ENERGY EFFICIENCY OF SHIPS: WHAT ARE WE TALKING ABOUT?


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How do you measure ship efficiency?
What is the best metric?
What is the potential for regulation?

CONTEXT

In July 2011, the International Maritime Organisation (IMO) adopted the 'Energy Efficiency Design Index' (EEDI), which sets minimum energy efficiency requirements for new ships built after 2013 (in terms of CO_2 per ton capacity-mile). The target requires stepped efficiency improvements of between 10 and 30 per cent between 2013 and 2025. The EEDI is the first globally binding climate measure and sets energy efficiency parameters for the design of new ships. Such a measure is long overdue; design speeds, the beam (the width of a ship) and Froude number (the speed-length ratio) of ships built in recent decades have all generally increased often resulting in the only improvements to ship efficiency being due to economies of scale.

In addition to implementation loopholes and the potential for delays in the EEDI, there is a growing realisation that the EEDI alone may not drive the adoption of the most efficient available technologies. There are already a number of ship technologies on the market, which are substantially below the 2025 EEDI target but the EEDI does not require their adoption leaving potential improvements unrealised.

Arguably the biggest drawback of the EEDI is that it only applies to new ships. Discussion took place at the IMO during the 63rd session of the Marine Environment Protection Committee (MEPC 63) on the merits of applying the EEDI requirements to existing ships as a way to set a benchmark measure of fleet efficiency. This proposal was ruled out although recognition that action is needed to reduce emissions from all ships led for calls at MEPC 64 for "immediate measures" starting with ways to measure fuel burn and possibly later the development of additional efficiency measures.

This paper investigates opportunities to establish such a benchmark measurement, studies different metrics and proposals already under consideration at the IMO or in the EU and identifies possible options in the current EU discussions on monitoring, reporting and verification.

FUEL CONSUMPTION, CO_2 EMISSIONS AND ENERGY EFFICIENCY

Fuel consumption: The most direct measure of the energy use of a ship is its fuel consumption which can be established by different methods: by calculating consumption on the basis of oil record books / bunker delivery notes, by using on-board fuel flow meters for the main and the auxiliary engines, by sounding the tanks, etc. Accuracy depends highly on the type of equipment used. While modern fuel flow meters and tank sounding systems (radar/electric) can be highly precise even given the wide range of fuel characteristics (e.g. fuel density, viscosity, etc.), methods relying solely on written documentation (oil record books and bunker delivery notes) are more questionable.

CO_2 emissions: CO_2 emissions are directly proportional to fuel consumption: the amount of CO_2 emitted by a ship is generally calculated on the basis of its fuel consumption by applying an emission factor. Fuel mass to CO_2 mass conversion factors have been established at the IMO for marine diesel, light and heavy fuel oils, liquefied petroleum and natural gas. As a result, the formula to calculate CO_2 emissions is very simple: fuel consumption multiplied by carbon conversion.

Energy efficiency: The energy efficiency of a ship depends not only on its fuel consumption but also on the amount of transport work undertaken and the level and intensity of activities, etc. Indeed, efficiency is defined as being "the difference between the amount of energy that is put into a machine in the form of fuel, effort, etc. and the amount that comes out of it in the form of movement" (Cambridge Dictionary). Limiting the monitoring requirements to fuel consumption only would inform one part of the equation (the 'input', i.e. the amount of energy used) without considering the output produced by the combustion, which can be calculated in the case of shipping in terms of distance sailed, available capacity, cargo carried, ship speed, etc.

TECHNICAL AND OPERATIONAL EFFICIENCY

There is an important nuance to be drawn between design efficiency and operational efficiency, as these two approaches refer to different measurements. Design efficiency (also known as technical efficiency) is based on the current state of engines and equipment, including the ship's design while operational efficiency varies according to actual fuel consumption under operational conditions and the transport work done. The two approaches do not only reflect methodological differences in establishing the ship efficiency but also represent fundamental differences in what is measured (and then compared).

Technical efficiency – the EEDI: The EEDI calculation reflects the theoretical design efficiency of a new-build ship and provides an estimate of CO_2 emissions per capacity-mile. Its calculation is based on assumptions regarding the specific fuel consumption of the engines (in g/kWh) compared to the power installed on the ship. The full EEDI formula (detailed in MEPC.1/Circ.681) includes several adjustments and factors tailored to suit specific classes of vessels and alternate configurations and operating conditions, but in a nutshell, the formula can be summarised as shown below.

