Consider EEDI for larger size sectors of tankers and bulk carriers (the background is that the current reference lines seem to be unfairly low as compared to the calculated EEDIs for all existing large bulk carriers and VLCCs);
- Consider improvement of Guidelines on Ships Energy Efficiency Operational Indicator (EEOI)

1.2.2 Clean Ship Index (CSI)

This index [3] has been developed by the Clean Shipping Project, Gothenburg, Sweden. It takes into account the major part of environmental effects, such as emission to air and water, use of chemicals, antifouling etc. This is a holistic approach to classify ships, where overall environmental effects are considered. The index is focused on the vessels' operational impact on the environment and scoring is obtained in five different areas: SO_X, NO_X, Particulate Matters (PM), and CO_2 emissions, Chemicals, Water and waste control. The scoring system is divided into 5 areas with a maximum total score of 150p, each areas having 30p maximum. This scoring system allows comparing, how good a vessel is performing for any specific criteria. The weighting together of all score gives a hint of the overall performance. Every area has several criteria and points. If the criteria are fulfilled, the ship will get the point.

CSI project recommends to define three levels of environmental performance in the colours of red (low performance), yellow (medium performance), and green (good performance). Detailed scoring system is developed (Table 2).

***Table 2**. Scoring system of CSI*

	Carriers	Vessels
Green	≥90% vessels reported. The carrier verified.	The vessel verified. Total score = 50%, and =30% in all five fields, scoring in all subgroups under chemical and waste & water.
	≥40% weighted total score	
Yellow	≥ 20% vessels reported	
	≥ 10% weighted total score	Total score =20%
Red	<20% vessels reported or.	
	<10% weighted total score	

1.2.3 KoFC's Green Ship Program

Korea Finance Corporation, KoFC has announced the green ship finance plan [4] in which incentives including a form of lower interest rates on loans will be provided to the ship owners who obtain the vessels designed to reduce emissions. In order to qualify for these financial incentives, the vessels must be built using technologies to reduce air pollutants (e.g. NOx, SOx, etc), CO_2, or GHG.

This is available for the Korean ship owners under the government's policy which will provide Korean ship owners for ship financing of a costlier green ship construction than other normal ship at a prime rate.

In order to take the advantage an applicant should first get certification on a green ship. The green ship is a ship equipped with devices helping to reduce of greenhouse gas emissions including NOx, SOx, CO_2 and other air pollutants. The green ship should be certified by DNV Korea recognized by the Korean government as a public certification organization before the applicant files the green ship program with KoFC.

1.2.4 Class notation by DNV

The Environmental Class Notations CLEAN and CLEAN DESIGN [5] are voluntary Class Notations, limiting the emissions of harmful pollutants, and limiting the probability and consequences of accidents.

CLEAN: MARPOL compliance with additional requirements.

CLEAN DESIGN: As for CLEAN, but with more stringent requirements, and in addition provisions for accident prevention and limitation.

The rules for Environmental Class are under constant development as legislation comes into force and new legislation is proposed. Vessels holding the Class Notation CLEAN or CLEAN DESIGN are in the forefront of the international legislative regime on environmental issues. This also means that as some requirements in the Rules for CLEAN and CLEAN DESIGN are becoming mandatory, the Rules must be developed by adopting new legislation not yet ratified.

- Vessels with CLEAN usually carry IMO NOx-certificates or equivalent for the relevant engines, thereby fulfilling the requirements of the Rules.
- For CLEAN DESIGN the engines must emit about 30% less NO_x than specified by the IMO NOx-curve, and this is difficult to achieve by engine tuning alone without compromising engine efficiency.
- In order to prove that the vessel is operated in accordance with the Rules, operational procedures should make sure only fuel with sulphur content less than the specified maximum limit is ordered.
- The vessels must also be able to prove that they operate with low sulphur fuel in Sulphur Emission Control Areas (SECA) and ports.

1.2.5 RINA's Green Star and Green plus Notation

Italian classification society RINA has further strengthened its commitment to environmentally friendly shipping by launching a new goal-based class notation, GREEN PLUS [6]. The voluntary notation will be based on an environmental performance index which covers all aspects of the vessel's impact on the environment, including carbon emissions.

RINA's GREEN STAR notation has become a watchword for environmental excellence in shipping, anticipating the requirements of MARPOL and other relevant legislation, and placing owners and operators in an advantageous position. Now, with GREEN PLUS, RINA is taking the process one stage further by introducing a new class notation only to be granted to new vessels which make a significant investment in design solutions, on board equipment, and operational procedures which contribute to an improvement in environmental performance beyond the minimum levels required by regulation.

Design solutions and on board equipment include anything which reduces the risk of pollution, or which lowers fuel consumption and air emissions. Innovative engine design, alternative fuels, high-efficiency propellers, optimal hull design and bio-degradable oils all fall into these categories.

Operational procedures covered by a GREEN PLUS notation include those which ensure that design solutions and on board equipment are correctly used, voyage planning programmes resulting in reduced fuel consumption and emissions, or training courses designed to increase the environmental awareness of officers and crews.

RINA envisages that it will be possible to transfer existing ships from GREEN STAR to GREEN PLUS notation, assuming that the requirements relating to onboard equipment, operational procedures and solutions can be satisfied.

1.2.6 Class regulations by Class NK

Additional requirement [7] other than MARPOL

- Reduction in NO_x emissions, 80% or below the bench level or the limit.
- The sulphur content of all fuel oils is not to be exceeding 0.1%.

1.2.7 Lloyd's register rules

The rules [8] for Environmental Protection, formulated using environmental risk assessment techniques are regularly updated using service experience and operational feedback to maintain them as the industry benchmark. The Rules consist of two parts: the core requirements and optional module. The core requirements are,

Attain a level of environmental Performance in excess of international legislative requirements and cover:

- Oxides of nitrogen (NO_x) and sulphur (SO_x) emissions
- Refrigerants and fire-fighting agents
- Oil pollution prevention
- Garbage handling and disposal
- Sewage treatment
- Hull anti-fouling systems
- Ballast water.

Optional modules, with more stringent requirements, cover:

- Hull anti-fouling
- Ballast water management

- Grey water
- NO_x emissions
- Oily bilge water
- Protected oil tanks
- Refrigeration systems
- SO_x emissions
- Vapour emission control systems.

1.2.8 ABS Enviro and Enviro+ notation

The ENVIRO notation [9] identifies the level of compliance with international environmental protection requirements and integrates associated ABS requirements which influence environmental protection. For the ENVIRO+ notation, this Guide invokes compliance with more stringent criteria for environmental protection related to design characteristics, management and support systems, sea discharges, and air discharges.

ENVIRO Notation complies with the applicable requirements of Annexes I, II, IV, V, and VI to the International Convention for the Prevention of Pollution from Ships, MARPOL 73/78, as amended, is a prerequisite for receiving the class notation ENVIRO.

ENVIRO+ Notation complies with applicable requirements of the ENVIRO notation and Annexes I, II, IV, V, and VI to the International Convention for the Prevention of Pollution from Ships, MARPOL 73/78, as amended, is a prerequisite for receiving the class notation ENVIRO+.

1.2.9 ISO Standard

The ISO 14000 [10] family addresses various aspects of environmental management. The very first two standards, ISO 14001:2004 and ISO 14004:2004 deal with environmental management systems (EMS). ISO 14001:2004 provides the requirements for an EMS and ISO 14004:2004 gives general EMS guidelines. The other standards and guidelines in the family address specific environmental aspects, including: labelling, performance evaluation, life cycle analysis, communication and auditing.

An EMS meeting the requirements of ISO 14001:2004 is a management tool enabling an organization of any size or type to:

- Identify and control the environmental impact of its activities, products or services, and to
- Improve its environmental performance continually, and to
- Implement a systematic approach to setting environmental objectives and targets, to achieving these and to demonstrating that they have been achieved.

ISO 14001:2004 does not specify levels of environmental performance. If it specified levels of environmental performance, they would have to be specific to each business activity and this would require a specific EMS standard for each business. That is not the intention.

ISO has many other standards dealing with specific environmental issues. The intention of ISO 14001:2004 is to provide a framework for a holistic, strategic approach to the organization's environmental policy, plans and actions.

ISO 14001:2004 gives the generic requirements for an environmental management system. The underlying philosophy is that whatever the organization's activity, the requirements of an effective EMS are the same.

This has the effect of establishing a common reference for communicating about environmental management issues between organizations and their customers, regulators, the public and other stakeholders.

Because ISO 14001:2004 does not lay down levels of environmental performance, the standard can be implemented by a wide variety of organizations, whatever their current level of environmental maturity. However, a commitment to compliance with applicable environmental legislation and regulations is required, along with a commitment to continual improvement – for which the EMS provides the framework.

1.3 Brief Literature Review

Within the framework of discussion and deliberation leading to the EEDI adoption and beyond, considerable work has been done in order to prepare a suitable EEDI formulation and pave the way towards its adoption by the shipping industry. Anink et al. [11] analyzed the EEDI formula and correlation between the index values for all individual ship types for several types of vessels. Deltamarin [12] evaluated the calculation of EEDI for conventional vessels, Ro-Ro and Ro-Pax ships. Larkin et al. [13] investigated the influence of design parameters on the energy efficiency design index. The International Council on Clean Transportation [14] issued a study indicating the key components of the calculation, benefits of the index and future expectations. United States Environmental Protection Agency (EPA) [15] investigated the EEDI standard and its benefits. Hughes [16] presented the EEDI, EEOI and SEEMP regulations and Hemming [17] evaluated the EEDI with questions and answers. BLUE Communications [18] edited news of popular magazines in the world regarding IMO emissions regulations and BIMCO produced an EEDI calculator. Longva [19] studied CO_2 emissions from ships, the latest IMO regulatory developments (EEDI and SEEMP) and their implications for bulk carriers. Det Norske Veritas [20] assists yards, designers, owners and operators to prepare the EEDI Technical File package with necessary documentation ready for verification. Lloyds Register [21] prepared a guidebook for owners, operators and shipyards. Cheng [22] evaluated IMO technical measures in reducing greenhouse gas emissions from ships from the perspective of Lloyds Register. Rightship [23], calculated and compared CO_2 emissions from the global maritime fleet. Bergholtz and Wiström [24] made a Swedish proposal for the inclusion of the Ro-Ro ship segment into the IMO energy efficiency regulatory framework. Hjortberg [25] analyzed the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) in the Scandinavian Maritime Conference, whereas. Germanischer Lloyd [26] also produced a relevant guidebook. Jain [27] investigated the impacts of energy design index in his Master of Science thesis. Borkowski et al. [28] evaluated the operational approach of energy efficiency design index of container vessel. Simic [29] has proposed a reliable tool for benchmarking energy efficiency and carbon emissions of inland waterway self-propelled cargo ships for UK, which should be similar to already accepted approach for seagoing ships. Lin et al. [30] proposed on energy efficiency deign index for sea going LNG carriers. Tran [31] calculated and assessed the EEDI index in the field of ship energy efficiency for bulk carrier. Sin and Oses [32] investigated the improvement of the energy efficiency of vessels as a measure for the reduction of greenhouses gases emission from sea shipping. Vladimir et al.

[33] analyzed the effect of ship on EEDI requirements for large container ships. Papunikolaou et al. [34] investigated on energy efficient ship operation. Frouws [35] calculated the emissions of sea going Ro-Ro carriers. Rehmatulla et al.[36] investigated the implementation of technical energy efficiency and CO_2 emission reduction measures in shipping.

1.4 Objectives

The objectives of this study are as follows:

- To develop a database of existing different types of ships plying in the inland waterways of Bangladesh.
- To assess the present status of existing inland vessels in term of EEDI.
- To investigate the influence of design parameters on the Energy Efficiency Design Index (EEDI) for the inland vessels of Bangladesh.
- To establish Energy Efficiency Design Index (EEDI) references lines for different types of inland vessels of Bangladesh.

1.5 Outline of the methodology

Primary data and information about different types of inland vessels of Bangladesh have been collected through interacting with structured, unstructured and open ended questionnaires from various government shipping organizations and private organization including shipyards. Secondary data and information have been collected from both external and internal means such as journals, thesis, books, reports, ship owner associations, enlisted ship designing houses, related private organizations, web sites and other sources. Based on collected information a data base has been developed for more than three thousand ships.

In order to establish EEDI reference lines, main types of inland vessels of Bangladesh such as Cargo ships, Oil tankers, Passenger vessels, Ferries & Sand carriers have been taken into consideration. A tool has been developed as mentioned in the background section above to find out the EEDI reference lines of different types of inland vessels as well as performing the parametric analysis of design parameters such as ship's draft, power, block coefficient, specific fuel consumption (sfc), and type of fuel.

Specific fuel consumption (sfc) of new engines as well as old ones has been collected from engine manufacturer data as well as field data.

Relevant ship design and drawing and software have been used to do sensitivity analysis on the basis of existing socio-economic and technical factors with respect to EEDI to improve the energy efficiency index**.**

1.6 Structure of thesis

This thesis has been divided into 10 chapters. The following is the brief summary of each chapter:

Chapter-1 This chapter describes the background and the present state of the problem. Objectives with specific aims and brief literature review have also discussed here.

Chapter-2 This chapter deals with the overview of Energy Efficiency Design Index. Each term related to EEDI has been explained in this chapter. Also Holtrop and Mennen's method has been discussed here which has been used later to evaluate power prediction.

Chapter-3 Formulation of the guidelines of EEDI for inland vessels in Bangladesh has been presented here. Also the verification and limitations in current evaluation of EEDI reference line has been discussed. Furthermore, the formulated EEDI reference lines of inland vessels of Bangladesh with other countries have been compared here.

Chapter-4 This chapter deals with the parametric study of EEDI. Influence of design parameters (e.g. ship's draft, main engine power, block coefficient, specific fuel consumption, type of fuel) on EEDI have been discussed here.

Chapter-5 In this chapter, present status of EEDI with respect to vessels length, capacity and main engine power of inland vessels of Bangladesh have been investigated.

Chapter-6 This chapter deals with the case study of existing inland vessels with respect to EEDI.

Chapter-7 In this chapter, case study of hull form optimization of existing inland vessels of Bangladesh has been performed.

Chapter-8 This chapter deals with the survey and verification procedure of EEDI during design and sea trail stage.

Chapter-9 In this chapter, some advance energy efficient technologies have been discussed.

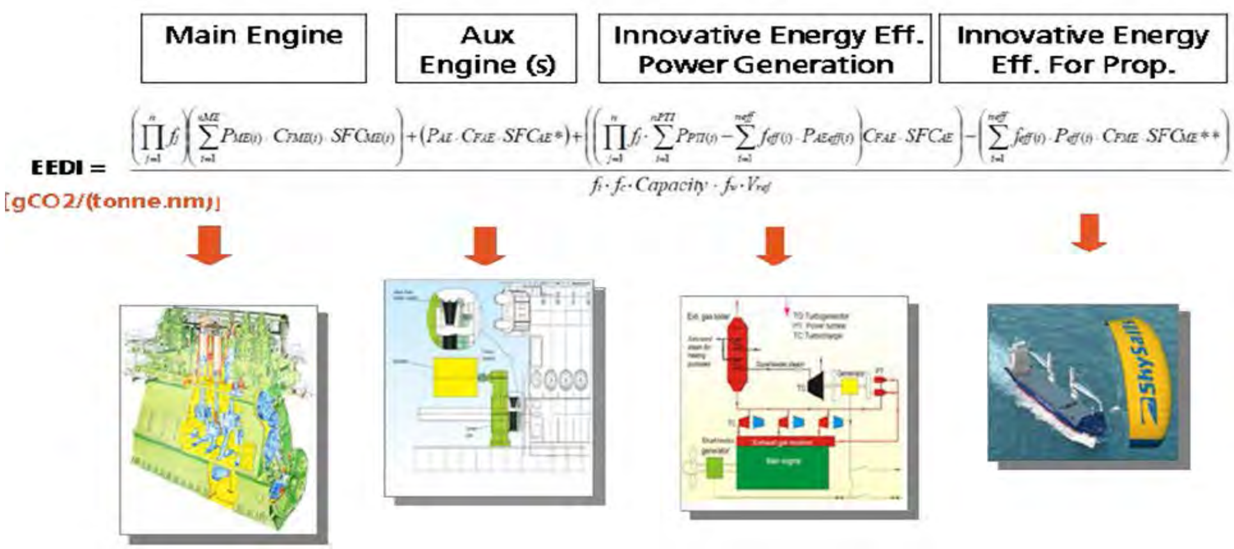
Chapter-10 This chapter contains conclusions of this research and some viable recommendations which can be applied in future for inland vessels of Bangladesh.

Chapter-2

Overview of Energy Efficiency Design Index (EEDI)

2.1 Overview

The Energy Efficiency Design Index has been developed at the IMO over the past several years through a series of submissions to MEPCs 57-59 and the 1st and 2nd Working Groups on Greenhouse Gases. After the 2nd Intersessional Meeting of the Working G roup on Greenhouse G as E missions f rom S hips, the equation w as refined to the following form for ocean going vessels:



The items that primarily influence EEDI are:

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

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

The equation retains this form in IMO [37]. In this study, the same equation and EEDI condition have been used for inland vessels.

2.2 EEDI Condition:

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

- Draught: Summer load line draught
- Capacity: Deadweight (or gross tonnage for passenger ships, etc.) for the summer load line draught (container ship will be 70% value)
- Weather condition: Calm with no wind and waves
- Propulsion shaft power: 75% of main engine MCR (conventional ships) with some amendments for shaft motor or shaft generator or shaft-limited power cases, where applicable
- Reference speed (Vref): Is the ship speed when measured/estimated under the above mentioned conditions

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

2.3 Explanation of terms

In order to study the impacts of EEDI formula, each component of EEDI formula must be studied separately. Every component of the formula which has been shown in Figure 1 has different variables those can be changed in order to meet the EEDI regulations. There can be various ways and technologies that can be used to meet the emissions regulations. The definition and meaning are given below in Figure 1 shows the frame for studying EEDI formula.

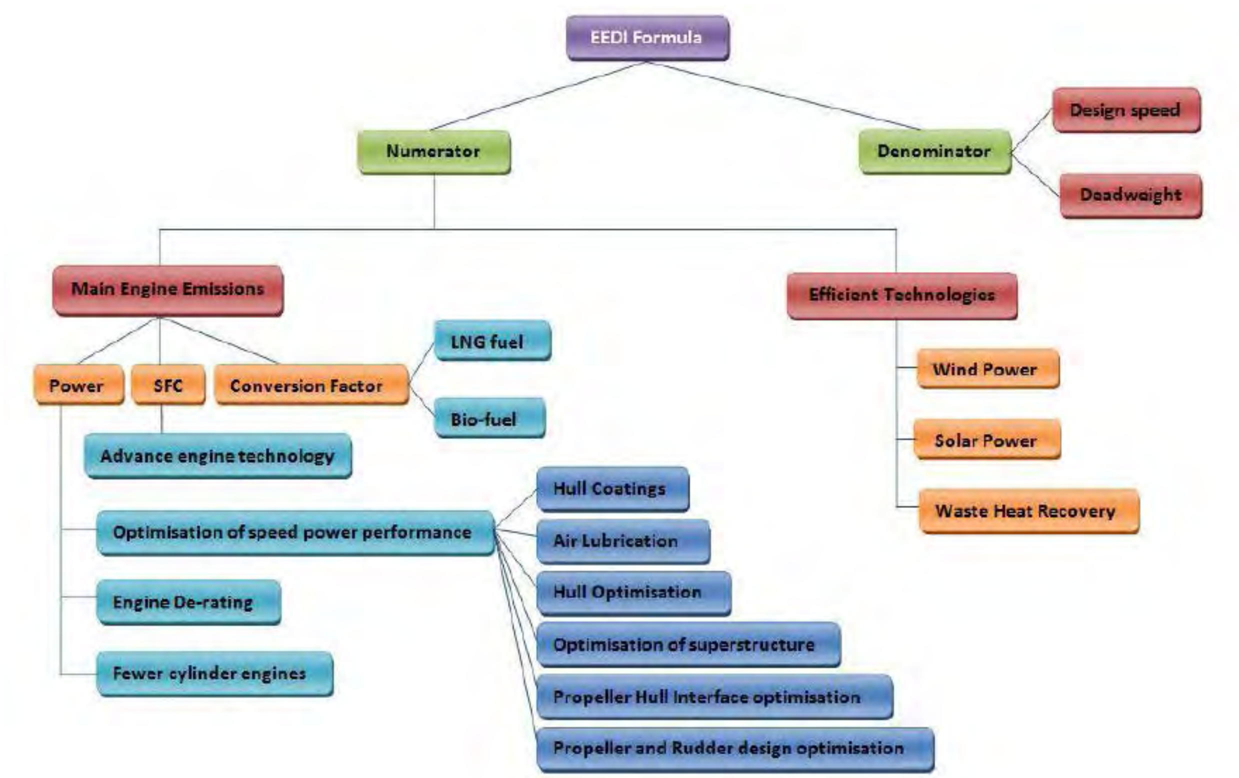


Figure 1: *Frame to study EEDI formula*

The details of each term of Figure 1 have been described below:

C_F is a non-dimensional conversion factor between fuel consumption measured in g and CO_2 emission also measured in gram based on carbon content. The subscripts *MEi* and *AEi* refer to the main and auxiliary engine(s) respectively. C_F corresponds to the fuel used when determining sfc listed in the applicable EIAPP Certificate. The values of the conversion factors, C_F are given in Table 3.

Table 3. *C_F values for different types of fuel [38]*

Type of fuel	**Reference**	**Carbon content**	**C_F (t-CO2/t-Fuel)**
Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206
Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.15104
Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.1144
Liquefied Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.0 3.03
Liquefied Natural Gas (LNG)		0.75	2.75

V_{ref} is the ship speed, measured in nautical miles per hour (knot), on deep water in the maximum design load condition (Capacity) at the shaft power of the engine(s) and assuming the weather is calm with no wind and no waves. The maximum design load condition shall be defined by the scantling draught with its associated trim, at which the ship is allowed to operate. This condition is obtained from the stability booklet approved by the administration.

Capacity is defined as

- For dry cargo carriers, tankers, gas tankers, containerships, ro-ro cargo and general cargo ships, deadweight should be used as Capacity.
- For passenger ships and ro-ro passenger ships, gross tonnage in accordance with the International Convention of Tonnage Measurement of Ships 1969, Annex I, Regulation 3 should be used as Capacity.
- For containerships, the capacity parameter should be established at 70% of the deadweight.

Deadweight means the difference in tonnes between the displacement of a ship in water of relative density of 1.025 kg/m^3 at the deepest operational draught and the lightweight of the ship.

'P' is the power of the main and auxiliary engines, measured in kW. The subscripts ***ME*** and ***AE*** refer to the main and auxiliary engine(s), respectively. The summation on ***i*** is for all engines with the number of engines (***nME***).

$P_{ME(i)}$ is 75% of the rated installed power (MCR) for each main engine (***i***) after having deducted any installed shaft generator(s):

$$P_{ME(i)} = 0.75 \times (MCR_{MEi} - P_{PTOi}) \quad (1)$$

Calculation of P_{ME} will also be found in Figure 2.

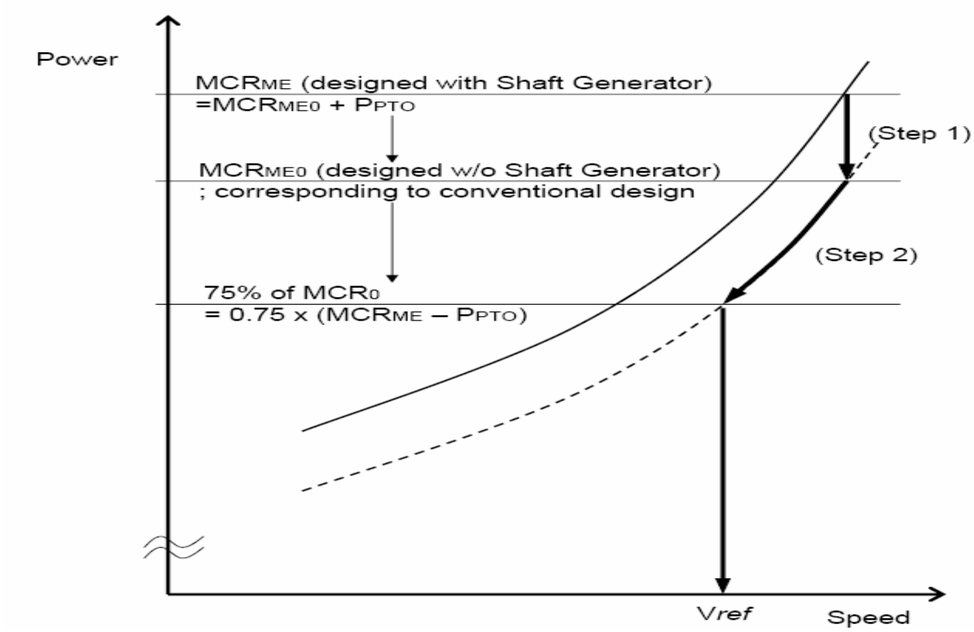


Figure 2: *Calculation of P_{ME}, as described in IMO circular 681[37]*

$\boldsymbol{P_{PTO(i)}}$ is 75% output of each shaft generator installed divided by the relevant efficiency of that shaft generator.

$\boldsymbol{P_{PTI(i)}}$ is 75% of the rated power consumption of each shaft motor divided by the weighted averaged efficiency of the generator(s). In case of combined *PTI/PTO*, the normal operational mode at sea will determine which of these to be used in the calculation.

$\boldsymbol{P_{eff(i)}}$ is 75% of the main engine power reduction due to innovative mechanical energy efficient technology. Mechanical recovered waste energy directly coupled to shafts need not be measured.

$\boldsymbol{P_{AEeff(i)}}$ is the auxiliary power reduction due to innovative electrical energy efficient technology measured at $\boldsymbol{P_{ME(i)}}$.

P_{AE} is the required auxiliary engine power to supply normal maximum sea load including necessary power for propulsion machinery/systems and accommodation, e.g., main engine pumps, navigational systems and equipment and living on board, but excluding the power not for propulsion machinery/systems, e.g., thrusters, cargo pumps, cargo gear, ballast pumps, maintaining cargo, e.g., reefers and cargo hold fans, in the condition where the ship engaged in voyage at the speed (***V_{ref}***) under the design loading condition of Capacity.

For cargo ships with a main engine power of 10000 kW or above, P_{AE} is defined as [38]:

$$P_{AE\,(\Sigma MCR_{ME(i)} \geq 10{,}000kW)} = \left(0.025 \times \left(\sum_{i=1}^{nME} MCR_{ME(i)} + \frac{\sum_{i=1}^{nPTI} P_{PTI(i)}}{0.75} \right) \right) + 250 \qquad (2)$$

For cargo ships with a main engine power below 10000 kW P_{AE} is defined as [38]:

$$P_{AE\,(\Sigma MCR_{ME(i)} < 10{,}000kW)} = \left(0.05 \times \left(\sum_{i=1}^{nME} MCR_{ME(i)} + \frac{\sum_{i=1}^{nPTI} P_{PTI(i)}}{0.75} \right) \right) \qquad (3)$$

For ship types where the P_{AE} value calculated by the above two equations is significantly different from the total power used at normal seagoing, e.g., in cases of passenger ships, the P_{AE} value should be estimated by the consumed electric power (excluding propulsion) in conditions when the ship is engaged in a voyage at reference speed (***V_{ref}***) as given in the electric power table, divided by the weighted average efficiency of the generator(s).

V_{ref}, ***Capacity*** and P should be consistent with each other.

SFC is the certified specific fuel consumption, measured in g/kWh, of the engines. The subscripts ***ME(i)*** and ***AE(i)*** refer to the main and auxiliary engine(s), respectively.

For ships where the P_{AE} value calculated by Equation 2 and 3 is significantly different from the total power used at normal seagoing, e.g., conventional passenger ships, the Specific Fuel Consumption (SFC_{AE}) of the auxiliary generators is that recorded in the EIAPP Certificate(s) for the engine(s) at 75% of P_{AE} MCR power of its torque rating. SFC_{AE} is the weighted average among $SFC_{AE(i)}$ of the respective engines ***i***.

For those engines which do not have an EIAPP Certificate because its power is below 130 kW, the ***SFC*** specified by the manufacturer and endorsed by a competent authority should be used.

f_j is a correction factor to account for specific ship design elements. For ice-classed ships are determined by the standard f_j shown in Table 4. For other ship types, f_j should be taken as1.0.

Table 4. *Correction factor for power f j for ice-classed ships [38]*

Ship type	fj	Limits depending on the ice class			
		IC	IB	IA	IA Super
Tanker	$\frac{0.516L_{PP}^{1.87}}{\sum_{i=1}^{nME} P_{iME}}$	{max 1.0 min $0.72L_{PP}^{0.06}$}	{max 1.0 min $0.61L_{PP}^{0.08}$}	{max 1.0 min $0.5L_{PP}^{0.1}$}	{max 1.0 min $0.4L_{PP}^{0.12}$}
Dry cargo carrier	$\frac{2.15L_{PP}^{1.58}}{\sum_{i=1}^{nME} P_{iME}}$	{max 1.0 min $0.89L_{PP}^{0.02}$}	{max 1.0 min $0.78L_{PP}^{0.04}$}	{max 1.0 min $0.68L_{PP}^{0.06}$}	{max 1.0 min $0.58L_{PP}^{0.08}$}
General cargo ship	$\frac{0.045L_{PP}^{2.37}}{\sum_{i=1}^{nME} P_{iME}}$	{max 1.0 min $0.85L_{PP}^{0.03}$}	{max 1.0 min $0.7L_{PP}^{0.06}$}	{max 1.0 min $0.54L_{PP}^{0.1}$}	{max 1.0 min $0.39L_{PP}^{0.15}$}

fw is a non-dimensional coefficient indicating the decrease of speed in representative sea conditions of wave height, wave frequency and wind speed (e.g., Beaufort Scale 6), and should be determined as follows:

It can be determined by conducting the ship-specific simulation of its performance at representative sea conditions. The simulation methodology should be prescribed in the guidelines developed by the organization and the method and outcome for an individual ship shall be verified by the administration or an organization recognized by the administration.

In case that the simulation is not conducted, f_w should be taken from the "Standard f_W" table/curve. A "Standard f_W" table/curve, which is to be contained in the guidelines, is given by ship type (the same ship as the "baseline" below), and expressed in a function of the parameter of Capacity (e.g., DWT). The "Standard f_W" table/curve is to be determined by conservative approach, i.e., based on data of actual speed reduction of as many existing ships as possible under representative sea conditions.

f_w should be taken as one (1.0) until the guidelines for the ship-specific simulation or f_W table/curve becomes available.

$\boldsymbol{f_{eff(i)}}$ is the availability factor of each innovative energy efficiency technology. $\boldsymbol{f_{eff(i)}}$ for waste energy recovery system should be 1.

fi is the capacity factor for any technical/regulatory limitation on capacity, and can be assumed one (1.0) if no necessity of the factor is granted.

fi for ice-classed ships are determined by the standard f_i shown in Table 5. For other ship types, ***fi*** should be taken as 1.0.

Table 5. *Capacity correction factor fi for ice-classed ships [38]*

Ship type	*fi*	Limits depending on the ice class			
		IC	IB	IA	IA Super
Tanker	$\frac{0.00115L_{PP}^{3.36}}{capacity}$	max 1.31 $L_{PP}^{-0.05}$ min 1.0	max 1.54 $L_{PP}^{-0.07}$ min 1.0	max 1.8 $L_{PP}^{-0.09}$ min 1.0	max 2.1$L_{PP}^{-0.11}$ min 1.0
Dry cargo carrier	$\frac{0.000665L_{PP}^{3.44}}{capacity}$	max 1.31 $L_{PP}^{-0.05}$ min 1.0	max 1.54 $L_{PP}^{-0.07}$ min 1.0	max 1.8 $L_{PP}^{-0.09}$ min 1.0	max 2.1$L_{PP}^{-0.11}$ min 1.0
General cargo ship	$\frac{0.000676L_{PP}^{3.44}}{capacity}$	1.0	max 1.08 min 1.0	max 1.12 min 1.0	max 1.25 min 1.0
Container ship	$\frac{0.1749L_{PP}^{2.29}}{capacity}$	1.0	max 1.25 $L_{PP}^{-0.04}$ min 1.0	max 1.6 $L_{PP}^{-0.08}$ min 1.0	max 2.1$L_{PP}^{-0.12}$ min 1.0
Gas tanker	$\frac{0.1749L_{PP}^{2.33}}{capacity}$	max 1.31 $L_{PP}^{-0.04}$ min 1.0	max 1.6 $L_{PP}^{-0.08}$ min 1.0	max 2.1 $L_{PP}^{-0.12}$ min 1.0	1.0

Length between perpendiculars, L_{pp} means 96 % of the total length on a waterline at 85 % of the least moulded depth measured from the top of the keel, or the length from the foreside of the stem to the axis of the rudder stock on that waterline, if that were greater. In ships designed with a rake of keel the waterline on which this length is measured shall be parallel to the designed waterline. The length between perpendiculars (L_{pp}) shall be measured in meters.

2.4 Holtrop and Mennen's Method

In this thesis, case study has been performed for various existing inland vessels and also hull form modification has been performed for different class vessels. To perform this case study power prediction needs to be determined for different vessels and to do this calculation Holtrop and Mennen's method has been used. Here the procedure of Holtrop and Mennen's method has been described.

For the evaluation of resistance, Holtrop and Mennen did a statistical evaluation of model test results, selected from the archive of the Netherlands Ship Model Basin. The evaluation was carried out using multiple regression analysis methods.

The total resistance of a ship is generally subdivided into components of different origin. The evaluation of each component was performed by applying multiple regression analysis to the results of 1707 resistance measurements, carried out with 147 ship models and the results of 82 trial measurements made on board 46 new ships.

A survey of the parameter ranges and ship types is given in Table 6.

***Table 6**. Parameter range for different ship types [39]*

Type of ship	L/B	B/T	C_p	F_n max.
Tankers, Bulkcarriers	$5.1 < \frac{L}{B} < 7.1$	$2.4 < \frac{B}{T} < 3.2$	$0.73 < C_p < 0.85$	0.24
General cargo	$5.3 < \frac{L}{B} < 8.0$	$2.4 < \frac{B}{T} < 4.0$	$0.58 < C_p < 0.72$	0.30
Fishing vessels, tugs	$3.9 < \frac{L}{B} < 6.3$	$2.1 < \frac{B}{T} < 3.0$	$0.55 < C_p < 0.65$	0.38
Containers ships, frigates	$6 < \frac{L}{B} < 9.5$	$3.0 < \frac{B}{T} < 4.0$	$0.55 < C_p < 0.67$	0.45
Various	$6.0 < \frac{L}{B} < 7.3$	$3.2 < \frac{B}{T} < 4.0$	$0.56 < C_p < 0.75$	0.30

The total resistance of a ship has been subdivided into :

$$R_{Total} = R_F \cdot (1+k) + R_{APP} + R_W + R_B + R_{TR} + R_A \quad (4)$$

R_F, frictional resistance of a ship according to the ITTC-1957 friction formula.

$1+k$, form factor describing the viscous resistance of the hull form in relation to R_F.

R_{APP}, resistance of appendages.

R_w, wave-making and wave-breaking resistance.

R_B, additional pressure resistance of bulbous bow near the water surface.

R_{TR}, additional pressure resistance of immersed transom stern.

R_A, model-ship correlation resistance.

