Green policies, legislation, and optimisations for the green transition of shipping

MAN Energy Solutions
Future in the making

Contents

Introduction

Shipping was one of the first industries to be subject to global legislation. At first the legislation focused on safety, stability, and survivability. Later, it was expanded to include protection of the marine environment, followed by air pollution regulations, and ultimately regulations to limit global warming.

Global warming is a global challenge, and many industries presently experience the effect of the first steps towards global legislation on their operation. They have to become accustomed to thinking with a global perspective, something which is already well known to the shipping industry. Shipping is a global industry, and global regulations have been the most predominant for decades.

However, more work on the IMO international legislation framework is urgently needed to provide tangible incentives for owners to move faster towards using the more expensive fuels and solutions required to reduce the impact of greenhouse gas emissions (GHG) from operation of both new ships as well as ships in the existing fleet.

The IMO carbon intensity indicator (CII) is the latest addition, contributing to the recently revised IMO ambition to reach net-zero GHG by the middle of the century, i.e. close to 2050. To ensure that this ambition can be achieved, checkpoints for the reduction of GHG emissions relative to 2008 have been established. At least 20%, striving for 30%, in 2030, and at least 70%, striving for 80%, in 2040 [1]. This means that serious steps must be taken already now to reduce the GHG emissions from ships entering the fleet.

Besides IMO, other legislators' pursuit of combatting global warming has made shipping face regionally differentiated legislation. The Fit for 55 package has introduced regional legislation to shipping in the European Union, both as a regulation of the carbon intensity of the fuel used on board ships by the FuelEU Maritime [2], and of the actual carbon dioxide emissions from the funnel by including shipping in the EU emission trading system (ETS) [3], including emissions of methane and nitrous oxides from 2026.

As outlined in this paper, the scope and extent of the various regulations of carbon dioxide emissions from shipping varies, i.e. CII, FuelEU Maritime, and EU ETS. The variation introduces different optimisation needs, both for the ship design and the operation of the ship.

However, they have one thing in common: energy efficiency is paramount. The fuel contributing the most to the transition of shipping towards net-zero operation, is basically the fuel not used. And the fuel with the lowest greenhouse warming potential (GWP) is likely the most expensive one.

Thus, energy efficiency will not only be of top priority from a legislative compliance perspective, but also in a commercial aspect. Alternative zero or net-zero carbon emission fuels are expected to be significantly more costly compared to present-day fossil fuels.

The next chapter outlines the differences in scope and the impact of the various legislation schemes towards optimisations, followed by a highlight of different efficiency-improving technologies:
- shaft generators / power take-off
- battery hybrid systems
- waste heat recovery
- air lubrication systems
- wind assisted propulsion
- aft ship optimisations.

Special attention will be given to the integration of these technologies into the propulsion system, and to the future development focused on increasing the overall plant efficiency, in which the two-stroke main engine will remain as the backbone. The aim is to pave the way for the most feasible and cost-effective green transition of global shipping.

All the technologies are at a stage where the first pilot plants have been constructed, tested in service, and quite a few have also been widely applied across newbuilding projects. This paper describes our experience with these systems, and presents vital considerations regarding the impact on the propulsion plant layout, and reflects on the learnings attained in recent years.

Legislation extent and scope of design and operation

Design compliance

IMO requirements towards the technical design capabilities of a ship design have been in place for decades. In relation to the propulsion plant, a regulation towards the manoeuvring capabilities was also introduced. Regulations on NO_X and SO_X emissions came later, and in the past decade the energy efficiency design index (EEDI) saw the light of day.

MAN B&W two-stroke engines are designed to match and comply with this legislation to attain design compliance. Adjustments are continuously performed to offer shipyards viable engine selections for various phases of the EEDI. Functionalities like the dynamic limiter function (DLF) [4] and the adverse weather condition (AWC) functionality [5] are examples of development measures taken in response to the EEDI. These ensure that also low-powered, EEDI-compliant ships have sufficient acceleration capabilities, and that they can attain compliance with minimum propulsion power requirements [6] by extending the engine load diagram.

Until now, these regulations have been imposed on a single design level, as illustrated in the left part of Fig. 10.1. Once verified in the design and demonstrated on sea trial, compliance with these regulations has been in place for the lifetime of the ship. Later, the existing ship energy efficiency design index (EEXI) was introduced to cater for the existing fleet of high-powered ships.

Operational compliance schemes
To limit the emission of carbon dioxide, the legislation now transitions from considering design compliance only, towards also setting requirements to and evaluating the actual operation of the ship. Both globally for the individual ships, and in some regional cases for a fleet as a whole, as outlined by the three different schemes:

- IMO CII
- EU emission trading system
- FuelEU Maritime.

IMO CII
The CII [7] is a prime example of a regulation on energy consumption of ships in service. The CII rates ships (Fig. 10.2) according to the annual carbon dioxide emissions divided by the annual transport work performed, expressed as the deadweight tonnage multiplied by the distance travelled.

Fig. 10.1: Design and operational compliance scheme grouped

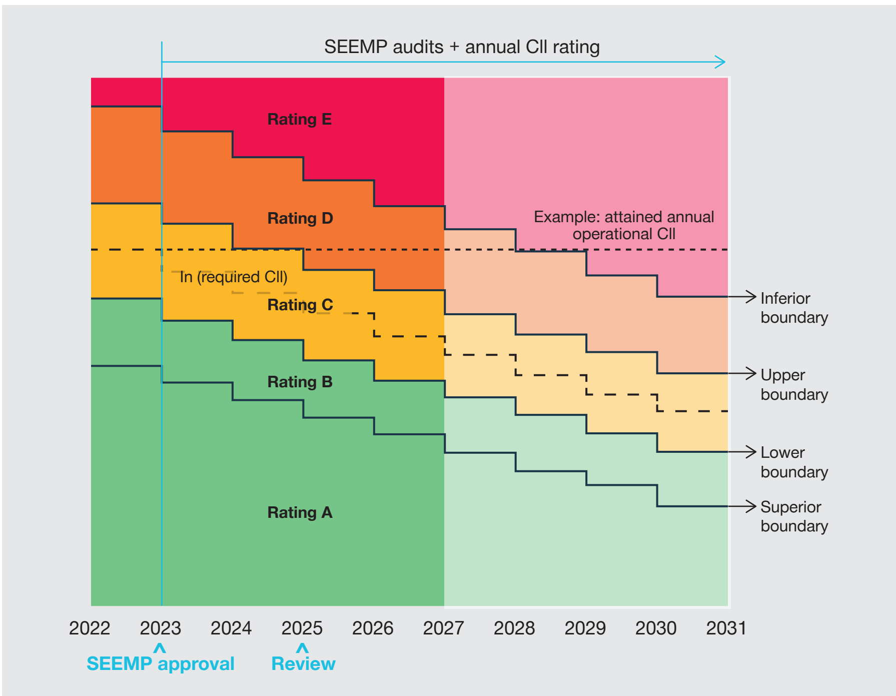

Fig. 10.2: CII and ratings. Reductions to 2027 agreed, reductions beyond 2027 are to be agreed by the 2025 review. MEPC.338(76)

Reductions are evaluated by comparing with 2019 as the basis, and tightened by 2% annualy until 2026, after which further reductions are to be decided, see Table 10.1.

Year	2023	2024	2025	2026	2027
Reduction from 2019	5%	7%	9%	11%	To be decided

Table 10.1: CII reduction rates relative to 2019

The CII considers emissions on a tank-to-wake basis for the individual ship, see Fig. 10.3 and Eq. 10.1.

$$\text{CII} = \frac{\text{Annual fuel consumption} \times \text{C}}{\text{Annual distance travelled x capacity}} \times \text{Correction factors}$$

Eq. 10.1: Calculation of the CII

Hereby, the CII rating expresses the actual fuel consumed, the carbon emitted, and the individual distance travelled. In this scheme, on-board efficiency is important, since a reduction of the fuel consumed directly impacts the rating attained. Likewise, the carbon content of the fuel used has a direct effect on the attained CII.

Thus, a strict tank-to-wake approach implies that the CII rating will not improve by operating on biodiesel. A tank-to-wake approach only considers emissions from burning the fuel on board and not any carbon uptake, nor emissions, from the production of the fuel.

However, at its 80th meeting, the IMO MEPC agreed to allow accounting for biofuels in the CII in accordance with the following conditions:

- If the biofuel demonstrates a certifiable GHG saving of minimum 65% compared to fossil MGO, the carbon factor (Cf) of the biofuel can be multiplied by 0.35.
- If the GHG saving is documented to be higher than 65%, the Cf can be reduced accordingly.
- The GHG saving must be certified by a certification scheme recognised by the International Civil Aviation Organization.