For new ships, the EEDI represents a measure of the "design" efficiency of the ship, but it does not give any indication concerning its operational efficiency. In this respect, two sister ships with the same EEDI may have different emissions depending on their load factor, sea conditions and the way the ship is operated. The EEDI is a static figure, unless the ship undergoes a major conversion.

$$EEDI = \frac{\text{Power installed} \bullet \text{Specific fuel consumption} \bullet \text{Carbon conversion}}{\text{Available capacity} \bullet \text{Speed}}$$

Operational efficiency – the EEOI: The IMO has also developed the Energy Efficiency Operational Indicator (EEOI), an indicator that provides information concerning the efficiency of the ship in operations. The calculation is based on an individual vessel's fuel consumption and data on the achieved transport work (e.g. cargo mass, number of passengers carried, etc.) resulting in a figure of CO_2 emissions per ton nautical mile. The full EEOI equation is contained in the circular letter MEPC.1/Circ.684 and can be summarised as shown below.

Unlike the EEDI, the EEOI is not limited to new vessels and can be used to measure the 'real' efficiency of a ship in operation and to gauge the effects of any changes, such as hull and propeller cleaning, slow steaming, improved voyage planning, etc. The EEOI can be improved by increasing the amount of cargo transported or by applying any measure aiming at reducing fuel consumption (e.g. slow steaming, vessel modifications, weather routing, etc.). However, as the EEOI calculation depends on ship activities and operations, it will vary, possibly considerably, over time and between voyages. It cannot therefore be used to establish a fixed figure – e.g. a 'label' reflecting the on-going performance of a vessel.

$$EEOI = \frac{\text{Fuel consumption} \bullet \text{Carbon conversion}}{\text{Distance sailed} \bullet \text{Cargo transported}}$$

Application of efficiency metrics: The EEDI was formally adopted by the IMO in July 2011 and applies to new ships built from 2013 onwards. During MEPC 63, some parties took a strong position against the application of the EEDI formula for existing ships and this view was endorsed by the Committee. The application of the EEOI remains non-mandatory but the EEOI has also now been included in the Ship Energy Efficiency Management Plan (SEEMP), as a possible index to verify and measure the SEEMP effectiveness. While the IMO decided not to use the EEOI indicator as a basis for regulation, the United States proposed (MEPC 64/5/6) to measure in-use or 'attained' ship efficiency essentially by using the EEOI formula. There is strong opposition from industry to making the EEOI indicator mandatory because some of the required data may be commercially sensitive (load factor, etc.) or because the blunt comparison of ships carrying very different types of cargo may be misleading. However the underlying resistance is most likely to be based on industry's strong aversion to their operations being regulated especially if this might lead to performance comparisons being made public.

ESTIMATING THE CO_2 EMISSIONS OF THE EXISTING FLEET: THE EVDI APPROACH

In an attempt to develop a single efficiency metric, the Carbon War Room, together with Rightship, developed the Existing Vessel Design Index (EVDI). The EVDI is based on IMO's EEDI methodology and can be calculated directly from the IHS Fairplay database (the IMO's EEDI reference line input database). The EVDI formula therefore replicates the EEDI formula (although Rightship has not divulged certain key elements of its calculations).

The main and significant difference between the EEDI and the EVDI concerns data collection. EEDI data is collected from the design data of new ships via classification societies at the time of certification, while EVDI data for existing ships is extracted from whatever data is available (such as IHS Fairplay, ship yards, classification societies) and may eventually be verified/corrected by ship-owners or ship operators if they so wish. EVDIs have been retrospectively calculated for over 60,000 existing vessels and these are available online. Their accuracy has been challenged in many cases possibly often more as a point of principle, i.e. an objection to applying the EEDI to existing ships.

IS IT POSSIBLE TO DEVELOP A SINGLE ACCEPTED METRIC?

At the moment, there is no single accepted efficiency metric that could be used for all ships to allow a clear and uncontested benchmarking of the entire fleet. Despite the lack of guidelines on energy efficiency measurement, parts of the shipping industry have developed voluntary approaches to measure ships' fuel consumption while public authorities rely on emissions models to establish shipping GHG inventories. Interestingly enough however, some ship-owners have already asked for the EEDI certification of their entire fleet (i.e. including the existing fleet) in order to take more informed business decisions in the future. This is for instance the case of Hapag-Lloyd, whose entire fleet has been EEDI certified by Germanischer Lloyd.