The viscous resistance, $R_F \cdot (1+k)$, represents approximately the 63% of the total resistance, and the wave-making and wave-breaking resistance represents approximately the 27% of the total resistance, for Froude number around 0.30. These components will be found by following equations.

$$(1+k) = c_{13} \cdot \left\{ 0.93 + c_{12} \cdot \left(\frac{B}{L_R} \right)^{0.92497} \cdot (0.95 - C_P)^{-0.521448} \cdot (1 - C_P + 0.0225 \cdot lcb)^{0.6906} \right\} \tag{5}$$

$$\frac{L_R}{L} = 1 - C_P + \frac{0.06 \cdot C_P \cdot lcb}{4 \cdot C_P - 1} \tag{6}$$

$$c_{12} = \begin{cases} \left(\frac{T}{L} \right)^{0.2228446} \rightarrow \frac{T}{L} > 0.05 \\ 48.20 \cdot \left(\frac{T}{L} - 0.02 \right)^{2.078} + 0.479948 \rightarrow 0.02 < \frac{T}{L} < 0.05 \\ 0.479948 \rightarrow \frac{T}{L} < 0.02 \end{cases} \tag{7}$$

$$c_{13} = 1 + 0.003 \cdot C_{stern} \tag{8}$$

The C_{stern} coefficient indicates the afterbody form. For V-shaped sections $C_{stern} = -10$, for normal sections shape $C_{stern} = 0$ and for U-shaped sections with Hogner stern $C_{stern} = 10$.

And lcb is the longitudinal position of the centre of buoyancy forward of 0.5l as a percentage of L.

$$R_W = c_1 \cdot c_2 \cdot c_5 \cdot \nabla \cdot \rho \cdot g \cdot \exp\left\{ m_1 \cdot F_n^d + m_2 \cdot \cos(\lambda \cdot F_n^{-2}) \right\} \tag{9}$$

$$c_1 = 2223105 \cdot c_7^{3.78613} \cdot \left(\frac{T}{B} \right)^{1.07961} \cdot (90 - i_E)^{-1.37565} \tag{10}$$

$$i_E = 1 + 89 \cdot \exp\left\{ -\left(\frac{L}{B} \right)^{0.80856} \cdot (1 - C_{WP})^{0.30484} \cdot (1 - C_P - 0.0225 \cdot lcb)^{0.6367} \cdot \left(\frac{L_R}{B} \right)^{0.34574} \cdot \left(100 \cdot \frac{\nabla}{L^3} \right)^{0.16302} \right\} \tag{11}$$

$$\lambda = \begin{cases} 1.446 \cdot C_P - 0.03 \cdot \frac{L}{B} \rightarrow \frac{L}{B} < 12 \\ 1.446 \cdot C_P - 0.36 \rightarrow \frac{L}{B} > 12 \end{cases} \tag{12}$$

$$m_1 = 0.0140407 \cdot \frac{L}{T} - 1.75254 \cdot \frac{\nabla^{1/3}}{L} - 4.79323 \cdot \frac{B}{L} - c_{16} \tag{13}$$

$$c_{16} = \begin{cases} 8.07981 \cdot C_P - 13.8673 \cdot C_P^2 + 6.984388 \cdot C_P^3 \rightarrow C_P < 0.8 \\ 1.73014 - 0.7067 \cdot C_P \rightarrow C_P > 0.80 \end{cases} \tag{14}$$

$$m_2 = c_{15} \cdot C_P^2 \cdot \exp\left(-0.1 \cdot F_n^{-2}\right) \tag{15}$$

$$c_{15} = \begin{cases} -1.69385 \rightarrow \frac{L^3}{\nabla} < 512 \\ 0.0 \rightarrow \frac{L^3}{\nabla} > 1727 \\ -1.69385 + \frac{\left(L / \nabla^{1/3} - 8.0 \right)}{2.36} \rightarrow 512 < \frac{L^3}{\nabla} < 1727 \end{cases} \tag{16}$$

$$d = -0.9 \tag{17}$$

$$c_3 = \frac{0.56 \cdot A_{BT}^{1.5}}{B \cdot T \cdot \left(0.31 \cdot \sqrt{A_{BT}} + T_F - h_B\right)} \tag{18}$$

In order to make the resistance prediction valid for ships and models of different size, the resistance components have to be expressed as dimensionless quantities depending on their respective scaling parameter. The form factor is a dimensionless quantity and the dimensionless quantity of the wave-making and wave-breaking resistance is the wave coefficient.

$$C_W = \frac{R_W}{\nabla \cdot \rho \cdot g} \tag{19}$$

A possible validation technique for the Holtrop and Mennen's model is to perform a linear regression analysis between the predicted and their corresponding experimental values. This analysis leads to a line y =a+b·x with a correlation coefficient R^2. A perfect prediction would give a=0, b=1 and R^2=1. Figure 3 and 4 illustrates a graphical output provided by this validation analysis. The predicted form factor and the wave coefficient are plotted versus the experimental ones as open circles. A solid line indicates the best linear fit.

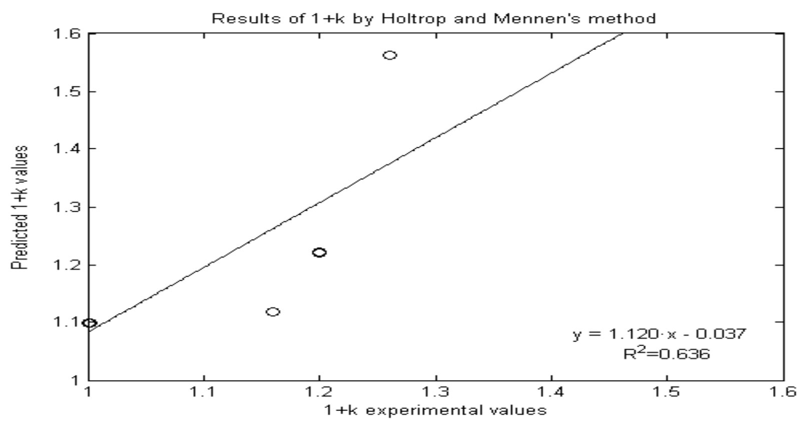


Figure 3. Form factor's linear regression analysis for the Holtrop and Mennen's Method[39]

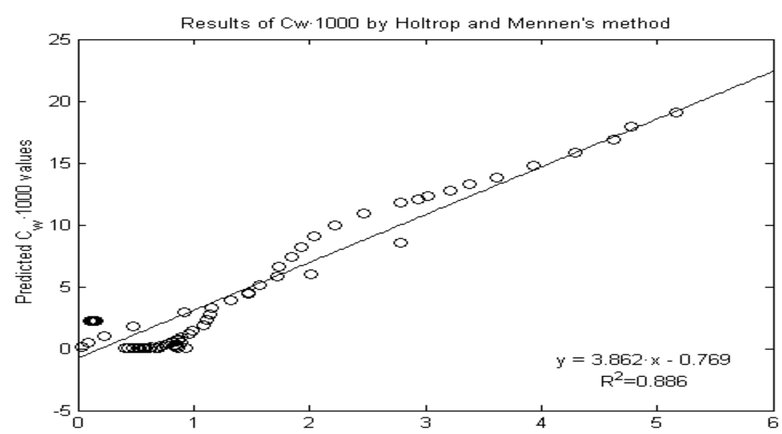


Figure 4. Wave coefficient linear regression analysis for the Holtrop and Mennen's Method [39]

The va lues of the linear regression parameters he re a re, $a_k = -0.037; b_k = 1.120; R^2 = 0.636$ for t he fo rm fact or and $a_W = 0.769; b_W = 3.862; R^2 = 0.886$ for the wave's coefficient.

The Ho ltrop and M ennen's m ethod s eems to tr ack t he e xperimental coefficients approximately well, and the R^2 values are acceptable. However, these results could be improved.

2.4.1 Holtrop and Mennen Method and it's Limitations

This is a very well-known approximate resistance and power prediction method for displacement and semi disp lacement vessels. However, not all types of ships are covered by this method. The approximate formulations are based on hydrodynamic theory with coefficients obtained from the regression analysis of the results of 334 ship model tests. This method works well for tankers, general cargo vessels, bulk carrier, c ontainer ship; f ishing v essels t ug boats a nd f rigates wi th a c ertain boundary of prismatic coefficient, L/B and B/T. The limitations are shown in Table 7. I n or der t o have the m ost a ccurate r esults f or the power prediction by th is method; these limitations were maintained in the analysis process.

***Table 7**. Limitations for Holtrop & Mennen's Method [39]*

Ship type	Max Froude no.	Cp		L/B		B/T	
		Min	Max	Min	Max	Min	max
Tankers, bulk carriers	0.24	0.73	0.85	5.1	7.1	2.4	3.2
Trawlers, tugs	0.38	0.55	0.65	3.9	6.3	2.1	3.0
Container ships, destroyers	0.45	0.55	0.67	6.0	9.5	3.0	4.0
Cargo liners	0.3	0.56	0.75	5.3	8.0	2.4	4.0
RoRo Ships, Car ferries	0.35	0.55	0.67	5.3	8.0	3.2	4.0

Chapter-3

Development of EEDI for Inland Vessels

3.1 Overview

In order to establish EEDI reference lines, main types of inland vessels of Bangladesh such as Cargo ships, Oil tankers, Passenger vessels, Ferries & Sand carriers have been taken into consideration. For Passenger vessels & Passenger ferries Gross Tonnage (GT) has been considered for calculation of EEDI. On the other hand 100% of deadweight has been used as capacity for other vessels as suggested by IMO. The calculation of EEDI has been performed for 75% of MCR of engine and with corresponding evaluated ship speed and the value of MCR has been obtained from power speed curve supplied by engine manufacturer. Adopted value of carbon emissions factor (C_F) for diesel fuel was 3.2 t CO_2/t fuel, as recommended in [38].

In Bangladesh, inland vessels use new and old engines and most of these vessels' engine power is generally in the range of 200 to 1000KW. Specific fuel consumption (sfc) of these new engine has been collected from engine manufacturer. The value of sfc for engines used for inland vessels has been cross checked by taking log-book data of actual fuel consumption in different routes. A sample calculation of 900KW engine log book data of actual fuel consumption has been shown in Table 8.

Table 8. *Engine log book data of fuel consumption*

Engine load (% of MCR)	SFC (g/KWh)
50%	195
55%	198
60%	197
65%	203
70%	217
75%	210
80%	215
85%	213
90%	207
95%	215
100%	213

3.2 Formulation of the guidelines of EEDI for inland waterway vessels in Bangladesh

In this study the reports of MEPC 60 were used as the basis for the calculations. MEPC 60 has been working for implementing the EEDI method on new building vessels within MARPOL Annex VI. Based on all collected data, values of EEDI of analyzed inland waterway vessels have obtained according to the equation introduced by IMO:

$$EEDI_{attained} = \frac{CO_2 Emission}{Transport\ work}$$

$$= \frac{Power * Specific\ Fuel\ Consumption * CO_2 Conversion\ Factor}{Capacity * Speed}$$

$$= \frac{Emission\ from\ Main\ Engine + Emission\ from\ Auxiliary\ Engine + Emission\ for\ running\ shaft\ motor - Efficient\ Tech.Reduction}{Capacity * Reference\ Speed}$$

$$= \left[\left(\prod_{j=1}^{n} f_j\right) * \left(\sum_{i=1}^{nME} P_{ME(i)} * C_{FME(i)} * SFC_{ME(i)}\right) + (P_{AE} * C_{FAE} * SFC_{AE}) + \left(\left(\prod_{j=1}^{n} f_j * \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} * P_{AEeff(i)}\right) * C_{FAE} * SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} * P_{eff(i)} * C_{FME} * SFC_{ME}\right)\right] * \frac{1}{f_i * f_c * Capacity * V_{ref} * f_w} \left(\frac{g_{CO_2}}{Tonne * knotical\ mile}\right) \tag{20}$$

The calculated EEDI for a ship is called the attained EEDI. The attained EEDI shall be calculated for:

1. Each new ship;
2. Each new ship which has undergone a major conversion; and
3. Each new or existing ship which has undergone a major conversion, that is so extensive that the ship is regarded by the Administration as a newly constructed ship.

The attained EEDI shall be specific to each ship and shall indicate the estimated performance of the ship in terms of energy efficiency, and be accompanied by the 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 shall be verified, based on the EEDI technical file, either by the Administration or by any organization duly authorized by it.

Required EEDI is necessary for each:

1. New ship;
2. New ship which has undergone a major conversion; and
3. New or existing ship which has undergone a major conversion that is so extensive that the ship is regarded by the Administration as a newly constructed ship

The Average Index Values are used as the basis for calculating an exponential regression line. The regression line expresses the baseline value, which can then be calculated by using the following formula:

$$\text{Reference line value} = a \times b^{-c} \tag{21}$$

Where a, b and c are the parameters given in Table 9. The reference line is based on the vessel database of Department of Shipping (DOS) in Bangladesh.

***Table 9**. Reference line parameter value of different types of vessel*

Ship type	**Parameters**			**R^2**	**Population**	**Excluded**
	a	**b**	**c**			
General Cargo	15831	DWT	0.789	0.2615	351	16
Oil Tanker	950.93	DWT	0.406	0.4132	85	5
Passenger Vessel	42477	GT	1.1015	0.6806	90	13
Passenger Ferry	$9X10^7$	GT	2.204	0.7914	36	2
Sand Carrier	2261.7	DWT	0.595	0.2592	2095	18

Here R^2 describes the correlation of the baseline value. A correlation close to 1 or -1 represents a high degree of correlation. Scatter values which are more than two standard deviations from the regression line are removed, and a new regression line is calculated. This ensures that erroneous data are excluded from the calculation. Here in Table 9, the term "Population" means numbers of vessels have been taken in to this study and "Excluded" means the number of vessels that have been deducted from this study.

Figure 5 shows EEDI reference line for inland Cargo vessels of Bangladesh.

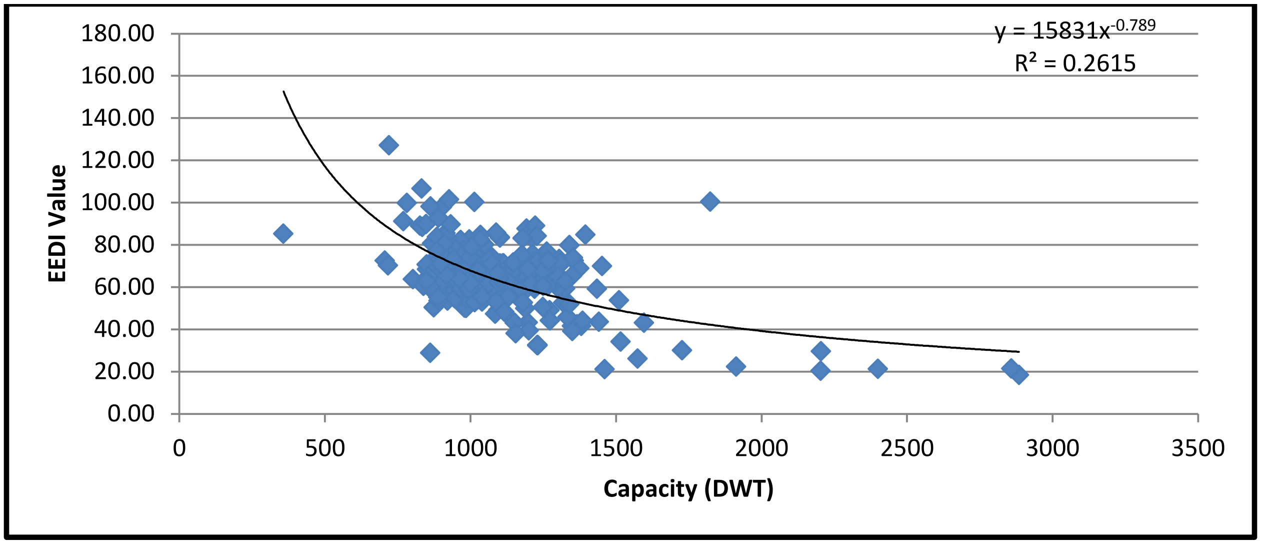


Figure 5: *EEDI Reference line for Inland Cargo Vessels of Bangladesh*

From Figure 5, it has been observed that the numbers of cargo vessels are smaller than 3000 DWT. Based on the data available, the regression line of cargo vessels has been plotted. A group of ships in the 1000-1500 DWT range have relatively index values around 70. These ships would fit in much better in the figure showing EEDI values of cargo ships. It has also been observed that the correlation of the regression line is low and many scatter points would be one of the reasons for that. Arbitrary engine selection of cargo vessels is one of the reasons to get more scatter points.

Figure 6 shows EEDI reference line for inland Oil tankers of Bangladesh.

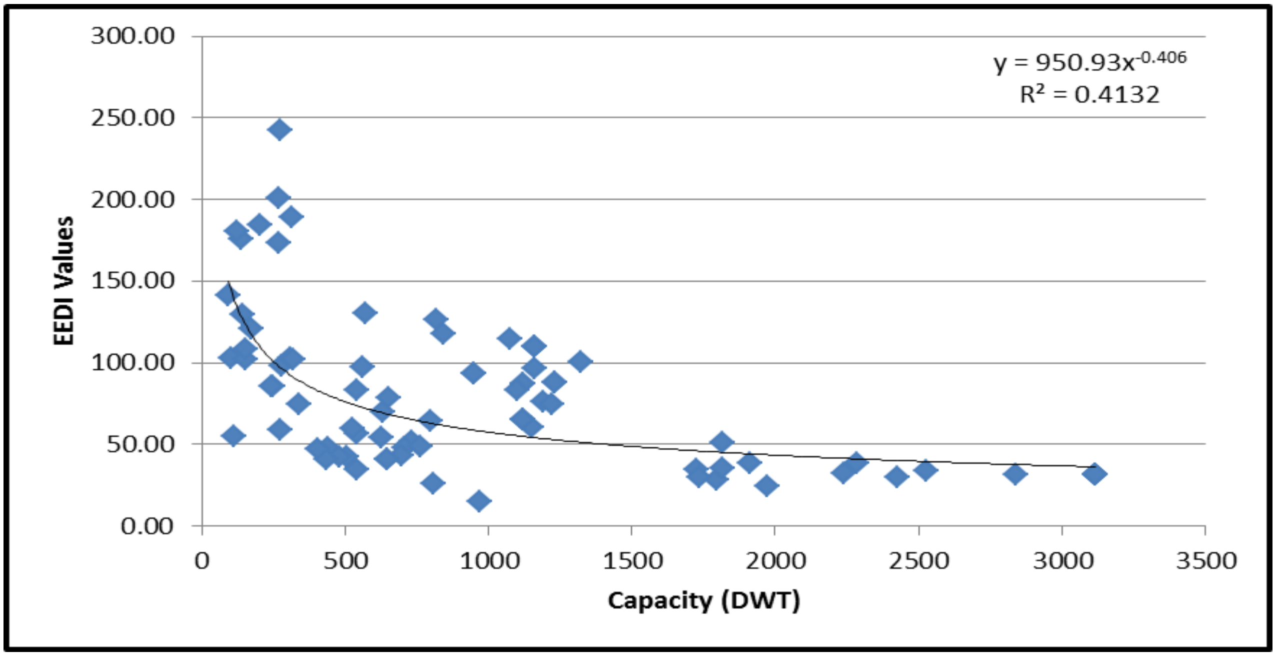


Figure 6: *EEDI Reference line for Inland Oil Tankers of Bangladesh*

From Figure 6, it has been observed that the numbers of oil tankers are smaller than 3000 DWT. Based on the data available, the regression line of oil tanker has been plotted. A group of ships in the 200-1200 DWT range have relatively index values around 80. These ships would fit in much better in the figure showing EEDI values of oil tanker. It has also been observed that the correlation of the regression line is low and many scatter points would be one of the reasons for that. Arbitrary engine selection of oil tankers is one of the reasons to get more scatter points.

Figure 7 shows EEDI reference line for inland Passenger vessels of Bangladesh.

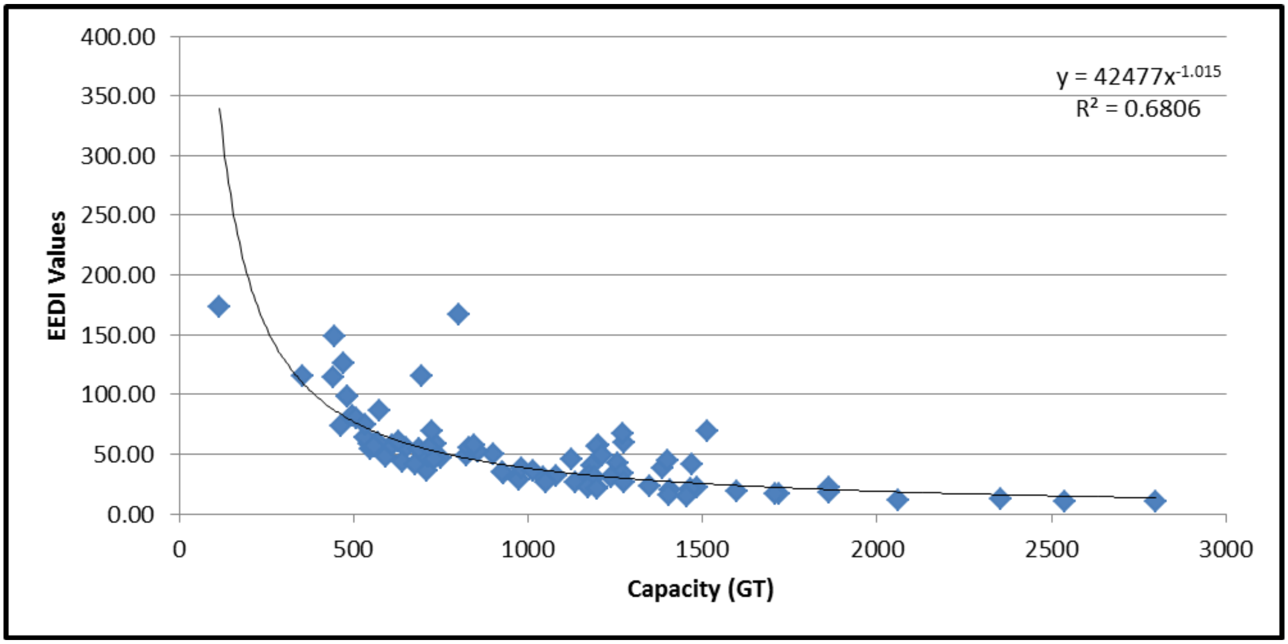


Figure 7: *EEDI Reference line for Inland Passenger Vessels of Bangladesh*

From F igure 7 , it ha s been o bserved th at the numbers of P assenger vessels a re smaller than 1500 GT. Based on the data available, the regression line of passenger vessel has be en pl otted. It ha s a lso be en observed t hat t he correlation of t he regression line is high and many of the points lie within the reference line.

Figure 8 shows EEDI reference line for inland Passenger ferries of Bangladesh.

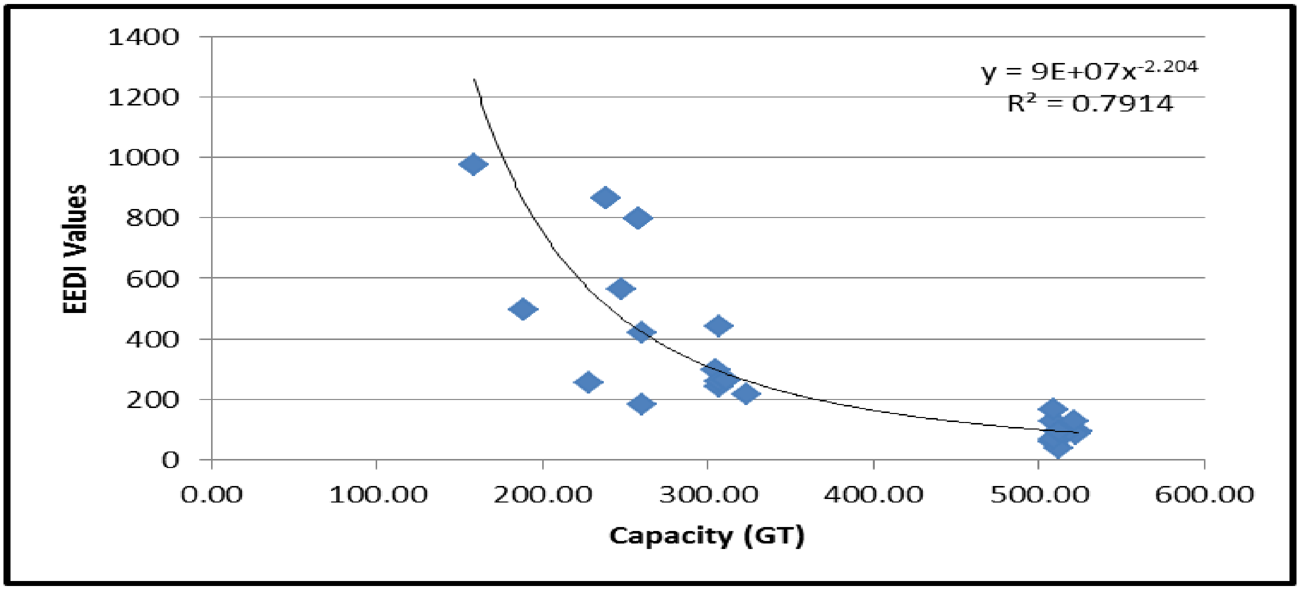


***Figure 8**: EEDI Reference line for Inland Passenger ferries of Bangladesh*

From F igure 8 , it h as be en o bserved t hat th e num bers of P assenger ferr ies are smaller than 550 GT. Based on the data available, the regression line of passenger ferry has been plotted. It has been also observed that the correlation of the regression line is high and many of the points lie within the reference line.

Figure 9 shows EEDI reference line for inland Sand carriers of Bangladesh.

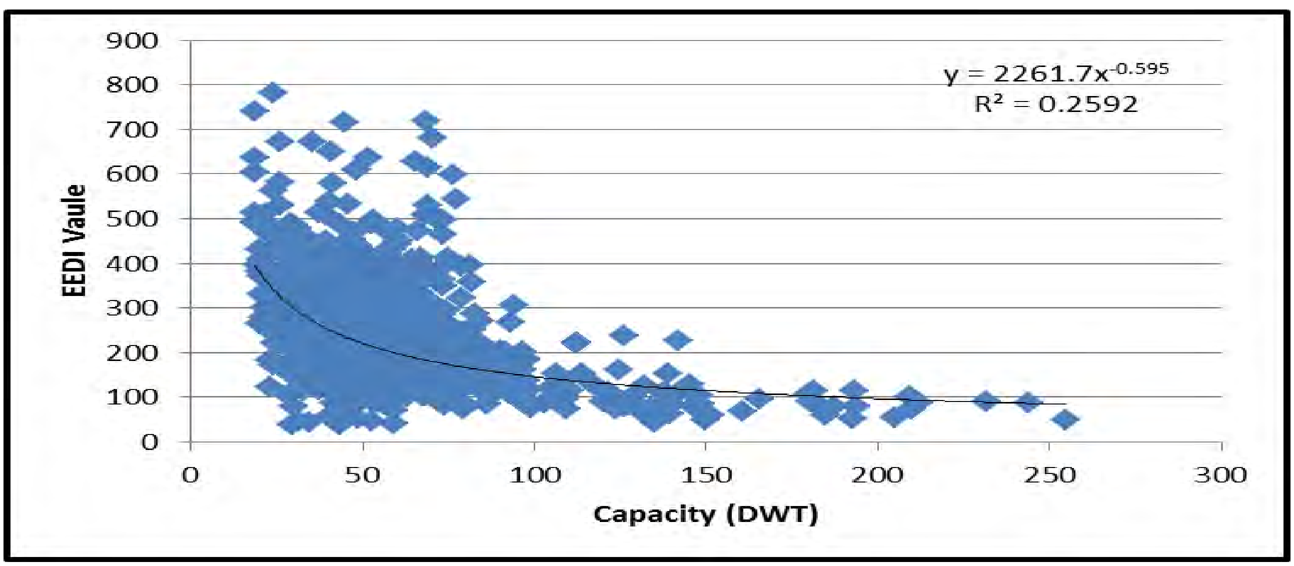


***Figure 9**: EEDI Reference line for Inland Sand Carriers of Bangladesh*

From Figure 9, it has been observed that the numbers of sand carriers are smaller than 300 DWT. A group of ships in the 30-150 DWT range have relatively index values around 200. These ships would fit in much better in the figure showing EEDI values of sand carriers. It has also been observed that the correlation of the regression line is low and more scatter points would be one of the reasons for that. Arbitrary engine selection of sand carriers is one of the reasons to get more scatter points.

Figures 5 to 9 shows the scattered result of EEDI at different capacity. A regression line has drawn among the data points. According to Equation 21 the values of a & c for different types of inland vessels have listed in Table 9. For example, a passenger vessel having GRT = 500 will not be allowed to emit $42477X500^{-1.1015}$ = 44.237 gmCO_2/tonne.mile. So the vessel must be designed in such way that this would not emit 44.237 gmCO_2/tonne.mile. It is possible to have more refine reference line when the number of ships under scrutiny is increased.

3.2.1 Reduction of EEDI reference line value of different phases

The Energy Emission Design Index adopted by the IMO in 2011 will affect most of these new ships. Time period for Phase -1 is from 1st Jan 2015 to 31st Dec 2019, for Phase -2 is from 1st Jan 2020 to 31st Dec 2024 and for Phase -3 is from 1st Jan 2025 to onwards. Phase -1 indicates the reference line value whereas Phase - 2 and 3 will force an EEDI reduction of respectively 20% and 30% relative to the reference line for the ship type. The design of the new buildings in the different phases must take the EEDI into account – this will affect the whole chain from naval architects to the ship owners to the yards. The attained EEDI shall be as follows:

Attained EEDI ≦ Required EEDI =(1-X/100)×Reference line value (22)

Where X is the reduction factor specified in Table 1 for the required EEDI compared to the EEDI Reference line.

This attained EEDI must be less than the reference EEDI or reference line.

Figure 10 to 14 shows phase wise EEDI reference line reduction value for various inland vessels of Bangladesh.

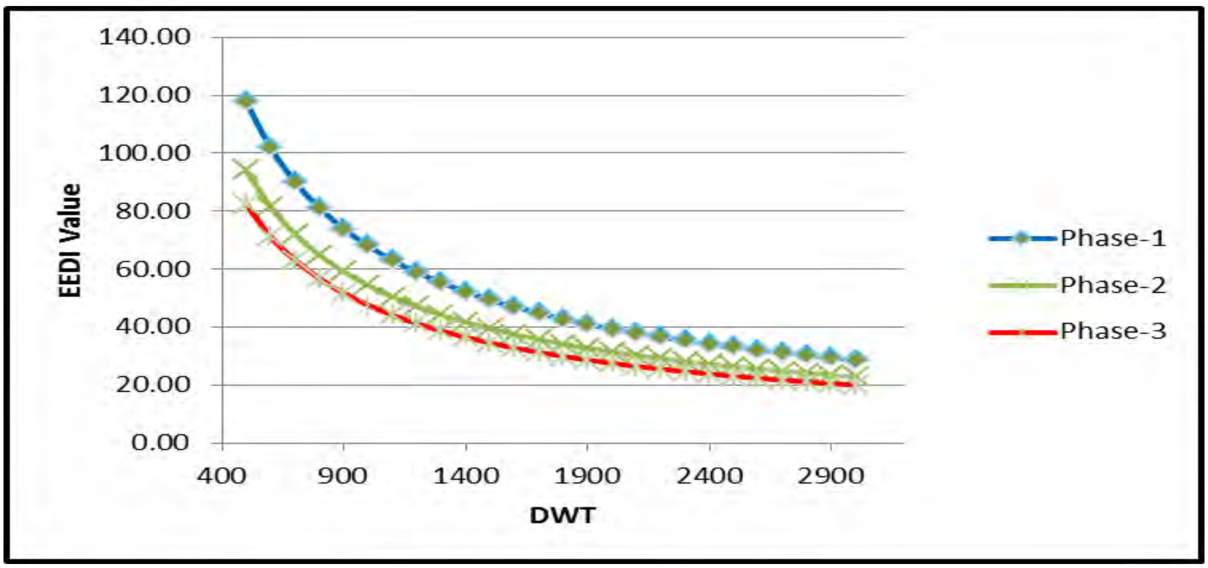


***Figure 10**: Phase wise EEDI Reference line reduction value for inland Cargo Vessels*

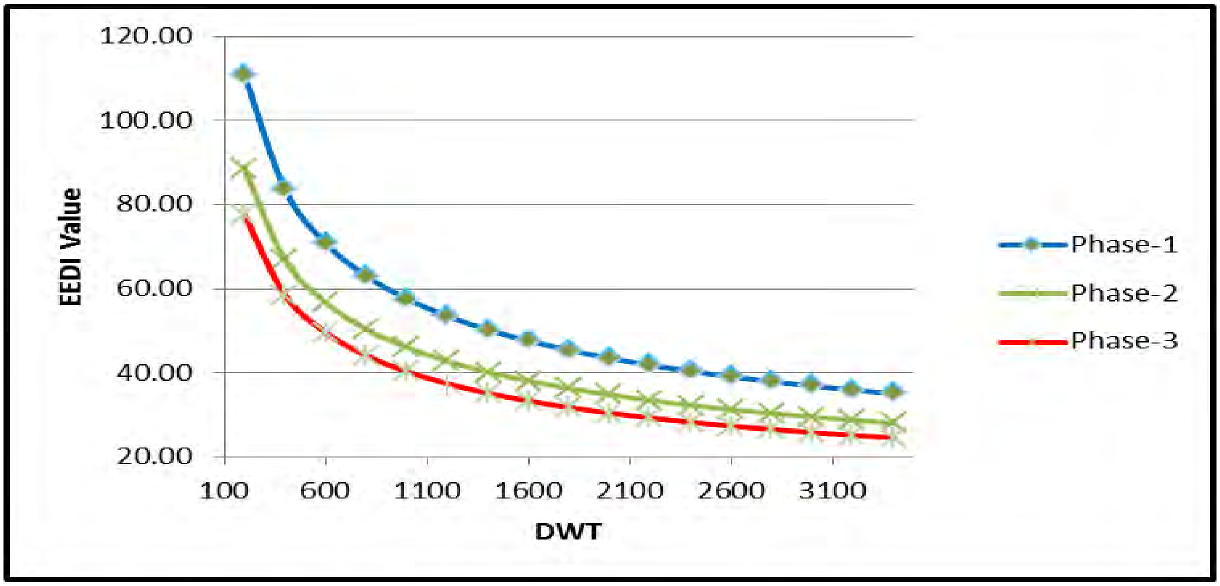


***Figure 11**: Phase wise EEDI Reference line reduction value for inland Oil Tankers*

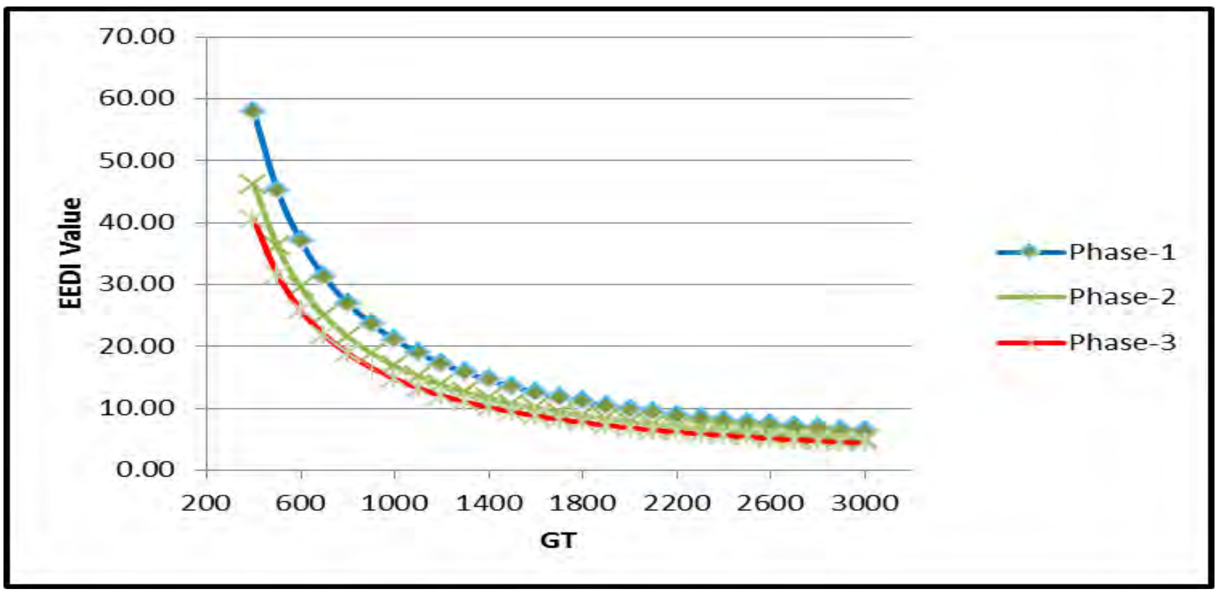


***Figure 12**: Phase wise EEDI Reference line reduction value for inland Passenger Vessels*

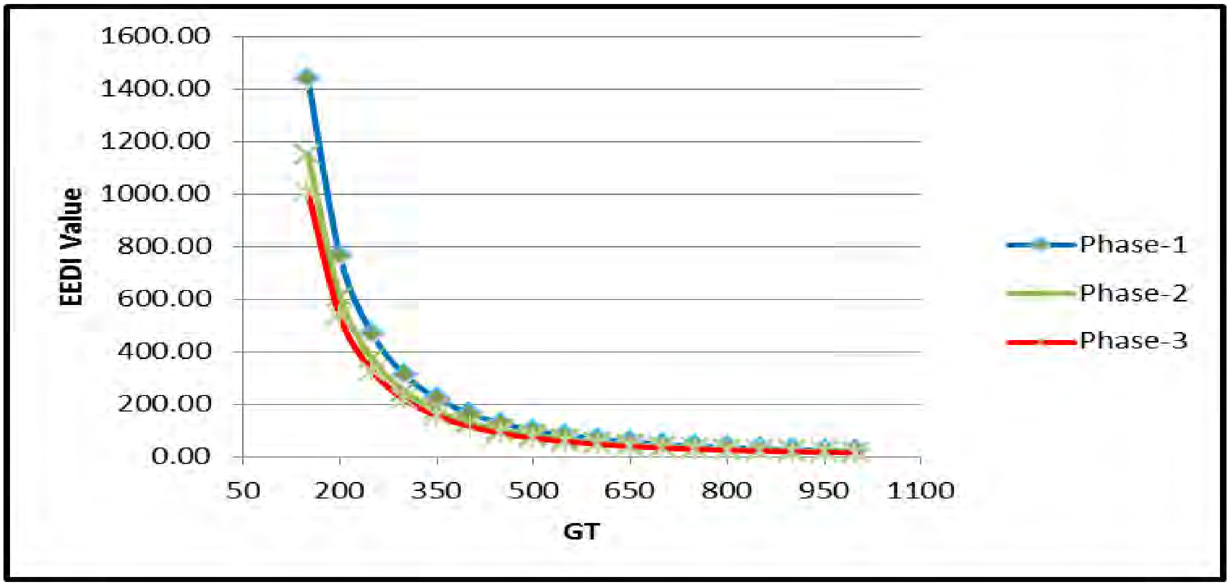


Figure 13: *Phase wise EEDI Reference line reduction value for inland Passenger Ferries*

