Retrofit Research Programme

ENERGY EFFICIENCY RETROFIT REPORT 2024:

Applying wind-assisted propulsion to ships

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Introduction

Energy efficiency has always been a competitive advantage in a market where fuel represents a major operating expense. With the emergence of maritime decarbonisation ambitions, it has become an imperative.

Optimising the fuel efficiency of ships will prolong compliance as new legislation demands stepped improvements in emissions, fuel consumption and energy intensity, minimise carbon costs as market-based measures emerge and – for vessel operators aiming for close to or full decarbonisation – significantly reduce spend on costly zero- or near-zero emission fuels.

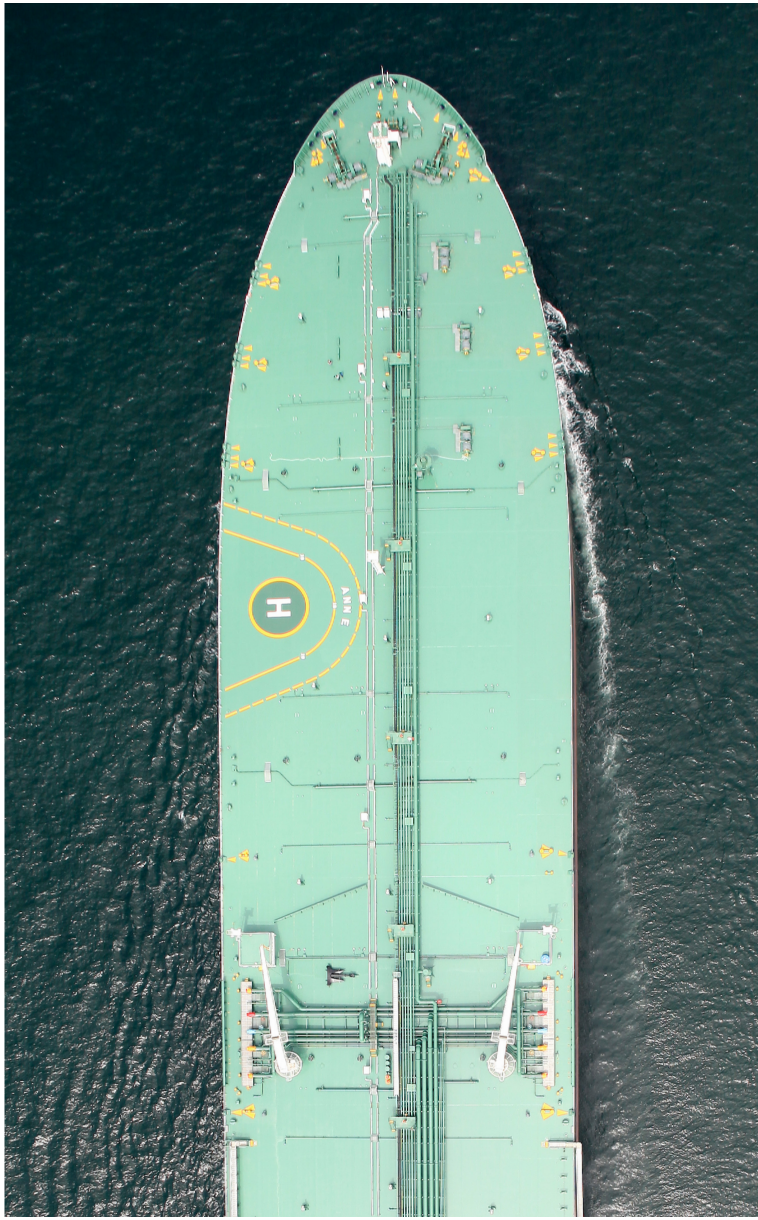
A range of energy efficiency technologies (EETs) are now being deployed by operators to stack incremental savings in engine power, propulsion and hull resistance. But the slow uptake of many such technologies speaks to the challenges in adopting them. EETs are at various stages of technology readiness and, as a result, many operators, designers and shipbuilders are not familiar with using or installing them. What limited service experience there is shows widely varying performance, often at odds with optimistic claims made before installation.

With no standardised method of verifying savings for some technologies, clarity on the true impact on operating costs can be elusive. So too does full understanding of the operational constraints entailed, with some solutions potentially affecting factors including vessel speed, cargo capacity and port access.

Introducing such measures as part of a newbuilding project, with a holistic consideration of energy use and operational implications from the initial design stage, is challenging enough. Adapting and attaching them to existing ships can be even more so, given the differing installation requirements and the added complexity of calculating potential efficiency gains and return on investment for mid-life vessels.