This interim guidance for biofuels will be rewoked when IMO has finalised and agreed on guidelines on how to perform life cycle analysis (LCA) of fuels. Establishing a life cycle guideline is part of establishing the IMO mid-term measures, to avoid shifting emissions to other sectors, and these are expected to be in place by 2027.

EU ETS

In the EU ETS, the extent of compliance is in itself not rated, nor limited to the individual ship. In principle, EU ETS is based on the emissions from burning the fuel

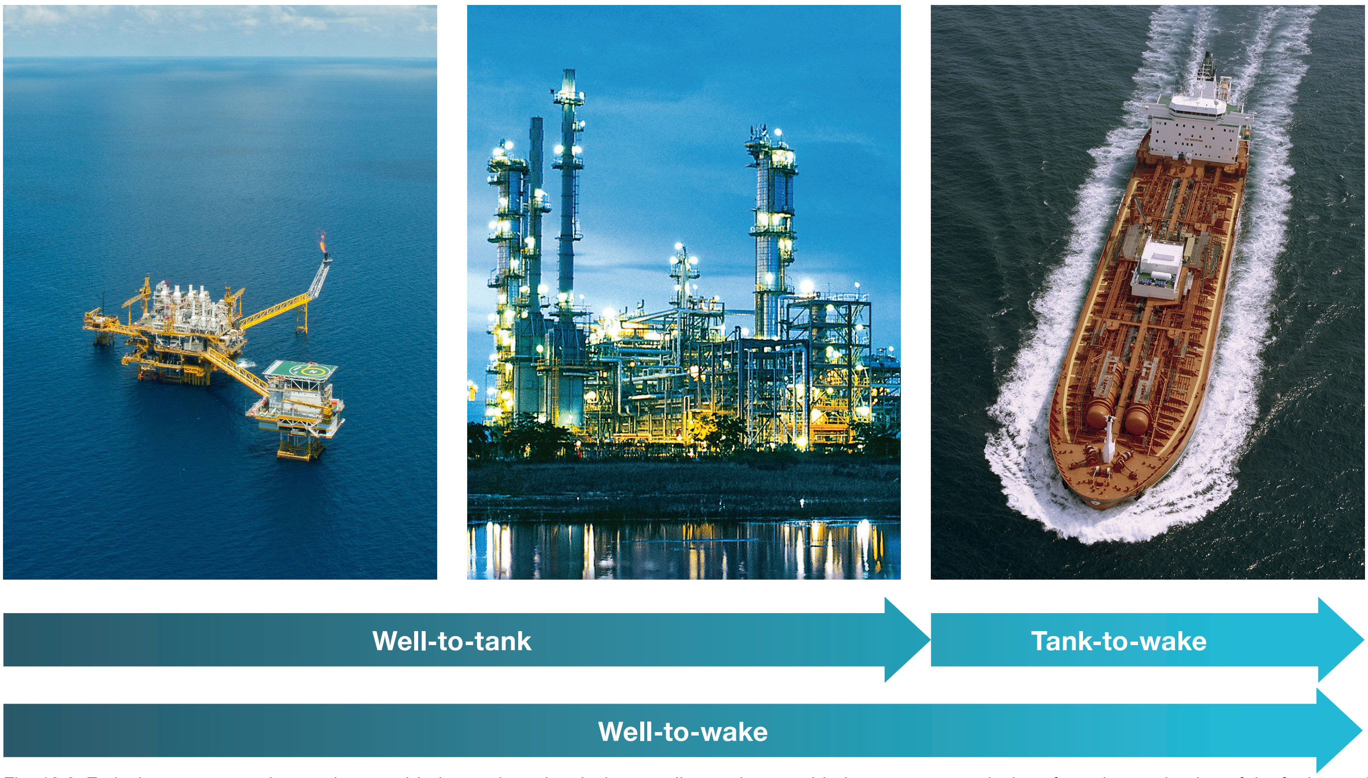

Fig. 10.3: Emission scopes: tank-to-wake, considering on-board emissions, well-to-wake, considering upstream emissions from the production of the fuel as well

onboard, similar to CII. However, the carbon dioxide emissions from use of biofuels and renewable fuels of non-biological origin (RFNBOs) will count as zero if the fuels comply with the criteria for sustainability and minimum GHG savings as defined in the Renewable Energy Directive.

The higher the emissions in the scope of the EU ETS, the higher the need for buying quotas. The emission quotas can be bought from other owners or industry segments. This again also makes efficiency important, either reducing the need for buying quotas or possibly even allowing trading with excess quotas. The EU ETS covers 100% of emissions on all intra-EU voyages and 50% of incoming and outgoing voyages.

The possibilities for transferring or trading quotas imply that the optimisation targets for a fleet of ships with the same holder of document of compliance (DoC), i.e. owner, differ from an individual ship-level compliance scheme, as the CII.

As for the EU ETS, it may be sensible to invest in efficiency-improving technologies for the ships with the highest energy consumptions. For these ships, the abated CO_2, relative to the investment, may be higher than for ships with a lower energy consumption. The CO_2 abated at relatively low cost on ships with a high energy consumption can be used to cover for potential excess emissions of smaller ships. However, it must be considered that the CII of these is evaluated individually.

Therefore, when exceeding compliance regulations, the potential for trading non-used emission quotas needs to be evaluated before investing in efficiency improvement technologies, since they might greatly boost the benefits of emission reductions.

FuelEU Maritime
FuelEU Maritime uses a well-to-wake (WtW) basis, see Fig. 10.4, for evaluating, not the amount of energy used on board, but the greenhouse gas (GHG) intensity of the fuel used on board – on a fleet level. The WtW values established by the EU have been proposed towards the IMO as per [8].

The legislation package set by the FuelEU Maritime is extensive and will not be described in detail here. In essence, the legislation seeks to reduce the GHG intensity of the fuel used on board by the values mentioned in Table 10.2, to promote the uptake of alternative fuels with a lower GHG intensity in a well-to-wake perspective.

To promote the uptake of alternative fuels further, a multiplier of two towards reductions of GHG intensity attained by sustainable e-fuels (RFNBOs) is implemented, valid in the years of 2025-2033.

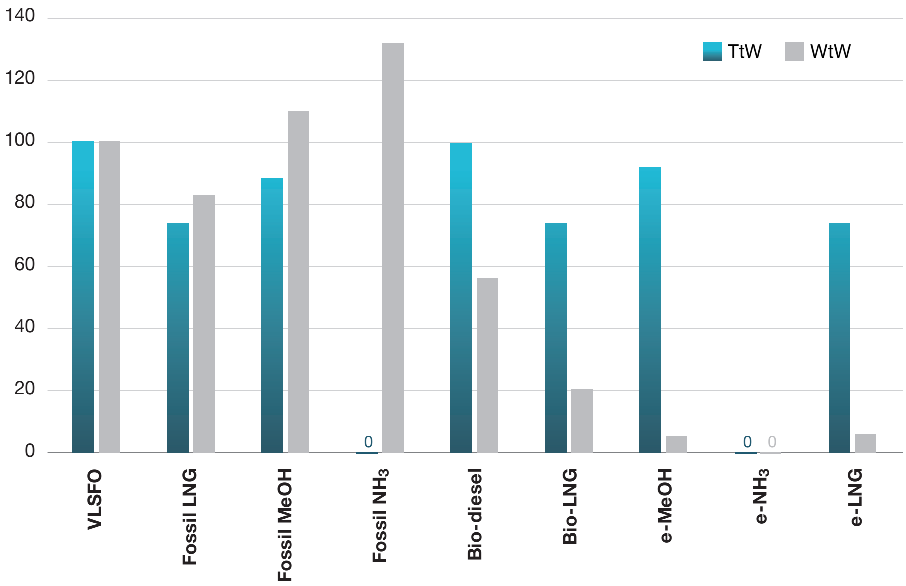

Fig. 10.4: Tank-to-wake and well-to-wake emissions of selected fuels relative to HFO [8], GWP100 of CH_4=29.8 CO_2eq

Year	2025	2030	2035	2040	2045	2050
Reduction from GHG intensity of 2020	2%	6%	14.5%	31%	62%	80%