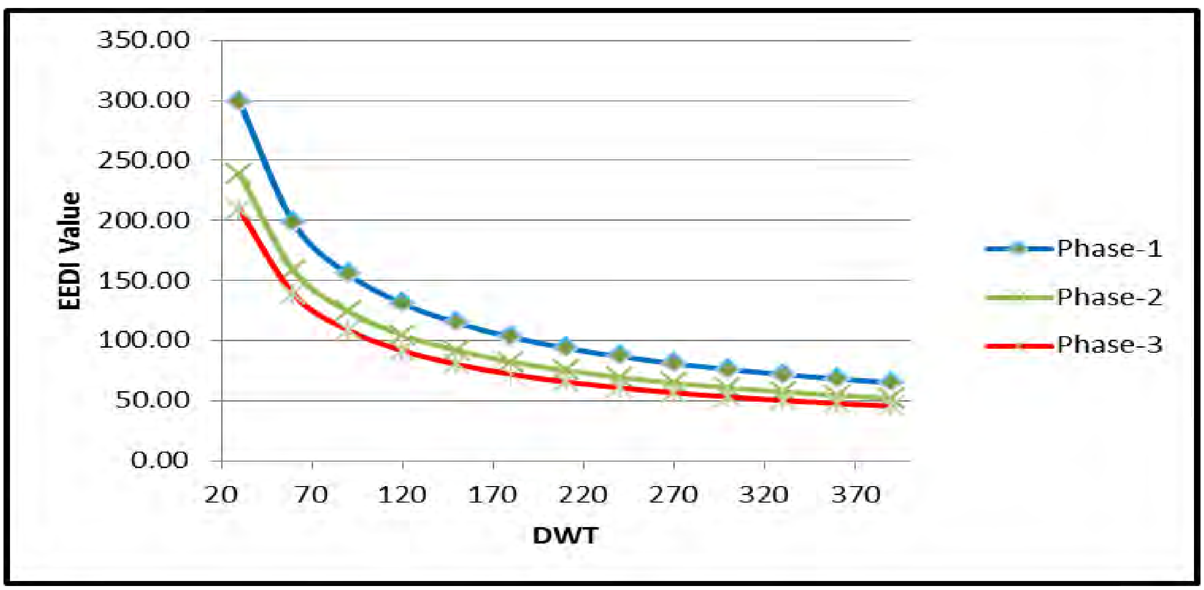


Figure 14: *Phase wise EEDI Reference line reduction value for inland Sand Carriers*

From Figure 10 to 14, we have seen that Phase -2 and 3 has much more restriction on EEDI reference line values. For example, a 1000 DWT cargo vessel is designed for Phase -1 should have required EEDI value 68 gmCO_2/tonne.mile. Whereas for

Phase -2 the required EEDI value will be 54.4 gmCO_2/tonne.mile and for Phase -3 the required EEDI value will be 47.6 gmCO_2/tonne.mile.

3.2.2 Verification of reference line formula

The verification of mathematical model with capacity as independent variable data for different types of vessels have been shown in Table 10 to 14. In this mathematical model the attained EEDI has been calculated using equation (20) and required EEDI has been formulated using equation (21).

Table 10.*Verification of mathematical model with capacity as independent variable for Cargo Vessel*

Sample Ship	Capacity (DWT)	Attained EEDI	Required EEDI	Difference
Cargo Vessel-1	1192	59.05	59.18	0.2%
Cargo Vessel-2	1319	52.65	54.64	3.6%
Cargo Vessel-3	1142	61.74	61.19	-0.9%
Cargo Vessel-4	1050	65.83	65.39	-0.7%
Cargo Vessel-5	1106	65.28	62.78	-4.0%
Cargo Vessel-6	1152	63.8	60.82	-4.9%
Cargo Vessel-7	1220	59.2	58.12	-1.9%
Cargo Vessel-8	1014	66.66	67.24	0.9%
Cargo Vessel-9	1160	62.11	60.46	-2.7%
Cargo Vessel-10	975	61.42	69.33	11.4%

Table 11*.Verification of mathematical model with capacity as independent variable for Oil Tanker*

Sample Ship	Capacity (DWT)	Attained EEDI	Required EEDI	Difference
Oil Tanker-1	652	78.31	68.48	-14.4%
Oil Tanker-2	1153	60.46	54.34	-11.3%
Oil Tanker-3	2528	33.94	39.5	14.1%
Oil Tanker-4	1914	38.49	44.23	13.0%
Oil Tanker-5	539	83.1	73.96	-12.4%
Oil Tanker-6	280	98.1	96.57	-1.6%
Oil Tanker-7	1815	51.16	45.19	-13.2%
Oil Tanker-8	798	64.06	63.09	-1.5%
Oil Tanker-9	629	69.69	69.46	-0.3%
Oil Tanker-10	2284	38.81	41.16	5.7%

Table 12*.Verification of mathematical model with capacity as independent variable for Passenger Vessel*

Sample Ship	Capacity (GT)	Attained EEDI	Required EEDI	Difference
Passenger Vessel-1	1864	22.05	20.35	-8.4%
Passenger Vessel-2	1137	26.89	33.62	20.0%
Passenger Vessel-3	1044	30.49	36.66	16.8%
Passenger Vessel-4	1080	31.88	35.42	10.0%
Passenger Vessel-5	824	49.18	46.61	-5.5%
Passenger Vessel-6	1175	33.07	32.51	-1.7%
Passenger Vessel-7	718	47.72	53.54	10.9%
Passenger Vessel-8	651	55.85	59.21	5.7%
Passenger Vessel-9	612	57.96	63.04	8.1%
Passenger Vessel-10	1270	33.68	30.05	-12.1%

Table 13.*Verification of mathematical model with capacity as independent variable for Passenger Ferry*

Sample Ship	Capacity (GT)	Attained EEDI	Required EEDI	Difference
Passenger Ferry-1	981	59.3	52.17	-13.7%
Passenger Ferry-2	856	92.2	69.47	-32.7%
Passenger Ferry-3	858	94.1	69.13	-36.1%
Passenger Ferry-4	956	71.4	55.08	-29.6%
Passenger Ferry-5	956	73.5	55.08	-33.4%
Passenger Ferry-6	960	70.4	54.6	-28.9%
Passenger Ferry-7	806	70.6	78.8	10.4%
Passenger Ferry-8	750	79.9	91.7	12.9%
Passenger Ferry-9	659	93.1	120.3	22.6%
Passenger Ferry-10	620	98.3	136.7	28.1%

Table 14.*Verificaation of mathematical model with capacity as independent variable for Sand Carrier*

Sample Ship	Capacity (DWT)	Attained EEDI	Required EEDI	Difference
Sand Carrier-1	108	135	139.5	3.2%
Sand Carrier-2	28	326	313.9	-3.9%
Sand Carrier-3	32	300	287.4	-4.4%
Sand Carrier-4	39	251	254.6	1.4%
Sand Carrier-5	37	281	262.8	-6.9%
Sand Carrier-6	54	197	210.2	6.3%
Sand Carrier-7	37	259	262.8	1.4%
Sand Carrier-8	70	171	180.1	5.1%
Sand Carrier-9	37	266	262.8	-1.2%
Sand Carrier-10	38	250	261.7	4.5%

It has been observed from Table 10 to 14 that, the difference is within the permitted range [30] between reference line value and actual EEDI value, so this reference lines formula can provide a reference for EEDI calculation of inland waterway vessels of Bangladesh. It has been also observed from Table 13 that the difference between attained EEDI and required EEDI is much higher than other vessels. One of the main reasons would be most of the ferries engine power is much higher than the required one.

Karim & Hasan [40] proposed reference line formula for Passenger Vessel, Cargo Vessel and Oil Tanker of Bangladesh.

Figures 15 to 17 shows the difference between the present and Karim & Hasan's proposed reference line formula for Passenger Vessel, Cargo Vessel and Oil Tanker of Bangladesh.

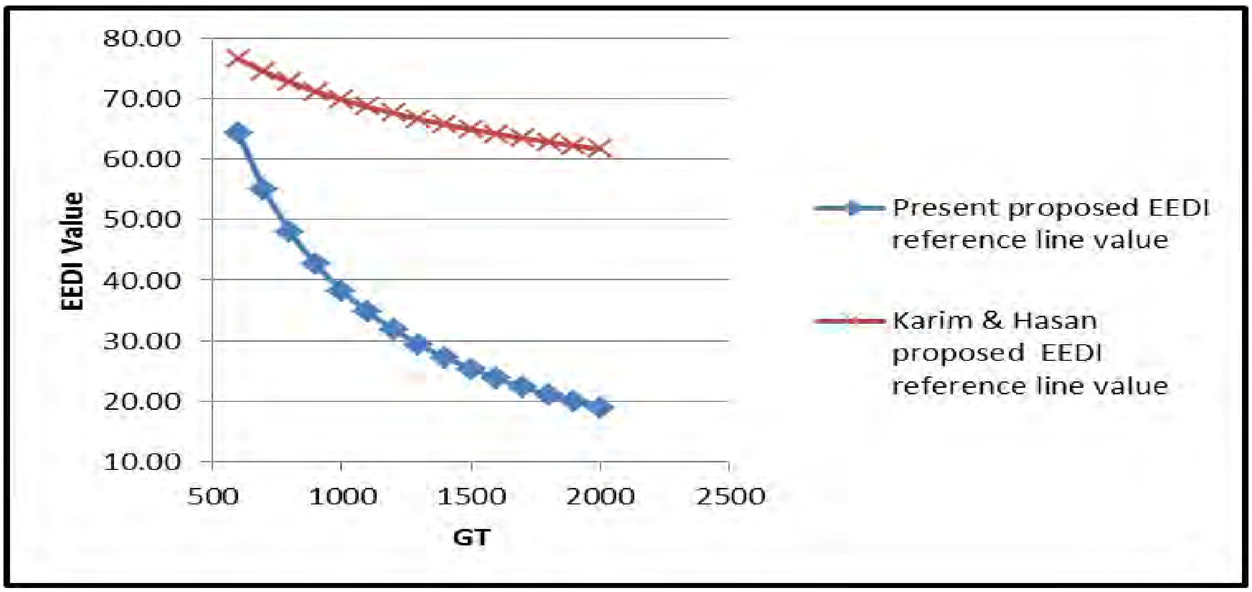


Figure 15*: Difference between present and Karim & Hasan proposed EEDI reference line for Passenger Vessels*

From Figure 15, we have observed that Karim & Hasan proposed EEDI reference line value is higher than present proposed value for Passenger Vessels. One of the main reasons for this difference would be that in this study 90 Passenger Vessels have been taken but Karim et al. took 32 Passenger Vessels in their study. Also the co efficient of regression value in Karim & Hasan's study is lower than present study.

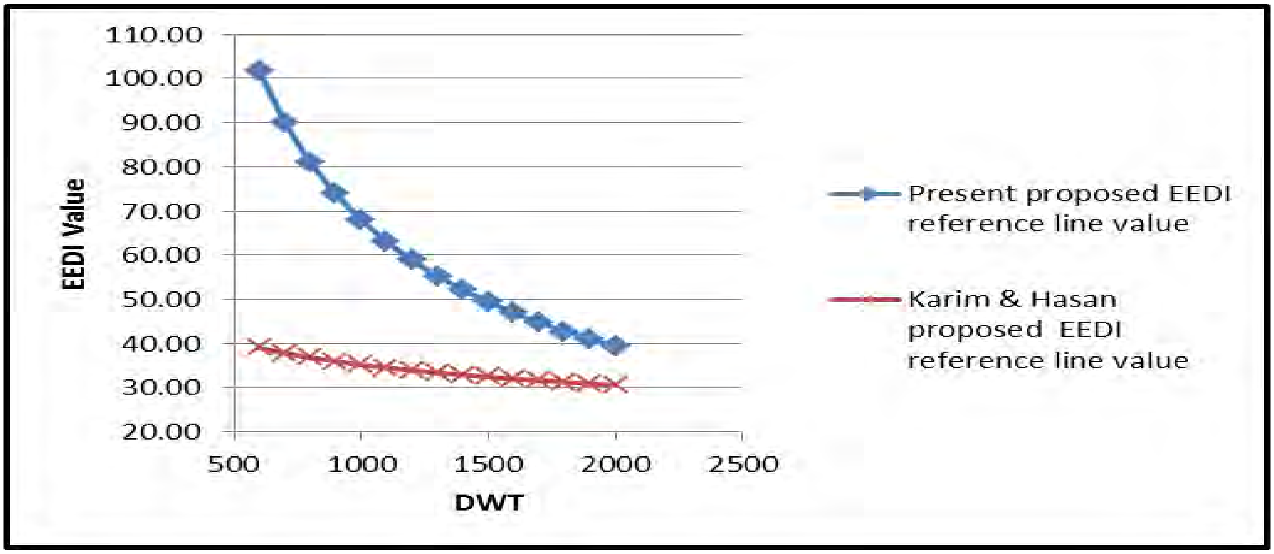


***Figure 16**: Difference between present and Karim & Hasan proposed EEDI reference line for Cargo Vessels*

From Figure 16, we have observed that Karim & Hasan proposed EEDI reference line value is lower than present proposed value for Cargo Vessels. One of the main reasons for this difference would be that in this study 351 Cargo Vessels have been taken but Karim & Hasan took 50 Cargo Vessels in their study.

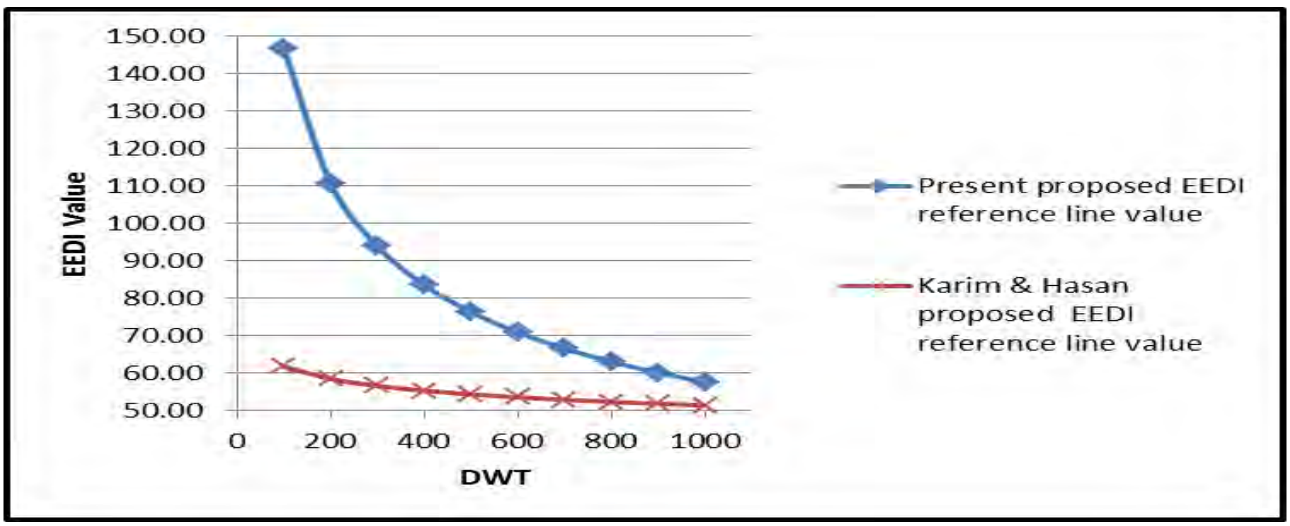


***Figure 17**: Difference between present and Karim & Hasan proposed EEDI reference line for Oil Tankers*

From Figure 17, we have observed that Karim & Hasan proposed EEDI reference line value is lower than present proposed value for Oil Tankers. One of the main reasons for this difference would be that in this study 85 Oil Tankers have been taken but Karim & Hasan took 41 Cargo Vessels in their study. Also the co efficient of regression value in Karim et al. study is lower than present study.

3.2.3 Limitations in current evaluation of EEDI reference line formula

In Bangladesh, based on available data from Department of Shipping (DOS), almost 2000 cargo vessels, 200 oil tankers, 250 passenger vessels, 70 passenger ferries and 3000 sand carriers are plying in inland waterways of Bangladesh. But due to unavailability of correct data it is not possible to use the total vessels in current evaluation of EEDI reference line. Also many of the data are not endorsed in the list correctly which gives more scatter points when reference has been drawn. Also in our calculation specific fuel consumption value 210 g/KWh has been taken. This value has been collected after collected information from Chinese engine manufacturer company. But in old used engines specific fuel consumption values may be different from this value. In this thesis, based on available data, Diesel has been considered for fuel for reference line calculation. But the present condition of fuel that has been used in inland vessels is unknown. This is also one of the limitations in current evaluation of EEDI reference line formula.

3.3 Calculation of IMO evaluated EEDI reference line parameters for different vessels

EEDI formula calculates the CO_2 emission efficiency of a vessel at the design stage in terms of grams of CO_2 emitted per tonne-nautical miles (gCO_2/tonnenm). In order to implement CO_2 emission regulations in a step by step manner, making emission criteria rigorous over time; IMO first developed the EEDI baseline from the data collected for existing ships using Lloyd's Register Fairplay database (IMO, Dec 2009). These baselines are developed for each category of the ship, differentiated by IMO as bulk carrier, gas carrier, tanker, container ship, general cargo ship, refrigerated cargo carrier, and combination carrier (IMO, Jul 2011). The EEDI reference lines refer to statistically average EEDI curves derived from data for existing ships The Secretariat commissioned IHS Fairplay to use their data to calculate the EEDI reference line parameters for relevant ship types in accordance with the draft guidelines for calculation of reference lines for use with the EEDI. The IMO evaluated EEDI reference line parameters for the different ship types are given below in Table 15.

Table 15. *Parameters for determination of reference line values calculated using a minimum ship size of 400 GT[1]*

Ship type	Ship size	Parameters		R^2	Population	Excluded
		a	c			
Bulk Carrier	≥400 GT	961.79	0.477	0.9289	2512	16
Gas tanker	≥400 GT	1120.00	0.456	0.9446	354	0
Tanker	≥400 GT	1218.80	0.488	0.9574	3655	14
Container ship	≥400 GT	186.52	0.200	0.6191	2406	32
General cargo ship	≥400 GT	107.48	0.216	0.3344	2086	47
Refrigerated cargo carrier	≥400 GT	227.01	0.244	0.5130	61	1
Combination carrier	≥400 GT	1219.00	0.488	0.9575	6	0

3.4 Comparison between IMO evaluated and formulated baseline equations

In Figures 18 and 19, a comparison has been done between IMO evaluated and formulated baseline equations for general cargo vessel and oil tanker. IMO evaluated EEDI formula is mainly for sea going vessels and for those vessels whose GT above 400. But in inland waterways vessels under GT 400 will be found.

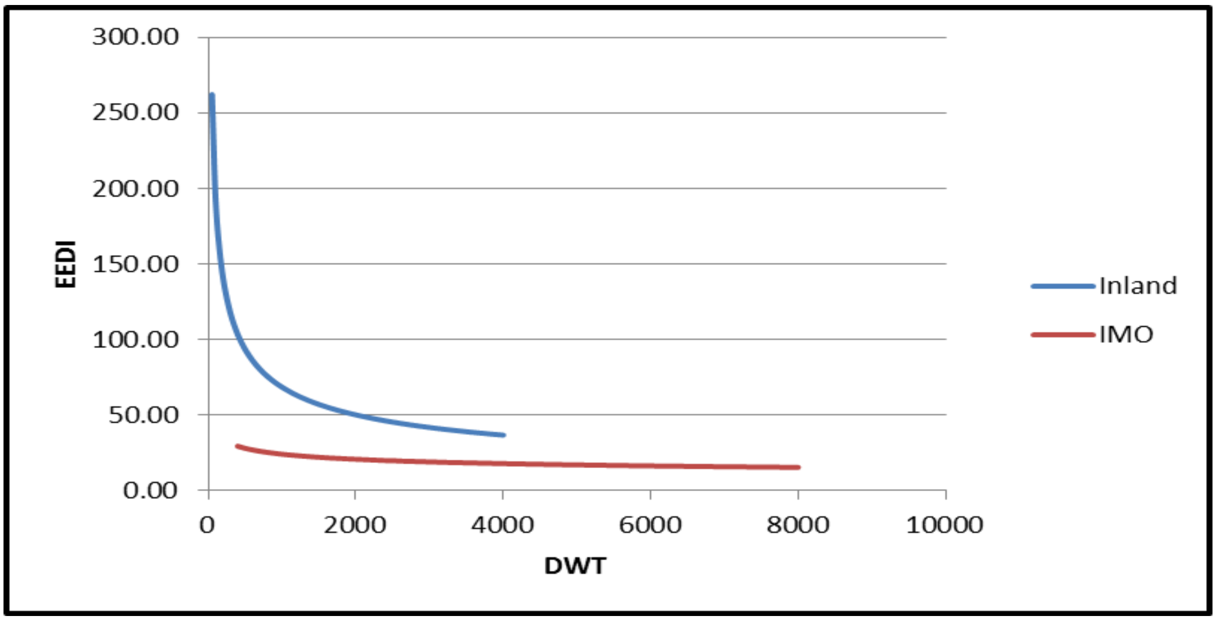


Figure 18: *IMO evaluated Vs formulated EEDI for Cargo Vessel*

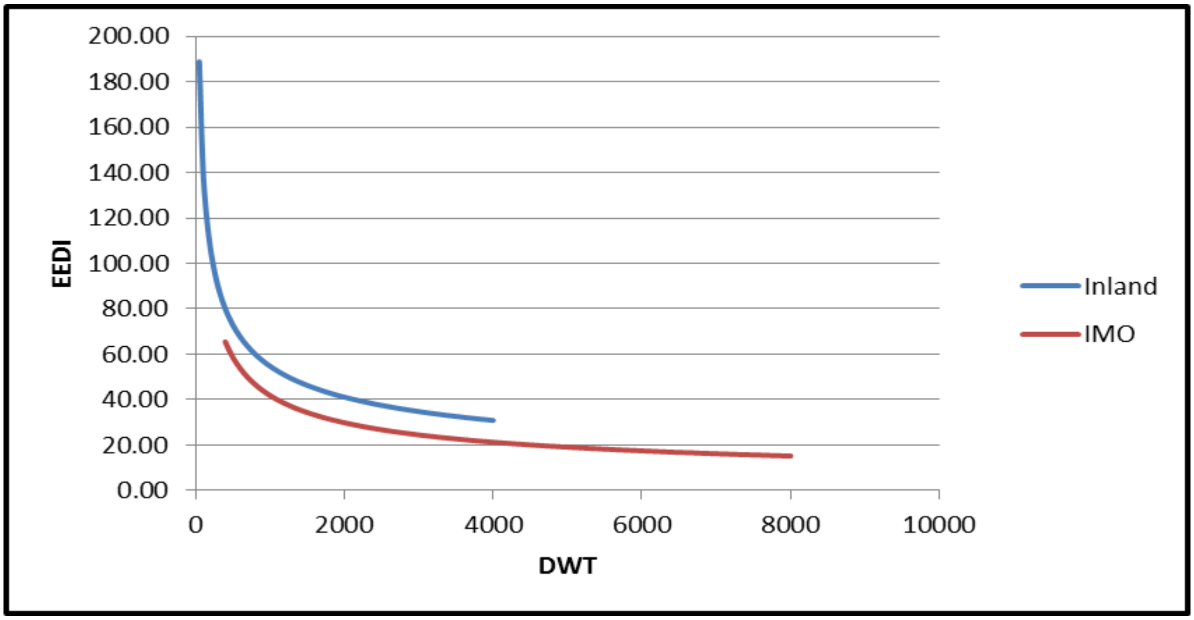


Figure 19: *IMO evaluated Vs formulated EEDI for Oil Tanker*

From Figures 18 and 19, it has been observed that IMO evaluated baseline equation lies much below than that of formulated one. One of the reason behind this is engine selection is inappropriate of most of the inland waterway vessels in Bangladesh. Another reason behind this is inland vessels needs to overcome geographical barriers like river depth, width, shallow water effects etc.

3.5 Comparison between various countries inland vessels EEDI reference lines

European countries have for a long time been concerned about the actual energy efficiency of ship designs, well before it was considered as a way to mitigate CO_2 emissions. The Netherlands Ministry of Transport, Public Works and Water Management are deeply involved in the development of the EEDI. Supported by maritime experts, the Dutch delegation contributes to the preparation of legislation in the regular and intersessional meetings of MEPC working group on green house gas emissions from ships. To gain insight into the effects of the EEDI on the Dutch fleet, the Ministry of Transport, Public Works and Water Management has tasked the foundation Centre for Maritime Technology and Innovation (CMTI) with this study. The main task in that study was to determine the EEDI values for ships within the Netherlands fleet and ships designed and built in the Netherlands between 1978 and 2008 [31]. Furthermore, in 2nd Session of Intersessional Meeting of the greenhouse gas working group in 4 th February, 2009, energy efficiency design index baselines was submitted by Denmark [41]. In this study Denmark & Netherlands formulated EEDI reference lines have been compared with the EEDI reference line of Bangladesh.

In Figures 20 and 21, a comparison has been done between various countries inland vessels EEDI reference lines for Cargo Vessel and Oil Tanker.

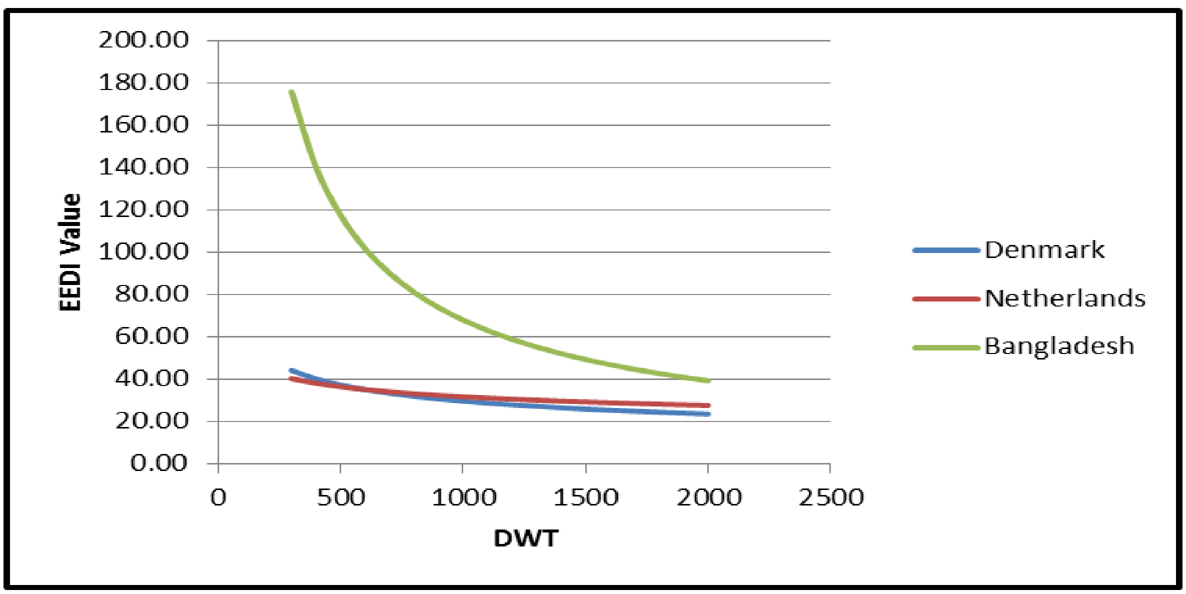


Figure 20: *Various countries inland vessels EEDI reference lines for Cargo Vessel*

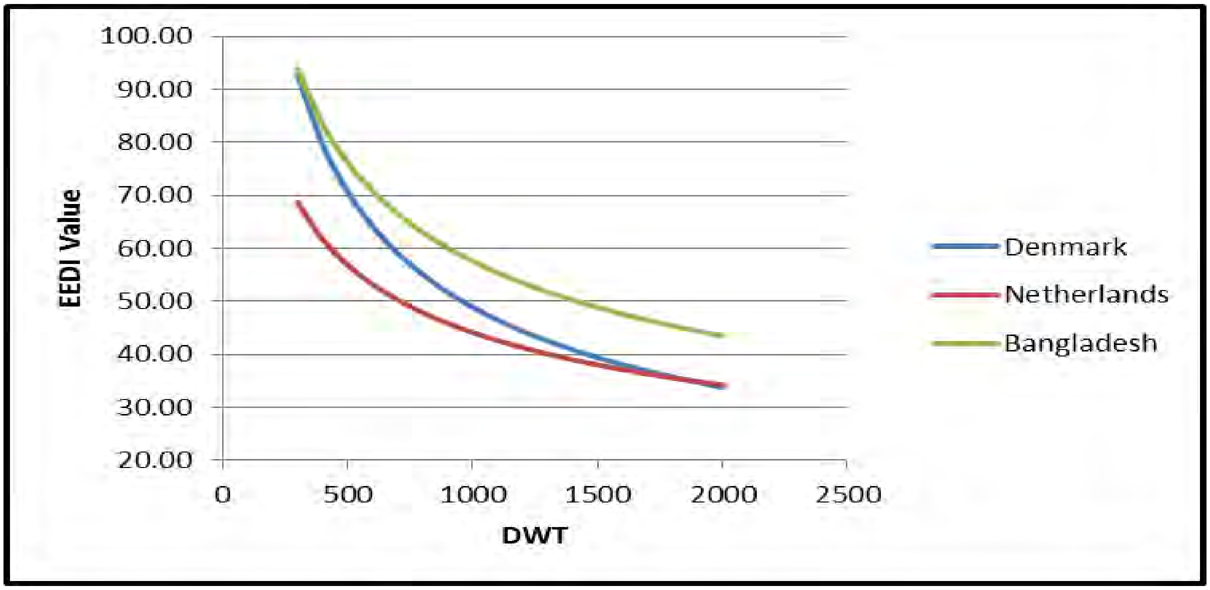


Figure 21: *Various countries inland vessels EEDI reference lines for Oil Tanker*

From Figures 20 and 21, it has been observed that EEDI reference lines for cargo vessels & oil tanker of Bangladesh lies much above than Denmark and Netherlands. For example, a 1000 DWT oil tanker is designed for Denmark should have required EEDI value 48.88 gmCO_2/tonne.mile. whereas for Netherlands the required EEDI value will be 44.09 gm CO_2/tonne.mile and for Bangladesh the required EEDI value will be 57.56 gmCO_2/tonne.mile. One of the main reasons behind this is inappropriate engine selections and inaccurate hull parameters selection that leads to higher EEDI value. Is has been also observed that the difference of EEDI reference line for oil tanker is much less than cargo vessel in Bangladesh with respect to Denmark and Netherlands. One of the reasons would be recently most of the oil tankers have been built in Bangladesh to follow the design rules but the same has not been followed for cargo vessels.

Chapter-4

Parametric Study

4.1 Influence of design parameters on the Energy Efficiency Design Index

In order to improve EEDI, lots of efforts have to be given at design stage. A vessel has to be design so that it's minimum resistance will achieve. Most of the inland vessels of Bangladesh do not follow these rules because at present there is no regulation on EEDI . Also the price of fuel has been the primary driver for improved efficiency and reduced fuel consumption on commercial ships. The highly competitive nature of the maritime industries meant that efforts to bring down fuel consumption were cost effective solutions, leading to overall optimization of the transport system. For assessing this situation, this thesis has conducted a study which investigates the robustness of the EEDI by evaluating a parametric series of designs for four different inland ship types: general cargo ships, oil tanker, passenger vessels, passenger ferries & sand carriers in Bangladesh. Based on the present situation of inland vessels the relative impact of ship's draft, type of fuel block coefficient, specific fuel consumption and main power on EEDI have also been analyzed. The purpose of this chapter is to show the guidelines to improve EEDI by changing vessels principal parameters at design stage.