The need for a harmonised approach to measure ship efficiency is nevertheless becoming more apparent both within the sector (in order to drive best practice and lead to more informed business decisions from ship-owners, cargo owners, fleet managers, etc.), from regulators as an indicator of ship performance and possibly as the basis of an efficiency regulation. A single efficiency metric would also have the potential to serve as a clear benchmark of vessel energy efficiency. Upcoming discussions at the IMO and in the EU on shipping efficiency should seriously consider this issue.

WHAT ARE THE COMMON ELEMENTS OF THE EEDI, EEOI, AND EVDI?

It is interesting to note that all these three metrics are expressed in grams of CO_2 per ton nautical mile (g/tnm). They all refer to fuel consumption (or CO_2 emissions) and in one way or the other also relate to distance and capacity. However, the similarities stop here and there are major differences in the way EEDI, EEOI or EVDI estimate or calculate fuel consumption, distance, and capacity.

- **Fuel consumption** (calculation vs. measurement): In the case of the EEDI and the EVDI, fuel consumption is calculated using data on the typical fuel consumption of certain engine types, depending on the age and the power range of the engine and on the fuel consumption at a specified engine load (e.g. 75 per cent for main engines). The EEOI is based on the actual reported fuel consumption of ships.
- **Distance** (design speed vs. distance sailed): The EEOI is based on the actual distance travelled. The EEDI and EVDI indirectly calculate the distance by using the design speed of the ship. By knowing the emissions of the engine to produce a certain amount of power over time (gCO_2/h) and the design speed (distance/h), it is possible to calculate the gCO_2/distance.
- **Capacity** (used capacity vs. available capacity): Ship capacity is considered very differently between the EEDI/EVDI and the EEOI. The capacity calculated for the EEOI is the used capacity (i.e. the amount of cargo transported or load factor), while the EEDI/EVDI relate solely to the available capacity (i.e. the deadweight of the ship).

	Fuel consumption	Distance	Capacity
EEDI	Engine power and specific fuel consumption	Design speed	Available capacity (deadweight)
EEOI	Actual reported fuel burn	Actual distance sailed	Used capacity (cargo transported)
EVDI	Engine power and specific fuel consumption	Design speed	Available capacity (deadweight)

As a result, EEDI and EVDI metrics calculate average / theoretical CO_2 emissions per ton capacity per nautical mile, while the EEOI measures real CO_2 emissions per ton transported per nautical mile. The equivalent comparison for road vehicles would be the rated fuel efficiency of new cars in gCO_2/km (test cycle) versus actual on-road performance.

HOW TO COMPARE SHIP EFFICIENCY?

One of the main benefits of establishing an energy efficiency indicator for the entire fleet would be the possibility of comparing the performance of different vessels enabling the sector and operators to make more informed decisions concerning which ship to charter, for which type of journey, etc.

Except for the EEDI, all options presented so far are not based on any reference lines that could be used to set efficiency targets. Establishing a historical or reference line for the entire sector, for different ship types, or ship sizes, could potentially minimise the data needed to make comparisons for example of fuel consumption / CO_2 emissions, distance sailed.

For instance, the EEDI reference lines were developed to reflect the average EEDI values for ships built between 1999 and 2009, differentiated by ship size (deadweight). If all ships were required to report their emissions, these figures could then be compared to the reference line to see how much the ship's actual performance differed from the historical reference. Another possibility to establish a reference line would be to monitor average emissions per ship type, or ship size over a reference year in order to set an efficiency target. So far there has been little discussion about efficiency comparisons or benchmarking, but this should be explored further. The main advantage of these two options is the possibility to set aside the question of capacity (as average load factor will be deemed to be constant).

AN EU MRV FIT FOR PURPOSE

The European Commission recently decided to step back from introducing a proposal to directly regulate CO_2 from European shipping and will instead, as a first step, establish an emissions monitoring, reporting and verification scheme (MRV). This announcement was a great disappointment as it effectively postpones action to address the issue of shipping emissions. The precise requirements to be contained in the EU MRV scheme are not yet known and the legislative proposal is not expected before the first quarter of 2013. The following table explores 5 possible efficiency metrics that the EU could adopt and assesses each of them as well as the type and amount of data that would be required.