Table 10.2: GHG intensity reduction requirements by FuelEU Maritime

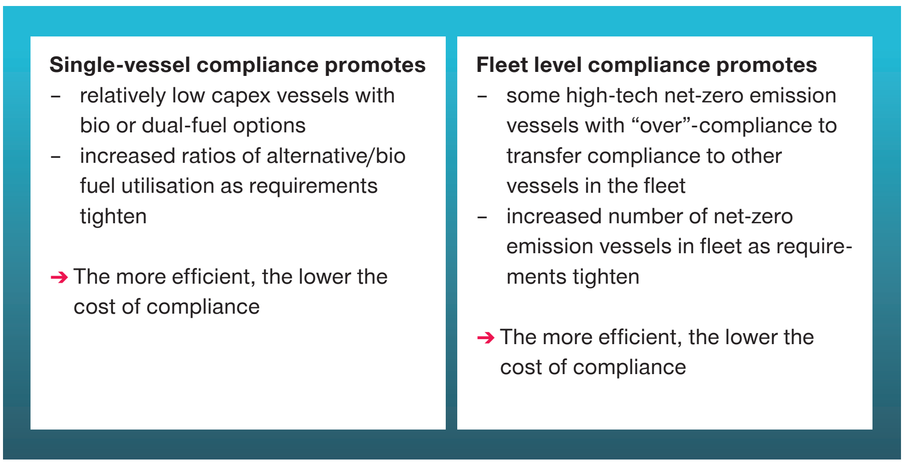

Fig. 10.5: Schematics on different optimisation scopes for different compliance levels and the common advantages of energy efficiency

Evaluating the GHG intensity in itself does not promote the uptake of energy efficiency. Ultimately, the amount of fossil fuel used will influence the total GHG intensity of the fleet and, if the limitations towards GHG intensity are exceeded, the magnitude of any fee to be paid.

Considering the fleet level approach, energy efficiency across the fleet will be paramount for the necessary investments in the fleet, in order to reach the GHG targets, as demonstrated in the following section.

Impact of compliance level
Besides regulating on different emission scopes, it is important to distinguish between considering operational compliance of a single ship or on a fleet level, because it is decisive for determining the specific optimum when attaining compliance. Fig. 10.5 sums up the optimisation scopes on different compliance levels.

Currently, IMO promotes efficiency improvements for single ships to ensure attractive CII ratings for all individual ships.

In a possible future consideration of well-to-tank, single ship compliance will motivate operation of the ship on an alternative low- or net-zero carbon fuel for a specific ratio of the operation. The ratio of operation in alternative fuel mode will have to increase as the required emission reduction rates increase. The option to operate on an alternative fuel will be needed for all vessels in a fleet, as every ship will need to operate increasingly on alternative fuels with increasing reduction requirements.

Fleet level compliance as in the FuelEU Maritime regulation scheme allows transfer of compliance between ships, allowing one vessel to operate continuously on an alternative low- or net-zero carbon fuel, while other members of the fleet can continue to operate on traditional bunker. On a fleet level, the share of energy covered by alternative bunker will have to increase as the reduction rates tighten.

Furthermore, for fleet level compliance it will be relevant to invest in operation on alternative low- or net-zero carbon fuels for the largest vessels, since the reduction of GHG intensity for the total fleet, relative to the investment, may be larger on such vessels.

In a fleet of vessels, it makes sense to reduce the energy consumption of ships that continue to trade on traditional bunker, as this will help to reduce the overall GHG intensity of the total fuel energy used. Again, this points towards maximising energy efficiency, also for single fuel ships.

Similar motivations can be found for complying with EU ETS, where the investments can be directed to the most impactful applications, however, promoting energy efficiency in general to limit the quotas needed.

As an engine designer, MAN Energy Solutions follows the development of the regulation schemes closely and evaluates the potential impact on the engine and fuel variant portfolio. It makes it possible to offer suitable engines, fuel types, and to balance capex and opex for any specific project despite the different optimisation criteria for the legislation schemes.

Efficiency-improving technologies

Despite the different scopes, and hereby optimisation criteria of the various regulations, an increasing efficiency will in all cases be desired in the years to come. The increasing energy efficiency will be a necessity to ensure the most feasible and efficient transition in a future fuel scenario where zero- or net-zero fuels in high demand, and thus more expensive, are to be applied.

The impact of various efficiency-improving technologies, and the considerations of MAN ES regarding their integration with the propulsion plant and ship design, will be treated in the following sections on individual technologies.

Shaft generators / power take off (PTO)

Shaft generators have been applied in different forms in different periods of time. Historically, it has been a challenge for vessels with fixed pitch propellers to attain a speed range of operation sufficiently wide with satisfactory stable electrical frequency. However, the reduced costs of power electronics over recent years have made a frequency converter a standard part of a shaft generator application. This makes the shaft generator available for the vast part of the ship operating profiles – but it also introduces challenges because the frequency converter introduces negative damping towards the speed set, see Fig. 10.6 and [9].

In the past three years, the uptake of shaft generators has increased rapidly, mainly driven by the uptake of alternative fuels. For example, for the alternative fuel LPG, gensets capable of operating on the alternative fuel are not available, and a PTO is therefore often the standard on LPG carriers to cater for the electricity production in seagoing condition. Similarly, the cost of green methanol is high, and a PTO is often part of the installation on ships intended for operation on methanol to increase the efficiency of the electricity production.

MAN ES continuously aims at improving the overall efficiency of the plant, and has developed an improved interface between the power management system (PMS) and the engine control system (ECS).

The interface is termed “PTO interface option C”, and it informs the PMS about the available power for the PTO. This allows for an increased automation of the load balancing between the auxiliary engines and the PTO, see Fig. 10.7.

Similarly, the PMS instantaneously informs the ECS about any changes in the PTO load. It means that the fuel index can be adjusted in advance, significantly reducing the instability introduced by the frequency converters to the speed set. Therefore, the interface is a prerequisite for plants with excessive PTO power relative to the engine rating.

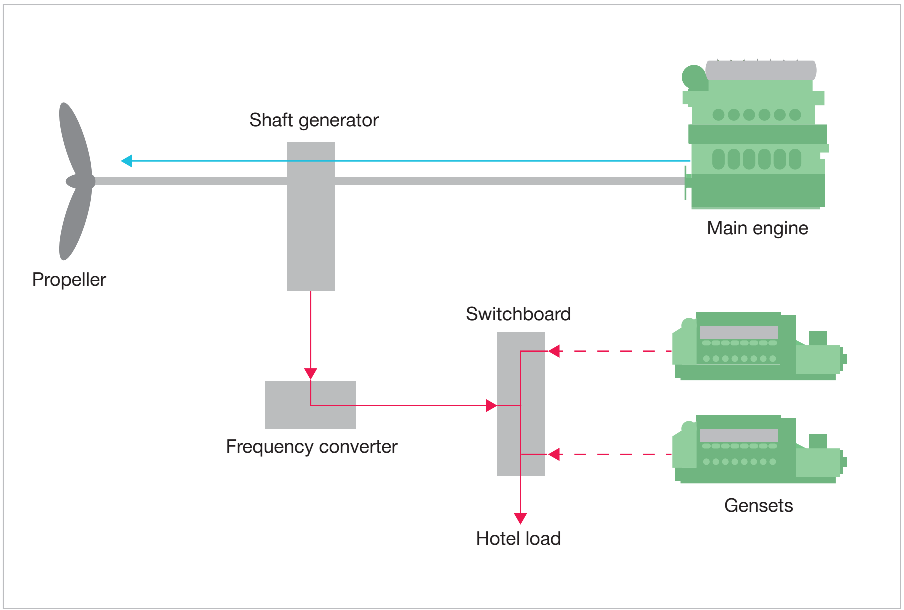

Fig. 10.6: Schematic illustration of a propulsion plant with shaft generator and integration with the electric power plant

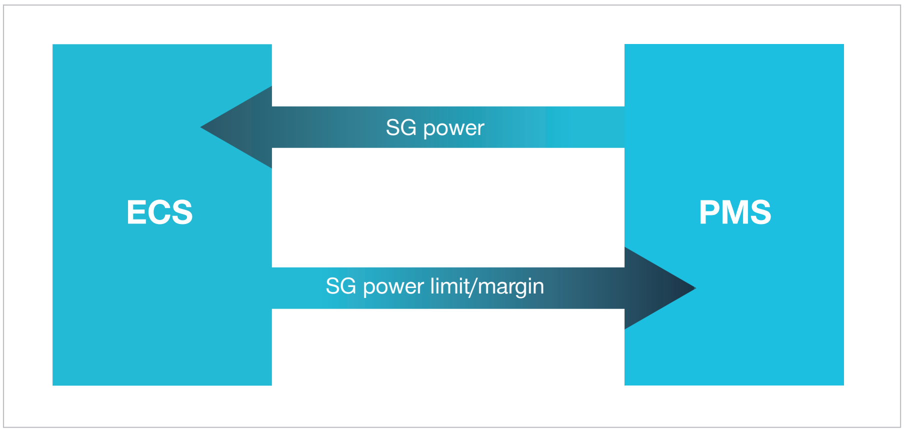

Fig. 10.7: Signals in interface option C

Similarly, MAN ES is also developing functionalities for the engine control system to support option 2 for inclusion of the PTO in the EEDI, see Fig. 10.8 and [10].