4.1.1 Influence of ship's draft on the Energy Efficiency Design Index

In this study, ship's draft has been increased by keeping displacement same and changing all other parameters. In Figures 22 to 24, Attained EEDI Vs draft graph has been shown for Oil tanker, Ferry and Sand carrier.

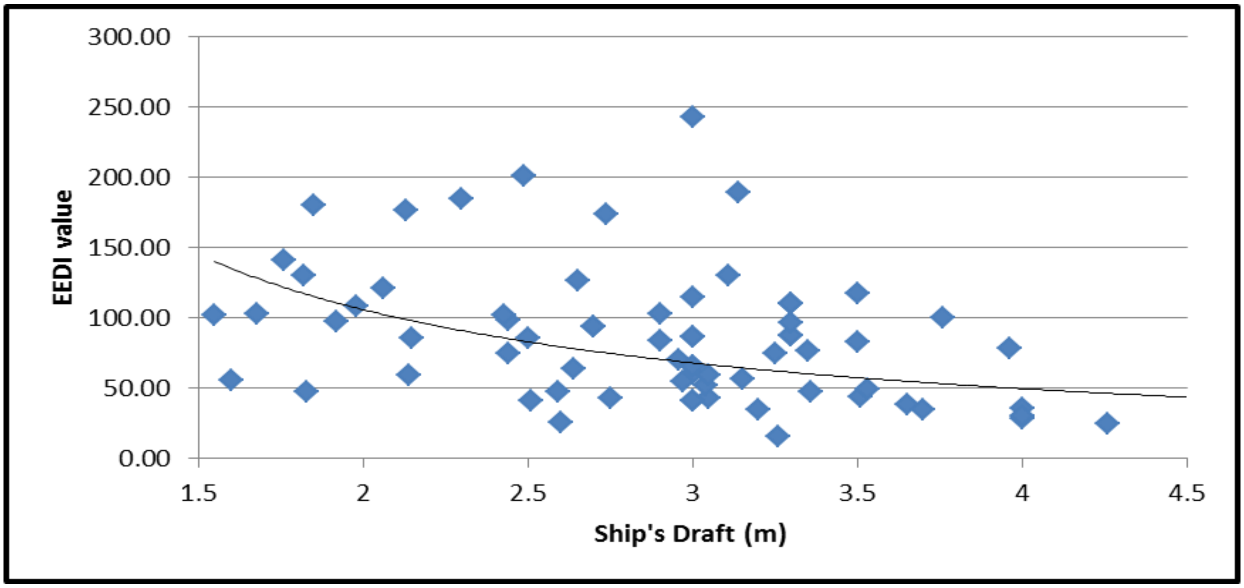


Figure 22: *EEDI Vs ship's draft for Oil Tanker*

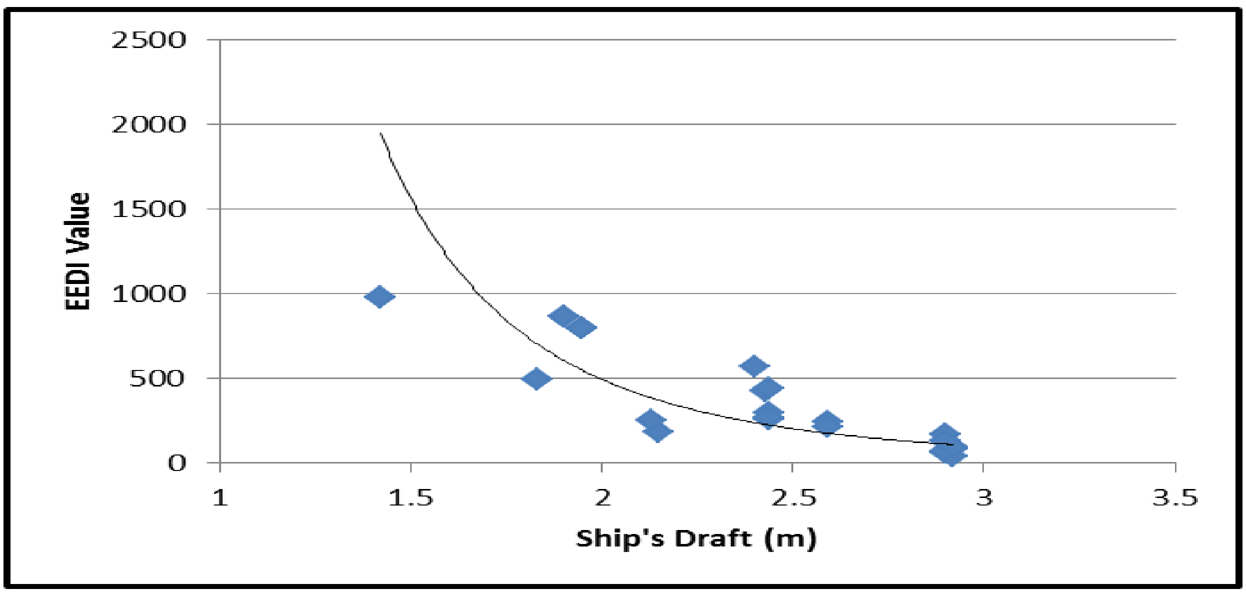


Figure 23: *EEDI Vs ship's draft for Ferry*

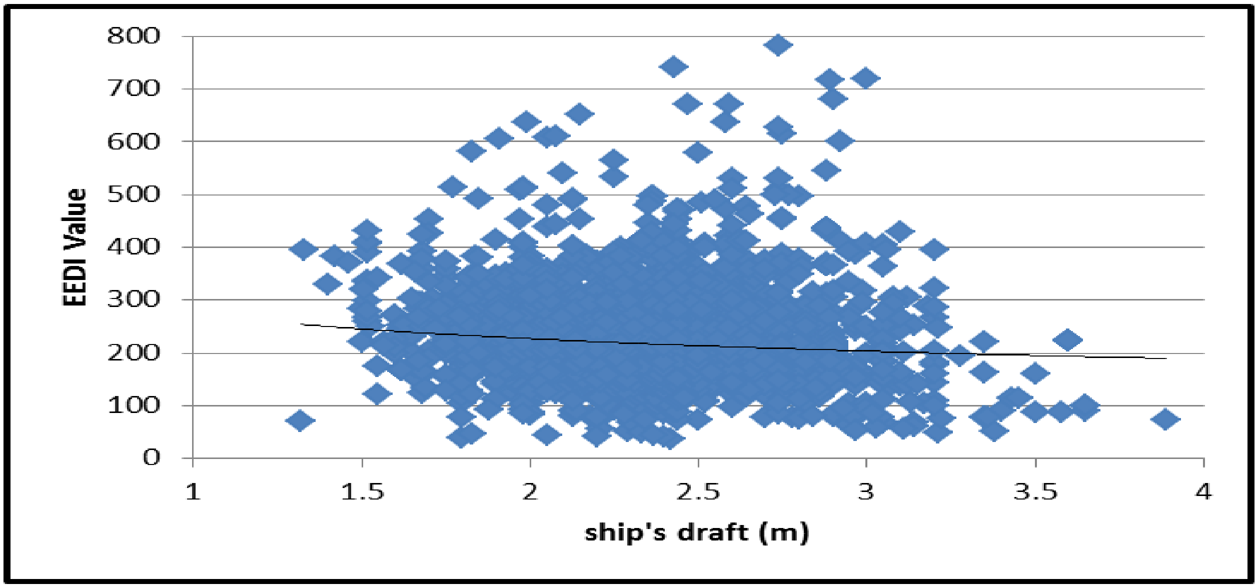


Figure 24: *EEDI Vs ship's draft for Sand Carrier*

From Figures 22 to 24, it has been observed that attained EEDI are decreasing with increases of ship's Draft. Thus, increasing ship's draft can significantly reduce the EEDI. But while doing this kind of optimization it should be kept in mind that change in draft may have huge impact on inland ships.

4.1.2 Influence of ship's main engine power on the Energy Efficiency Design Index

With the high cost of fuel and the regulatory efforts to reduce harmful emissions, it is important that the engines operate in as efficient manner as practical. Enhanced efficiency can be achieved via new equipment and systems or by improved operating procedures. This analysis is focused on propulsion and auxiliary power systems driven by diesel engines, since this is the most common solution employed on ships. Diesel propulsion for commercial oceangoing ships is primarily low-speed diesel engines (RPM less than 400 and crosshead type construction) and medium-speed diesel engines (RPM 400 to 1,400 and trunk piston construction). Smaller ships, tugs, ferries and high-speed craft can have high-speed diesel engines (RPM over 1,400). The EEDI is particularly sensitive to the service speed, as the required power increases by roughly the cube of the variation in service speed. When assessing the powering requirements in Bangladesh, Nigbo CSI engine (mostly used in inland ships) has selected for such scenario. The engine is assumed to be de-rated to the power required to attain the design speed with the main engine operating at 75% MCR. The smaller engines associated with the slower service speeds may have higher rpm's. The propulsive coefficient is reduced at the higher rpm which somewhat mitigates the benefits of the lower service speed. The installed power is a dominant factor in the EEDI formulation. This parameter is mainly determined by the design speed and the efficiency of hull and propulsion. This study has been performed on the basis of present status of inland vessels of Bangladesh.

In Figures 25 to 27, Attained EEDI Vs P_{ME} graph has been shown for Cargo Vessel, Ferry and Sand Carrier.

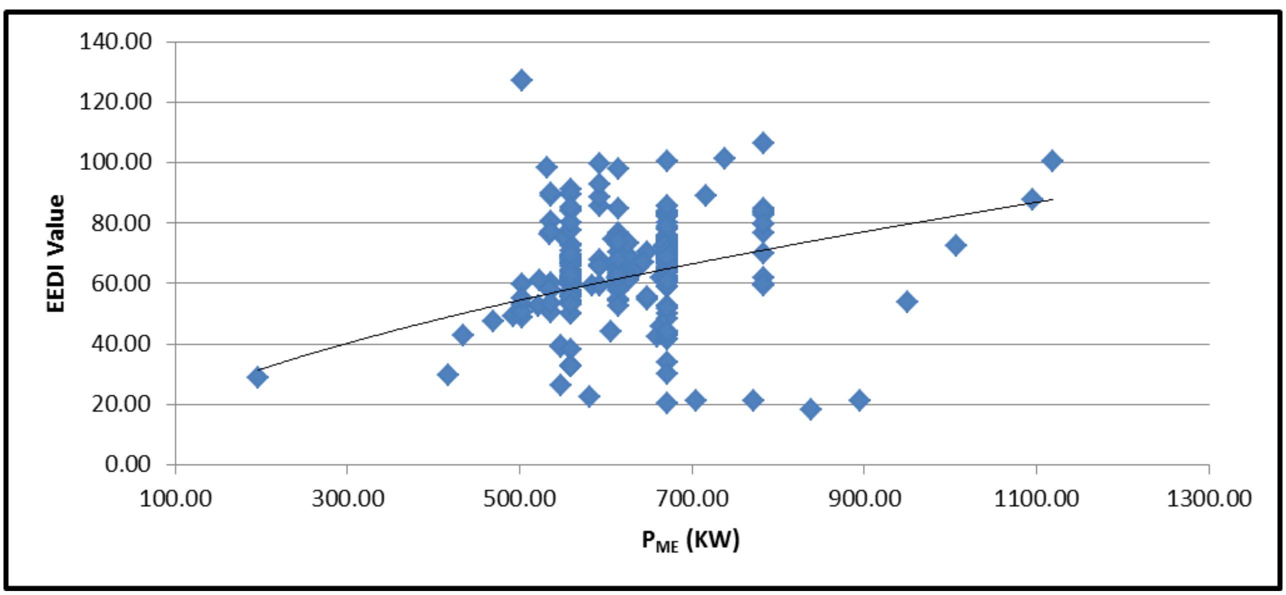


***Figure 25**: EEDI Vs ship's P_{ME} for Cargo Vessel*

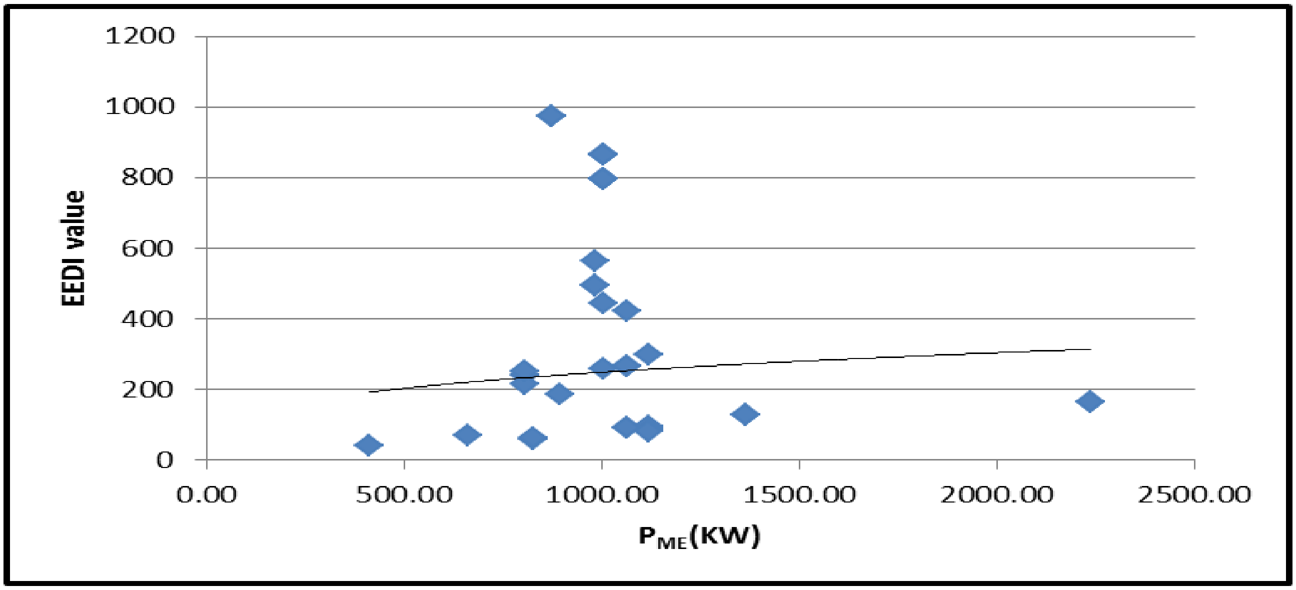


Figure 26: *EEDI Vs ship's P_{ME} for Ferry*

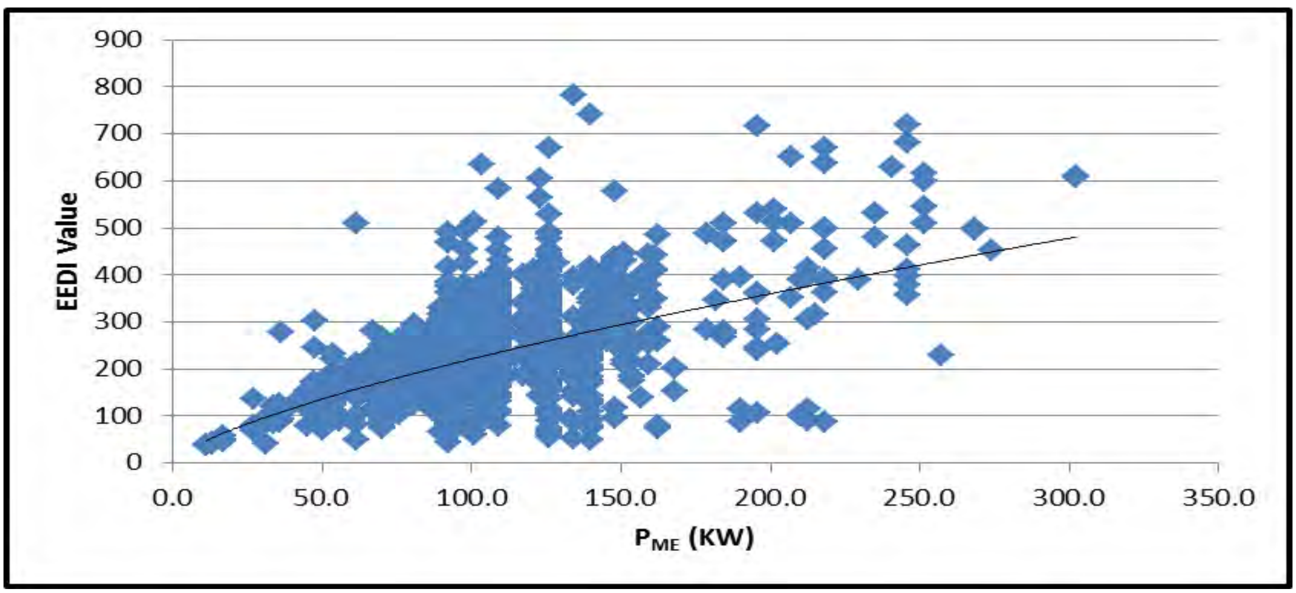


Figure 27: *EEDI Vs ship's P_{ME} for Sand Carrier*

In Figures 25 to 27, the relation between installed engine power and EEDI has shown. In Bangladesh, most of the inland general cargo vessels engine power is around range 500 to 700 KW, the engine power of most of passenger ferry is about

1000 KW and majority of oil tanker's engine power is around 600 KW whereas most of the passenger vessels engine power is around range 600 to 1200 KW & for sand carrier the engine power is about range 50 to 250 KW. It has been also observed from above figure that EEDI increases with the increases of P_{ME}.

4.1.3 Influence of block coefficient on the Energy Efficiency Design Index

In this thesis work, four different types of vessels design has evaluated over a range of block coefficients, from Cb = 0.70 to Cb = 0.85. For this analysis, input parameters including design speed, displacement and the summer load line draft have been kept constant. As Cb is reduced, the capacity is reduced as well as the required power. At the lower block coefficients, the construction cost is reduced, primarily due to reduced powering requirements. The reduced powering requirements also result in a significant reduction in fuel consumption for the voyage. For example, a 800 DWT oil tanker when it's block coefficient will be 0.85 then EEDI value will be 108.12 gm CO_2/tonne.mile but when it's block coefficient will be 0.7 then EEDI value will be 90.85 gmCO_2/tonne.mile.

In Figures 28 to 32, influence of Cb on EEDI has been shown for Cargo Vessel, Oil Tanker, Passenger Vessel, Ferry and Sand Carrier.

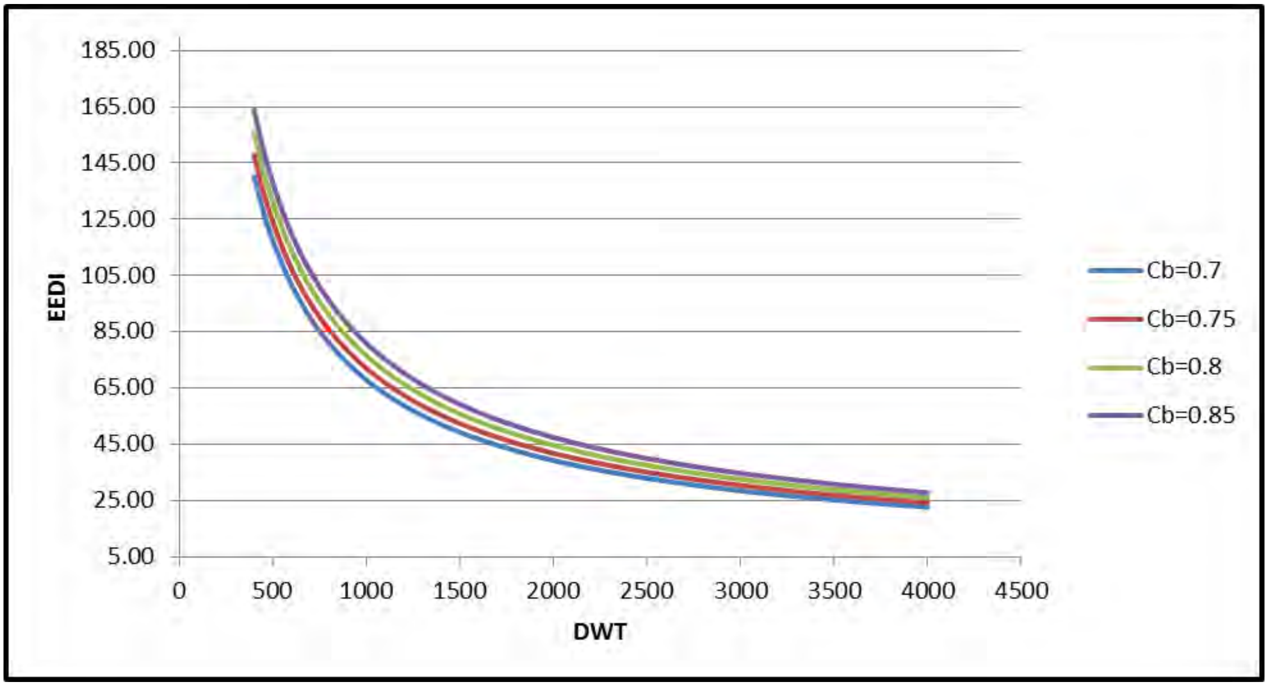


***Figure 28**: Effect of Cb on EEDI for Cargo Vessel*

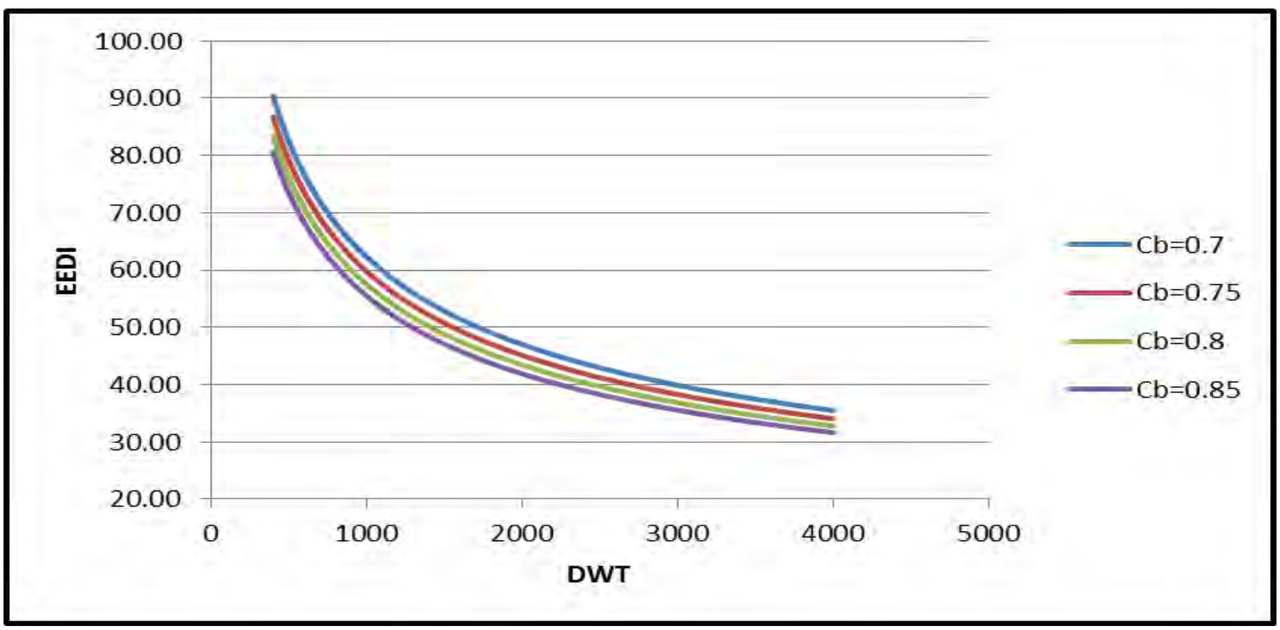


***Figure 29**: Effect of Cb on EEDI for Oil Tanker*

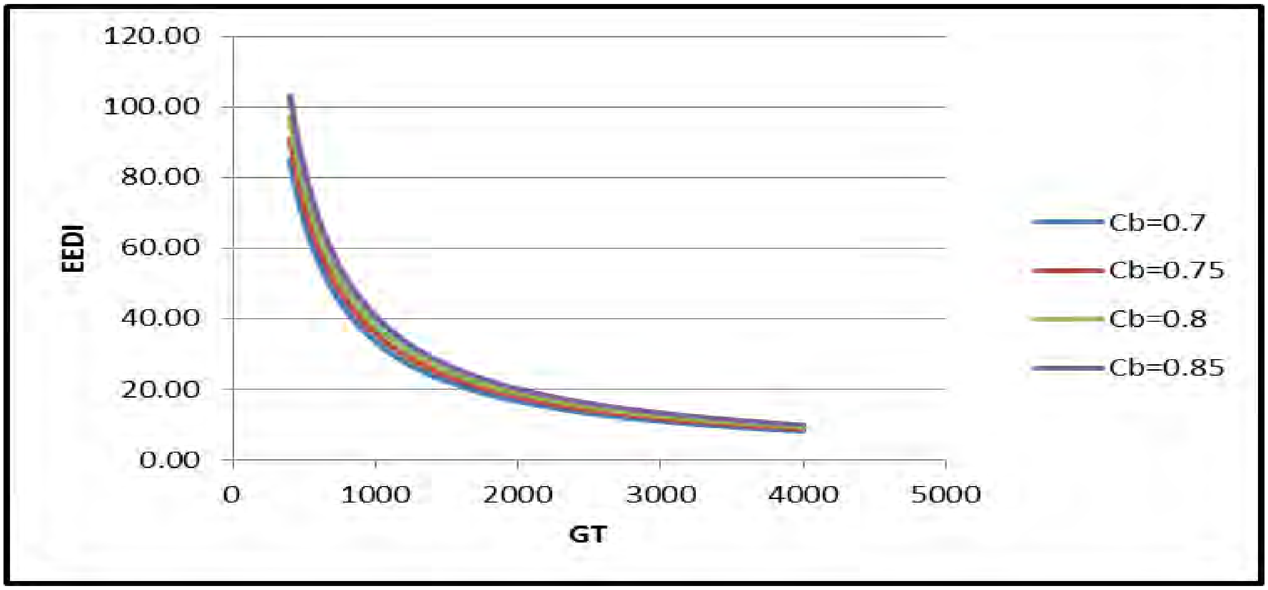


Figure 30*: Effect of Cb on EEDI for Passenger Vessel*

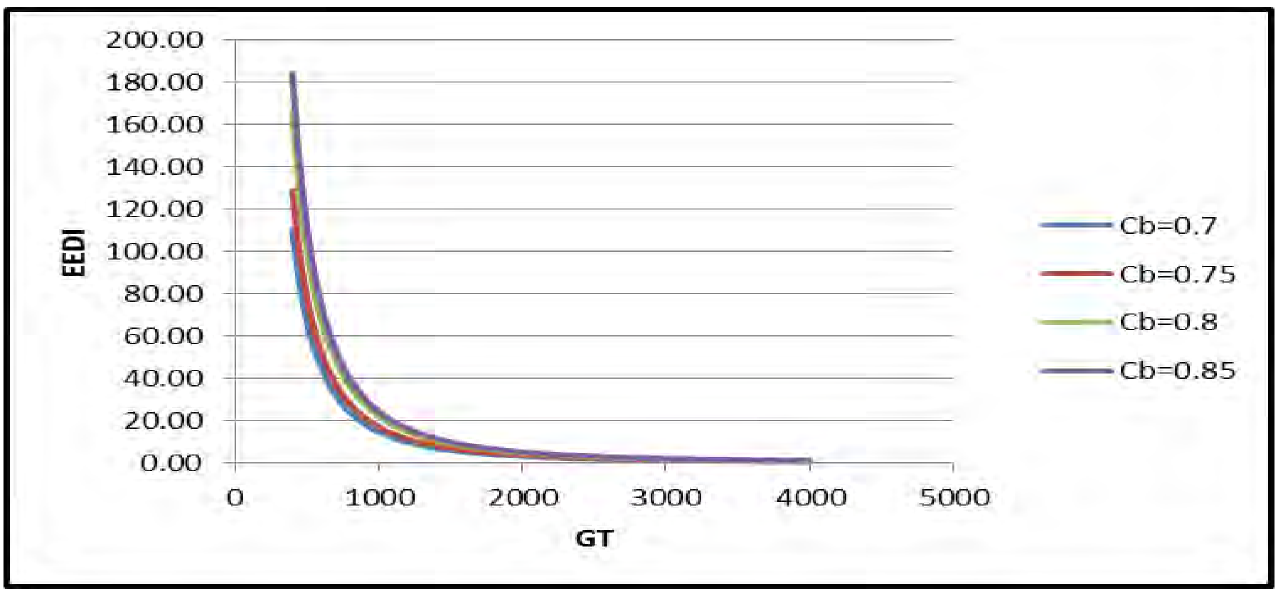


Figure 31*: Effect of Cb on EEDI for Ferry*

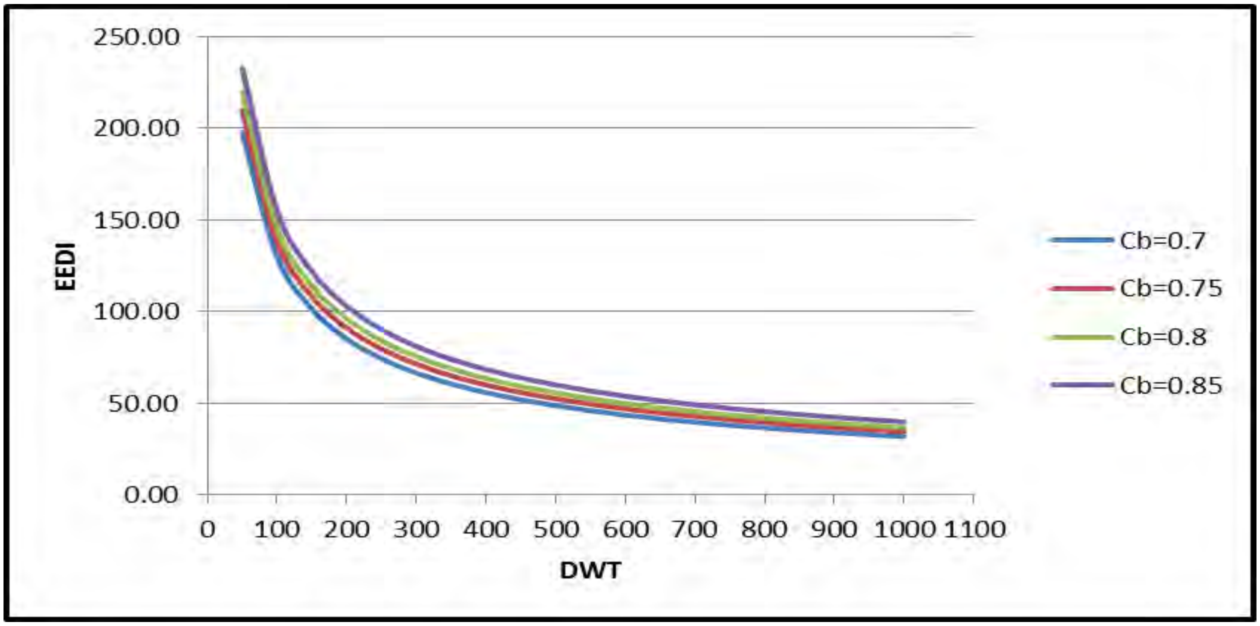


***Figure 32**: Effect of Cb on EEDI for Sand Carrier*

From Figures 28 to 32, it has been observed that EEDI decreases with decreases of block coefficient. So that means lower the block coefficient lower the EEDI. It has also been observed that the EEDI trend with respect to Capacity follows the same for General Cargo Vessel, oil tanker, passenger vessel, passenger ferry & sand carrier.

4.1.4 Influence of specific fuel consumption on the Energy Efficiency Design Index

As evident from the EEDI formula, lower the specific fuel consumption (sfc) of the engine, lower would be the main engine emissions component of the formula and thus lower EEDI value. This means lowering the sfc of the main engine can be a good option to meet the EEDI regulations without affecting the design speed, deadweight and operation pattern of the ship. SFC of an engine depends on the engine efficiency. Higher the engine efficiency, lower would be the sfc. In this study four different types of Marine diesel engines (Nigbo CSI, Weichai, Yanmar & Cummins) are used.

***Table 16**: Specific Fuel Consumption of different marine diesel engines*

Marine Diesel Engine	SFC (Main Engine)(g/KWh)	SFC (Auxiliary Engine)(g/KWh)
Cummins	165	185
Yanmar	190	210
Weichai	200	220
Nigbo CSI	210	230

In Figure 33 to 36, influence of specific fuel consumption on EEDI has been shown for Cargo vessel, Oil tanker, Passenger vessel and Ferry.