The new LR Energy Efficiency Retrofit Report series aims to support industry uptake of EET's on existing ships. This report, focused on wind-assisted propulsion systems (WAPS), examines current deployment and readiness of the main technology candidates, as well as highlighting drivers and potential challenges to future uptake – including supply and installation capacity, safety and regulatory frameworks and operational considerations.

This publication follows the release of the initial Engine Retrofit Report last year, outlining the market and technology status of engine conversions for alternative zero- or near-zero emission fuels. Combined with the Fuel for Thought series exploring new fuels, and future instalments of this report focused on other EET categories, the suite of documents from LR represents a comprehensive insight into the challenges of adapting existing vessels for operation in the era of decarbonisation.



A return to wind

Calling wind propulsion a 'new' technology may be something of a mis-representation for shipping. But while they harness the same free, widely available energy resource, the solutions using wind to support propulsion on today's vessels bear little resemblance to those of bygone eras. Even where similar terms like sails are used, the materials, structures and methods of control for WAPS technologies are more akin to those used on space shuttles than schooners.

Understanding how WAPS technologies can be integrated onto modern vessels requires a similar leap forward if maritime operators are to take advantage of their potential to support decarbonisation. The analysis in this report suggests that WAPS technologies are poised for a dramatic increase in uptake as shipowners seek solutions that can both contribute to emissions reduction and partially offset the costs of other decarbonisation measures. But there are several obstacles still to be overcome if that widespread adoption is to be realised.

The four WAPS technologies most commonly deployed today - Flettner rotors, rigid sails, suction wings and kites – each come with their own challenges, operating constraints and installation considerations, alongside savings that can vary significantly depending on how they are deployed. Other technologies, including soft sails and hybrid versions of existing solutions, are also emerging as the sector evolves. These have not been considered here as their current base of installations and orders on merchant vessels is limited.

Across all technologies, there are supply issues to be addressed in light of growing demand that is expected to accelerate even further as decarbonisation targets tighten and the cost of operating on conventional fuel increased.

Supply chain evolution will need to be supplemented by increased installation capacity and capability, with only around 16 yards to date having carried out WAPS retrofits.

In the face of these uncertainties, choosing whether to deploy WAPS, which technology to select and how to plan installation is a daunting task. LR has been helping shipowners make these choices since the very first retrofit projects. And it has been deploying that experience to the benefit of the industry at large, for example developing an online, open-access savings calculator for those considering **Flettner Rotors**.

LR has delivered multifaceted support for this emerging sector. Alongside the core role of ensuring ships are built to class and fulfil statutory requirements, those services include:

- **Feasibility:** Techno-economic feasibility studies; Independent third-party performance studies; System impact studies; Climate resilience analysis; Navigation and route studies; Port and commercial compatibility; Scoping and tendering support.
- **Engineering:** Engineering and conceptual designs; Structural FEA analysis and CFD modelling.
- **In-service:** Short- and long-term performance verification; Port emission inventories.

In addition to these services, LR participates in industry-wide knowledge building as a member of the International Wind Ship Association (IWSA), recently participating in the first Wind Propulsion Technologies Roundtable held by IMO Low Carbon Global Industry Alliance.

Several of the learnings gained through this deep experience are illustrated in the recently published LR Guidance Notes on wind-assisted propulsion systems. This report supplements that by examining the market, drivers and challenges specific to retrofitting WAPS technologies on existing vessels. As always, LR does not favour any specific technology, preferring to present a balanced case that recognises the advantages each may have in different applications.

While some stakeholders advocate a return to full wind power for vessels, in LR's opinion that option remains limited to some very specific trades and vessel types. But wind as a supplementary propulsion provider is eminently feasible across a wide range of vessel types - if the challenges noted in this report can be addressed.

The role of LR is to support technology providers, shipowners and shipyards in managing those challenges, identifying the ways in which shipping could maximise its use of this unlimited, emission-free energy source.

Claudene Sharp Patel,
Global Technical Director,
Lloyd's Register

Foreword

The world of shipping is moving inextricably forwards with an energy transition that not only rivals but surpasses any such transition our industry has achieved before. The move from human power to wind, from wind to coal and steam and then onto oil were all tremendous, fundamental changes but they were undertaken with smaller ships, a less numerous fleet over a longer period than we have today, and we were moving towards an abundant and cheap energy source.