Based on information about the actual PTO power provided to the ECS, the ECS limits the total engine power in order to never exceed the limit for power delivered to the propeller. This functionality reduces the attained EEDI and, at the same time, ensures that sufficient shaft generator power is available for vessels with a high electricity consumption, i.e. various gas carriers or container vessels.

Battery-hybrid systems

The first commercial battery hybrid installations in marine applications went into service about a decade ago. Initially for integration into diesel-electric propulsion plants. Within recent years, battery-hybrid systems have found their way into the electric grid of some ocean-going ships, which were otherwise propelled by a diesel-mechanic two-stroke solution.

MAN ES continuously monitors and participates in the development of battery-hybrid solutions to establish the best possible utilisation of these and to support our customers in attaining the greatest benefit of the technology. Especially battery-hybrid systems on ocean-going ships benefit from being combined with a shaft generator [11]. During the voyage, the shaft generator charges the batteries, which then act as a spinning reserve during manoeuvring, and possibly also covers the electricity consumption during port stays. Near-shore local emissions can be greatly reduced along with the running hours clocked on the gensets.

Such applications of battery-hybrid systems, and a possible integration with the two-stroke main engine via a PTO/PTI, naturally foster an interest in hybridisation of the diesel-mechanic propulsion plant itself. MAN ES has carried out comprehensive evaluations to uncover whether hybridisation or

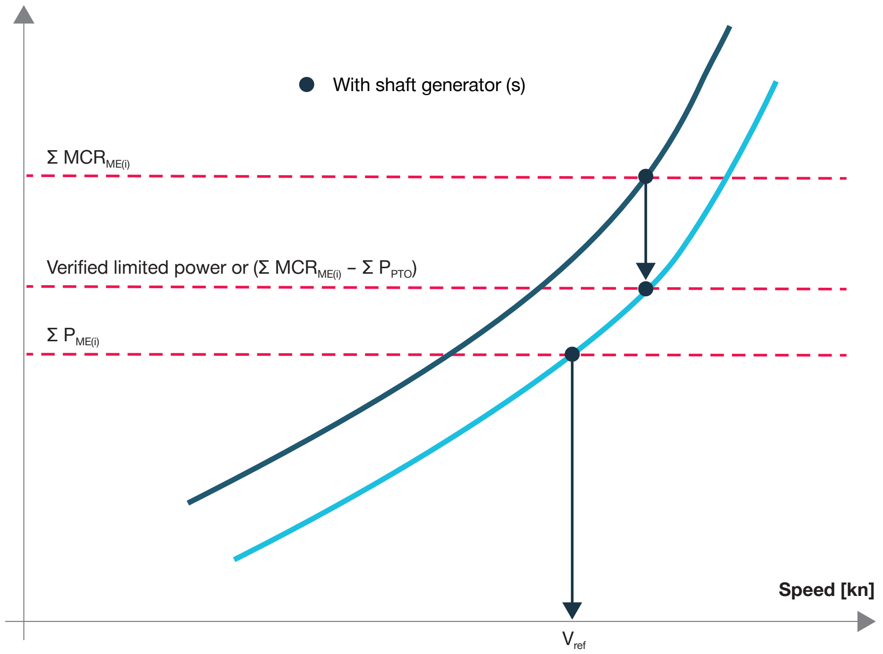

Fig. 10.8: Option 2 for inclusion of a PTO to the EEDI [10]

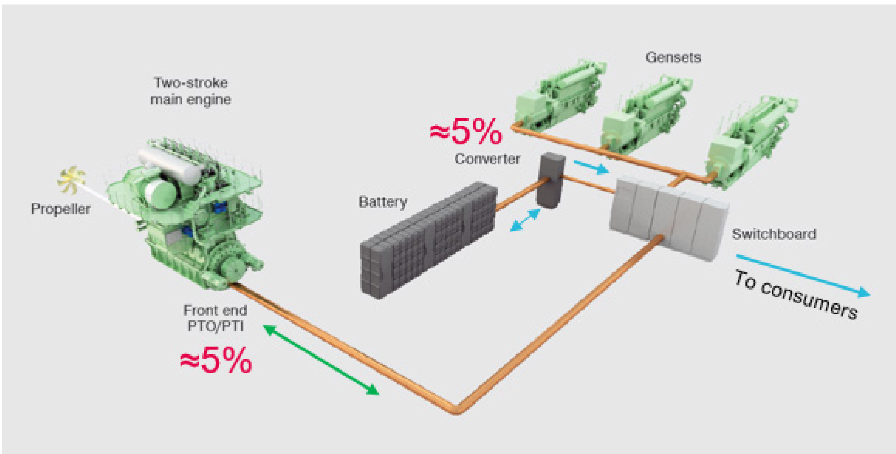

Fig. 10.9: Assumed losses in energy conversions for evaluating peak shaving of a diesel-mechanic propulsion plant

peak shaving of a dynamically loaded Diesel-cycle main engine benefits the overall efficiency.

These simulations have shown that when converting mechanical energy on the shaft to electrical energy via the PTO, and to chemical energy in the batteries, and vice versa, the losses (see Fig. 10.9) exceed the efficiency gain obtained by smoothening the engine load, even when the ship is sailing in adverse weather conditions/heavy seas.

To verify the simulations, tests have been performed while actually operating a PTO/PTI plant in the described way. Through careful analysis of the test results, it has been concluded that the simulation results were confirmed, i.e. an average higher load was observed for the peak shaved system, owing to the losses needed to be overcome.

PTO and battery-hybrid case study

In 2019, MAN ES, DNV, and Corvus made a case study on a 1,700 teu container feeder vessel with on-board cranes operating in Northern Europe [12]. Since then, there has been a vast development related to fuel and battery costs, and the study has been updated to provide the latest insights into the benefits of battery hybridisation along with a PTO.

A 6S60ME-C10.5-GI engine is used as the main engine, the number of 8L23/30DF gensets has been varied, and in some cases a 2,000 kWe PTO has been included, as illustrated in Fig. 10.10.

By simulating a typical trading profile for a container feeder, the energy consumption of the various systems can be calculated and compared to the conventional case, as shown in Fig. 10.11.

Relative energy consumption

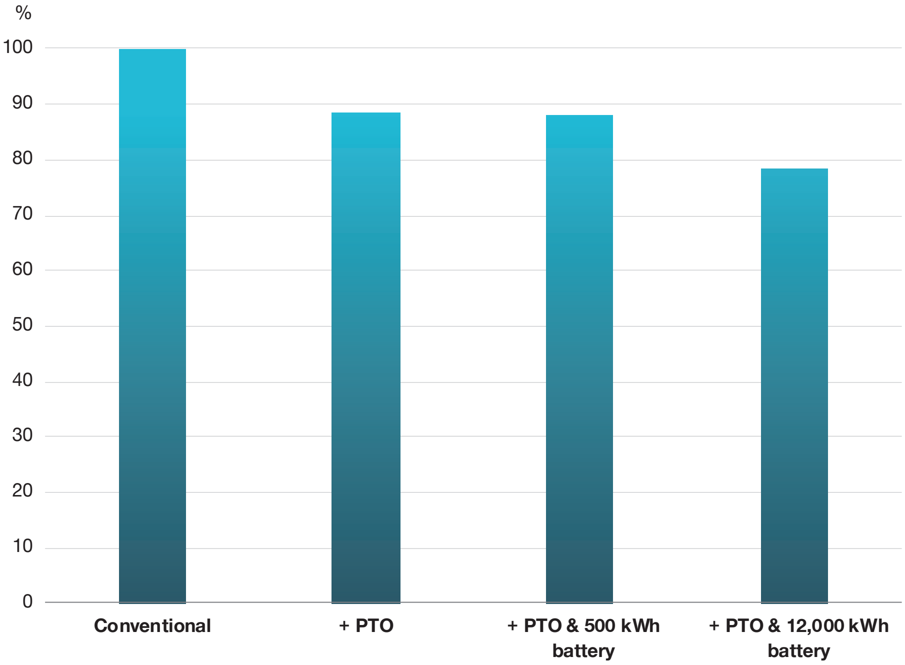

Fig. 10.11: Relative energy consumption by including a PTO and various battery capacities in the power generation system for a 1,700 teu container feeder