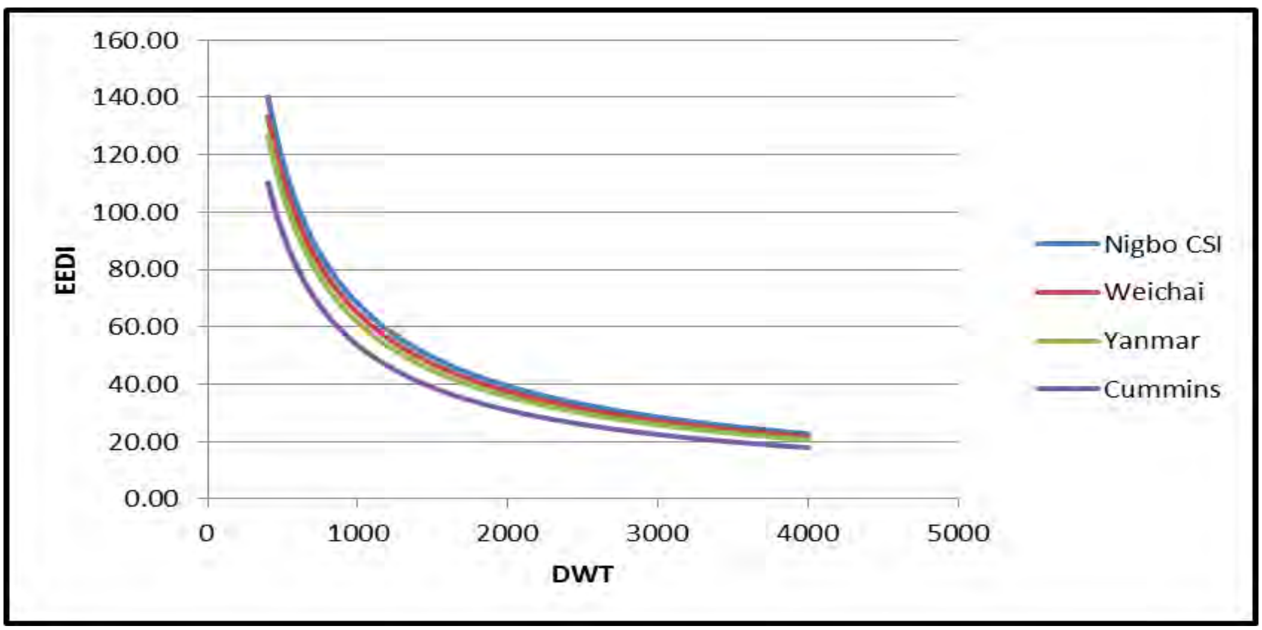


***Figure 33**: Effect of SFC on EEDI for Cargo Vessel*

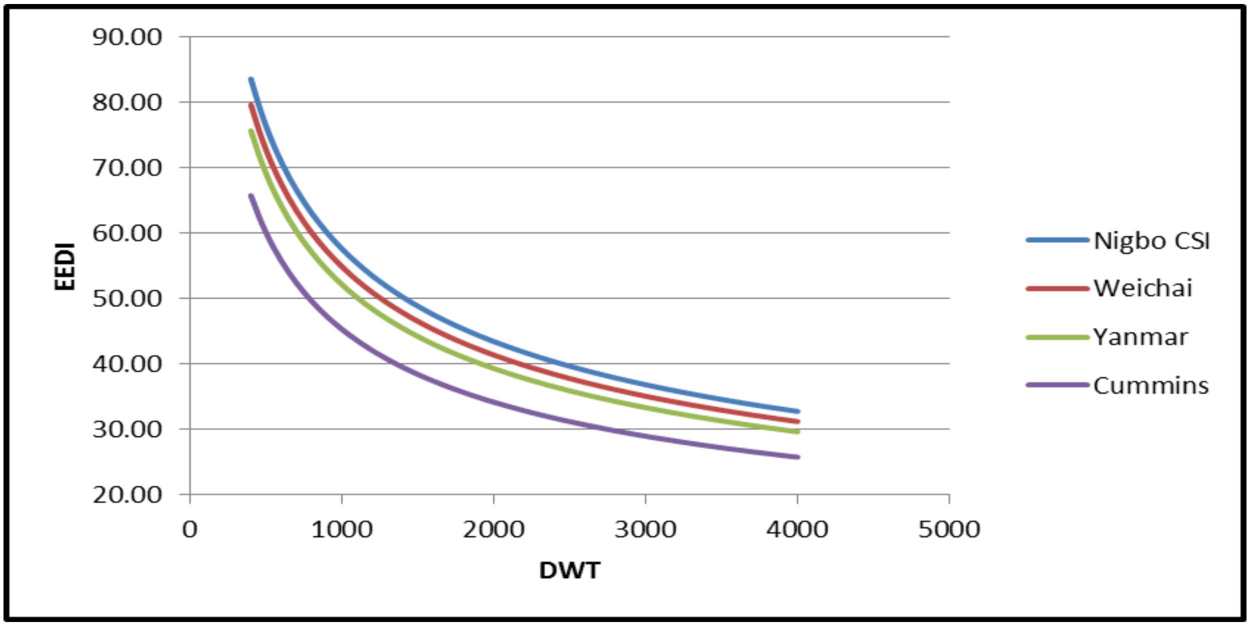


***Figure 34**: Effect of SFC on EEDI for Oil Tanker*

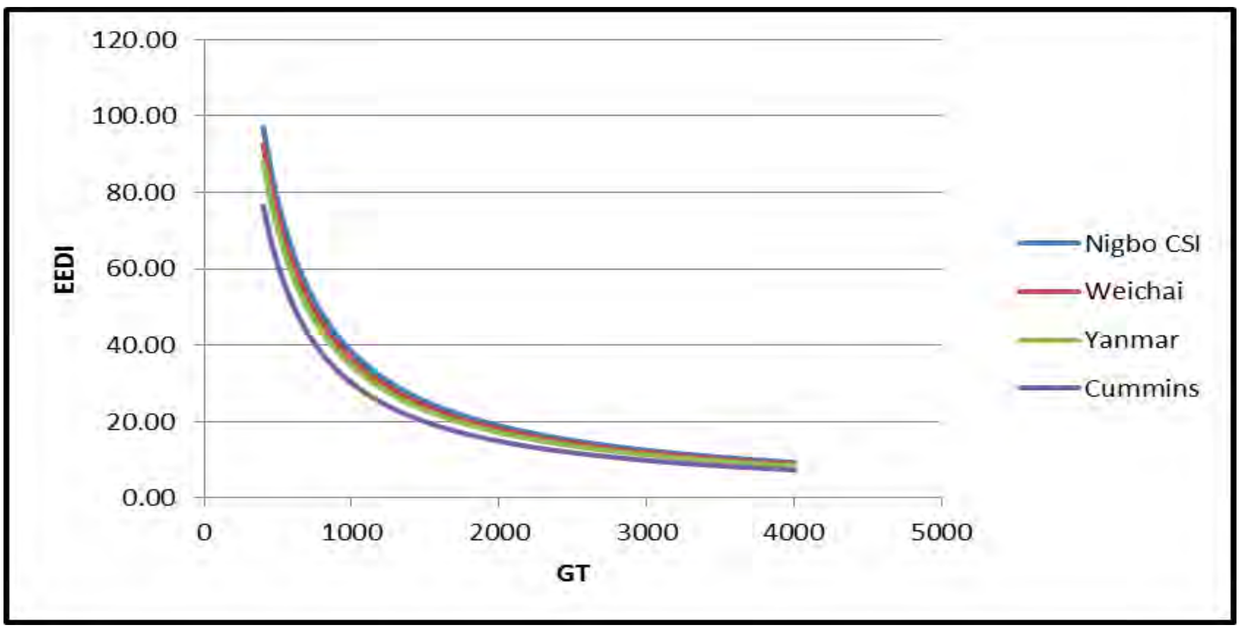


***Figure 35**: Effect of SFC on EEDI for Passenger Vessel*

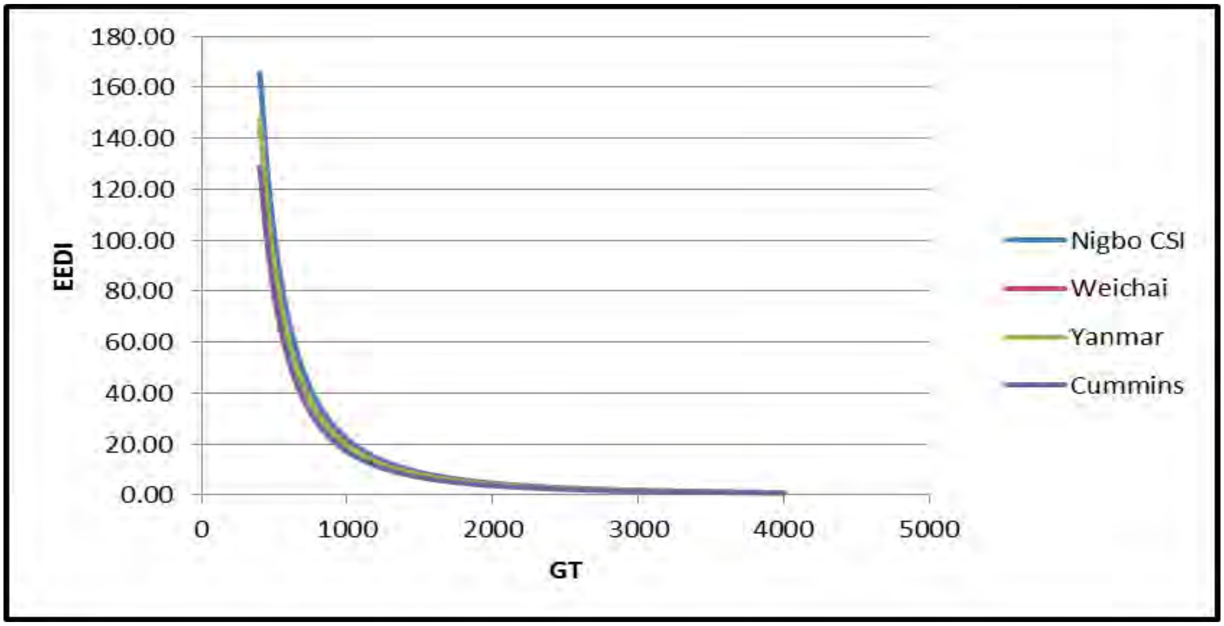


***Figure 36**: Effect of SFC on EEDI for Passenger Ferry*

From the above Figures it has been observed that Nigbo CSI engine has higher EEDI value because of high sfc and Cummins engine has lower EEDI value because of low sfc. So it means that engine with low sfc has low EEDI value. Also it has been observed from Figures 33 to 36, that the EEDI trend with respect to Capacity follows the same for General Cargo Vessel, oil tanker, passenger vessel, passenger ferry & sand carrier. For example, a 1000 DWT cargo vessel when uses Nigbo CSI engine then it's EEDI will be 67.99 gmCO_2/tonne.mile but when uses Cummins engine the EEDI value will be 53.51 gmCO_2/tonne.mile.

4.1.5 Influence of various type of fuel on the Energy Efficiency Design Index

The CO_2 emission is computed from the fuel consumption taking into account the carbon content of the fuel. The conversion factor C_F and the specific fuel consumption, sfc, are determined from the results recorded in the parent engine NOx Technical File. The fuel grade used during the test of the engine in the test bed measurement of sfc determines the value of the C_F conversion factor (Table 3). The use of LNG as an alternative fuel in order to comply with the CO_2 emissions restrictions is an option that is in use on existing vessels and planned for new vessels. Natural gas stored as LNG is the alternative fuel that is considered the most likely option in the short to future because of the available engine and system technology, class/statutory regulations, operational experience, fuel cost and availability of natural gas worldwide. The environmental benefits of using LNG as fuel are significant. Compared to the use of diesel fuel, use of LNG will reduce the NOx emission by approximately 90% on a lean burn gas fuelled engine, and the SOx and particle matters emissions are negligible without the need on any abatement technologies. If LNG will be used as a fuel then the CO_2 emissions are about 20% lower compared to diesel fuel because of the lower carbon content.

In Figure 37 to 40, influence of type of fuel on EEDI has been shown for Cargo vessel, Oil tanker, Passenger vessel and Ferry.

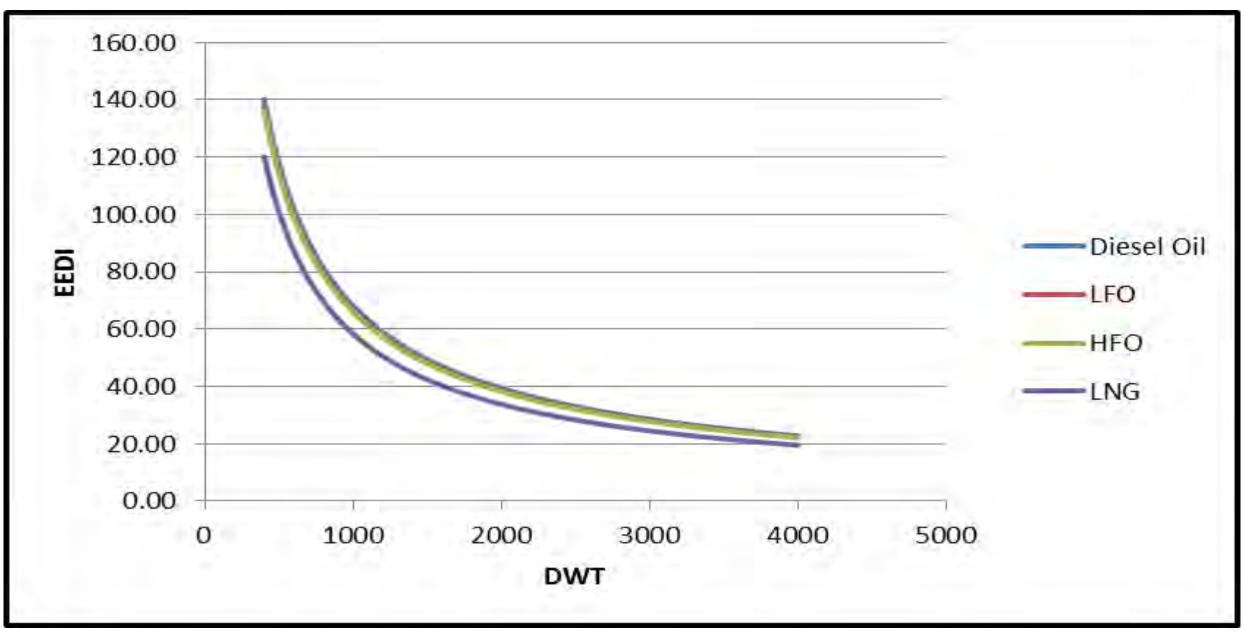


***Figure 37**: EEDI Vs various type of fuel for Cargo Vessel*

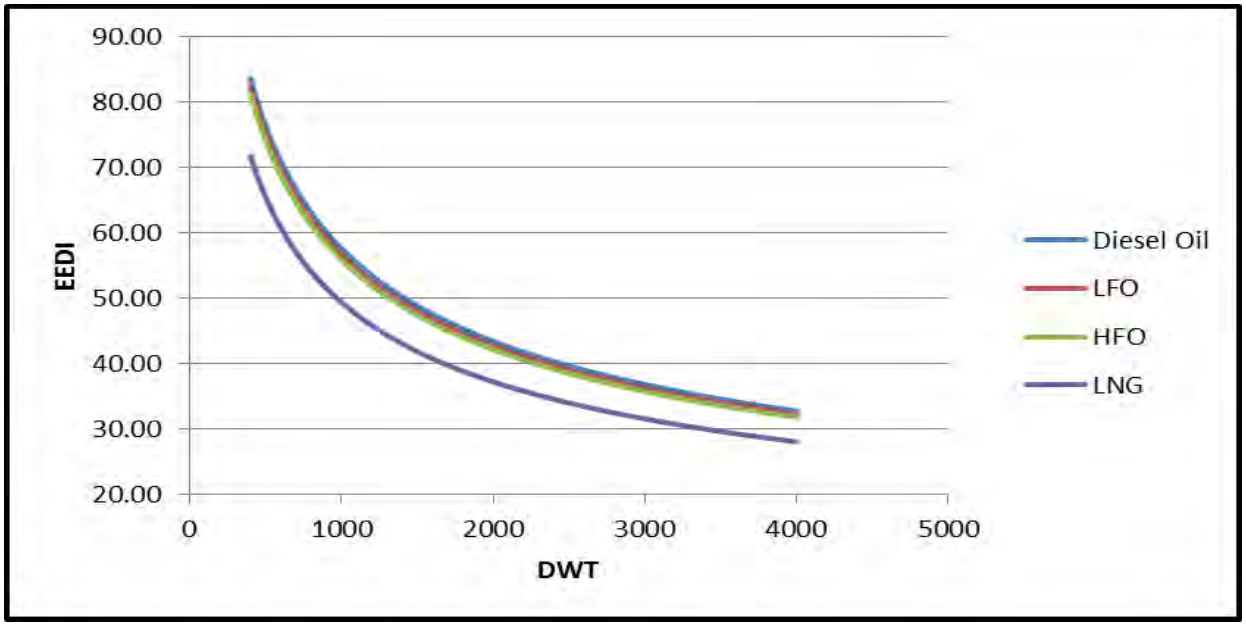


Figure 38*: EEDI Vs various type of fuel for Oil Tanker*

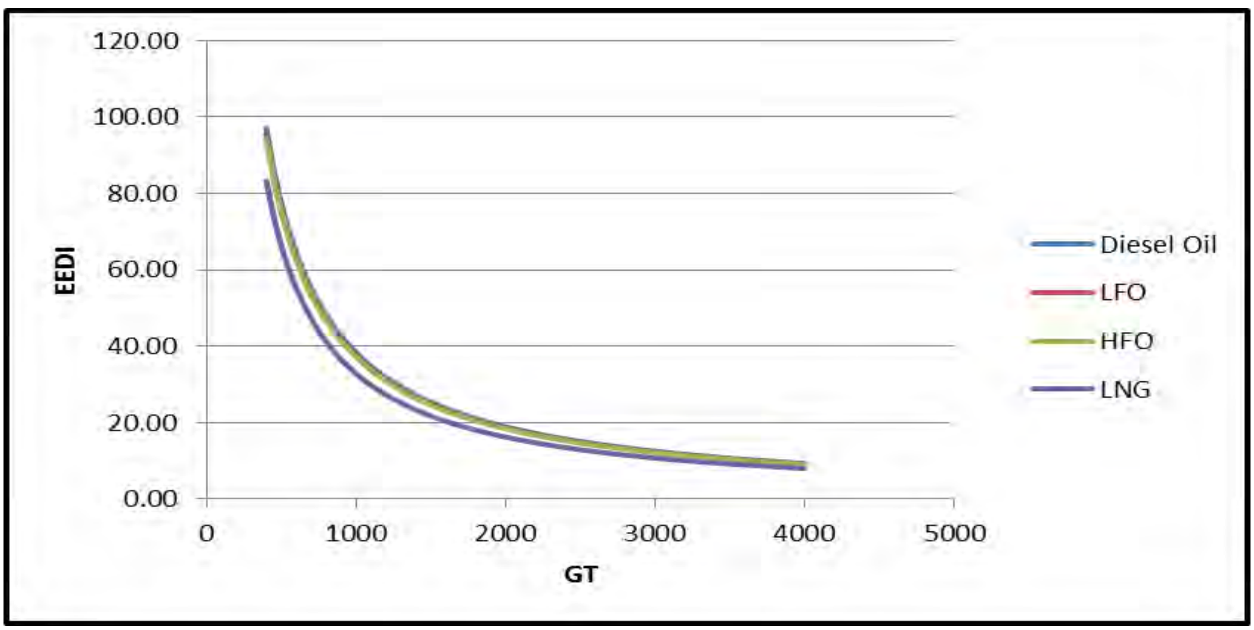


Figure 39*: EEDI Vs various type of fuel for Passenger Vessel*

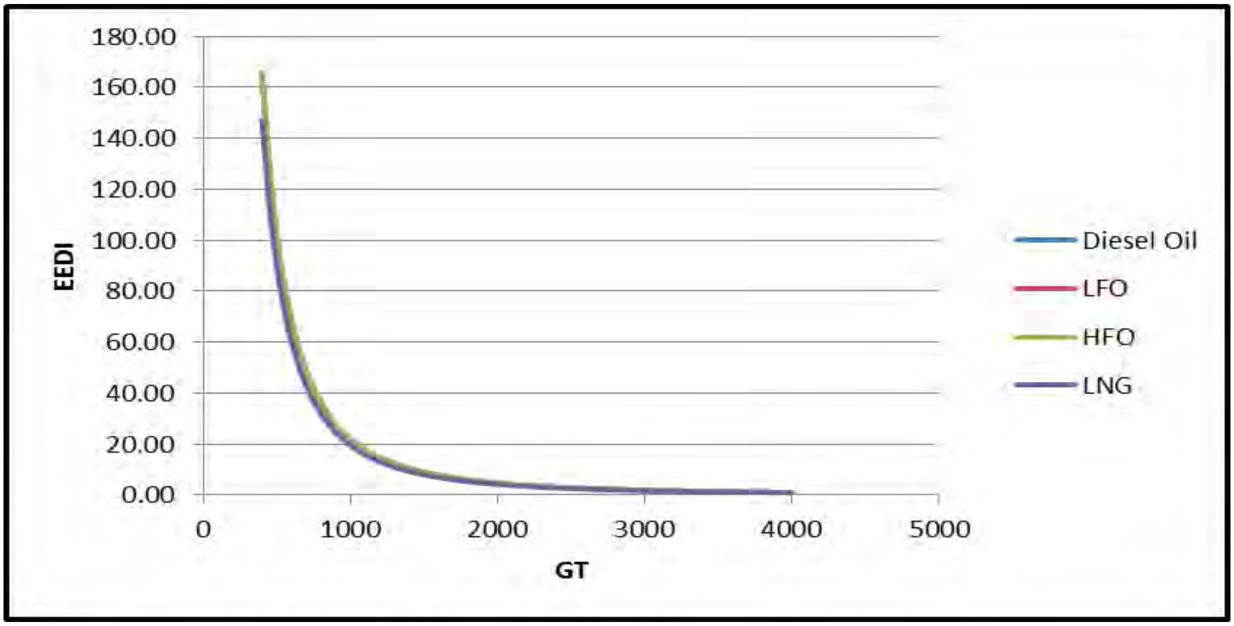


***Figure 40**: EEDI Vs various type of fuel for Ferry*

From Figures 37 to 40, it has been observed that attained EEDI are decreasing with fuel type which has low carbon content. For example, a 1000DWT cargo vessel when uses diesel oil as a main fuel then EEDI will be 67.99gmCO_2/tonne.mile but when uses LNG the EEDI value will be 58.32gmCO_2/tonne.mile. Thus, using of Liquefied Natural Gas (LNG) as main fuel can significantly reduce the EEDI.

Chapter-5

Present status of inland vessels of Bangladesh with respect to EEDI

5.1 Overview

More than four years have been passed since IMO regulations regarding the required energy efficiency of seagoing ships became mandatory. These regulations introduced massive application of already existing technologies, which were neglected without proper incentives, and also initiated development of new solutions for reduction of unnecessary energy dissipation during ship navigation. As it turned out, in some cases even simple (well known) solutions in combination with already existing technologies can provide significant increase of energy efficiency of a ship.

Since inland waterways is an important medium for the communication system of Bangladesh and more than 10,000 inland vessels are plying in the waterways but still there is no regulation of energy efficiency for these vessels. Moreover, the absence of appropriate energy and emissions benchmarks for inland ships is a large impediment to performance improvements of these ships. In this thesis work, a considerable effort has been devoted to this matter; so far there are no suggested benchmarks that could be used for assessment of inland ship efficiency during design stage or for comparison of existing ships with respect to energy and emission efficiency. In this study, Phase 1, 2 & 3 have been applied to assess the present status of inland cargo vessels of Bangladesh. Time period for Phase -1 is from 1st Jan 2015 to 31st Dec 2019, for Phase -2 is from 1st Jan 2020 to 31st Dec 2024 and for Phase -3 is from 1st Jan 2025 to onwards. Phase -1 indicates the reference line value whereas Phase - 2 and 3 will force an EEDI reduction of respectively 20% and 30% relative to the reference line for the ship type.

5.2 Present status of EEDI with respect to vessel's length

Present status on EEDI with respect to vessel's length for Cargo Vessel has been shown in Figure 41.

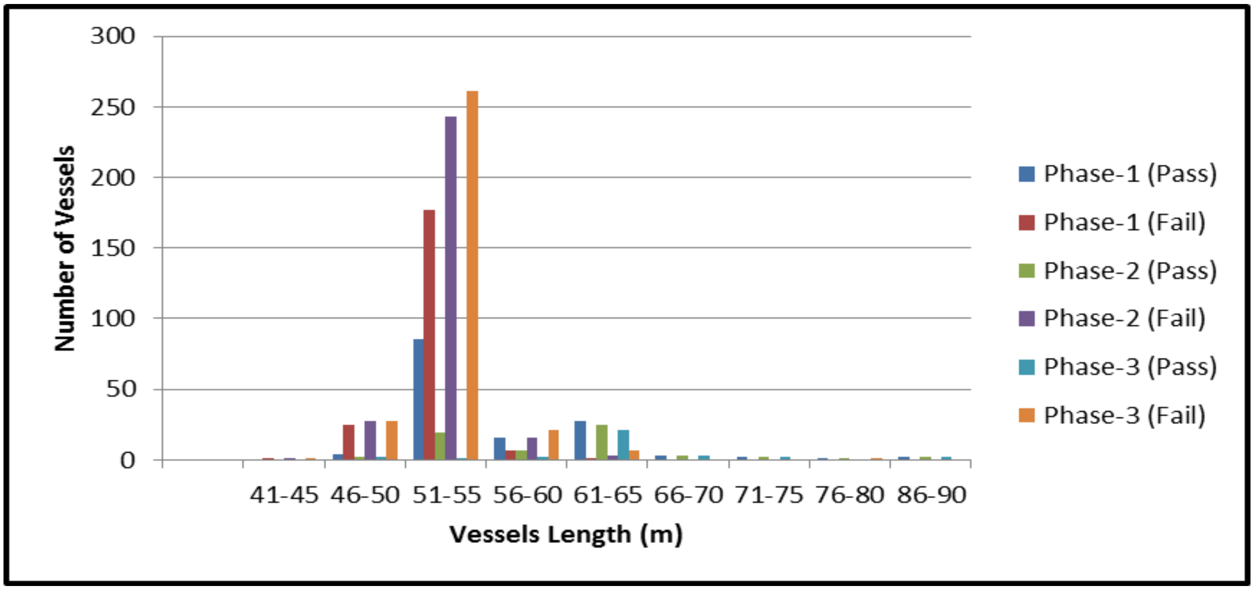


Figure 41: *Present status on EEDI with respect to vessel's length for Cargo Vessel*

From Figure 41, it has been observed that in Bangladesh most of the inland cargo vessels length is between 51to 55m. In this range there are presently 262 vessels out of them 85 vessels pass in terms of EEDI which is 32.5% of the total vessels of that range and the rest of the vessels EEDI exceed the required value in Phase 1. As the phase increases more vessels exceed the required EEDI value. It has been also observed that larger length vessels EEDI lies below the reference line. So we can say that bigger length vessels are more effective in terms of EEDI.

Present status on EEDI with respect to vessel's length for Oil Tanker has been shown in Figure 42.

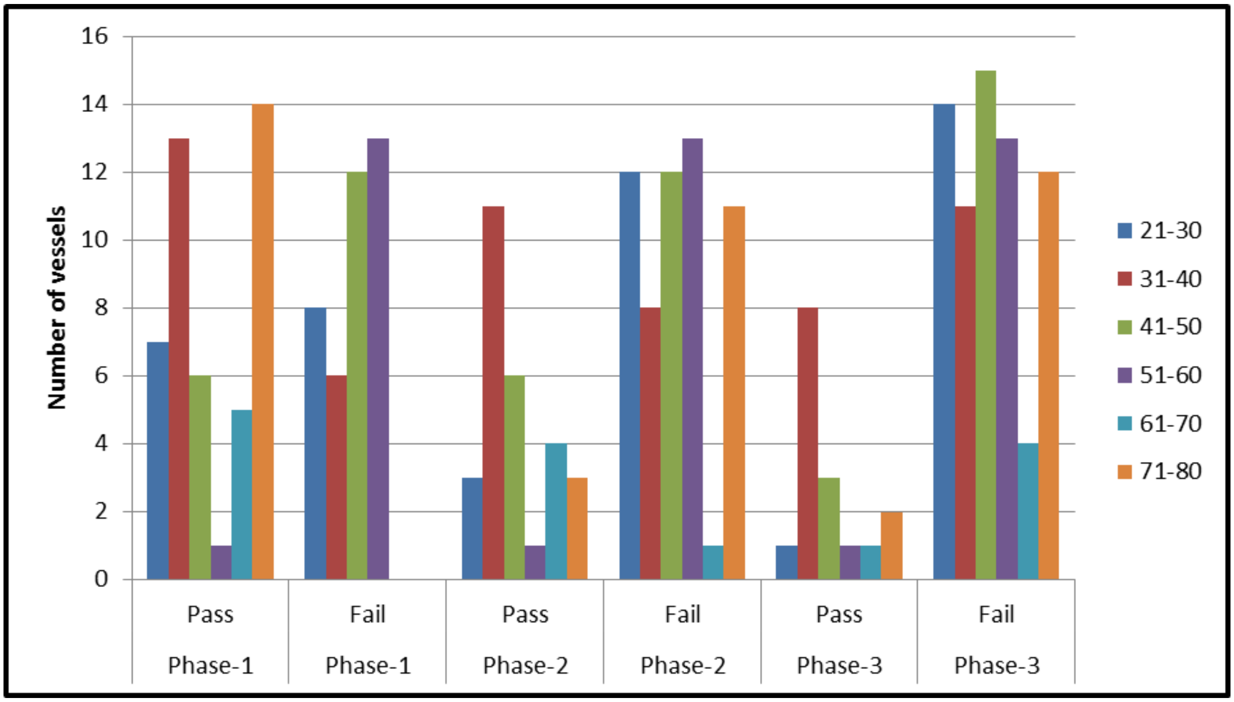


Figure 42: *Present status on EEDI with respect to vessel's length for Oil Tanker*

From Figure 42, it has been observed that in Bangladesh most of the inland Oil Tankers length is between 31to 40m. In this range there are presently 19 vessels out of them 13 vessels pass in terms of EEDI which is 68.4% of the total vessels of that range and the rest of the vessels EEDI exceed the required value in Phase 1. As the phase increases more vessels exceed the required EEDI value. In vessel's length between 51 to 60m, most of the vessels EEDI exceed the reference line. It has been also observed that larger length vessels EEDI lies below the reference line. In this case in vessels length range between 61 to 80m, there is no such vessel which meets EEDI reference line.

Present status on EEDI with respect to vessel's length for Passenger Vessel has been shown in Figure 43.

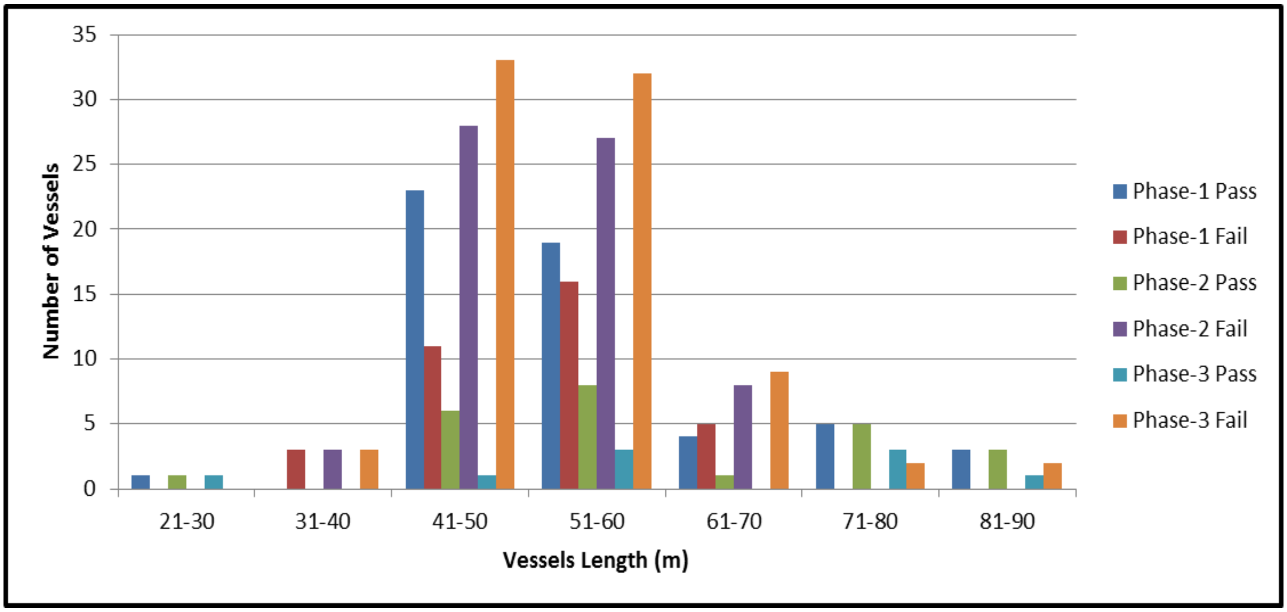


Figure 43: *Present status on EEDI with respect to vessel's length for Passenger Vessel*

From Figure 43, it has been observed that in Bangladesh most of the inland passenger vessels length is between 41to 60m. In this range there are presently 69 vessels out of them 42 vessels pass in terms of EEDI in terms of EEDI which is 60.8% of the total vessels of that range and the rest of the vessels EEDI exceed the required value in Phase 1. It has been also observed that larger length vessels EEDI lies below the reference line. In this case in vessels length range between 71 to 90m, there is no such vessel which meets EEDI reference line.

Present status on EEDI with respect to vessel's length for Passenger Ferry has been shown in Figure 44.

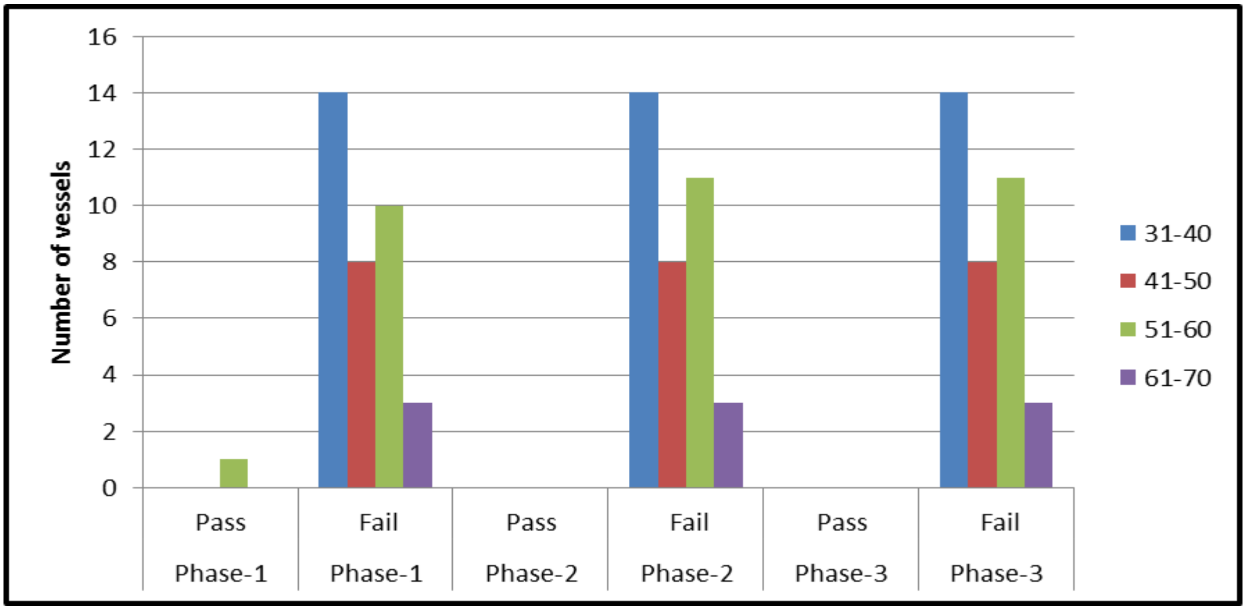


Figure 44: *Present status on EEDI with respect to vessel's length for Passenger Ferry*

From Figure 44, it has been observed that in Bangladesh almost all inland passenger ferries EEDI lies above the reference line.

Present status on EEDI with respect to vessel's length for Sand Carrier has been shown in Figure 45.

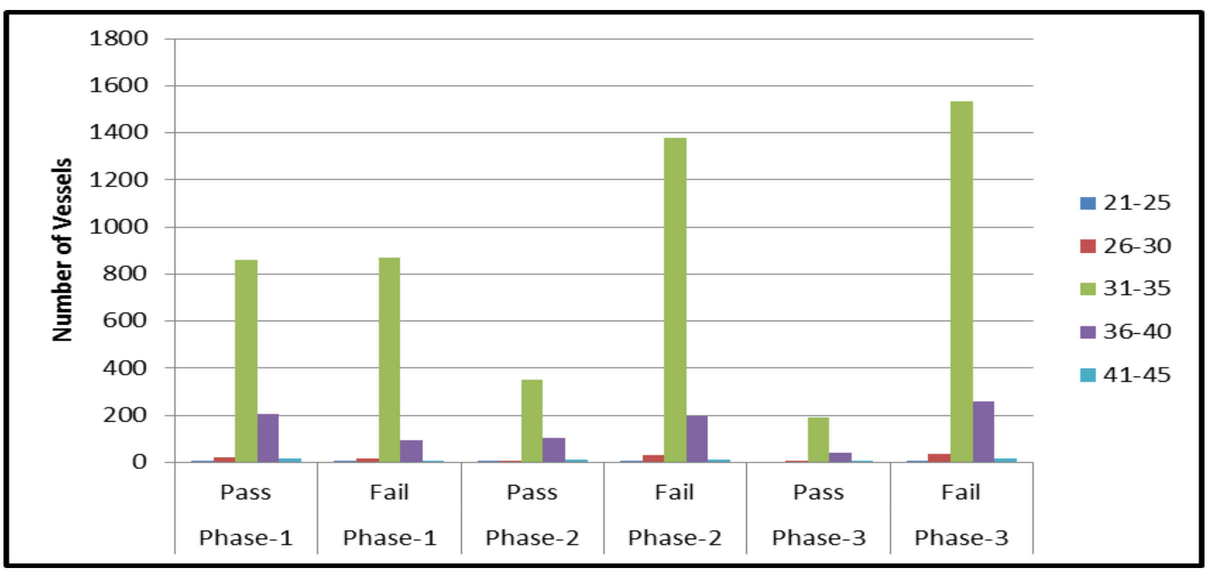


Figure 45: *Present status on EEDI with respect to vessel's length for Sand Carrier*

From Figure 45, it has been observed that in Bangladesh most of the inland sand carrier length is between 31to 35m. In this range there are presently 1729 vessels out of them 860 vessels pass in terms of EEDI which is 49.7% of the total vessels of that range and the rest of the vessels EEDI exceed the required value in Phase 1. It has been also observed that larger length vessels EEDI lies below the reference line. So we can say that bigger length vessels are more effective in terms of EEDI.