Now we face the same challenge but with few of those advantages, except when it comes to revisiting wind energy and once again using that commercially to move the fleet. But rather than 'rewinding', we are 're-winding' using new and improved technologies to harness the energy, enhanced materials that they are made from and the know how to optimise the use of this energy source. These systems are being installed across a spectrum from ones that generate a limited amount of power referred to as 'wind-assist' to more powerful systems installed on optimised new builds referred to by the term 'primary wind' that can provide most or even all of the propulsive energy required.

The potential of this field to transform how ships are propelled drew me to this sector twenty years ago. The thought of using a zero-emissions, zero-impact energy source that is abundant, delivered to the point of use, globally available, free of charge and accessible to all was a powerful brew. For the past decade, I have headed up the global association that represents wind propulsion technologies, and that brew continues to be an inspirational one.

However a critical part of the challenge is how to harness that energy and ensure those systems and solutions are safely installed, well operated and deployed countless times in some of the most challenging conditions that machinery can operate in. And not for months or years, but for decades. It is the answers to these questions that reports and guidelines such as this deliver to the industry, building on five thousand years of collective wind ship knowledge and decades of modern shipping knowhow.

Our industry is far from a unitary body. Different segments do different jobs with different vessels, They use varied technologies and various fuels in variable configurations, operating in alternating environments, alternate crews and owned by rotating companies. However one of the things that unites us is that these vessels float. And if they float, they can be moved by the wind.

Gavin Allwright,
Secretary,
International Windship Association

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Executive Summary

Executive summary

LR's analysis of the current Wind-Assisted Propulsion Systems (WAPS) market finds that uptake is on the verge of a tipping point, expected to pass the 100-installation milestone in the next 2-3 years.

There is some uncertainty on exact order numbers as the established industry data does not fully match disclosures from technology providers, considerably overestimating the number of suction wing orders by, LR believes, including several 'wind-ready' projects that are not yet firm orders. However, it is clear that the shape of the market is evolving; more orders are coming from a wider range of vessel segments, often with more units per installation, reflecting greater confidence in the technology. The number of projects featuring WAPS from initial design, as opposed to the retrofits commonly used for pilot projects, also highlights growing confidence in the fuel-saving advantages and technical feasibility.

Beyond 100 installations, market forecasts indicate that orders will accelerate rapidly, notably in the bulk and tanker vessel segments, with analysis of top-end potential identifying nearly 14,000 candidate vessels over the next 26 years. Uptake is being driven by increasingly well-established savings in the face of energy efficiency and emissions regulations that impose significant stepped reductions in energy intensity, as well as dramatically increasing the cost of greenhouse gas emissions. Fuel reductions from WAPS technologies, like other EETs, also act to improve the viability of adopting zero- or near-zero emissions fuels to meet long-term reduction targets.

Wind challenges

However, notable challenges remain in the application WAPS technologies. First is the uncertainty around actual fuel savings, with no standardised criteria for validating savings claims. The potentially hidden costs around WAPS – including the full scope of engineering work and operational costs – also contribute to uncertainty around the business case.

The ramp-up of the supply chain will be critical to meet rapidly growing demand. For technology suppliers to meet existing orders would entail them delivering around 2.5 times the number of units they have installed in the past five years. To achieve uptake on around 15% of the global fleet – as anticipated in the most optimistic forecasts would require a 75-fold increase on that level, requiring a dramatic increase in production capacity. Several suppliers are bolstering production capacity, but understanding how partners plan to deliver and maintain reasonable lead times amid the ramp up will be a crucial question for shipowners.

To date only around 16 yards have conducted WAPS retrofits, indicating that installation capacity needs to be far more widespread if future installations are to be met. While there are no showstopping capabilities for shipyards, planning projects will require careful consideration. One option considered is for a two-stage retrofit process, with WAPS foundations and cabling prepared during a scheduled drydocking – or even from newbuild – and the WAPS solution itself attached during a second docking or, in some cases, during an extended port call. Optimising installation timing to meet regulatory emissions reductions or to maximise payback will require some consideration, as will the alignment of project schedules to component lead times.

The complex considerations around WAPS technologies and the remaining uncertainties listed above – and others detailed throughout this report - mean that trusted expert advisory will be indispensable across the retrofit process, from exploring feasibility to technology selection, installation and validation of performance.

1 Current market

Source: Anemoi Marine Technologies

Global fleet uptake

As of the end of February 2024, Clarksons data - drawn from a fleet of more than 108,000 existing and more than 6,000 on-order vessels - identify 101 ships on which WAPS systems have been or are planned to be installed since 2018. The orderbook for 2024 and beyond highlights the accelerating uptake of WAPS systems, with 72 orders compared to the 29 vessels on which WAPS systems were installed between 2018 and 2023.