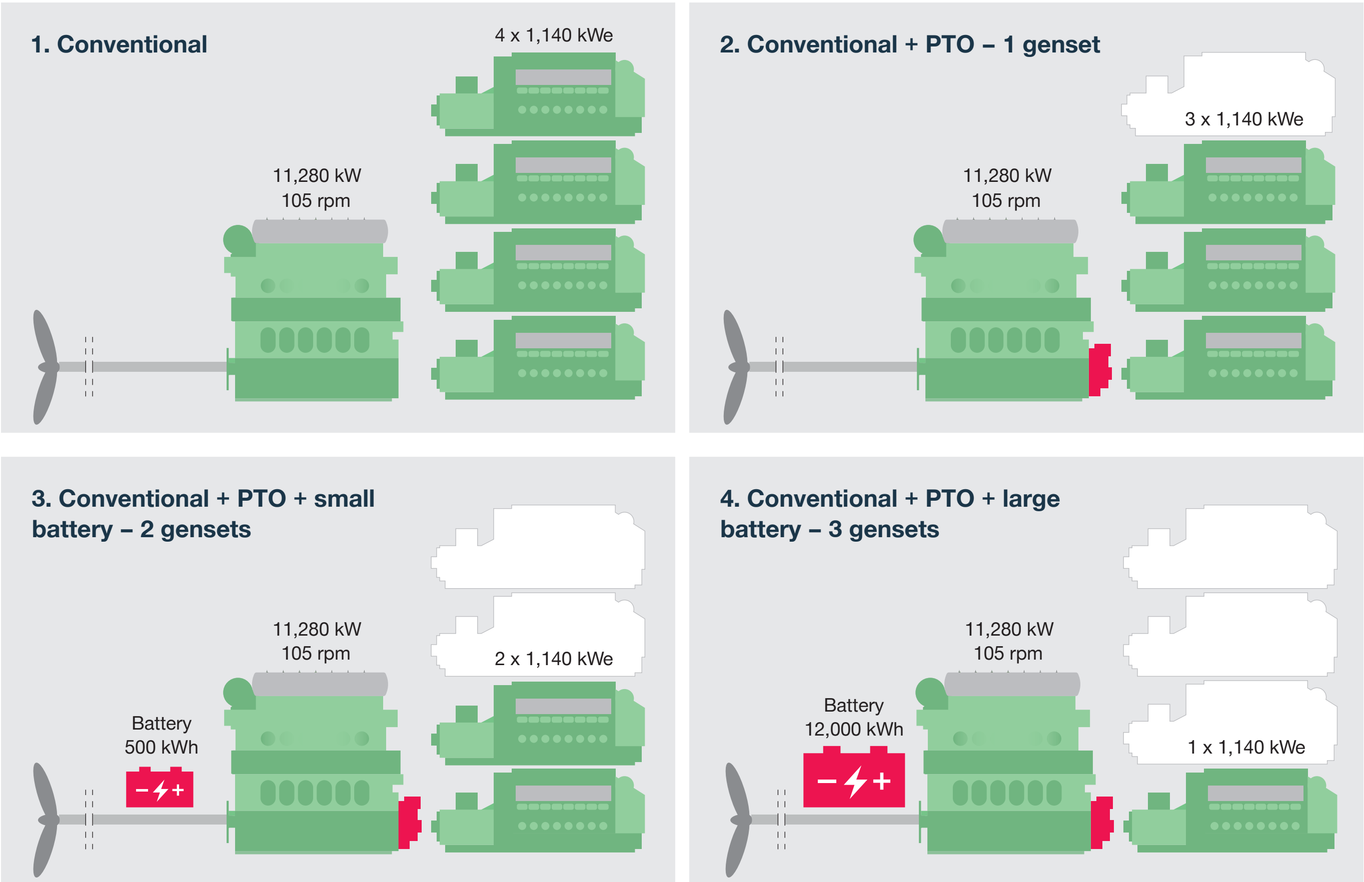

Fig. 10.10: Topology of four propulsion plants with various degrees of hybridisation for a container feeder

Fig. 10.12 shows net present values for the various solutions and highlights the benefits of the PTO and the increased benefits of combining it with a battery, the main economic advantage being the reduction of genset running hours and derived costs.

The short return on investment of both PTO and battery is attained by the reduced number of gensets, and in itself made possible by adding the PTO and the battery.

The fourth plant considered represents a case allowing for emission-free port stays, which by other value propositions may be beneficial for specific trades, especially feeder operations near city ports, even if relatively more costly.

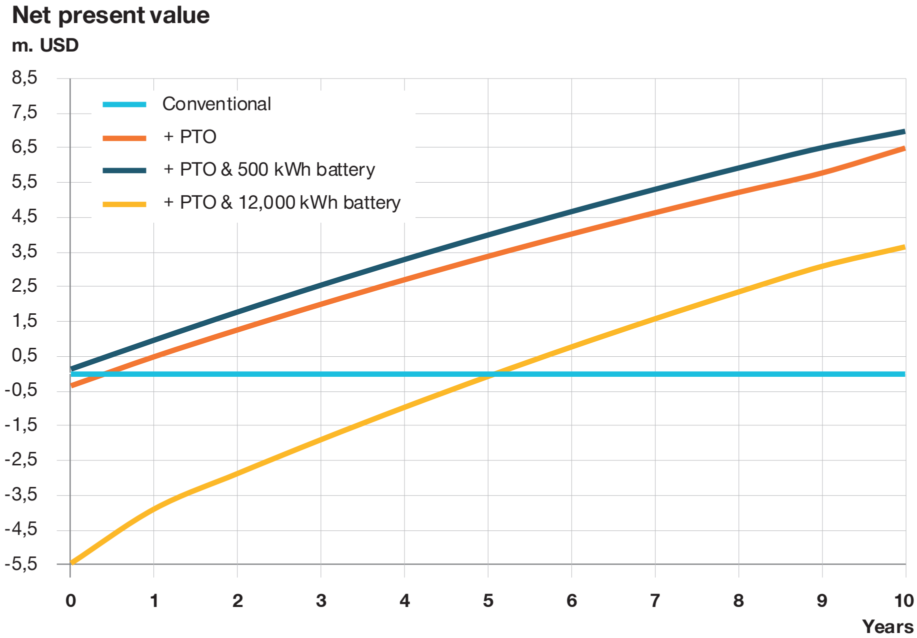

Fig. 10.12: Net present value of investing in PTO and batteries for a 1,700 teu feeder operating in Northern Europe

Waste heat recovery

Improved efficiency can also be achieved by installing a waste heat recovery system (WHRS). The WHRS suitable for a specific vessel depends on the level of complexity acceptable to the owner, shipyard, and the needed hotel load. In general, the larger the SMCR power, the more economically feasible the WHRS will be – if the average engine load is not too low.

Previously, steam turbine generators (STG) and power turbine generators (PTG) were the most dominant WHRS on the market [13]. The system was mostly used on ULCVs with a relatively uniform operating profile. These systems utilised the exhaust gas energy as the heat source and, in the past, they delivered an electrical power production of up to 15% SMCR power, contributing to a significant increase of the plant efficiency. As the main engine has been developed to become more efficient, the exhaust gas flow has been decreasing. This reduces the possibilities for tapping into the exhaust gas energy, lowering the available power to 10% SMCR power for the latest plants.

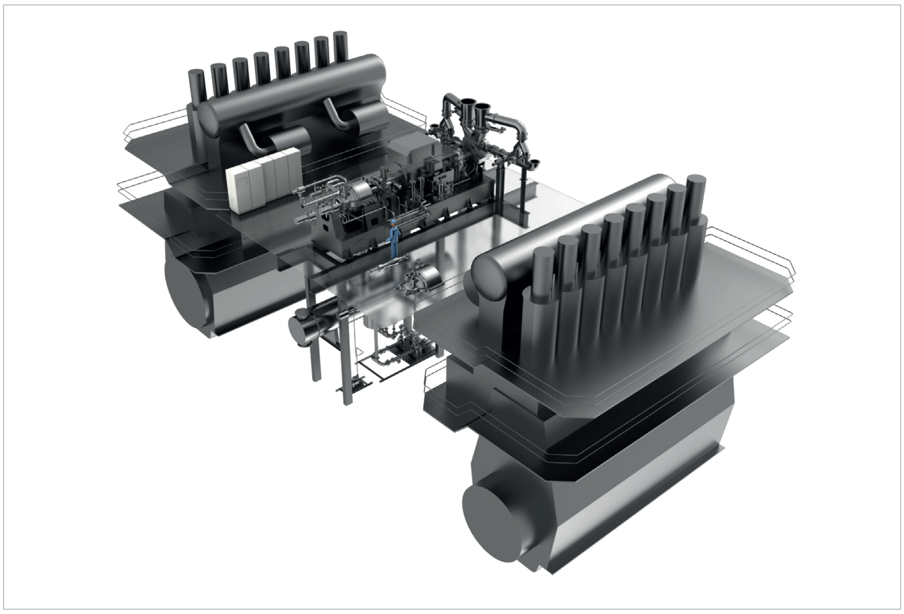

Fig. 10.13: WHRS with PTG + STG – design for twin-screw vessel

To reach such energy levels, the turbocharger efficiency was reduced to make more power available for the WHRS, while introducing a fuel penalty to the main engine. By decreasing the turbocharger efficiency slightly, an overall higher plant efficiency of the engine and WHR system combined can be attained.