Finally, From Figures 41 to 45, it has been observed that with respect to vessel's length, in Phase-1, 40% vessels have been passed in terms of EEDI and 60% vessels have been failed. In Phase-2, 17% vessels have been passed in terms of EEDI and 83% vessels have been failed. In Phase-3, 9% vessels have been passed and 91% vessels have been failed.

5.3 Present status of EEDI with respect to vessel's capacity

Present status on EEDI with respect to vessel's capacity for Cargo Vessel has been shown in Figure 46.

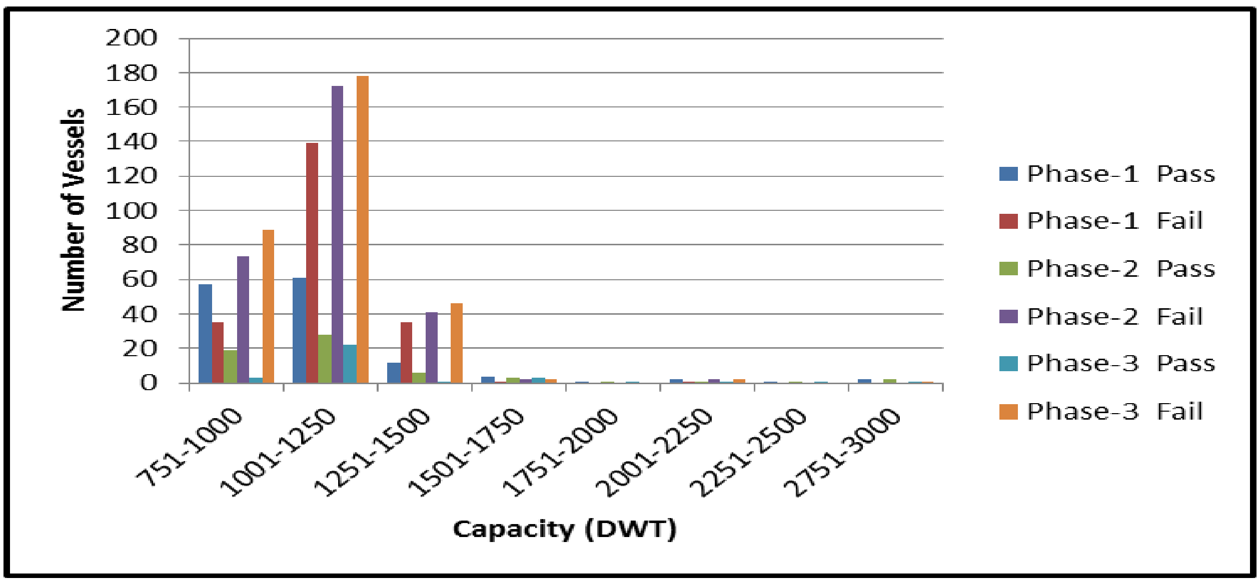


Figure 46: *Present status on EEDI with respect to vessel's capacity for Cargo Vessel*

From Figure 46, it has been observed that in Bangladesh most of the inland cargo vessels capacity is between 1001to 1250T. In this range there are presently 200 vessels out of them 61 vessels pass in terms of EEDI which is 30.5% of the total vessels of that range and the rest of the vessels EEDI exceed the required value in Phase 1. As the phase increases more vessels exceed the required EEDI value.

Present status on EEDI with respect to vessel's capacity for Oil Tanker has been shown in Figure 47.

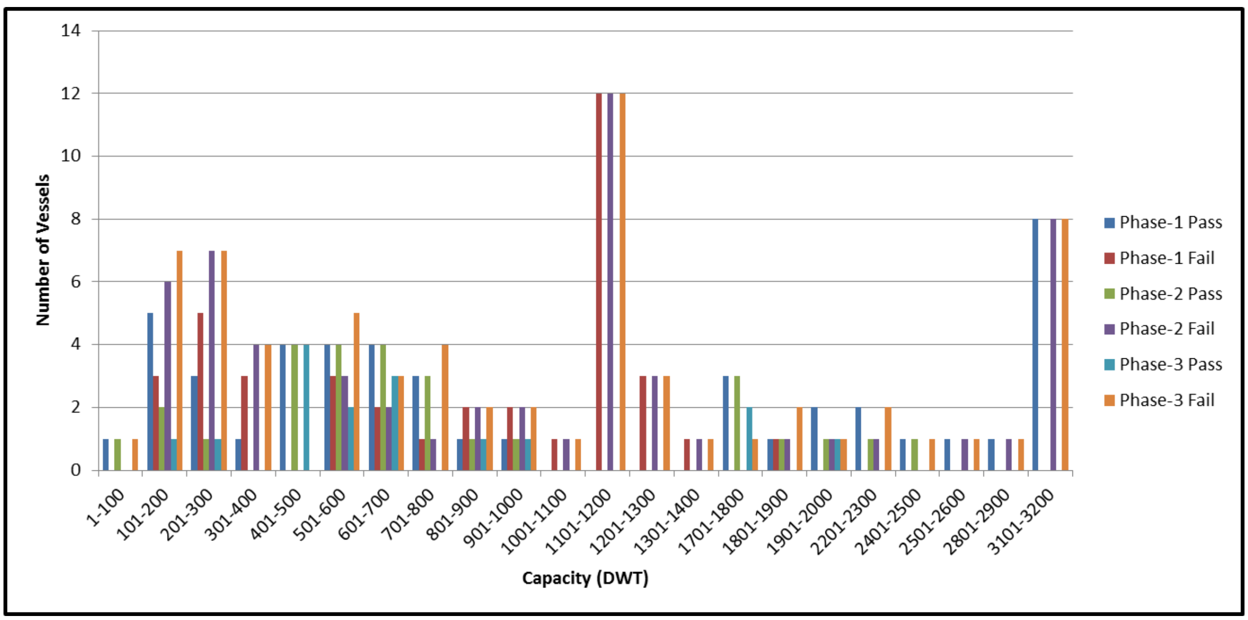


Figure 47: *Present status on EEDI with respect to vessel's capacity for Oil Tanker*

From Figure 47, it has been observed that in Bangladesh most of the inland oil tankers capacity is between 1101to 1200T. In this range there are presently 12 vessels out of them all vessels EEDI exceed the required value which is 100% of the total vessels of that range. It has been also observed that larger capacity vessels EEDI lies below the reference line. In this case in vessels capacity range between 1901 to 3200 T, there is no such vessel which meets EEDI reference line.

Present status on EEDI with respect to vessel's capacity for Passenger Vessel has been shown in Figure 48.

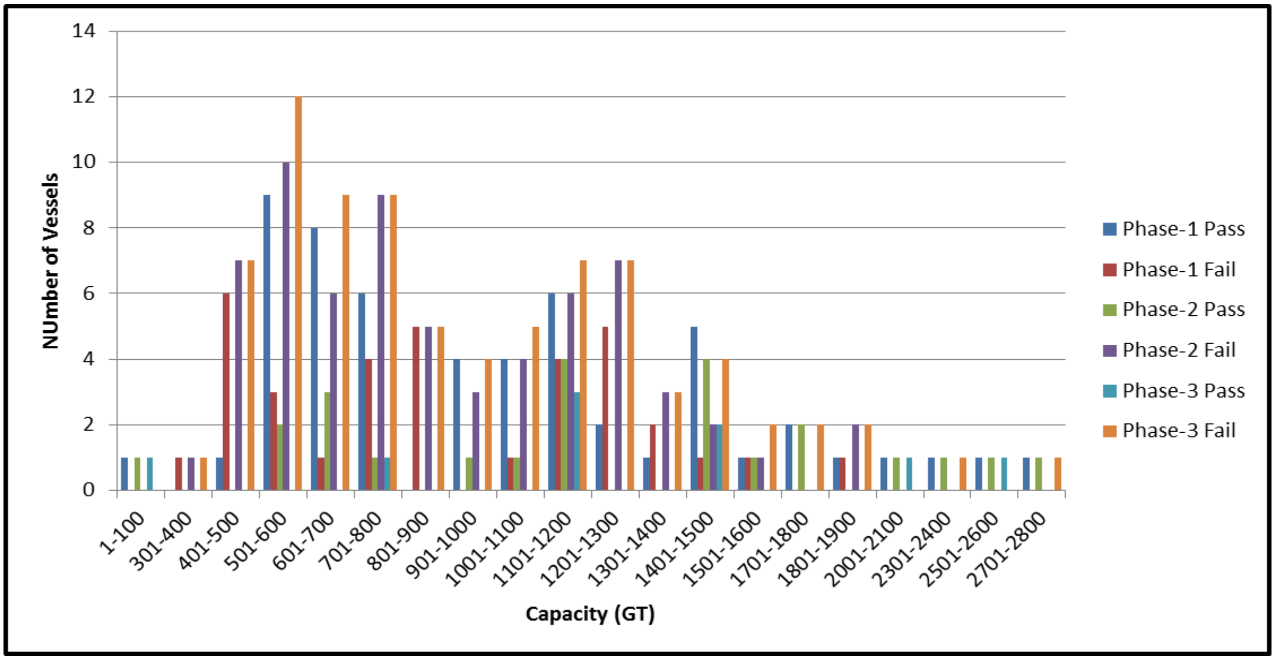


Figure 48: *Present status on EEDI with respect to vessel's capacity for Passenger Vessel*

From Figure 48, it has been observed that in Bangladesh most of the inland passenger vessels capacity is between 501to 800GT. In this range there are presently 31 vessels out of them 23 vessels pass in terms of EEDI which is 74.2% of the total vessels of that range and the rest of the vessels EEDI exceed the required value in Phase 1. As the phase increases more vessels exceed the required EEDI value. In vessel's capacity between 801 to 900 GT, all of the vessels EEDI exceed the reference line. It has been also observed that larger capacity vessels EEDI lies below the reference line. In this case in vessels capacity range between 2001 to 2800 T, there is no such vessel which meets EEDI reference line.

Present status on EEDI with respect to vessel's capacity for Passenger Ferry has been shown in Figure 49.

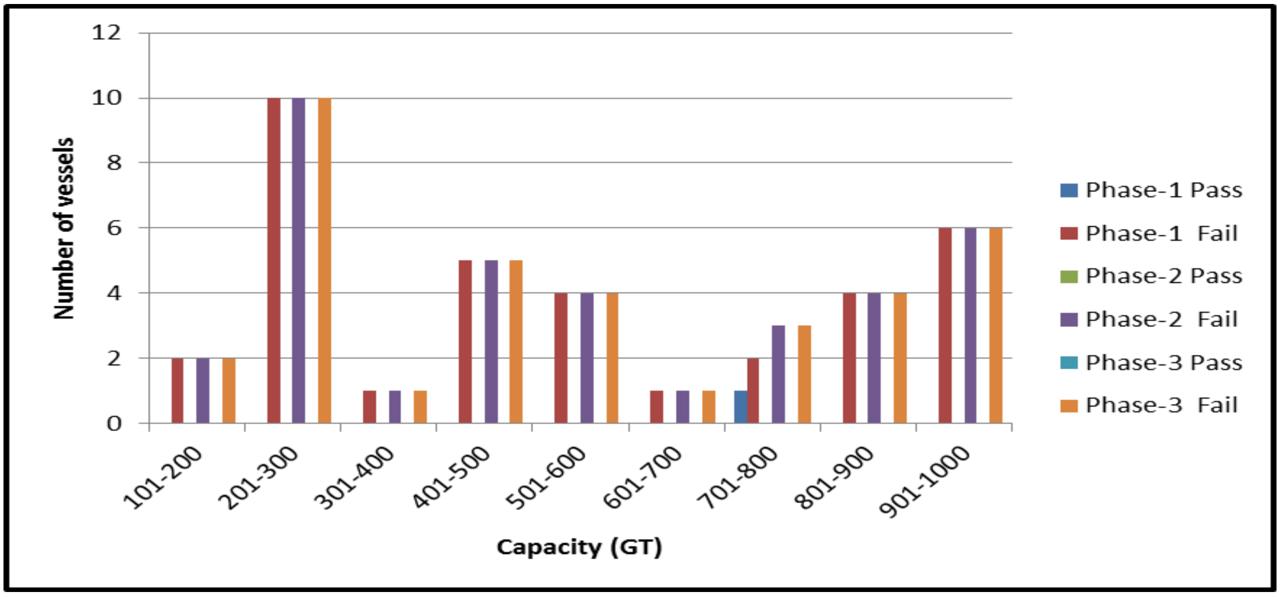


Figure 49: *Present status on EEDI with respect to vessel's capacity for Passenger Ferry*

From F igure 49, it ha s been observed tha t i n B angladesh a lmost a ll i nland passenger ferries EEDI lies above the reference line.

Present status on EEDI with respect to vessel's capacity for Sand Carrier has been shown in Figure 50.

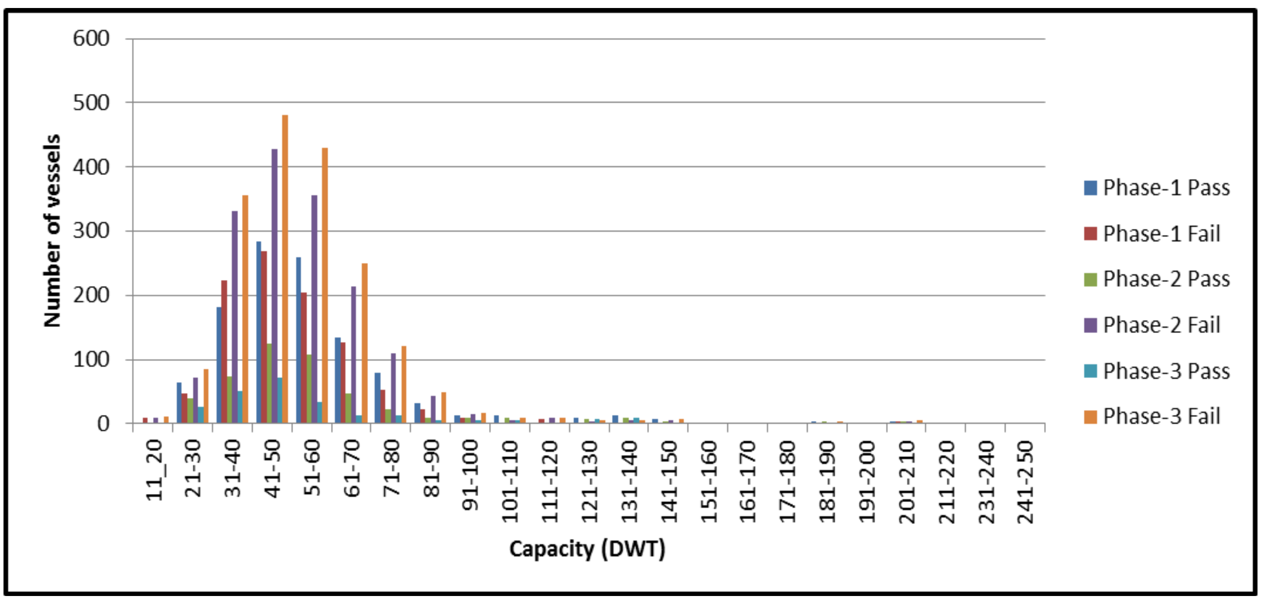


Figure 50: *Present status on EEDI with respect to vessel's capacity for Sand Carrier*

From Figure 50, it has been observed that in Bangladesh most of the inland sand carrier capacity is between 31to 60T. In this range there are presently 1421 vessels out of them 724 vessels pass in terms of EEDI which is 50.9% of the total vessels of that range and the rest of the vessels EEDI exceed the required value in Phase 1. As the phase increases more vessels exceed the required EEDI value.

Finally, From Figure 46 to 50, it has been observed that with respect to vessel's capacity, in Phase-1, 40% vessels have been passed in terms of EEDI and 60% vessels have been failed. In Phase-2, 17% vessels have been passed in terms of EEDI and 83% vessels have been failed. In Phase-3, 9% vessels have been passed and 91% vessels have been failed.

5.4 Present status of EEDI with respect to vessel's main engine power

Present status on EEDI with respect to vessel's MCR $_{ME}$ for Cargo Vessel has been shown in Figure 51.

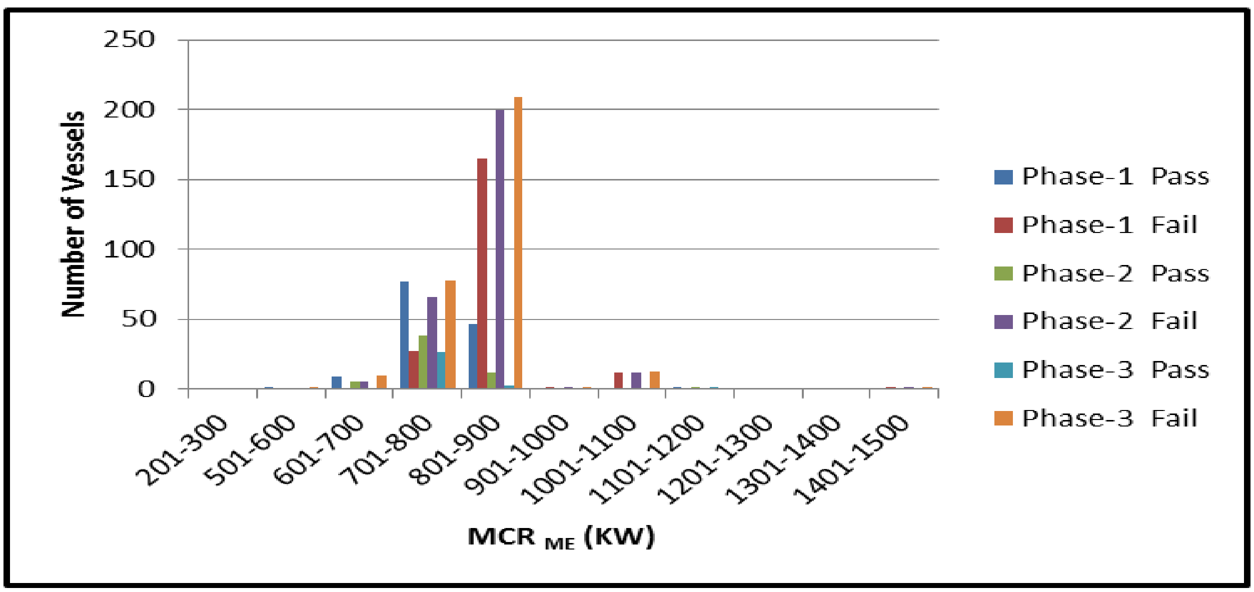


Figure 51: *Present status on EEDI with respect to vessel's MCR $_{ME}$ for Cargo Vessel*

From Figure 51, it has been observed that in Bangladesh most of the inland cargo vessels main engine power is between 701to 900 KW. In this range there are presently 316 vessels out of them 124 vessels pass in terms of EEDI which is 39.2% of the total vessels of that range and the rest of the vessels EEDI exceed the required value in Phase 1. As the phase increases more vessels exceed the required EEDI value. In vessel's main engine power between 801 to 900 KW, most of the vessels EEDI exceed the reference line. It has been also observed that smaller main engine power vessels EEDI lies below the reference line. So we can say that smaller main engine power vessels are more effective in terms of EEDI.

Present status on EEDI with respect to vessel's MCR_{ME} for Oil Tanker has been shown in Figure 52.

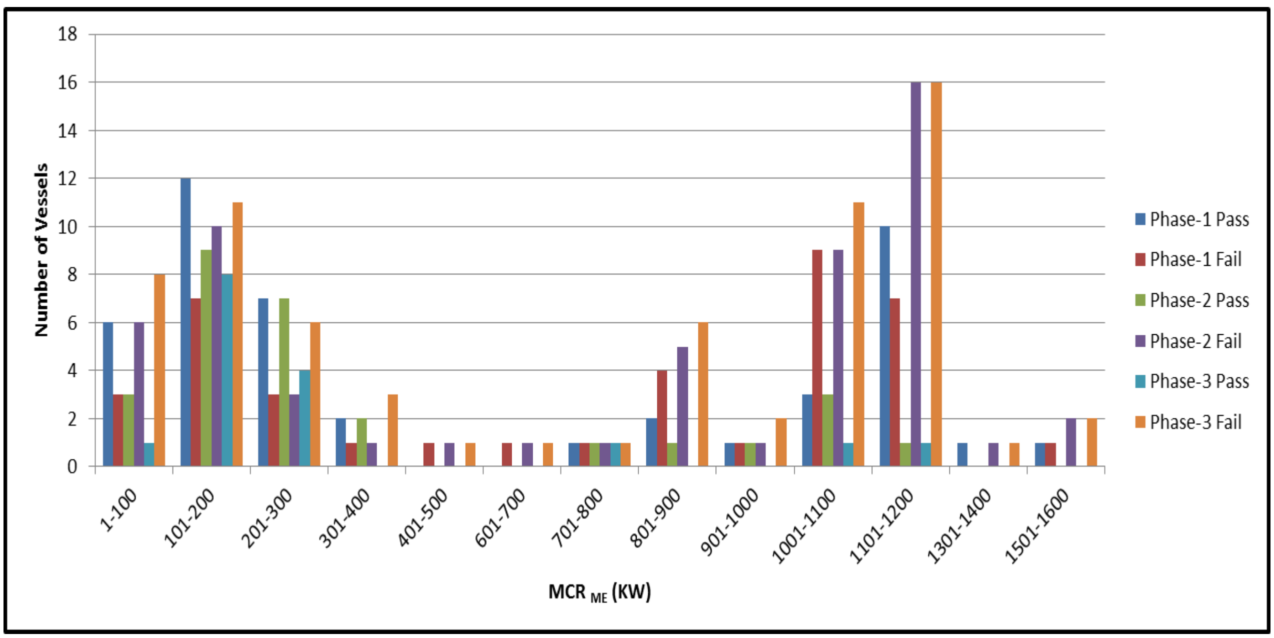


Figure 52: *Present status on EEDI with respect to vessel's MCR_{ME} for Oil Tanker*

From Figure 52, it has observed that in Bangladesh most of the vessels EEDI exceed the reference line. It has also been observed that smaller main engine power vessels EEDI lies below the reference line.

Present status on EEDI with respect to vessel's MCR $_{ME}$ for Passenger Vessel has been shown in Figure 53.

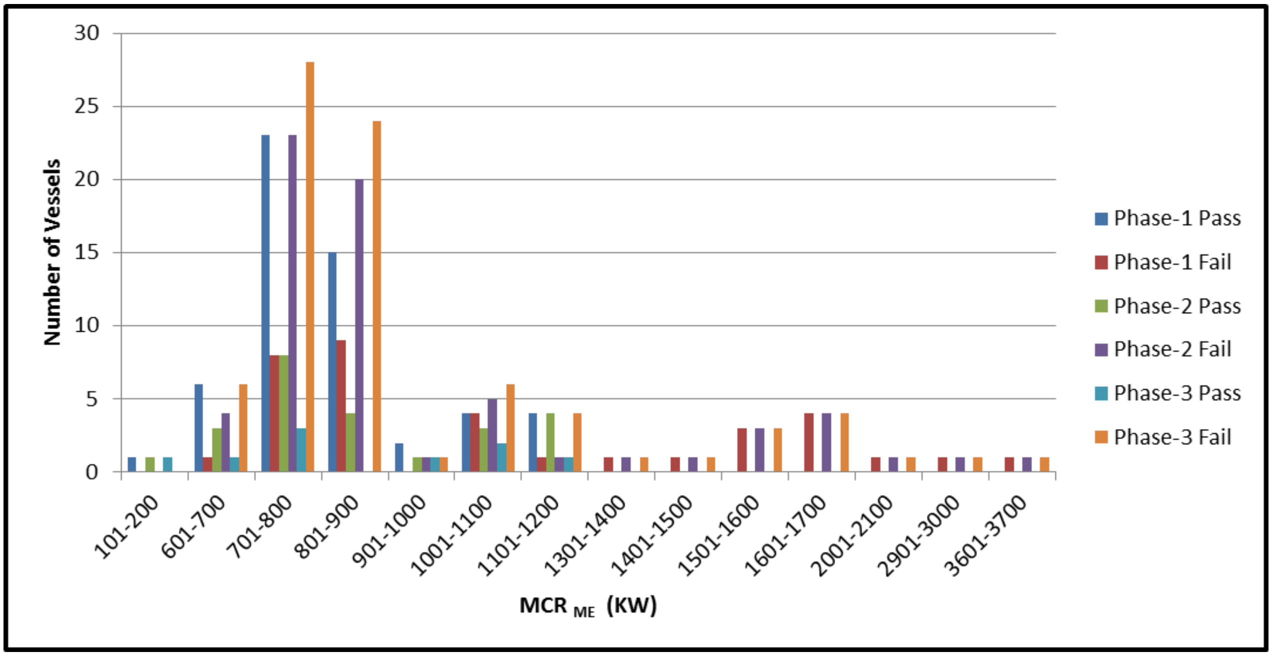


Figure 53: *Present status on EEDI with respect to vessel's MCR $_{ME}$ for Passenger Vessel*

From Figure 53, it has been observed that in Bangladesh most of the inland passenger vessels main engine power is between 701 to 900 KW. In this range there are presently 55 vessels out of them 38 vessels pass in terms of EEDI which is 69.1% of the total vessels of that range and the rest of the vessels EEDI exceed the required value in Phase 1. As the phase increases more vessels exceed the required EEDI value. It has been also observed that larger main engine power vessels EEDI lies above the reference line. In this case in vessels main engine power range between 1301 to 3700 KW, there is no such vessel which meets EEDI reference line.

Present status on EEDI with respect to vessel's MCR $_{ME}$ for Passenger Ferry has been shown in Figure 54.

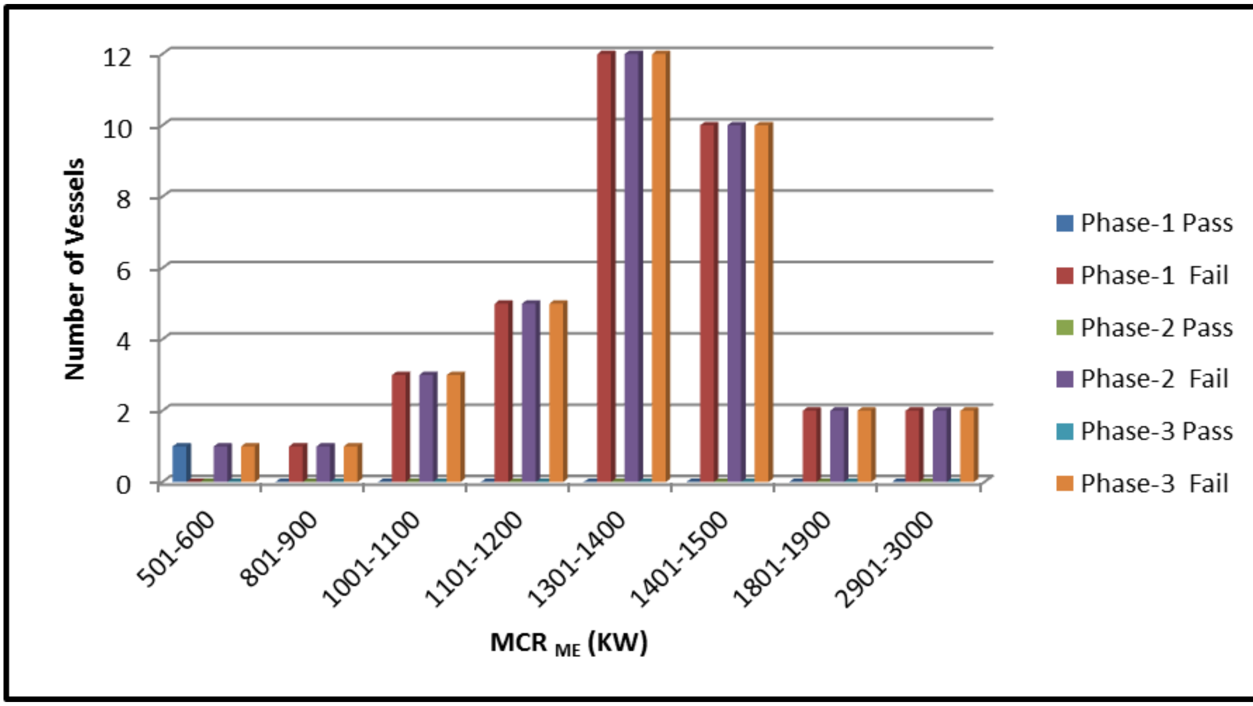


Figure 54: *Present status on EEDI with respect to vessel's MCR $_{ME}$ for Passenger Ferry*

From Figure 5 4, it ha s been observed tha t i n B angladesh a lmost a ll i nland passenger ferries EEDI lies above the reference line.

Present status on EEDI with respect to vessel's MCR $_{ME}$ for Sand Carrier has been shown in Figure 54.

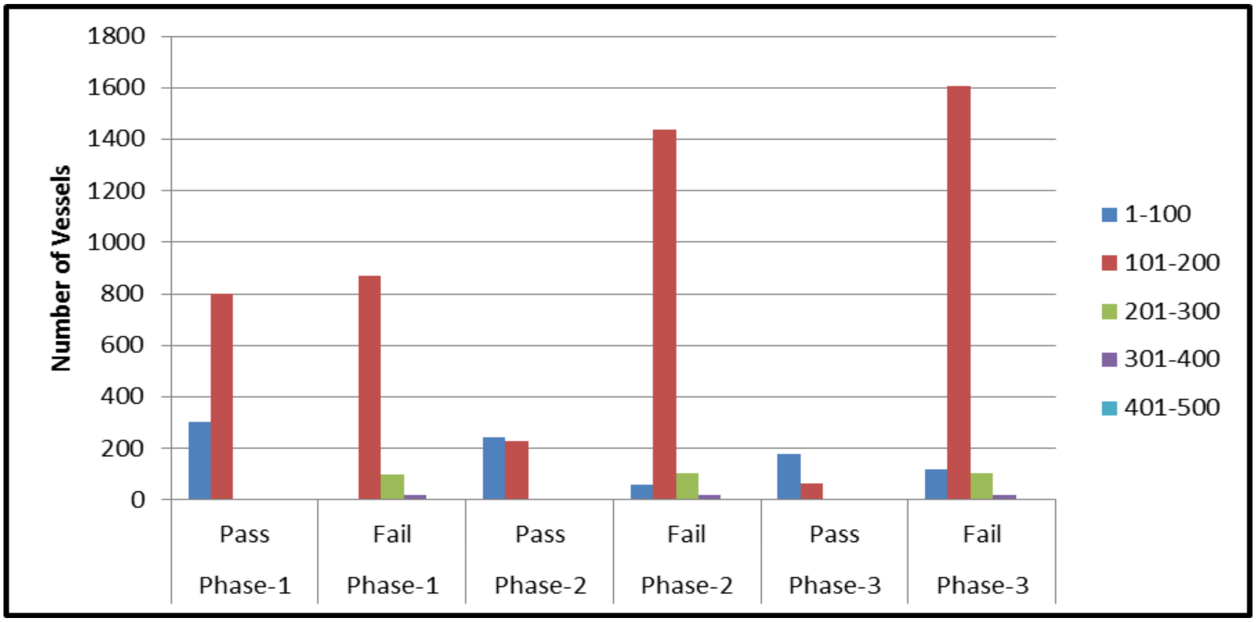


Figure 55: *Present status on EEDI with respect to vessel's MCR $_{ME}$ for Sand Carrier*

From Figure 55, it has been observed that in Bangladesh most of the inland sand carrier main engine power is between 101to 200 KW. In this range there are presently 1670 vessels out of them 801 vessels pass in terms of EEDI which is 47.9% of the total vessels of that range and the rest of the vessels EEDI exceed the required value in Phase 1. As the phase increases more vessels exceed the required EEDI value. In vessel's main engine power between 201 to 500 KW, most of the vessels EEDI exceed the reference line. It has been also observed that smaller main engine power vessels EEDI lies below the reference line.

Finally, From Figure 51 to 55, it has been observed that with respect to vessel's main engine power, in Phase-1, 40% vessels have been passed in terms of EEDI and 60% vessels have been failed. In Phase-2, 17% vessels have been passed in terms of EEDI and 83% vessels have been failed. In Phase-3, 9% vessels have been passed and 91% vessels have been failed.

Chapter-6

Case study of existing inland vessels of Bangladesh with respect to EEDI

6.1 Overview

According to the EEDI, the energy efficiency of ships is defined as the ratio of the mass of CO_2 emissions from main, auxiliary engines and additional shaft per unit of transport work for a particular ship design. Therefore detailed design data, such as speed, engine power, fuel oil consumption, deadweight etc., are required in order to calculate the correct EEDI values which are closely related to the economic performance of the ship. During the design stage of the vessel, for known demands, hull form should be determined at the beginning. Based on principal ship parameters, it is possible to estimate the attained EEDI and to compare it with the required value. In Bangladesh, at present there are no rule exists for inland vessels in terms of EEDI. If we have to comply EEDI then the vessel should be optimized in terms of EEDI. In this chapter, the method how vessels should be optimized by keeping the capacity same has been discussed. The main goal of this section is to provide some procedures which lessen EEDI value.

Procedure for evaluation of energy efficiency of a new ship during design stage has been shown in Figure 56.

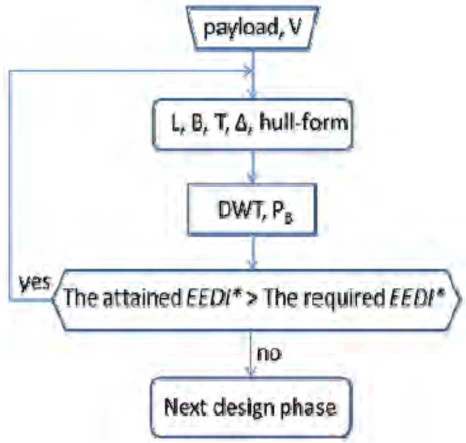


Figure 56: *Procedure for evaluation of energy efficiency of a new ship during design stage [23]*

If a criterion described in Figure 56 is fulfilled, something should be changed (improved) within the project, otherwise it is allowed to proceed to the next design stage. Naturally, results should be confirmed during the speed trials as is recommended to be done for the seagoing ships. In this study, the same procedure has been followed for inland vessels.

6.2 Sample Ship-1 (Oil Tanker)

Sensitivity of EEDI has been exemplified through a set of calculations for a case Oil Tanker. For demonstration purposes, an existing 2774 dwt Oil Tanker design has been used as an example.

Principal particulars of the Sample Ship-1 have been shown in Table 17.