Looking at the difference between installed and on-order projects, it is worth noting that Flettner rotors are the WAPS technology with the largest installed base. As orders stand, they may be overtaken by suction wings over the coming years, although an element of uncertainty remains based on current data; based on LR analysis of orders claimed by manufacturers, several suction wing projects included in the Clarksons analysis are not at firm order stage, possibly overstating the project pipeline. Kite sails remain of niche interest, both in the number of installations and orders.

Vessel segments

Bulk carriers are the largest single segment to install wind propulsion to date (10 vessels) and will remain so based on existing orders (18 vessels). Tankers, passengers and Ro-Ro vessels all have orderbooks similar to the number of installations already performed. Orders for the first WAPS installations on gas carriers (both LNG and LPG), container ships and car carriers reflect the increasing and broadening uptake of wind power.

WAPS installations and orders by technology, number of vessels

Source: Clarksons, 29 February 2024

	2018-2023 (installed)	2024+ (on order)	Total vessels
Suction wing	7	37	44
Flettner rotor	13	25	38
Rigid sail	7	9	16
Kite sail	2	1	3
Total	**29**	**72**	**101**

WAPS installations and orders by ship type, number of vessels

Source: Clarksons, February 2024

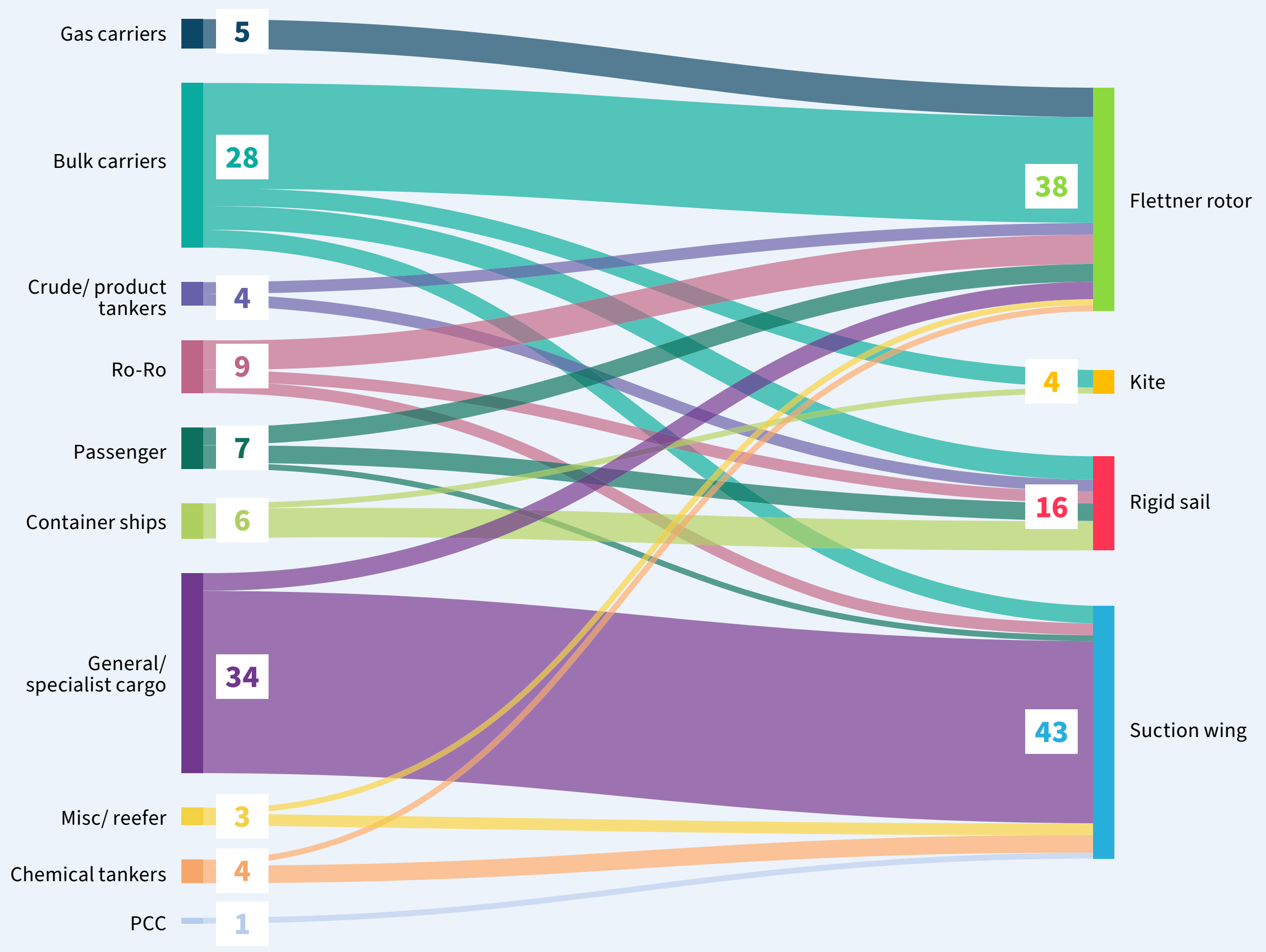
	2018-2023 (installed)	2024+(on order)	Total vessels
Bulk carrier	10	18	28
Container ship	0	6	6
Gas carrier	0	5	5
Tanker	3	5	8
Passenger	4	3	7
Pure Car Carrier (PCC)	0	1	1
Ro-Ro	4	5	9
Other	8	29	37
Total	**29**	**72**	**101**