In general, STG and PTG systems are highly reliable, but with a higher capex, and applications have been limited in recent years. However, with the increasing cost of alternative fuels, a revitalisation may be experienced.

As an alternative to a high capex system, new methods for waste heat recovery have been introduced. One of these methods is the Organic Rankine Cycle (ORC). ORC is often modular based and can thereby be combined to increase the electrical power output. Typically, an ORC system is able to transform 7-9% of the thermal energy available to electric power. Depending on the waste heat available, the ORC can increase the plant efficiency by approximately 1%.

The ORC does not need the same large heat input as the PTG and can use alternative low-quality heat input from the jacket water cooler, and scavenge air cooler, but also the exhaust gas heat. If utilising heat for the scavenge air cooler, a two-stage cooler is needed, ensuring that high amounts of energy can be drawn. The multiple heat sources make ORC independent of the exhaust gas amount and temperature, making WHRS possible for smaller vessels as well.

Air lubrication systems

In recent years, the application of air lubrication systems has surged. Various suppliers of air lubrication technologies are on the market. They offer different concepts for distributing air bubbles, around the bottom plate of the hull, but the principal operating principle and the considerations regarding the layout of the propulsion plant are the same.

Air lubrication systems by various methods emit bubbles under the flat bottom of the hull, either only under the bow or in bands at different lengths to reduce the frictional resistance component of the hull surface. This implies that the gain of an air lubrication system is most significant for ships where the flat bottom constitutes a large part of the total wetted surface of the hull area. This points towards ships carrying relatively light cargos, like LNG and container ships [14].

However, the purpose of the air lubrication system is to reduce the frictional resistance of the hull. Therefore, the relatively largest efficiency improvements are obtained at ship speeds, i.e. Froude numbers, just below speeds where waves are created, as illustrated in Fig. 10.14.

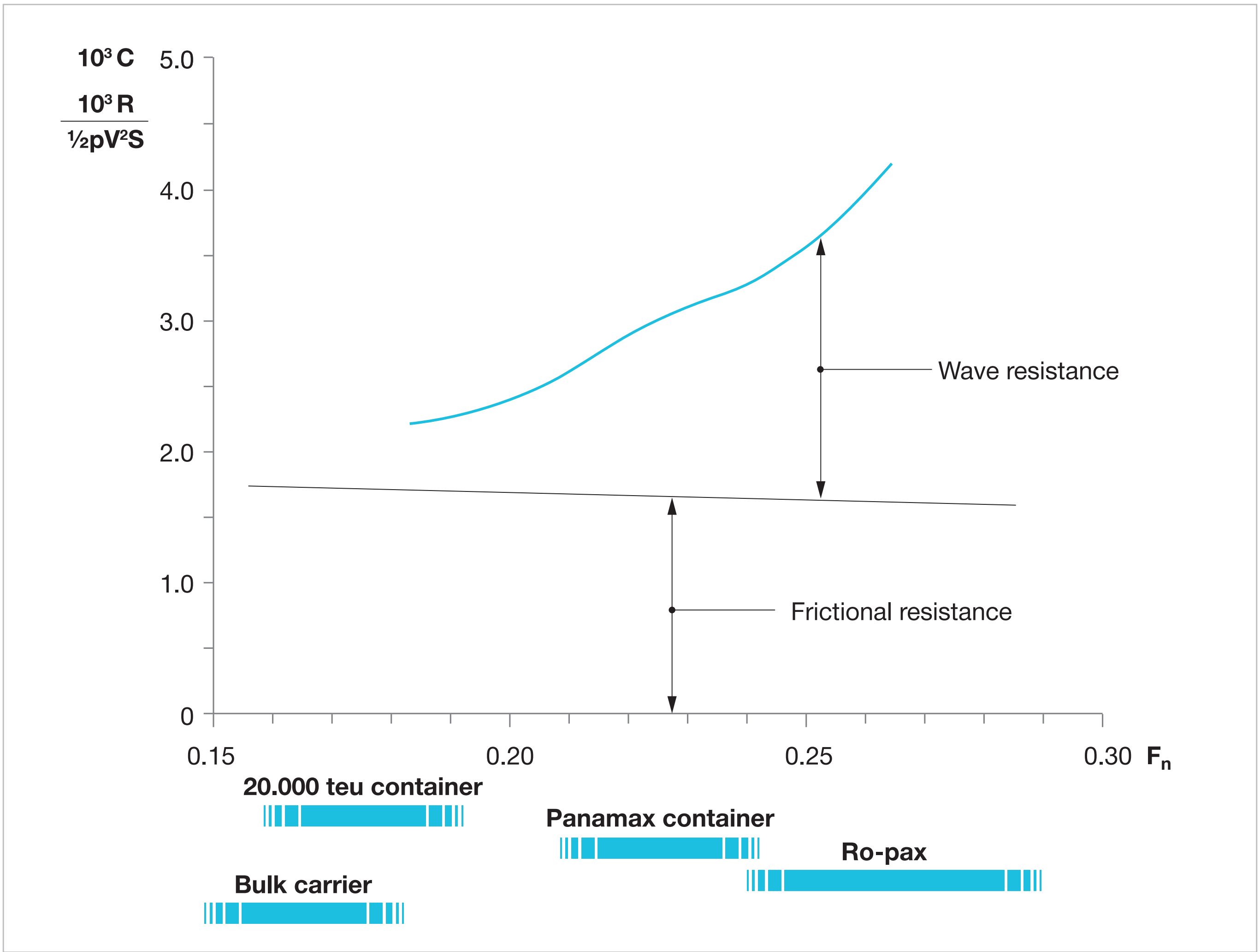

Fig. 10.14: Simplified illustration of the components of the total resistance as a function of the Froude number

The reduction of the frictional resistance component leads to a slightly lighter running propeller, but the lower power required to attain a similar ship speed, as illustrated in Fig. 10.15, results in the main saving.

It is common to all air lubrication systems that an increased motion of the hull, especially rolling, as experienced in a seaway will reduce the relative reduction of the frictional resistance. In encounters of heavy seas with rolling, the bubbles will more quickly escape the bottom, and the energy required for the air compression will be lost. Due to this phenomenon, and the resulting lack of a resistance reduction in heavy seas, it is not recommended to incorporate the frictional reduction offered by an air lubrication system into the layout of the propulsion plant. This applies for a reduction of the main engine power, but especially for a reduction of the propeller light running margin, which is not recommended.

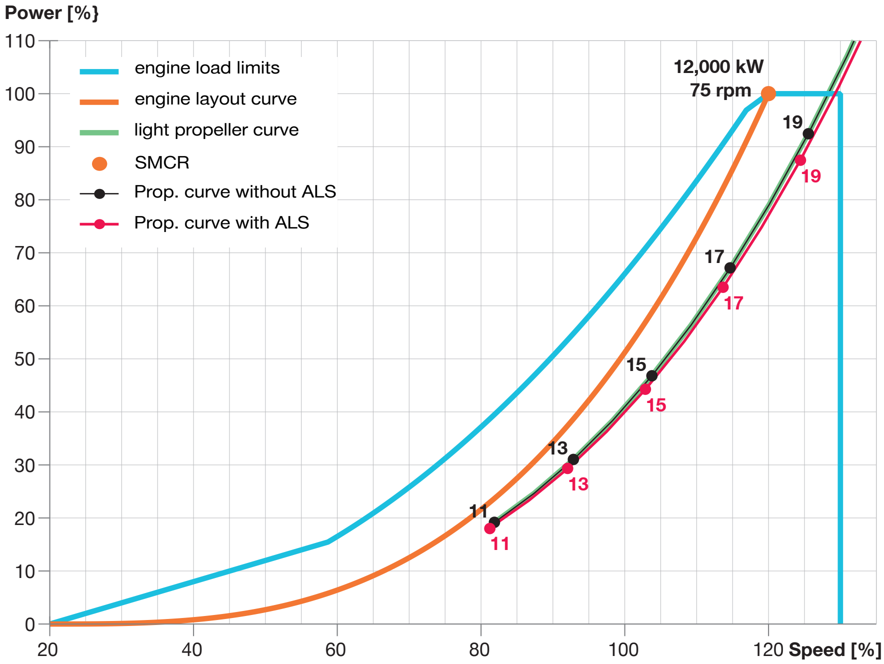

Fig. 10.15: Propeller curves with and without an active air lubrication system

Wind-assisted ship propulsion

Currently, different wind-assisted propulsion technologies like rotor sail, kite, hard wingsail, and retractable sail are available on the market, see Fig. 10.16.