Data collection and possible metrics from an EU MRV

Type of data required	Data required	Potential measures / use of the data: A	B	C	D	E
Ship information **Emissions** (per voyage)	IMO number Ship category Last port of call EU port of destination Position (GPS, AIS, LRIT?) Fuel burn and info on fuel quality (to determine the CO2 EF) *or* Directly measured emissions to air	Minimum data requirement. Can be used for a MBM, an EU GHG inventory or an emission target. Insufficient to develop a ship efficiency measure. metric: **absolute CO2 emissions**	Data from columns A & B. Gives first idea of ship efficiency - though limited to emissions per distance. No additional reporting required. metric: **CO2/nm**	Data from columns A,B&C. Measures a ship's efficiency based on its total capacity. No additional reporting requirements metric: **CO2/dwt tnm**	Data from columns A,B,C&D EEOI (full operations data) Calculates the efficiency of *operations* per voyage metric: **CO2/tnm**	EEDI metric: **CO2/tnm (available capacity)**
Activity	Distance (last port / to next port) Number of voyages					
Available capacity	Deadweight					
Operation	Cargo quantity (tons, TEU, PAX) Type of cargo Load factor / ballast leg Weather conditions					
Designed efficiency	EEDI calculation (i.e. Power, consumption, capacity, design speed)					
Additional data	Journey time or average speed	Journey time plus distance = average speed. Speed information critical to understand variations in emissions over time.				

The specific details of the EU MRV are yet to be made public, but it is our understanding that the system will be based on port-state control and would therefore require fuel consumption data for voyages to EU ports (and potentially originating from EU ports) during the reporting period. Emissions would presumably be measured on a ship-by-ship basis, for all types of ships and for the entire journey. For all options, fuel consumption can be continuously monitored on-board using fuel flow meters, tank soundings, etc. Another approach would be to directly collect emissions data at the stack through the use of direct continuous emissions monitoring systems. This latter approach would also allow the creation of a single framework to measure all pollutants at the stack (including for example SOx, NOx and PM emissions).

OPTION A: This is the simplest option and consists of collecting static ship information (e.g. IMO number, etc.) and emissions data (either by requiring a monitoring of fuel consumption or by measuring air emissions directly at the stack). While absolute CO_2 emissions data can be used for establishing an MBM, an EU GHG inventory or an emissions reduction target, it will not be sufficient to develop a ship efficiency measure.

OPTION B: This option constitutes the first step to a measurement of ship efficiency. It reports the CO_2 emissions according to the distance sailed over the reporting period. The metric would be CO_2 emissions per nautical mile. This approach does not necessarily require additional data, as the distance between the last port and the EU port is known (a fixed distance could be used which could be corrected for actual distance if necessary by the ship operator).

OPTION C: This compares emissions to available ship capacity (deadweight). In this case, emissions will not only relate to CO_2/nm but also to the capacity (size and available volume) of the ship. This formula will require data on capacity that can be obtained from the deadweight of the ship. Again additional reporting is not required as information on the deadweight of ships is publicly available. This option seems to be the best alternative between an approach based on CO_2 emissions 'only' and a complete operational index such as the EEOI.

OPTION D: This indicator replicates the EEOI formula and goes beyond the previous metric based on available capacity by taking into account the actual utilisation of the ship's capacity. Results will clearly differ if the ship is fully loaded or in ballast. Additional reporting of cargo loaded and load factor data is required and some of this information may be commercially sensitive. Different variations are nevertheless possible, e.g. data could be corrected only for the ballast legs. In order to fully reflect operating conditions, data on weather and sea conditions could be added.

OPTION E: The last metric presented in the chart would require the EEDI calculation for all ships, which may be controversial in light of the recent IMO decision. This metric would not reflect emissions from ships in operation, but rather their design efficiency.

Finally, additional data could be included in the reporting system to provide greater clarity on the efficiency measurements. For instance, comparisons of ship efficiency using the above approaches could be quite misleading if there was no correlation with actual ship speed; two ships might be equally efficient and fully laden but the slower ship will have better efficiency and lower emissions. The speed element could be incorporated in any of the above-mentioned options by requiring the reporting, for example, of AIS or LRIT position data or the elapsed journey time (to be combined with the known distance from last port), or simply by requiring average speed to be reported.

Voluntary measurement of ships' efficiency is already common practice in the industry. However, there is no single politically accepted efficiency metric to benchmark the entire fleet. The need for a harmonised approach to measure ship efficiency is nevertheless becoming more apparent within the sector, for policy makers and to become the basis of an efficiency regulation. Upcoming discussions at the IMO and in the EU on shipping efficiency should seriously consider the adoption of a single efficiency metric as a first step towards a strategy for in-sector GHG reductions.

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