The chart highlights WAPS technology uptake by vessel sector. The strong future uptake of suction wings based on interest from beyond the core merchant segments of bulk, tanker and container vessels is noteworthy, with 27 forthcoming installations in the general/specialised cargo segment. Meanwhile, Flettner rotor orders are primarily destined for the bulk carrier segment, with gas carriers emerging as new user based on five planned installations.

Bulk carriers are the most diversified WAPS users to date, with installation or orders for all technologies, while Flettner rotors and suction wings are both the widest used technologies overall and the most diversely applied across vessel segments.

WAPS deployment (installed and on order) by vessel and technology type

Source: Clarksons, 29 February 2024



Technologies and suppliers

The relatively small number of wind installations is accounted for by around 16 technology companies, including shipyards as well as WAPS specialists. There may be more suppliers, with 45 systems on order not linked to named suppliers, and more are certainly on the way; the International Wind Ship Association (IWSA) identifies more than ten companies with technologies at the pre-market stage and at least 20 more at the research and development stage . At present , suppliers deliver four main system types (**see Technology section** for details). Note that unlike the other charts in this chapter, the table below shows numbers for units, rather than vessels. Each vessel will have one or more units installed.

A noteworthy trend hidden in the aggregation of data is that the number of devices per ship has been increasing since 2022, as WAPS installations move past pilot testing and demonstration purposes. Taking Flettner rotors as an example, in 2018, two out of four vessel installations deployed just one unit each. In 2023, all four vessels were fitted with more than one unit. This trend illustrates the advancing market acceptance and lower perceived risk associated with wind propulsion.

Newbuild vs retrofit

To date, the vast majority of WAPS installations (83%) have been applied to existing vessels, with just five newbuilds including wind propulsion devices from the initial design stage. But as acceptance of the technology is increasing, wind systems are being applied to new vessels more frequently, with 72% of planned installations to take place at shipbuilders rather than conversion yards. The trend is consistent across the different wind technologies.

The scaling up of newbuild wind installations is expected to continue at the same time as a sizeable retrofit market emerges. While the proportion of newbuilds deploying wind propulsion will continue to increase, there is a large fleet of existing vessels that are likely to consider WAPS systems to meet impending decarbonisation requirements and reduce carbon cost exposure (**see Drivers section**).