***Table 17**: Principal Particulars of 2774 DWT Oil Tanker*

Length (O.A)	78.85m	DWT	2774
Length (B.P)	76.30m	Main Engine (Cummins-QSK60M)	2X1492 KW@100% MCR
Breadth (mld)	12.50m	SFC (ME)	165 g/KWh
Depth (mld)	6.50m	Main Generator	2X443KW
Draft	5.00m	SFC (AE)	185 g/KWh

Lines plan of sample Ship-01 has been shown in Figure 57.

***Figure 57:** Lines plan of 2774 DWT Oil Tanker*

For calculation of EEDI for the sample Ship-1, exact and ship specific model test data has been used and the calculation has been made according to the latest calculation guidelines as described in IMO [37]. Calculated EEDI for the sample ship is 50.84 g CO_2/tnm. According to the formulated oil tanker baseline, the requirement for 2774 dwt Oil Tanker is 38.04gCO_2/tnm, thus the sample ship is about 33.64% above the baseline. However actual EEDI of the sample ship would need to be improved by 33.64% to match with the requirement. In this study, resistance has been calculated using Holtrop and Mennen's Method [39].

The relative high power of the installed shaft generator (P_{PTO}) has a huge impact on the EEDI value. If the ship is equipped with a large shaft generator that has to supply power to other systems on top of the power for the basic auxiliary systems, will decrease the EEDI value to great extent. It should be considered that, by installing a higher powered shaft generator, we are actually reducing P_{ME} and thus EEDI is getting decreased, as P_{ME} is the numerator in the EEDI equation. If we decrease P_{ME} by increasing installed shaft generator that would mean that, V_{REF} is also decreased. V_{REF} being a denominator in the EEDI equation will try to increase EEDI. Thus, it can be said that, installing higher power shaft generator is not favorable; rather, optimum effect of P_{PTO}, P_{ME} and V_{REF} on EEDI should be analyzed for the best design.

6.2.1 Change in Length of the Vessel

Table 18 shows the optimization of ship's length with respect to EEDI for the sample Ship-1.

Table 18*: Optimization of ship's length with respect to EEDI*

Condition	Length (m)	Breadth (m)	Draft (m)	Cb	Displacement (T)	$P_{ME\ (KW)}$	MCR_{ME} (KW)	Total Resistance (KN)	EEDI (Attained)
Basis	76.3	12.5	5	0.857	4086	2217	2956	189.67	36.35
5% less	72.485	13.16	5	0.857	4086	2368	3158	202.59	38.83
10% less	68.67	13.88	5	0.857	4086	2662	3550	227.77	43.66
5% more	80.12	11.9	5	0.857	4086	2111	2815	180.6	34.6
10% more	83.93	11.36	5	0.857	4086	1998	2664	170.93	32.7

When increasing vessels length, the relative increase in power will generally be smaller than the relative increase in length, other factors being equal and keeping the capacity same as basis ship. This suggests that increasing the vessels length will tend to decrease the EEDI value. From this table it has been also observed that, total resistance and main engine power (P_{ME}) decreases with the increase of length.

6.2.2 Change in Breadth of the Vessel

Table 19 shows the optimization of ship's breadth with respect to EEDI for the sample Ship-1.

***Table 19**: Optimization of ship's breadth with respect to EEDI*

Condition	Length (m)	Breadth (m)	Draft (m)	Cb	Displacement (T)	$P_{ME\ (KW)}$	MCR_{ME} (KW)	Total Resistance (KN)	EEDI (Attained)
Basis	76.3	12.5	5	0.857	4086	2217	2956	189.67	36.35
5% less	80.31	11.875	5	0.857	4086	2106	2808	180.15	34.53
10% less	84.77	11.25	5	0.857	4086	1970	2627	168.5	32.3
5% more	72.66	13.125	5	0.857	4086	2359	3145	201.78	38.67
10% more	69.36	13.75	5	0.857	4086	2591	3455	221	42.49

From Table 19, it has been observed that EEDI (attained) increases with the increase of breadth at 12.5 knot speed and keeping the displacement same as basis ship. From Table 19, it has been also observed that, total resistance and main engine power (P_{ME}) increases with the increase of breadth.

6.2.3 Change in Speed of the Vessel

Table 20 shows the optimization of ship's speed with respect to EEDI for the sample Ship-1.

***Table 20**: Optimization of ship's speed with respect to EEDI*

Condition	Speed (Knot)	$P_{ME\ (KW)}$	MCR_{ME} (KW)	Total Resistance (KN)	EEDI (Attained)
Basis	12.5	2217	2956	189	36.35
5% less	11.875	1958	2611	176	33.8
10% less	11.25	1355	1807	128	24.7
5% more	13.125	2851	3802	232	44.5
10% more	13.75	4575	6100	355	68.2

From Table 20, it has been observed that EEDI (attained) increases with the increase of speed. The EEDI is particularly sensitive to the service speed, as the required power increases by roughly the cube of the variation in service speed ($P \propto V^3$). From Table 20, it has been observed that EEDI (attained) decreases with the increase of length at 12.5 knot speed, but increases at higher speeds. The reason behind it is the wave resistance that increases at high speed. It has been also observed that, total resistance and main engine power (P_{ME}) increases with the increase of speed. It can be decided easily that low speed gives the better performance in terms of EEDI.

6.2.4 Change in Block Coefficient of the Vessel

Table 21 shows the optimization of ship's block coefficient with respect to EEDI for the sample Ship-1.

***Table 21**: Optimization of ship's block coefficient with respect to EEDI*

Condition	Length (m)	Breadth (m)	Draft (m)	Cb	Displacement (T)	$P_{ME\ (KW)}$	MCR_{ME} (KW)	Total Resistance (KN)	EEDI (Attained)
Basis	76.3	12.5	5	0.857	4086	2217	2956	189.67	36.35
5% less	76.3	13.16	5	0.814	4086	1744	2326	149.2	28.6
10% less	76.3	13.88	5	0.77	4086	1573	2098	134.63	25.8
5% more	76.3	11.9	5	0.89	4086	3776	5034	323	61.9
10% more	76.3	11.77	5	0.91	4086	4632	6176	396	75.9

From Table 21, it has been observed that EEDI (attained) increases with the increase of block coefficient. It has been also observed that, total resistance and main engine power (P_{ME}) increases with the increase of block coefficient. It can be decided easily that, at any speed it is better to have small block coefficient.

6.2.5 Change in Engine Model of the Vessel

Table 22 shows the optimization of ship's engine model with respect to EEDI for the sample Ship-1.

***Table 22**: Optimization of ship's engine with respect to EEDI*

Engine Name	SFC (g/Kwh)	Price (USD)	EEDI (Attained)
Cummins	165	950000	36.35
Yanmar	190	810000	38.04
Weichai	200	630000	41.82
Nigbo CSI	210	600000	44

From Table 22, it has been observed that EEDI (attained) increases with the increase of specific fuel consumption value. It has been also observed that, the price of engine increases which has low SFC value. It can be decided easily that low sfc gives the better performance in terms of EEDI. But considering the economic factor in Bangladesh, if the EEDI values between two engines are nearer then the engine which has high sfc would be used.

6.3 Sample Ship-2 (Cargo Vessel)

Sensitivity of EEDI has been exemplified through a set of calculations for a case Cargo vessel. For demonstration purposes, an existing design of 2700 DWT Cargo Vessel has been used as an example.

Principal particulars of the Sample Ship-2 have been shown in Table 23.

***Table 23**: Principal Particulars of 2700 DWT Cargo Vessel*

Length (O.A)	76.0m	DWT	2700
Length (B.P)	72.87m	Main Engine (Yanmar)	2X849 BHP@100% MCR
Breadth (mld)	15.0m	SFC (ME)	190 g/KWh
Depth (mld)	7.0m	Main Generator	2X191KW
Draft	3.8m	SFC (AE)	210 g/KWh

Lines plan of sample Ship-2 has been shown in Figure 58.

***Figure 58:** Lines plan of 2700 DWT Cargo Vessel*

For calculation of EEDI for the sample Ship-2, exact and ship specific model test data has been used and the calculation has been made according to the latest calculation guidelines as described in IMO [37]. Calculated EEDI for the sample ship is 37.41 gCO_2/tnm. According to the formulated cargo vessel baseline, the requirement for 2700 dwt cargo vessel is 31.05gCO_2/tnm, thus the sample ship is about 20.5% above the baseline. However actual EEDI of the sample ship would need to be improved by 20.5% to match with the requirement. In this study, resistance has been calculated using Holtrop and Mennen's Method [41].

6.3.1 Change in Length of the Vessel

Table 24 shows the optimization of ship's length with respect to EEDI for the sample Ship-2.

***Table 24**: Optimization of ship's length with respect to EEDI*

Condition	Length (m)	Breadth (m)	Draft (m)	Cb	Displacement (T)	$P_{ME\ (KW)}$	MCR_{ME} (KW)	Total Resistance (KN)	EEDI (Attained)
Basis	72.87	15	3.8	0.857	3559	953	1271	101.93	23.09
5% less	69.22	15.79	3.8	0.857	3559	993	1325	106.26	24.07
10% less	65.58	16.67	3.8	0.857	3559	1040	1387	111.23	25.19
5% more	76.51	14.28	3.8	0.857	3559	929	1238	99.23	22.5
10% more	80.15	13.63	3.8	0.857	3559	913	1217	97.6	22.11

From Table 24, it has been observed that EEDI (attained) decreases with the increase of length at 10 knot speed and without changing its carrying capacity. So, longer vessels are performing well in terms of EEDI. From this table it has been also observed that, total resistance and main engine power (P_{ME}) decreases with the increase of length.

6.3.2 Change in Breadth of the Vessel

Table 25 shows the optimization of ship's breadth with respect to EEDI for the sample Ship-2.

***Table 25**: Optimization of ship's breadth with respect to EEDI*

Condition	Length (m)	Breadth (m)	Draft (m)	Cb	Displace ment (T)	$P_{ME\ (KW)}$	MCR_{ME} (KW)	Total Resistance (KN)	EEDI (Attained)
Basis	72.87	15	3.8	0.857	3559	953	1271	101.93	23.09
5% less	76.7	14.25	3.8	0.857	3559	927	1237	99.2	22.47
10% less	80.96	13.5	3.8	0.857	3559	909	1212	97.2	22.02
5% more	69.4	15.75	3.8	0.857	3559	991	1321	105.97	24
10% more	66.24	16.5	3.8	0.857	3559	1031	1375	110.33	24.99

From Table 25, it has been observed that EEDI (attained) increases with the increase of breadth at 10 knot speed and keeping carrying capacity same as basis ship. From this table it has been also observed that, total resistance and main engine power (P_{ME}) increases with the increase of breadth.

6.3.3 Change in Speed of the Vessel

Table 26 shows the optimization of ship's speed with respect to EEDI for the sample Ship-2.

***Table 26**: Optimization of ship's speed with respect to EEDI*

Condition	Speed (Knot)	$P_{ME\ (KW)}$	MCR_{ME} (KW)	Total Resistance (KN)	EEDI (Attained)
Basis	10	953	1271	101.92	23.09
5% less	9.5	817	1090	92.04	20.85
10% less	9	687	916	81.64	18.49
15%less	8.5	585	780	73.64	16.68
20%less	8	498	664	66.56	15.08

From Table 26, it has been observed that EEDI (attained) increases with the increase of speed. It has been also observed that, total resistance and main engine power (P_{ME}) increases with the increase of speed. It can be decided easily that low speed gives the better performance in terms of EEDI.

6.3.4 Change in Block Coefficient of the Vessel

Table 27 shows the optimization of ship's block coefficient with respect to EEDI for the sample Ship-2.

***Table 27**: Optimization of ship's block coefficient with respect to EEDI*

Condition	Length (m)	Breadth (m)	Draft (m)	Cb	Displacement (T)	$P_{ME\ (KW)}$	MCR_{ME} (KW)	Total Resistance (KN)	EEDI (Attained)
Basis	72.87	15	3.8	0.857	3559	953	1271	101.93	23.09
5% less	72.87	15.79	3.8	0.814	3559	847	1129	90.6	20.52
10% less	72.87	16.67	3.8	0.771	3559	786	1049	84.12	19.05
15% less	72.87	17.64	3.8	0.728	3559	747	996	79.9	18.1
20% less	72.87	19.19	3.8	0.67	3559	721	962	77.17	17.48

From Table 27, it has been observed that EEDI (attained) increases with the increase of block coefficient. It has been also observed that, total resistance and main engine power (P_{ME}) increases with the increase of block coefficient. It can be decided easily that, at any speed it is better to have small block coefficient.

6.3.5 Change in Engine Model of the Vessel

Table 28 shows the optimization of ship's engine model with respect to EEDI for the sample Ship-2.

***Table 28**: Optimization of ship's engine with respect to EEDI*

Engine Name	SFC (g/Kwh)	Price (USD)	EEDI (Attained)
Cummins	165	950000	20.07
Yanmar	190	810000	23.09
Weichai	200	630000	24.29
Nigbo CSI	210	600000	25.5

From Table 28, it has been observed that EEDI (attained) increases with the increase of specific fuel consumption value. It has been also observed that, the price of engine increases which has low SFC value. It can be decided easily that low sfc gives the better performance in terms of EEDI. But considering the economic factor in Bangladesh, if the EEDI values between two engines are nearer then the engine which has high SFC would be used.

6.4 Sample Ship-3 (Passenger Vessel)

Sensitivity of EEDI has been exemplified through a set of calculations for a case passenger vessel. For demonstration purposes, an existing design of 754 person carrying capacity Passenger Vessel has been used as an example.

Principal particulars of the Sample Ship-3 have been shown in Table 29.

__Table 29__: Principal Particulars of Passenger Vessel

Length (O.A)	75.6m	GT	1743
Length (B.P)	73.25m	Main Engine (Yanmar)	2X600 BHP@100% MCR
Breadth (mld)	12.5m	SFC (ME)	190 g/KWh
Depth (mld)	3.0m	Main Generator	2X40KW
Draft	1.6m	SFC (AE)	210 g/KWh

Lines plan of sample Ship-03 has been shown in Figure 59.

Figure 59: *Lines plan of Passenger Vessel*

For calculation of EEDI for the sample Ship-3, exact and ship specific model test data has been used and the calculation has been made according to the latest calculation guidelines as described in IMO [37]. Calculated EEDI for the sample ship is 22.23 gCO_2/tnm. According to the formulated passenger vessel baseline, the requirement for 1743GT passenger vessel is 21.7gCO_2/tnm, thus the sample ship is about 2.44% above the baseline. However actual EEDI of the sample ship would need to be improved by 2.44% to match with the requirement. In this study, resistance has been calculated using Holtrop and Mennen’s Method [41].

6.4.1 Change in Length of the Vessel

Table 30 shows the optimization of ship’s length with respect to EEDI for the sample Ship-3.

***Table 30**: Optimization of ship's length with respect to EEDI*

Condition	Length (m)	Breadth (m)	Draft (m)	Cb	Displacement (T)	$P_{ME\ (KW)}$	MCR_{ME} (KW)	Total Resistance (KN)	EEDI (Attained)
Basis	73.25	12.25	1.6	0.85	1220	675	900	72.17	25.32
5% less	69.58	12.9	1.6	0.85	1220	696	928	74.43	26.12
10% less	65.93	13.6	1.6	0.85	1220	714	952	76.3	26.79
5% more	76.9	11.67	1.6	0.85	1220	660	880	70.5	24.76

From Table 30, it has been observed that EEDI (attained) decreases with the increase of length at 10 knot speed and keeping the carrying capacity same as basis vessel. From this table it has been also observed that, total resistance and main engine power (P_{ME}) decreases with the increase of length.

6.4.2 Change in Breadth of the Vessel

Table 31 shows the optimization of ship's breadth with respect to EEDI for the sample Ship-03.

***Table 31**: Optimization of ship's breadth with respect to EEDI*

Condition	Length (m)	Breadth (m)	Draft (m)	Cb	Displacement (T)	$P_{ME\ (KW)}$	MCR_{ME} (KW)	Total Resistance (KN)	EEDI (Attained)
Basis	73.25	12.25	1.6	0.85	1220	675	900	72.17	25.32
5% less	77.1	11.63	1.6	0.85	1220	659	878	70.4	24.73
10% less	81.3	11.03	1.6	0.85	1220	645	860	67.9	23.8
5% more	69.76	12.86	1.6	0.85	1220	695	926	74.3	26.08

From Table 31, it has been observed that EEDI (attained) increases with the increase of breadth at 10 knot speed and keeping the capacity same as basis ship. From this table it has been also observed that, total resistance and main engine power (P_{ME}) increases with the increase of breadth.

6.4.3 Change in Speed of the Vessel

Table 32 shows the optimization of ship's speed with respect to EEDI for the sample Ship-03.

***Table 32**: Optimization of ship's speed with respect to EEDI*

Condition	Speed (Knot)	$P_{ME\ (KW)}$	MCR_{ME} (KW)	Total Resistance (KN)	EEDI (Attained)
Basis	10	675	900	72.17	25.32
5% less	9.5	586	782	66.03	23.17
10% less	9	503	671	59.86	21
5% more	10.5	787	1050	80.2	28.14

From Table 32, it has been observed that EEDI (attained) increases with the increase of speed. It has been also observed that, total resistance and main engine power (P_{ME}) increases with the increase of speed. It can be decided easily that low speed gives the better performance in terms of EEDI.

6.4.4 Change in Block Coefficient of the Vessel

Table 33 shows the optimization of ship's block coefficient with respect to EEDI for the sample Ship-3.

***Table 33**: Optimization of ship's block coefficient with respect to EEDI*

Condition	Length (m)	Breadth (m)	Draft (m)	Cb	Displacement (T)	$P_{ME\ (KW)}$	MCR_{ME} (KW)	Total Resistance (KN)	EEDI (Attained)
Basis	73.25	12.25	1.6	0.85	1220	675	900	72.17	25.32
5% less	73.25	12.89	1.6	0.8075	1220	620	827	66.3	23.2
10% less	73.25	13.61	1.6	0.765	1220	584	779	62.5	21.9
5% more	73.25	11.67	1.6	0.8925	1220	812	1083	86.9	30.49

From Table 33, it has been observed that EEDI (attained) increases with the increase of block coefficient. It has been also observed that, total resistance and main engine power (P_{ME}) increases with the increase of block coefficient. It can be decided easily that, at any speed it is better to have small block coefficient.

6.4.5 Change in Engine Model of the Vessel

Table 34 shows the optimization of ship's engine model with respect to EEDI for the sample Ship-3.

***Table 34**: Optimization of ship's engine with respect to EEDI*

Engine Name	SFC (g/Kwh)	Price (USD)	EEDI (Attained)
Cummins	165	700000	22.01
Yanmar	190	650000	25.32
Weichai	200	480000	26.65
Nigbo CSI	210	350000	27.97

From Table 34, it has been observed that EEDI (attained) increases with the increase of specific fuel consumption value. It has been also observed that, the price of engine increases which has low sfc value. It can be decided easily that low sfc gives the better performance in terms of EEDI. But considering the economic factor in Bangladesh, if the EEDI values between two engines are nearer then the engine which has high sfc would be used. Here in this study, the ship building cost has been taken into consideration but not the increase in the operating cost (fuel cost) during ship life cycle.

Chapter-7

Hull Form Modification

7.1 Overview

Due to limitations it is possible always to change the main particulars (e.g. length, breadth, draft) of the vessel to reduce the EEDI value. So, the vessel need to be modified by it's hull form. In the process of ships, the determination of hull lines is complicated and pivotal, in respect that ships main performance in terms of resistance and propelling, maneuverability and seakeeping would be influenced directly. However to obtain the hull shape of the minimum resistance is the primary goal of designers. EEDI value of vessels can be improved by choosing correct hull form. In this chapter, some case study of existing inland vessels of Bangladesh has been performed by changing vessels hull form. Then the modified hull form has been compared with the original hull form.

7.2 Case study of hull form modification

7.2.1 Sample Ship-1 (Oil Tanker)

The principal particulars of the existing sample Ship-1 are shown in Table 35.

***Table 35**: Principal particulars of Oil Tanker*

Length (O.A)	62m	DWT	1350
Length (B.P)	58.8m	Main Engine (Nigbo CSI)	2X720 BHP@100% MCR
Breadth (mld)	10.10m	SFC (ME)	210 g/KWh
Depth (mld)	5.7m	Main Generator	2X200KW
Draft	4.0m	SFC (AE)	230 g/KWh
Speed	10 Knots		

General Arrangement of 1350 DWT Oil Tanker has been shown in Figure 60.

***Figure 60:** General Arrangement of 1350 DWT Oil Tanker*

According to the specifications, we have found that the EEDI value for this vessel is 62.98 g CO_2/ton mile and the maximum EEDI value for this vessel is 50.9 g CO_2/ton mile. So, this vessel exceeds it's EEDI value and needs the optimization of hull form.

The comparison of body plans between the original hull form and the modified hull form for Oil Tanker has been shown in Figure 60.

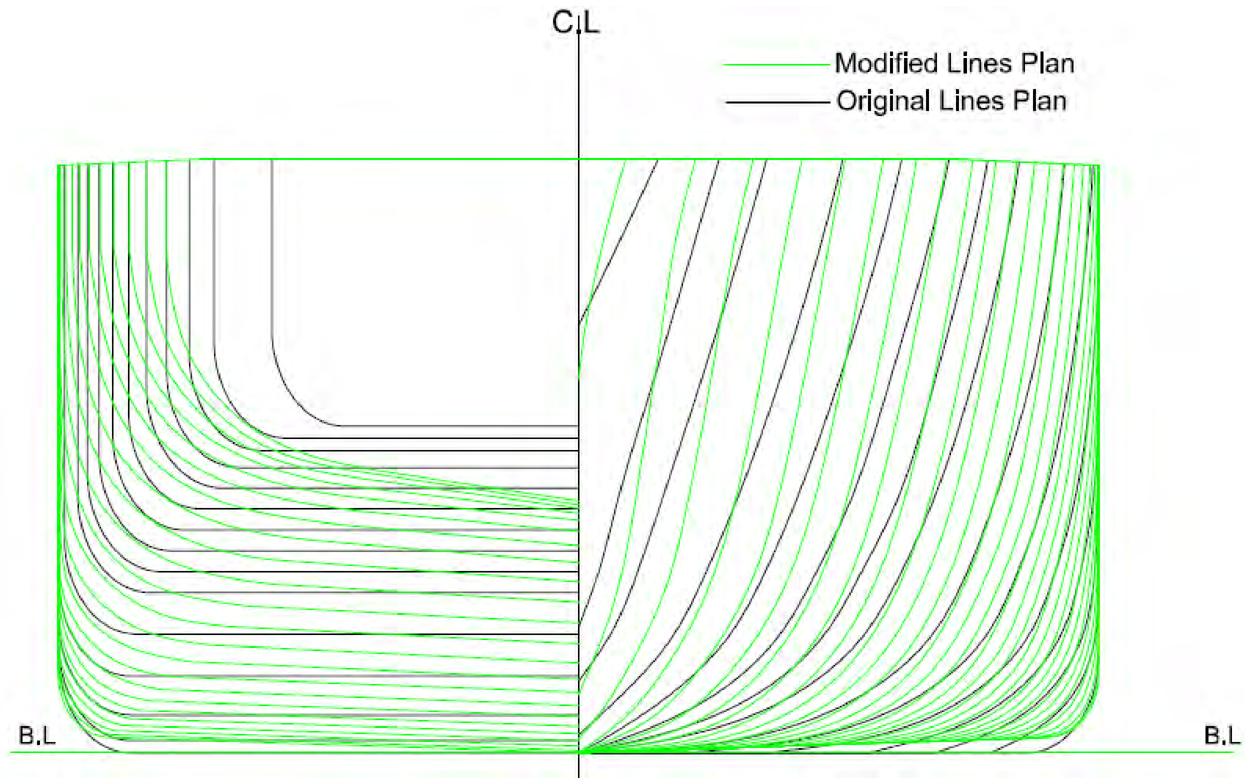


Figure 61: *The comparison of body plans between the original hull form and the modified hull form for Oil Tanker*

The comparisons of body plans between the modified hull form and the original hull are shown in figure 61 and in this figure yellow line shows the original body plan & green line shows the modified body plan. In this comparison ship's hull has been o ptimized by ke eping i t's pr incipal pa rameters (e.g. le ngth, br eadth, d raft same). In original model the displacement is 2136 T but in improved model same displacement has been used.

In Figure 62, Resistance Vs Speed graph for Oil Tanker has been shown.

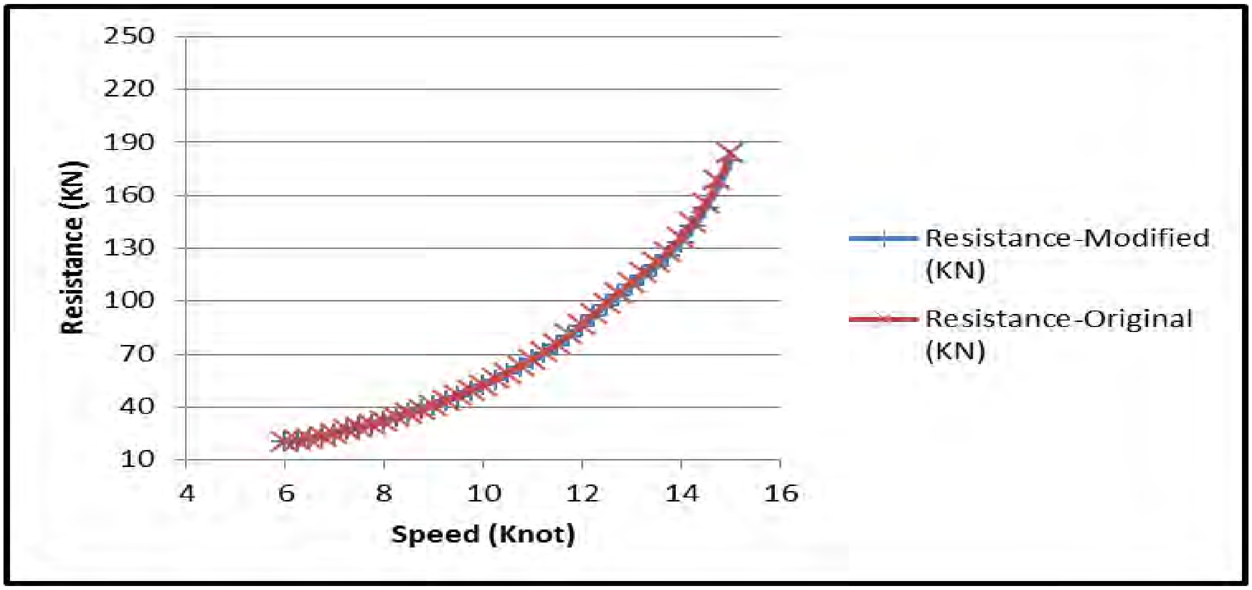


Figure 62: *Resistance Vs Speed Graph for Oil Tanker*

From Figure 62, we have seen that whereas in original lines plan resistance have found 52.2KN but in modified lines the resistance value is 50.5KN at 10 Knot service speed. So, the modified lines have given less resistance than the original one.

In Figure 63, Power Vs Speed graph for Oil Tanker has been shown.

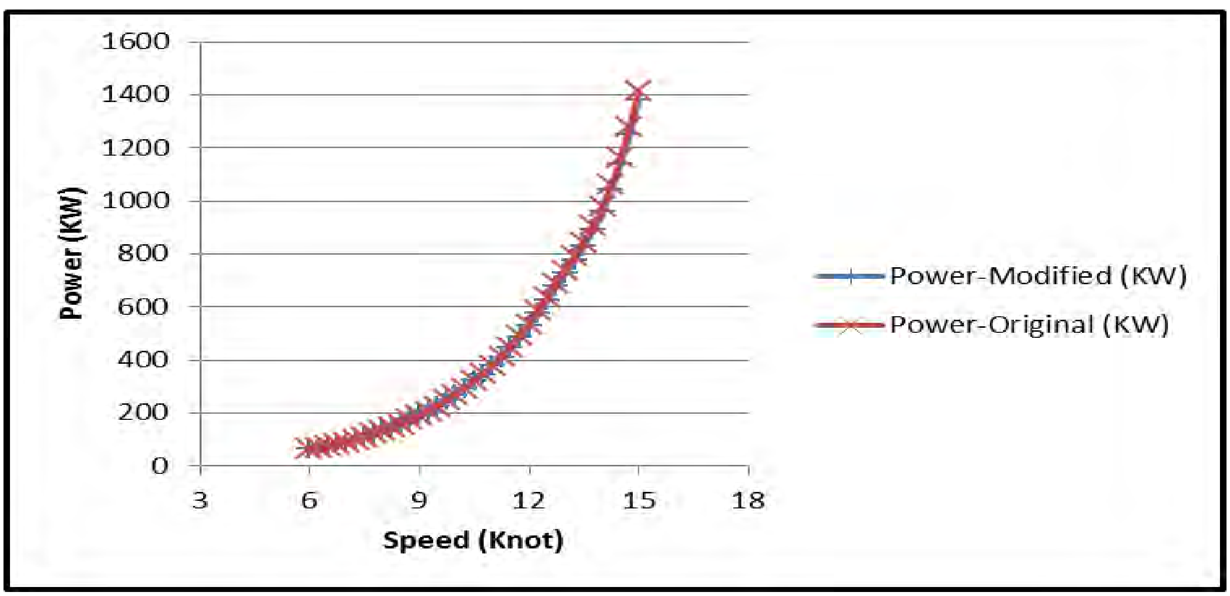


Figure 63: *Power Vs Speed Graph for Oil Tanker*

From Figure 63, we have seen that whereas in original lines plan required main engine power is 800KW but in modified lines the required power is 770KW. By original lines plan we have found the EEDI value for the vessel is 81.69 g CO_2/ton mile but the modified lines plan we have found the EEDI value 79.69 g CO_2/ton mile. Though originally 1045 KW power has been provided in this vessel but this vessel needs 800KW. So, we can say that a better and smooth hull design gives lesser resistance and hence gives better EEDI values.

7.2.2 Sample Ship-2 (Passenger Ferry)

The principal particulars of the existing passenger vessel are shown in Table 36.

Table 36*: Principal Particulars of Passenger Ferry*

Length (O.A)	60m	GT	1250
Length (B.P)	58m	Main Engine (Yanmar)	2X600 BHP@100% MCR
Breadth (mld)	12.2m	SFC (ME)	200 g/KWh
Depth (mld)	2.9m	Main Generator	2X200KW
Draft	1.52m	SFC (AE)	220 g/KWh
Speed	10 Knots		

General Arrangement of Passenger Ferry has been shown in Figure 64.

Figure 64: *General Arrangement of Passenger Ferry*

According to the specifications, we have found that the EEDI value for this vessel is 57.1 g CO_2/ton mile and the maximum EEDI value for this vessel is 13.45 g

CO_2/ton mile. So, this vessel exceeds it's EEDI value and needs the optimization of hull form.

The comparison of body plans between the original hull form and the modified hull form for Passenger Ferry has been shown in Figure 65.

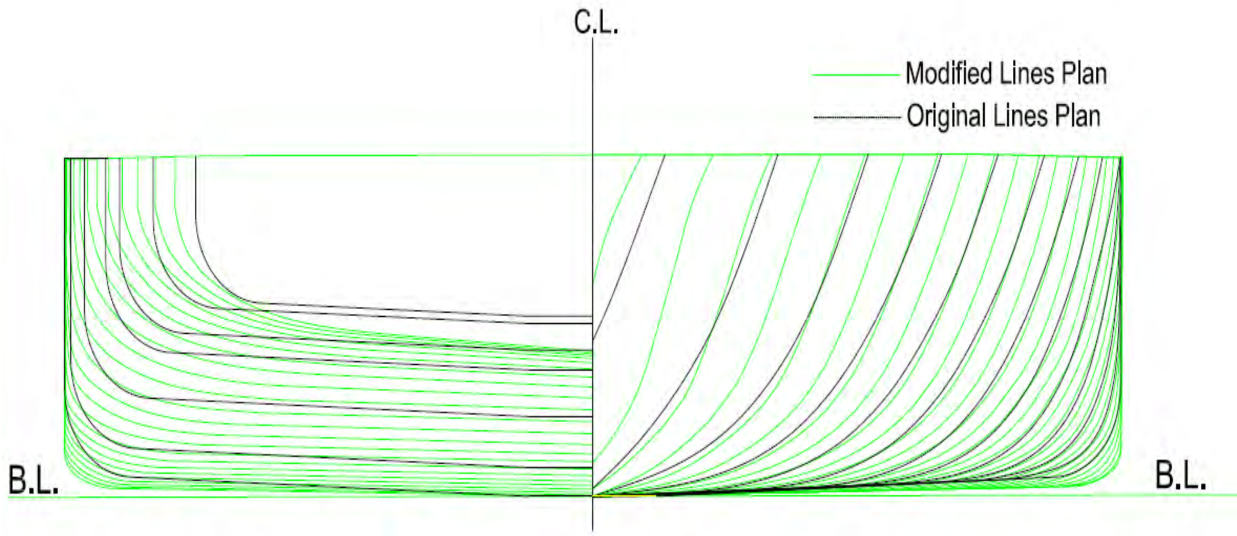


Figure 65: *The comparison of body plans between the original hull form and the modified hull form for Passenger Ferry*

The comparisons of body plans between the modified hull form and the original hull are shown in Figure 65 and in this figure yellow line shows the original body plan & green line shows the modified body plan. In this comparison ship's hull has been optimized by keeping it's principal parameters (e.g. length, breadth, draft same). In original model the displacement volume is 840 m^3 but in improved model the displacement volume is 753 m^3.

In Figure 66, Resistance/Displacement Volume Vs Speed graph for Passenger Ferry has been shown.

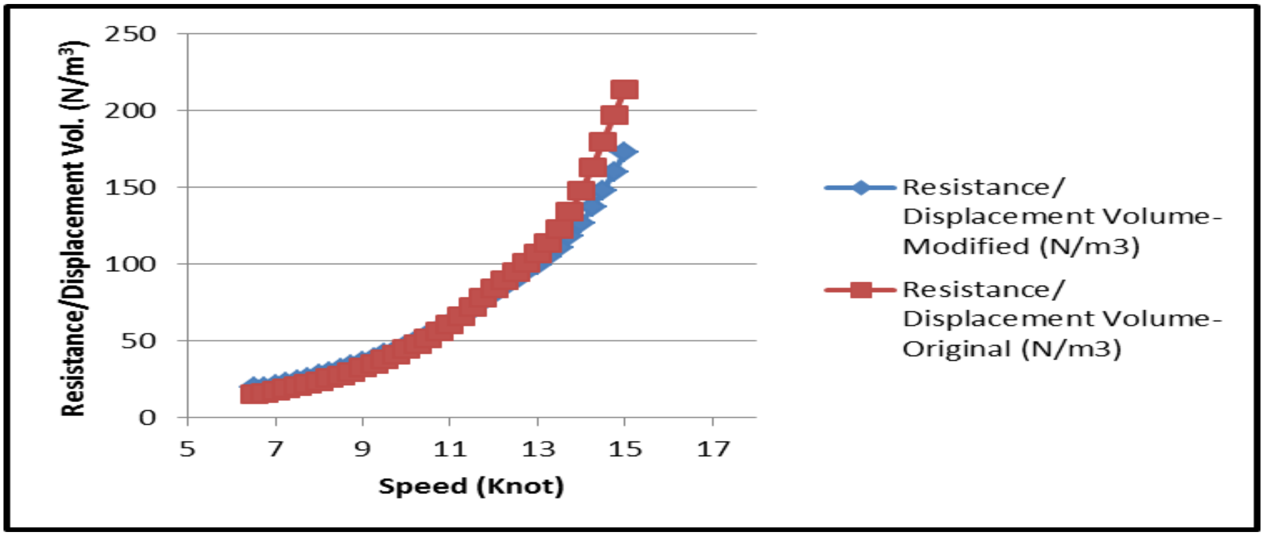


Figure 66: *Resistance/ Displacement Volume Vs Speed Graph for Passenger Ferry*

From Figure 66, we have seen that whereas in original lines plan resistance/displacement volume have found 47 N/m^3 but in modified lines the resistance/ displacement volume value is 44 N/m^3 at 10 Knot service speed. So, the modified lines have given less resistance/ displacement volume than the original one.