Wind-assisted ship propulsion (WASP) technologies generate thrust which reduces the power required by the engine, the fuel consumption, and the emission of greenhouse gasses [15].

Even though different methods are used to capture the wind, the working principle that determines the efficiency is the same, and the impact on the main engine running conditions is the same. The main impact on the engine and the propeller is:

- Lower effective power, since less thrust is required by the propeller for the same ship speed.
- Increased advance number of the propeller, since the flow condition to the propeller remains the same, but with less loading to the propeller.
- Propeller light running, and the open water efficiency increases.

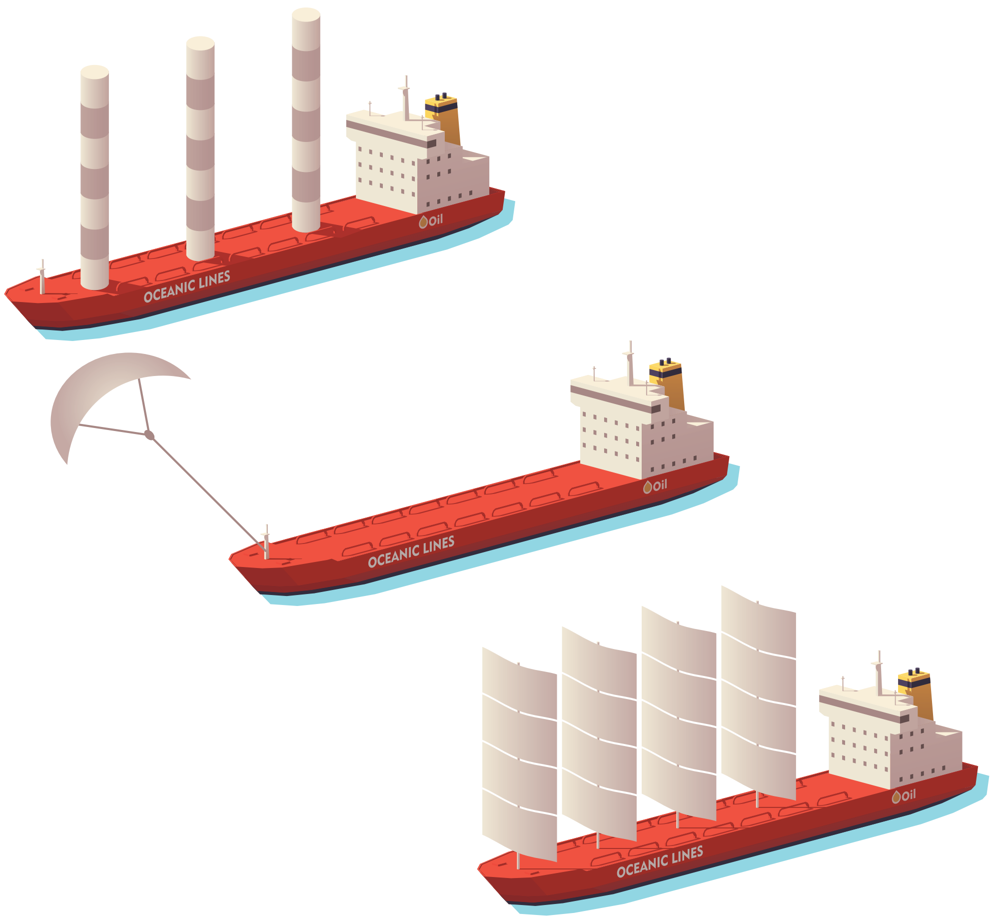

Fig. 10.16: Different types of wind-assisted propulsion technologies

Thrust delivered from WASP systems varies greatly with wind condition and, hence, route and season. Therefore, it is not easy to establish a general saving trend, it must be evaluated for the specific operational profile. The variability of the thrust delivered by the WASP will result in a greater variation of the operational points experienced by the main engine, and an increased part-load and low-load operation can be expected, see Fig. 10.17. However, the resulting load variations are of a similar magnitude to other typical engine load variations as a result of laden or ballast operation, heavy seas or calm waters, fouled or clean hull, which is presently well accommodated within the load diagram of a two-stroke propulsion plant.

The changes introduced are not considered to be of an extent that justifies alterations to a typical propulsion plant.

It is important to consider any resistance added by the WASP during head-wind and head-seas. Especially, if the system cannot fold down, or if the sails are allowed to feather, it will add de facto resistance. This is very important in an evaluation of the propeller light running margin and the minimum propulsion power. It is not recommended to decrease the SMCR due to WASP since the manoeuvrability and survivability of the ship may be compromised.

Aft-ship optimisations and engine matching

By optimising the aft ship, it is possible to improve the ship performance significantly, reduce fuel consumption and emissions, and enhance the overall sustainability.

Several key factors need to be considered in the aft-ship optimisation process, such as the ship's operating speed, cargo capacity, and matching between hull, engine, and propeller. MAN ES can advise on these factors.

The aft-ship optimisation can be divided into the following three main categories.

Aft body optimisation

Optimising the aft body involves various measures to minimise the impact of stern waves, enhance water flow towards the propeller, and prevent turbulence. An appropriate design of the stern reduces crest waves and deep wave troughs, as well as minimises the generation of stern waves. This can significantly improve the efficiency of the ship's propulsion system. Enhancing the flow characteristics of the aft body can also lead to improved propulsive efficiency.

Propeller optimisation and engine selection

One important aspect of aft-ship optimisation is the selection of the propeller and its configuration,

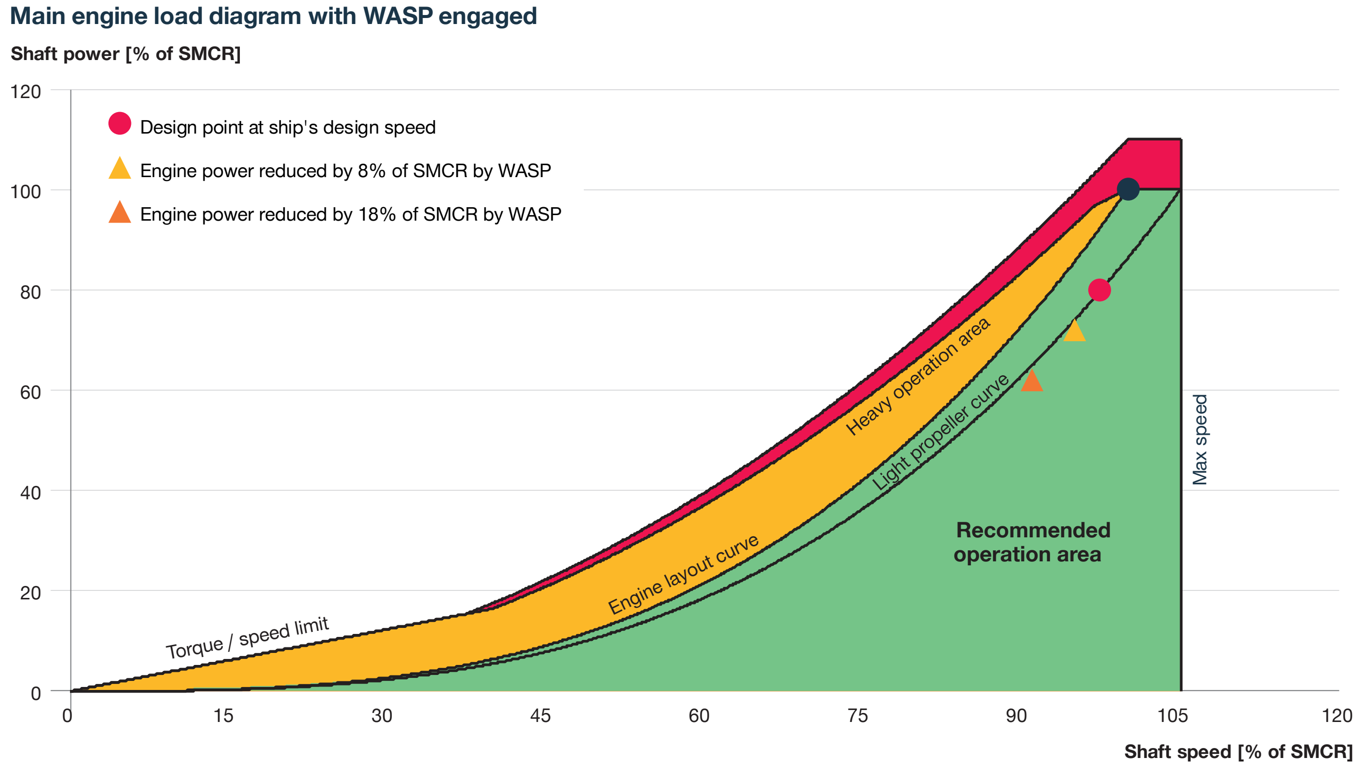

Fig. 10.17: Impact on the engine running with different thrusts provided by WASP. The contribution from a WASP system varies greatly depending on the wind direction and speed. Notice is given to somewhat lighter running of the propeller as the propeller does not need to deliver the full thrust.