WAPS installations and orders by technology, number of units

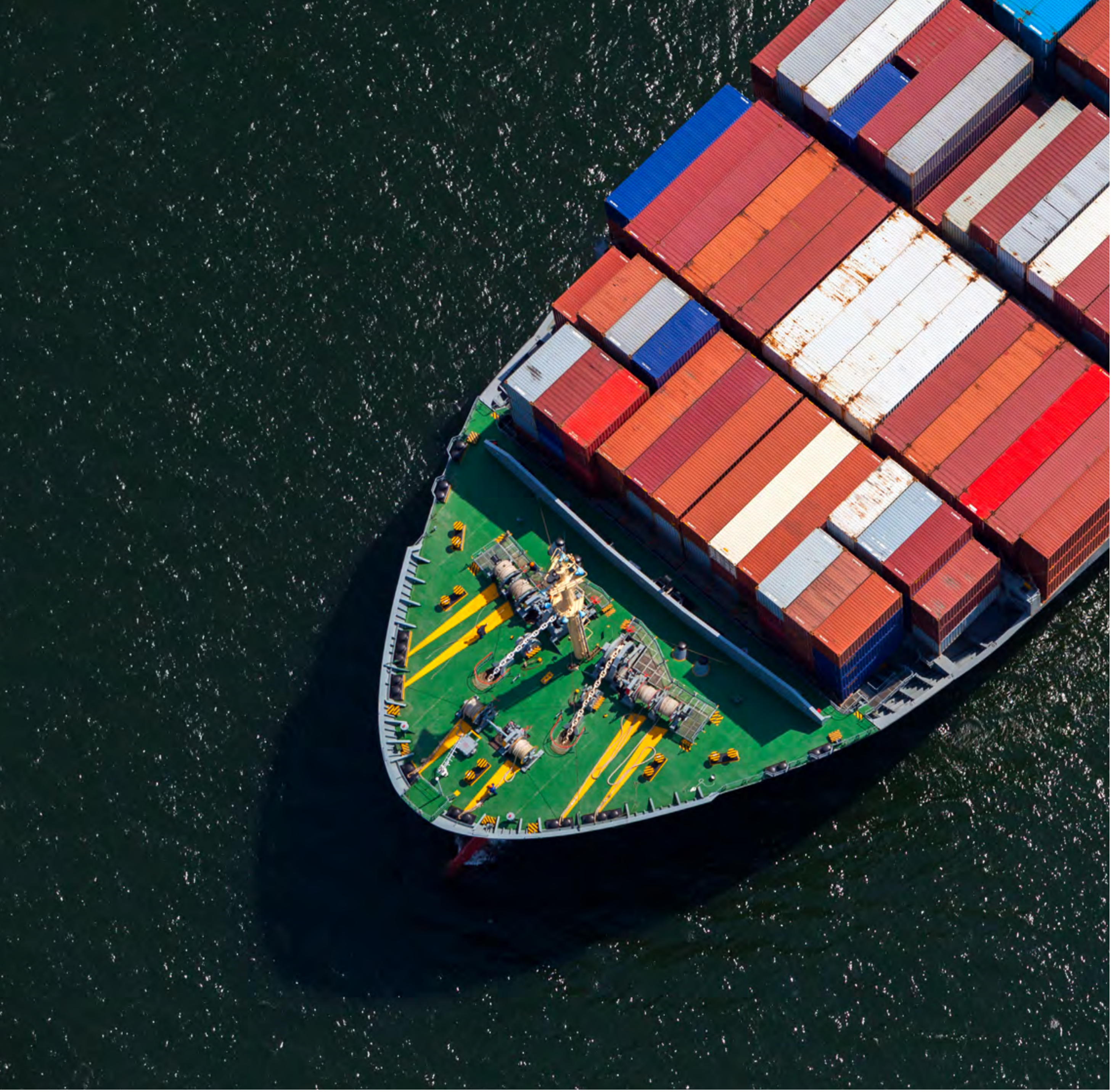
Source: Clarksons, 29 February 2024

	2018-2023 (installed)	2024+ (on order)	Total units
Suction wing	14	79	93
Flettner rotor	30	54	84
Rigid sail	18	39	57
Kite sail	2	1	3
Total	**64**	**173**	**237**

WAPS installations and orders, retrofit vs newbuild, number of vessels

Source: Clarksons, 29 February 2024

	2018-2023 (installed)	2024+ (on order)	Total units
Retrofit	24	20	44
Newbuild	5	52	57
Total	**29**	**72**	**101**



Observations

Current market data highlight three key considerations for the uptake of wind-assisted propulsion, which will be explored in greater detail throughout this report:

Operator experience: WAPS systems are installed on less than 0.03% of the global fleet, with planned installations taking that to just under 0.1%. Stretched across multiple technology types and several suppliers, that equates to very limited industry familiarity with any particular WAPS system. This low level of experience is a result of the novel technologies being deployed, their low technology maturity relative to other EET's and perhaps the limited safety and operational guidance from regulators around WAPS systems.

Scaling supply: For technology suppliers to meet existing orders would entail them delivering around 2.5 times the number of units they have installed in the past five years. To achieve uptake on around 15% of the global fleet would require a 75-fold increase on that level, requiring a dramatic increase in production capacity.

Installation capability: With just five newbuild WAPS vessels built yet more than 50 on order, shipyards will need to rapidly scale up competencies to meet demand – even more so if ambitious forecasts of uptake are accurate **(see Market Forecast)**. Although more retrofit experience has been gained so far, it remains limited in absolute terms and conversion yards will also need to ensure they have the skills required in anticipation of strong growth.