In Figure 67, Power /Displacement Volume Vs Speed graph for Passenger Ferry has been shown.

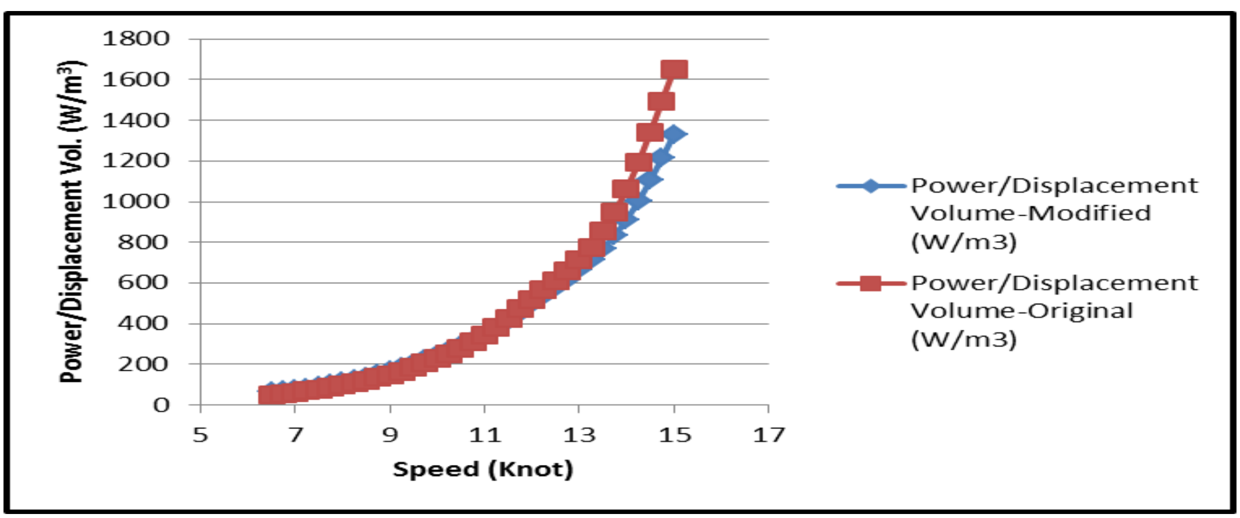


Figure 67: *Power/ Displacement Volume Vs Speed Graph for Passenger Ferry*

From Figure 67, we have seen that whereas in original lines plan required main engine power/displacement volume is 243 W/m^3 but in modified lines the required power/ displacement volume is 243 W/m^3. By original lines plan we have found the EEDI value for the vessel is 66.17 g CO_2/ton mile but the modified lines plan we have found the EEDI value 63.6 g CO_2/ton mile. So, we can say that a better and smooth hull design gives lesser resistance/ displacement volume and hence gives better EEDI values.

Chapter-8

Survey and Verification of the Energy Efficiency Design Index

8.1 Overview

In Bangladesh, there is no verification of EEDI during design stage of inland vessels. Also there are no such procedures to verify EEDI during sea trail stage. A vessel has given EEDI certificate by the flag Administration or International Classification Societies after successful verification of EEDI during sea trail stage. If inland vessels have to comply EEDI then its verification during design and sea trail stage is mandatory. In this chapter, a clear idea of survey and verification of EEDI during design and sea trail stage has been discussed and also a case study of existing Passenger Vessel during design and sea trail has been shown. EEDI verification is carried out by flag Administration or International Classification Society using corresponding data and documents and observing the ship's model tank tests and ship's commissioning sea trials. Full details of the EEDI verification are described in the relevant IMO Guidelines [41]. In this study, a brief discussion of IMO guidelines [41] has been discussed. Accordingly, the EEDI verification takes place in two stages:

- Pre-verification
- Final verification

Pre-verification is done at the ship's design stage whereas final verification is carried out after construction and as part of the ship's commissioning sea trials; at the end of ship construction. Relevant ship design data, tank test data and speed trial data will be subject to scrutiny and verification by ROs.

EEDI verification process has been shown in Figure 68.

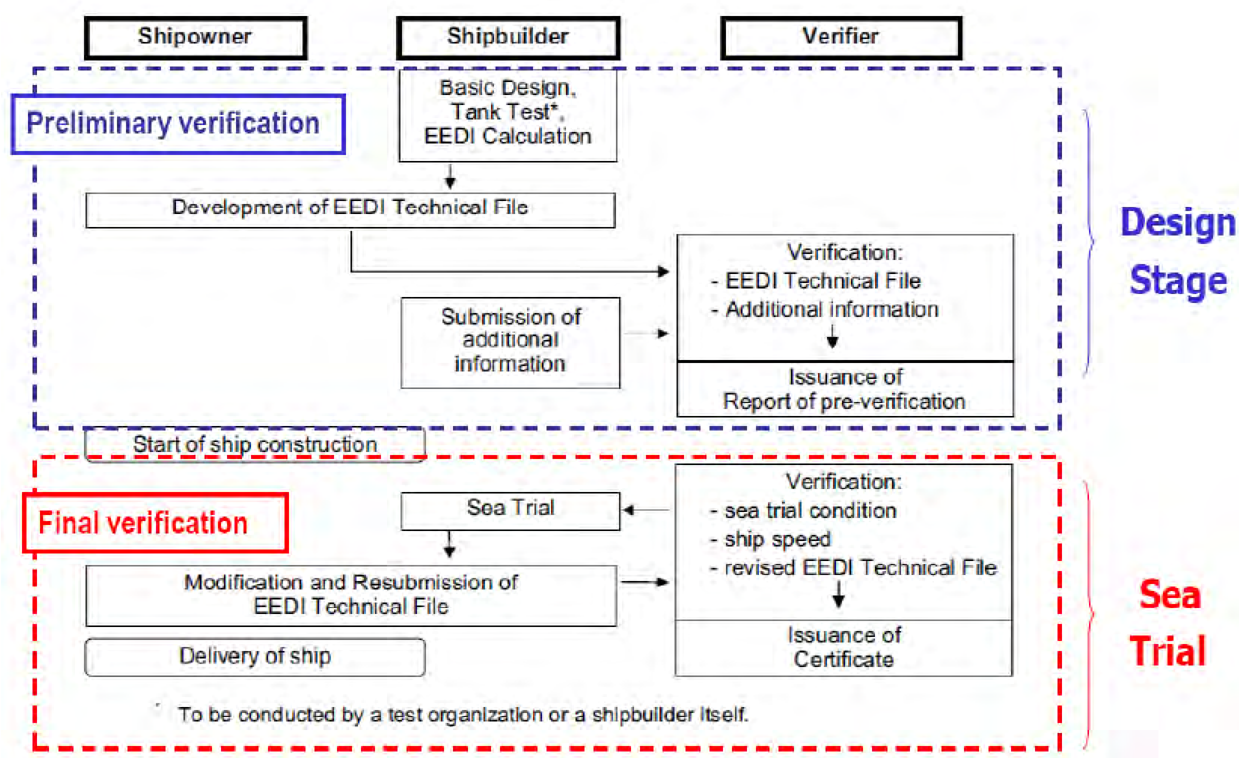


Figure 68: *EEDI Verification Process*

8.2 EEDI Technical File

Calculation of Attained EEDI involves the determination / measurement / calculation of all the terms as identified in Chapter-2 and their verification. Also, determination of Required EEDI is done via formulations provided in Chapter-3. For verification purposes and subsequent implementation and enforcement purposes by flag and port States, it is a requirement that all the relevant terms and their values shall be recorded in an "EEDI Technical File" and then submitted to the verifiers (normally Recognized Organization on behalf of flag State) that will carry out the certification on behalf of flag Administration. Also, the "EEDI Technical File" needs to be kept on board and forms a supplement to International

Energy Efficiency Certificate. IMO in its EEDI survey and verification guidelines [42] have provided a sample "EEDI Technical File". This sample indicates that all data necessary for verification purposes including all the terms defined in Chapter-2 need to be recorded in this technical file.

8.3 Preliminary Verification

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

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

The EEDI Technical File should be developed by the submitter (normally ship designer at this stage) inclusive of all the data required. The content of an EEDI Technical File was discussed in Section 8.2 and will include all the required data for EEDI calculations

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

- Description of the tank test facility including test equipment and calibrations
- Lines of the model and the actual ship for the verification of the similarity of model and actual ship

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

The most important element of preliminary verification is the ship's model tank test. According to IMO guidelines [42]:

"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", upon agreement of the ship-owner and shipbuilder and with approval of the verifier. For ensuring the quality of tank tests, ITTC (International Towing Tank Conference) quality system should be taken into account. Model tank test should be witnessed by the verifier."

8.4 Final Verification

Sea trails and verification of ship's speed-power curve is an essential element of the final verification. As part of the final verification, all relevant aspects of EEDI calculation will be re-visited and verified. Aspects that need to be considered for sea trail are elaborated further here using the relevant IMO guidelines [42]

8.4.1 Sea trials – Observation

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

- Trial plan and test procedure: Description of the test procedure to be used for the speed trial, with number of speed points to be measured and indication of PTO/PTI to be in operation, testing area and method, etc.
- The final displacement table and the measured lightweight, or a copy of the survey report of deadweight. Final stability file including lightweight of the ship and displacement table based on the results of the inclining test or the lightweight check. This will form the basis for verification of Capacity.
- A copy of engines' "NOx Technical File" as necessary.

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

- Propulsion and power supply system.
- Particulars of the engines, and other relevant items described in the EEDI Technical File.
- Draught and trim: Should be confirmed by the draught measurements taken prior to the sea trial.
- Sea conditions: should be measured in accordance with ITTC Recommended Procedure 7.5-04-01-01.1 Speed and Power Trials Part 1; 2014 or ISO 15016:2015 [42].
- Ship speed: should be measured in accordance with ITTC Recommended Procedure 7.5-04-01-01.1 Speed and Power Trials Part 1; 2014 or ISO 15016:2015, and at more than two points of which range includes the power of the main engine as specified in Paragraph 2.5 of the EEDI Calculation Guidelines [42].
- Shaft power of the main engine: Should be measured by shaft power meter or a method which the engine manufacturer recommends and the verifier approves.
- Results of on-board simplified measurement method of SFC: Only if on-board measurements are used for the calculation of SFC of an engine, copy of the measurements and documented calculation of the SFC correction will need to be provided.

8.4.2 Speed Trial: Ship speed-power curve

The main output of the speed trial will be the actual measured ship speed-power curve and its corrected/extrapolated equivalent for the EEDI Conditions. As most of the ships are normally tested under ballast conditions, the speed trial to EEDI

Condition need to be developed through a number of corrections not only for sea and weather conditions but also extrapolated from ballast condition to EEDI loading condition (summer load line draught).

The required corrections for sea and weather conditions will need to be based on ITTC Recommended Procedure 7.5-04-01-01.2 Speed and Power Trials Part 2; 2014 or ISO 15016:2015 standard. The speed adjustment and correction from ballast condition to EEDI Condition plays and important role in an accurate estimation of EEDI. An example of a simplified method of the speed adjustment is given in Figure 69 as is included in IMO EEDI survey and verification guidelines.

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

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

where:

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

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

α_P: power ratio

Figure 69 shows an example of scheme of the conversion to derive the resulting ship speed at EEDI condition at EEDI power.

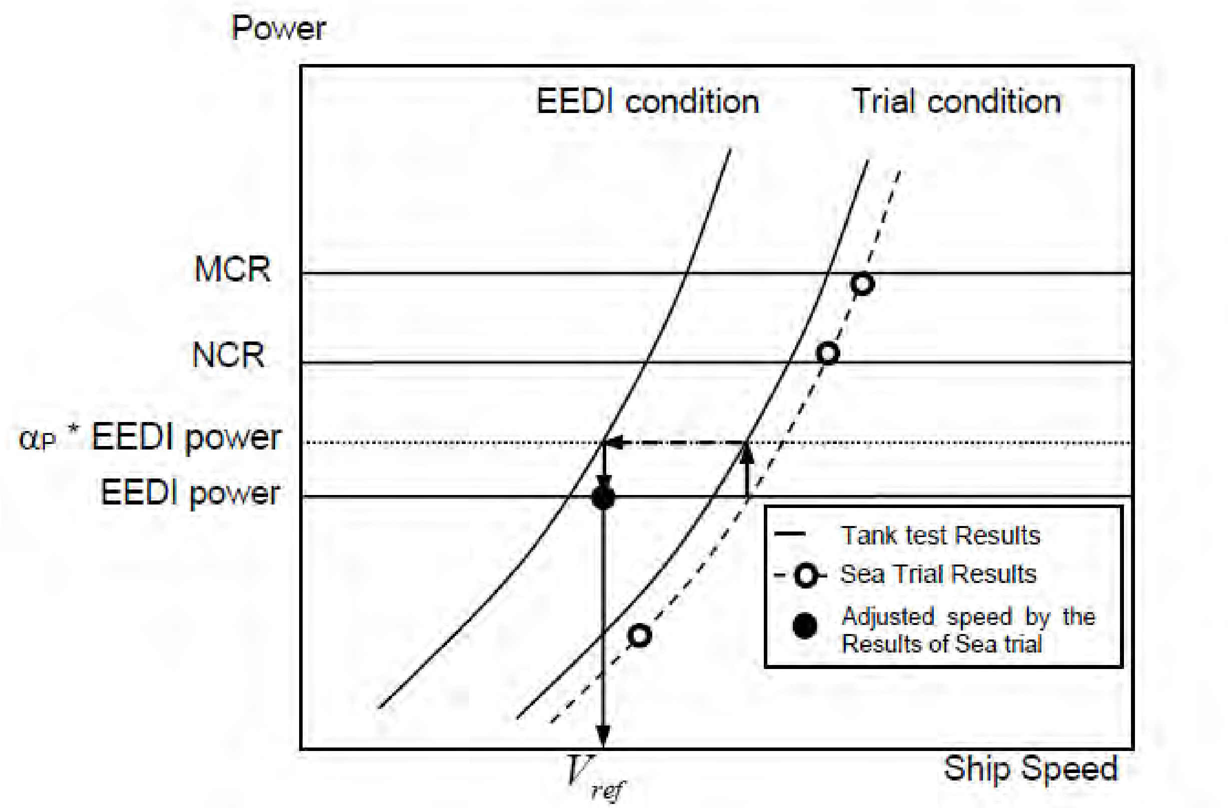


***Figure 69**: A scheme of conversion from trial condition to EEDI condition [43]*

The verifier is required to ensure that both correction and extrapolation of data to EEDI condition is done correctly and accurately. For this purpose, it is required that the full report of sea trials with detailed computation of the corrections allowing determination of the reference speed Vref to be supplied to the verifier. Additionally and to ensure consistency and accuracy, the submitter should compare the power curves obtained as a result of the sea trial and the estimated power curves at the design stage. In case of differences, the attained EEDI should be recalculated.

8.5 Verification of the attained EEDI for major conversions

In case of a major conversion, the ship-owner should submit to a verifier an application for an additional Survey with the EEDI Technical File duly revised based on the conversion made and other relevant background documents.
The background documents should include at least but are not limited to:

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

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

8.6 Case Study-1 (Passenger Vessel)

In Table 37, Ship specifications of Passenger Vessel has been shown.

***Table 37**: Ship Specifications of Passenger Vessel*

Principal particulars

Length Overall	44.32 m
Length between perpemdiculars	38.56 m
Breadth, moulded	9.90 m
Depth, moulded	4.10 m
Summer Load Line Draught, moulded	2.60 m
Gross Tonnage	approx 499

Main engine

Manufacturer	Yanmar Co
Model Number	6EY17W
Maximum Continuous Rating (MCR)	480 kW
SFOC at 75% MCR	202 + 5% g/kWh
SFOC addition for LO pump	3 g/kWh
SFOC addition for cooling water pumps	2 g/kWh
Number of engines	2
Fuel Type	Diesel oil

Ship speed

Service Speed	11.5 knots
Ship Speed at 75% MCR	Approx 12.0 knots

Auxiliary engine

Manufacturer	Yanmar Co
Model Number	4HAL2-TN
Maximum Continuous Rating (MCR)	115 kW
SFOC at 75% MCR	226 g/kWh
Number of engines	1
Fuel Type	Diesel oil

Main generator

Manufacturer	TBC
Model Number	TBC
Rated Output	110 kWe
Voltage	AC 415 V 50 Hz
Number of sets	1

PTO generator

Manufacturer	MeccAlte SpA
Model Number	ECO 38
Rated Output	150 kWe
Voltage	AC 415 V 50 Hz
Number of sets	2

EEDI Result (Design stage)

For the calculation of Pae, the method described in 2.5.6.3 of Annex 8, Resolution MEPC.212 (63), was used since she is a passenger ship.

The attained value of EEDI at design stage= **87.21** g CO_2/ton mile

EEDI Result (Sea trail stage)

Speed Vs power curve during sea trail stage has been shown in Figure 70.

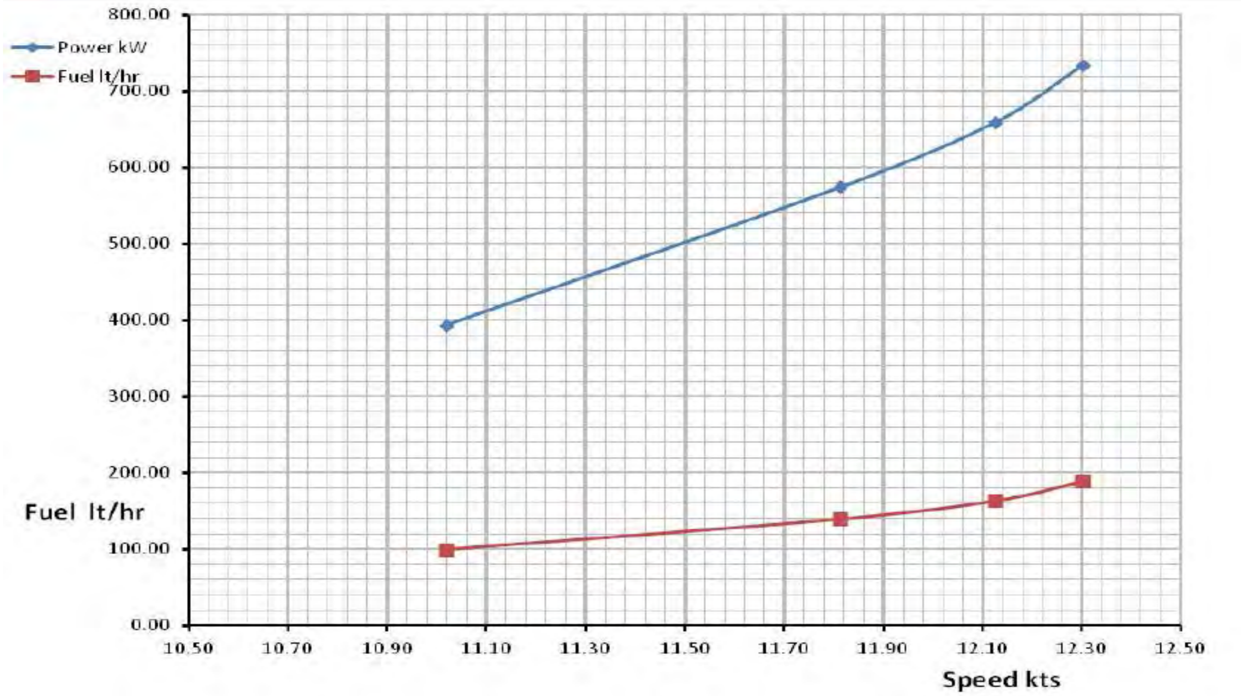


***Figure 70**: Speed Vs Power curve during sea trail stage*

From figure 70 , we ha ve ob served tha t d uring s ea t rail, wi th t he m ain e ngines operating a t 75% M CR, the propulsive power a vailable is 665 K W. F rom the power curve presented above, this is equivalent to a ship speed of 12.5Kt and this value has been used in this calculation. The GT value has been modified from 499, as assumed at the design stage, to 498 as measured. The specific fuel consumption value is 212.9g/KW.hr ha s b een taken f rom pa rent e ngine te st r eport d uring se a trail.

So, the attained value of EEDI at sea trail stage= **84.89** g CO_2/ton mile

From the above we can see that, the attained EEDI value of sea trail stage is lesser than de sign stage. S o, the ve ssel could be provided EEDI c ertificate f rom Authority.

Chapter-9

Future Development

9.1 Introduction

In Chapter 5, we have seen that most of the inland vessels of Bangladesh exceed the proposed reference line value. At present, in exiting vessels of Bangladesh it will be difficult to comply the EEDI rule unless energy efficient technologies will be introduced. It can be used as well as new building vessels to make the vessel more efficient. In this chapter, some energy efficient technologies have been described.

9.1.1 Energy Efficient Technologies

According to the EEDI formula, use of energy efficient technologies gives an advantage by deducting their effect from main engine and auxiliary emissions. As per the formula, recovered power due to the use of such energy saving technologies is subtracted from the main power or auxiliary power, whatever is the case. Thus, using such technologies would reduce the EEDI value. Various energy efficient technologies available are waste heat recovery, wind power, solar power, and nuclear power. Nowadays a lot research has been going on to reduce EEDI value by introducing new energy efficient technologies. Dimitris S. Marantis [44] has studied the improvement of energy efficiency of existing by energy saving devices. Jain [5] has also studied the energy efficient technologies. International Renewable Energy Agency (IRENA) [45] has published an article on Renewable energy options for shipping.

9.1.1.1 Waste heat recovery

Waste heat recovery (WHR) system uses the exhaust gas energy from the waste heat of the engines to drive turbines for electricity production, leading to less fuel consumption by auxiliary engine and increase in the total efficiency of the ship [46]. Technology with power turbines in combination with high-efficiency turbochargers and boilers corresponds to a 10% increase in efficiency and 10% lower fuel consumption and CO_2 emission [46]. If waste heat recovery is combined with NOx reduction methods and scavenging air moisturisation or exhaust gas recirculation, 14% to 18% of engine efficiency can be gained [46].

This system is available in market for last 25 years and thus the technology is quite mature [46]. A WHR system is applied to ships having a high production of waste heat and a high consumption of electricity. Ships with main engines of higher than 20,000 kW power and with auxiliary engines of higher than 1,000 kW power can thus effectively use this system [46].

According to the report submitted by Deltamarin Ltd to EMSA [2] research conducted on 11,350dwt Ro-Ro case ship showed that the technology costs 3.5 million euros (US$ 4.2 million) and it results in fuel saving of 1100 tonnes per annum with 7.5% EEDI reduction.

Waste heat recovery is a proven technology and it can be used on large ships effectively recovering the engine power by up to 18%. This technology has some initial investment but it results in huge savings on fuel thereby reducing operating costs. Moreover, it is also effective in reducing EEDI value greatly. Ship owners should not have any reluctance in opting WHR system to meet the EEDI regulations. But inland waters vessels are not so large in Bangladesh and also it's cost is also high. So, in this perspective it is not an effective solution to reduce EEDI value in Inland waterways vessels of Bangladesh.

9.1.1.2 Wind power

Wind power can be used on ships to assist in ship propulsion using kites, sails and wind engines thereby reducing the fuel consumption of the main engine and thus less CO_2 emissions. It affects the P_{eff} component of the EEDI formula thereby reducing the EEDI value taking advantage of main engine power reduction.

9.1.1.2.1 Towing Kites/Sails

Wing shaped sails are installed on the deck and the kite is attached to the bow of the ship, both of which uses the wind energy to add forward thrust to assist in ship propulsion [47]. Kites can be installed on all type of ships while sails are restricted to only a few types of vessels such as bulk carriers.

Kites are more advantageous than sails because they operate at high altitude where wind speeds are much greater than on the sea surface which allows them to generate five times more propulsion power per square meter of sail than that generated by conventional sails [48] but towing kite works effectively on ships with maximum average speed of 16 knots having a minimum length of 30 m. Due to this restriction on speed, only tankers and bulk carriers are considered as potential users .

Towing kite system has been installed on a small number of commercial sea-going ships including MS Beluga SkySails which is world's first cargo ship partially powered by a computer-controlled kite [49] has been shown in Figure 71.

Till now only kites with up to 640 m^2 area are available but kites up to an area of 5,000 m^2 have been planned. The standard condition for operating such kites is when the vessel is cruising at a speed of 10 knots at a true wind course of 130º with wind speed of 25 knots and waves of up to 60 cm high [50].

***Figure 71**: Towing kite system and wing shaped sails [51 & 47]*

According to the report submitted by Deltamarin Ltd to EMSA [2] research conducted on 11,350dwt Ro-Ro case ship showed that this technology resulted in fuel saving of 700 tonnes per annum with 5% EEDI reduction. Wartsila has estimated that this system could result in around 21% annual fuel savings for tankers and 20% annual fuel savings for car carriers [47].

Price and engine equivalent power generated depends on the area of the kite. A kite with 160 m^2 area can generate 600 kW power while a kite with an area of 320 m^2

can generate 1200 kW power and it costs about 480,000 US$ which increases to 19,200 kW power at 3,430,000 US$ for the kite having an area of 5000 m^2 [50]. Other costs associated with this system include installation cost of 7.5% of the purchase price and a certain percentage of purchase price as operational costs per annum (IMO, Apr 2011). According to Wartsila [47] payback time of kite/sail system is quite high around 12-15 years. Cost details and engine equivalent power generated for kites with different are given in the following table.

***Table 38**: Power and costs for different kite areas [50]*

Kite Area (m^2)	Power (KW)	Purchase price (Thousand US$)	Installation cost (% of purchase price)	Operational cost per annum (% of purchase price)
320	1200	480	7.5%	5-7%
640	2500	920	7.5%	7-9%
1280	4900	1755	7.5%	9-11%
2500	9600	2590	7.5%	11-13%
5000	19200	3430	7.5%	13-15%

Kite system is available in the market and it has been tried and tested on few commercial ships successfully. From ship owners' point of view, though this system has initial capital investment but since it results in EEDI benefit and huge fuel savings resulting in less operating costs, it seems to be a promising technology. On the other hand, an important drawback with this system is that it works effectively only in certain specific weather conditions as explained above which cannot be experienced by a vessel every time it is at sea.

9.1.1.2.2 Wind engines

Wind engines are the rotors placed on deck of a ship which can generate thrust taking advantage of the Magnus effect [50]. Wind engines also called as Flettner rotors are vertical rotors installed on the ship which rotate due to the wind and convert wind power into thrust in the perpendicular direction of the wind which implies that in side wind conditions the ship can benefit from the added thrust resulting in reduced required engine power [47].

According to IMO, Greenwave, a UK-registered charity that helps shipping industry to meet environmental obligations has estimated that crude oil tankers, chemical tankers, product tankers, and bulk carriers more than 10,000 dwt are appropriate to use this system immediately. A four engine system (two forward and two aft) is preferably applicable to bulkers to keep the engines out of the way of cargo holds while a three engine system (centre-line configuration) is applicable to tankers as crane operations are not involved on tankers [50].

This technology can help ship owners with around 30% fuel savings annually as estimated by Wartsila [47]. Greenwave estimates that the cost of manufacturing and installing four wind engines is in the range of US$ 0.8 million to US$ 1 million but operational costs are not known.

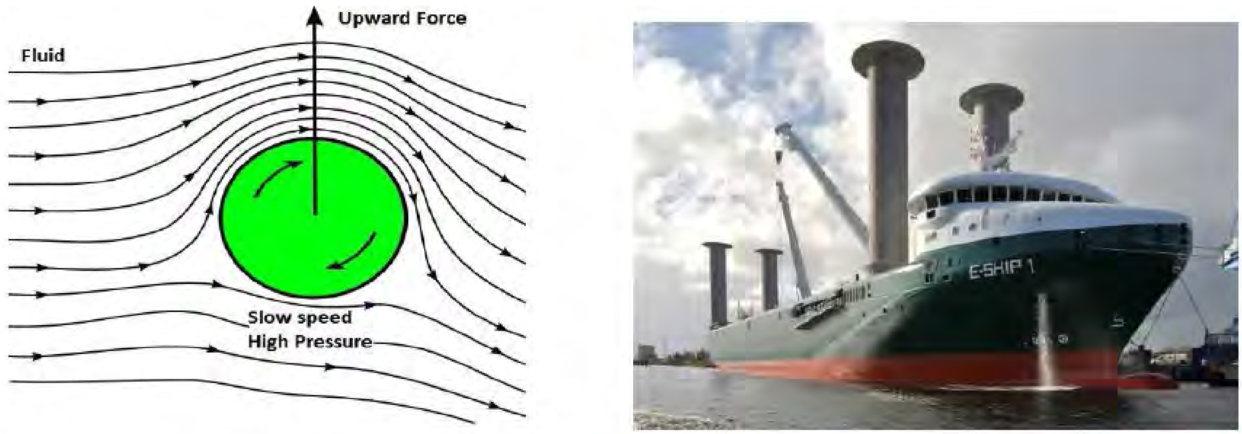


***Figure 72**: Magnus effect and E-ship 1[52]*

Flettner rotor system has been installed on the ship called E-ship 1, shown in Figure 72, which is owned by Enercon, a German wind power engineering company and the system reduces the fuel consumption of this 123m long cargo ship by up to 30-40% [52]. On this ship Flettner rotors are not driven by wind, instead exhaust gas from the diesel engines of the main propulsion is utilized to drive the steam turbine that generates additional electricity which is used to spin four Flettner rotors [52]. On this ship, WHR is used to generate the power required to drive Flettner rotors which in turn reduce the power required by main engine.

This technology has not been used commercially on large scale thus operational costs and problems associated with it are not known. But, if this technology is developed further, it can help ship owners with reduced fuel consumption and reduced EEDI at reasonable costs considering the cost estimate carried out by Greenwave, without any sacrifice to design speed and change in deadweight, parameters which are of paramount importance to ship owners for generating revenue.

9.1.1.3 Solar Power

Use of solar power on ships would benefit in reducing EEDI; reduction factor calculated through the PAE_{eff} component in the numerator of the EEDI formula.

Solar energy can be used on ships based on the solar photovoltaic power generation system [53]. Solar panels can be installed on a ship's deck to generate electricity which can be used for various purposes including electric propulsion engine and auxiliary ship systems and heat can also be generated using solar panels for use on various ship systems [47]. This technology is still under development and present day solar cell technology is such that even if the entire deck area were to be covered with photovoltaic cells, it would be sufficient only to fulfil a fraction of the auxiliary power demand of a tanker ship [54]. It cannot replace the ship's primary power source.
Efficiency of current solar cells is about 13% and the best technology which is used in laboratories and space crafts has an efficiency of approximately 30% while efficiencies are expected to reach 45% to 60% when third generation photovoltaic cells are developed [55].

***Figure 73**: MV Auriga Leader (left) with solar panels (right) installed on deck [56]*

The major drawback with solar power is that it is not available during night-time. Therefore, backup power would be needed or else energy storage system is required [55] on board to store the energy during day time which can be used at night when there is no sun. Another drawback is that solar cells can only be placed on ships that have sufficient deck space available which means that they can only be used on tankers, car carriers and Ro-Ro ships.

Solar panels have been installed on a car carrier, MV Auriga Leader, shown in Figure 73, owned by a Japanese company NYK line. This ship has 328 solar panels installed on its deck which are capable of generating 40 kW auxiliary power accounting for 10% (40kW) of the energy used while the ship is berthed [56]. The investment costs of these solar cells are known to be around US$1.67 million. The International Maritime Organization believes that the cost of solar power may decrease in future when the technology becomes mature and applied to large number of ships.

According to the report submitted by Deltamarin Ltd to EMSA [2] research conducted on 11,350dwt Ro-Ro case ship showed that this technology resulted in fuel saving of only 30 tonnes per annum with less than 0.3% EEDI reduction. Cost of installing solar panels on case ship's deck house having an area of about 600 m^2 came around 0.25 million euro (300,000 US$) [2].

Current state of solar cell technology is not mature enough to convince ship owners to install solar panels on ships. With drawbacks such as unable to use the technology at all times and very poor efficiency, ship owners are not likely to use solar panels on ships. Moreover, considerable amount of investment in solar panels gives only a little EEDI benefit and helps in meeting only a small part of auxiliary power requirement of a ship. This means that if a ship owner uses this technology, there would be an increase in capital cost of the ship, though small but the benefit is almost negligible. If this technology gets further developed and more efficient solar cells at reasonable cost are developed, then it can be considered as a potential technology that might be embraced by ship owners to meet the EEDI regulations.

Chapter-10

Conclusions and Recommendations

10.1 Conclusions:

Having in mind the significance of energy efficiency benchmarking, which already has a huge influence on the global marine shipbuilding industry, this study has been performed on the basis of available data of existing vessels of inland waterways in Bangladesh and the following conclusions can be made on the basis of the study:

- Since the EEDI introduced by IMO for evaluation of energy efficiency of sea going vessels can't be used for proper evaluation of energy efficiency of inland vessels, developed EEDI can be used to calculate required EEDI value for different types of inland vessels of Bangladesh.

- Comparing the formulated baseline equations for EEDI for Bangladesh with the lines formulated by other countries like Denmark & Netherlands, it is found that EEDI for Bangladesh lies much above than that of other countries. For example, Oil Tanker's EEDI reference line value of Bangladesh lies 18% above Denmark's reference line value and 31% above Netherlands reference line value. For Cargo Vessel, EEDI reference line value of Bangladesh lays 67% above Denmark's reference line value and 42% above Netherlands reference line value.

- From the investigation of developed database of inland vessels, it is found that most of the inland vessels in Bangladesh use high main engine power than the required power found from the calculation. This arbitrary engine selection leads to higher EEDI value and thus inland shipping contributes to release higher amount of CO_2 to the environment.

- From the parametric study, it is found that comparatively longer vessel is favorable from the EEDI point of view. A slender hull form, which will create a smaller pressure difference between bow and stern, is more favorable. Also, the value of EEDI decreases with the increase of ship's draft. But while doing this kind of optimization it should be kept in mind that change in draft may have huge impact on inland ships due to draft restrictions in inland waterways.

- The EEDI is particularly sensitive to the service speed as the required power increases by roughly the cube of the variation in service speed. So, reducing service speed will improve EEDI and selection of engine power is from environmental point of view.

- Attained EEDI is decreasing with fuel type which has low carbon content. Thus, using of Liquefied Natural Gas (LNG) as main fuel can significantly reduce the EEDI.

- When the block coefficient of the vessel is reduced then the capacity as well as required power is also reduced and it leads to a significant reduction in fuel consumption and thus improves EEDI.

- To reduce CO_2 emission by inland shipping, regulatory authority may introduce EEDI certificate for preliminary verification at design stage as well as final verification after necessary test and trail. This study could provide a vital guideline to implement such regulation in future for inland vessels in Bangladesh.

10.2 Recommendations

- Strict laws should be enforced by government authorities to comply the EEDI rule in design stage which will reduce the arbitrary engine selection in Bangladesh.

- To cope with the modern world energy efficient technologies like waste heat recovery system, wind power, wind engine, solar power could be introduced in Bangladesh which will lessen the EEDI value.

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