including diameter, pitch, and the number of blades. The propeller must be carefully designed to match the power requirements of the ship for the desired speed and operating conditions, and the engine must be selected accordingly.

Recently, MAN ES published a white paper "Improved efficiency propulsion plants" about the possibilities for improving the propulsion efficiency towards EEDI phase 3 [16]. One option is three-bladed propellers with a higher propeller efficiency at a higher optimum propeller speed, which sometimes lead to a more suitable match of engine efficiency and dimensions.

Energy saving devices and the influence on light running margin

Energy saving devices (ESDs) encompass various devices designed to optimise the flow of water to, around, or after the propeller. These devices are primarily intended to improve propeller inflow or eliminate propeller losses, such as hub vortices, tip vortices, etc. By reducing the turbulence and improving the water flow, ESDs can enhance the hydrodynamic performance of a ship and lead to an improved energy efficiency.

It is crucial to evaluate the potential saving of all ESDs and compare them to the additional wetted surface and the resistance created. Furthermore, it is paramount to evaluate the impact on the propeller light running margin, since an altered propeller inflow will influence the propeller performance and, consequently, the light running margin.

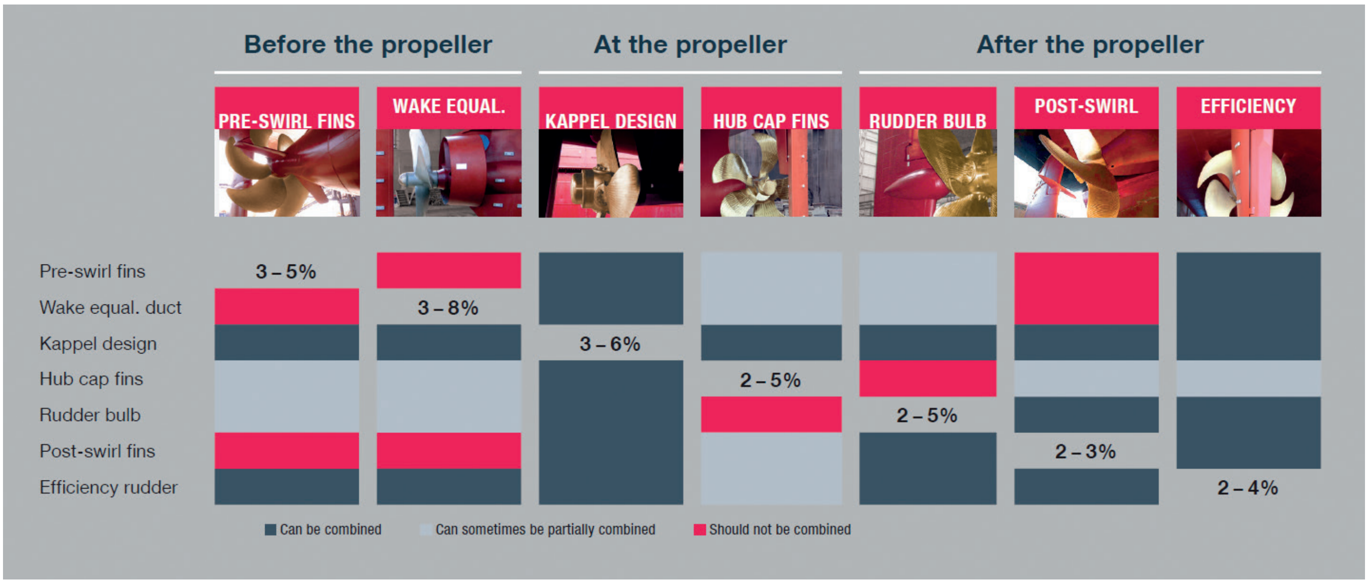

Fig. 10.18: Possibilities for combining energy saving devices, including individual saving potentials

Conclusion and Outlook

The utilisation and increased uptake of efficiency-improving technologies is vital regardless of the legislation format and the level of compliance.

The greatest possible reduction of the maritime energy consumption is a necessity. In particular, when considering the large demand for costly net-zero or zero-emission fuels which currently are scarce but play a major role in the transition. As an engine designer, MAN ES supports this transition by enabling the integration of efficiency-improving technologies with the propulsion plant, along with the development of different options for alternative fuels, to best suit the specific ship and its trade.

To illustrate the remaining combined potential of the energy efficiency-improving technologies mentioned in this paper, and the contribution to the transition of the maritime industry, the impact on a ship is considered in an example.

According to the IMO data collection system (DCS), an average single-fuel bulk carrier above 20,000 dwt in the global fleet has a capacity of 84,000 dwt and has emitted 4.04 gCO_2/dwt/nm as per 2020 [17].

If the fleet is updated to comply with EEDI phase 3 requirements by a power reduction, and in addition uses the efficiency-improving measures most relevant for a bulk carrier, as described above, this number can be reduced to approx. 2.5 gCO_2/dwt/nm. This corresponds to a 38% reduction, as illustrated by Fig. 10.19.

A reduction of the energy needed can reduce the cost of the green transition significantly and foster the investment in efficiency-improving technologies.

The extent of the advantages of efficiency-improving technologies varies with ship type and trading profile, but it is necessary for all ship types to carefully evaluate how the most efficient propulsion plant is attained.

As demonstrated in this paper, MAN ES continuously develops new functionalities to improve the interface between various parts of the propulsion plants, and new tools to analyse the impact. MAN ES offers support and guidance on the maximum efficiency, with the aim of easing the transition of the maritime industry towards a carbon neutral future to the greatest extent possible.

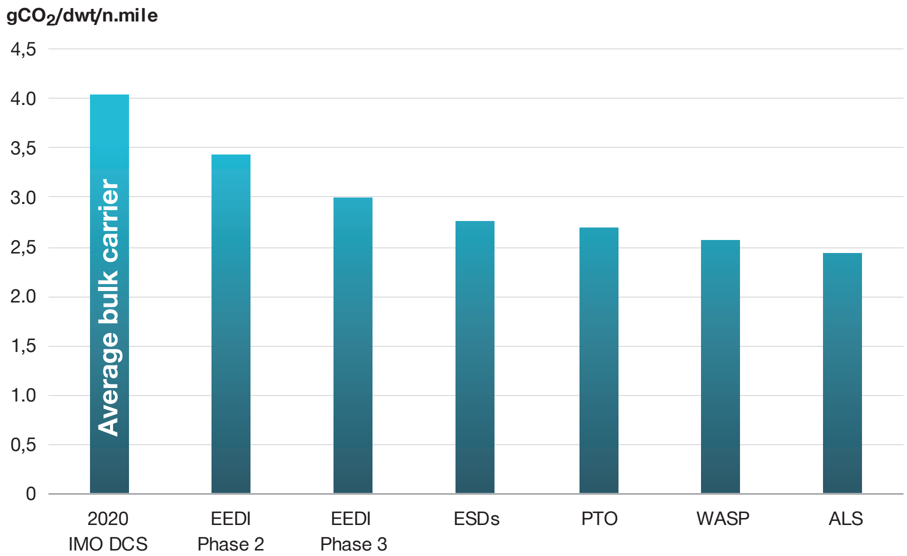

Fig. 10.19: Present CO_2 emissions [gCO_2/dwt/nm] in IMO DCS for an average bulk carrier (84,000 dwt) together with the estimated impact of applying alternative technologies

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5510-0277-00ppr Oct 2023. Printed in Denmark