2 Cost drivers

Source: Anemoi Marine Technologies

As with all EET's, the key drivers to uptake of WAPS technologies are cost and compliance. These factors are increasingly entwined as the introduction of market-based measures – already in effect on a European level and under development at the International Maritime Organization (IMO) – mean that successful adopters of wind propulsion can benefit not just from fuel cost savings but also from reduced exposure to emissions trading requirements, penalties for exceeding greenhouse gas (GHG) intensity targets and fuel levies. And, in some cases, notably the FuelEU Maritime regulation, deployment of WAPS brings enhanced benefits in the form of dedicated reward factors, granting an outsized offset against ships' fuel use.

Fuel savings

WAPS offers the opportunity for ship operators to reduce the power demanded by engines maintaining the same operational speed, and therefore the associated emissions and fuel cost. Average fuel savings claims made by technology suppliers range from around 5% to greater than 15%. However, calculating, validating and confirming the fuel savings associated with wind propulsion is not straightforward due to the many variables that influence its performance. These include:

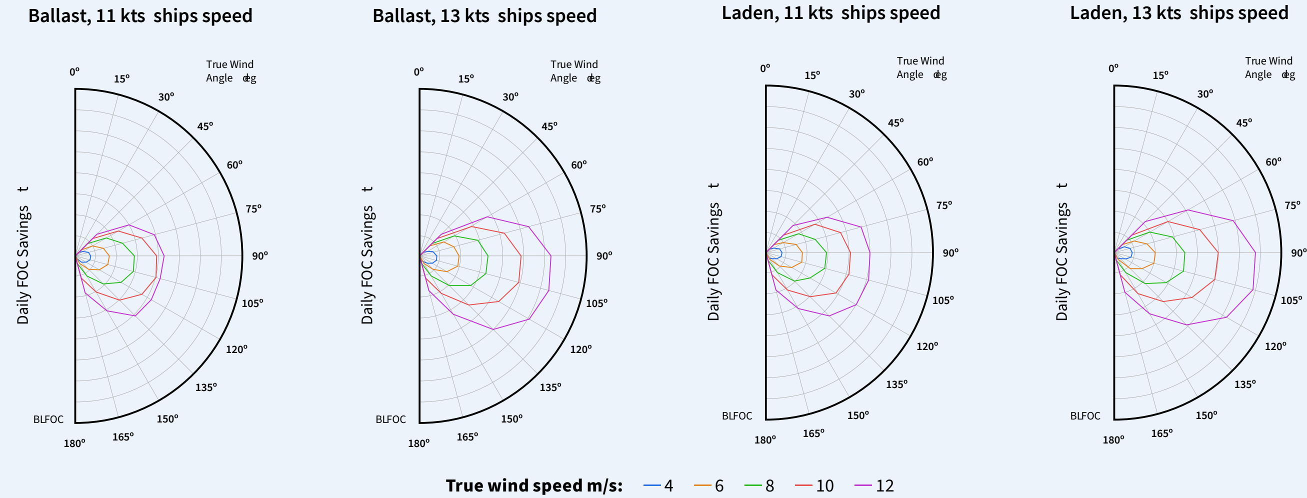
- **WAPS type, size number of devices and position**
- **Wind speed and direction**
- **Ship size (relative to WAPS type and size), speed and direction**
- **Route, speed and draft**

As a result, a thorough understanding of the vessel operating profile as well as the specific WAPS (including its weight and aerodynamic effects) are needed to calculate potential fuel savings. As an example, LR's online **Flettner rotor savings estimator** uses inputs based on vessel type and size, route, time of year, loading condition, vessel speed, rotor size and rotor position on deck to deliver a projection of a vessel's performance, showing power reductions in relation to wind speeds and angles, its monthly fuel reduction potential across the route's wind conditions, and the yearly average savings under global wind conditions for major trading routes as defined by the IMO[ii].

For more accurate projections in feasibility studies, to support operators when selecting a technology and supplier, LR generates wind probability matrices to estimate the potential savings of WAPS for different vessel routes under different operative conditions. This enables the tailored estimation of the potential savings and return on investment for the specific application. The example below shows the daily and annual fuel savings for a vessel on all legs (ballast and laden) of a transatlantic route between Bangladesh and Argentina.

Fuel oil consumption savings under different wind conditions, example vessel (Bangladesh to Argentina)

Source: LR



Condition (Baseline daily condition)	WAPS saving	Fuel savings (t)	Yearly fuel savings (t)
Ballast condition @ 11kts	8.2%	1.88 t	686
Ballast condition @ 13kts	8.4%	2.27 t	829
Laden condition @ 11kts	8.7%	2.69 t	982
Laden condition @ 13kts	9.7%	3.20 t	1,168
Average	**8.8%**		**916**

Estimated Return on Investment (RoI): 5.5 years

Fuel savings verification

Operators should note that there is little standardisation of fuel-saving claims or calculations at present, meaning that extra caution should be taken to validate forecasts.

LR has conducted and developed robust methodologies for independent feasibility studies for owners considering WAPS technologies, as well as both short-term (sea-trial) and long-term, in-service validations. It is also participating in the **WiSP 3 project** run by the Marine Research Institute Netherlands (MARIN), concluding in 2026, which aims to harmonise class rules around WAPS applications, improve predictions and develop standards for determining the performance of wind propulsion systems.

It should also be noted that feasibility studies must go well beyond fuel savings to consider factors including deck space availability, structural integrity, port requirements, client priorities, finance and operational behaviours. These factors are considered in greater detail in **Section 5**.

Capital expenditure

The cost savings associated with WAPS to a shipowner must be evaluated in comparison to other EETs. As the vessel example here illustrates, wind-assisted propulsion systems can offer the greatest fuel cost reduction potential of any EET – estimated at around 10% as an average across available technologies – but at a substantial cost, estimated at around US$2.5 million.

Retrofit options, 10-year old bulk carrier (50,000+ DWT)
Source: LR

	Retrofit details / datA		
	Typical cost of retro fit, (USD)	Fuel saving (on an annual total vessel basis)	Retrofit installation requirements (i.e. dry dock)
Propeller optimisation	400,000	2.0%	Dry Dock
Propeller Boss Cap Fin	150,000	1.5%	Dry Dock / can be done at berth
Engine Tuning	75,000	2.0%	Dry Dock / can be done at berth
Wake Equalising Duct	500,000	4.0%	Dry Dock
Rudder bulb	300,000	2.5%	Dry Dock
Wind assist	2,500,000	10.0%	Dry Dock
Air lubrication	1,500,000	3.0%	Dry Dock

Operating expense

Alongside capital costs of technology and installation, operators should also consider the operating expense of annual maintenance and repair, energy consumption (where applicable) and crew training.

The European Maritime Safety Agency (EMSA) has summarised the per unit (not vessel) costs of WAPS technologies in the table below, differentiating between minimum and maximum sizes. Worth noting are the significantly higher installation costs for retrofit installation compared to newbuild, at around 25% of asset cost compared to around 18%. This reflects the added complexity of applying new structures, that have not been designed into initial drawings, on existing vessels. However, yard prices are likely to vary widely depending on slot availability, type of WAPS technology, type of base (e.g., fixed) and shipowner relationships.

Cost indications for a single WAPS device

Source: EMSA, 2023[iii]

	WAPS	Rotor sail		Suction wing		Hard sail		Kite	
	Costs (EUR 1,000)	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**
CAPEX	Asset costs	560	1,050	200	900	438	876	340	2,345
CAPEX	Installation costs (new build)	84	158	1	135	66	130	51	351
CAPEX	Installation costs (retrofit)	140	263	2	225	109	219	85	586
One-off costs	Training	10	10	1	10	10	10	10	10
OPEX	Annual maintenance & repair	12	22	4	18	8	18	17	117
OPEX	Annual energy consumption WAPS	26	79	26	53	No data available			

3 Compliance drivers

Source: Anemoi Marine Technologies

At the current time, the major environmental regulations on which WAPS can have an impact are the EU Fit for 55 legislation, specifically EU ETS and FuelEU Maritime which has direct impacts on any ships calling at an EEA port or anchorage, and the IMO regulations specific to international shipping.

Although not laid out in detail in this report, it should be noted that WAPS will have similar impacts on other national GHG regimes and contribute to reductions in air pollution (and potentially underwater noise) from ships, stipulated by IMO, regional and individual port regulators.

IMO EEXI and EEDI

The formulae for calculating a vessel's attained Energy Efficiency Design Index (EEDI) and Energy Efficiency Existing Ship Index (EEXI) rating both take into account the energy-saving potential of wind technologies since the adoption of 2021 Guidance on Treatment of Innovative Energy Efficiency Technologies for Calculation and Verification of the Attained EEDI and EEXI[iv].

Issues persist around the precise treatment of hybrid and alternative power sources for both measures, as well as the use of specific matrices for wind power. For example, the use of the global wind matrix in the formula can underestimate or overestimate the actual efficiency achieved where winds on the actual routes a vessel plies are more favourable. These issues are being considered in ongoing IMO discussions.

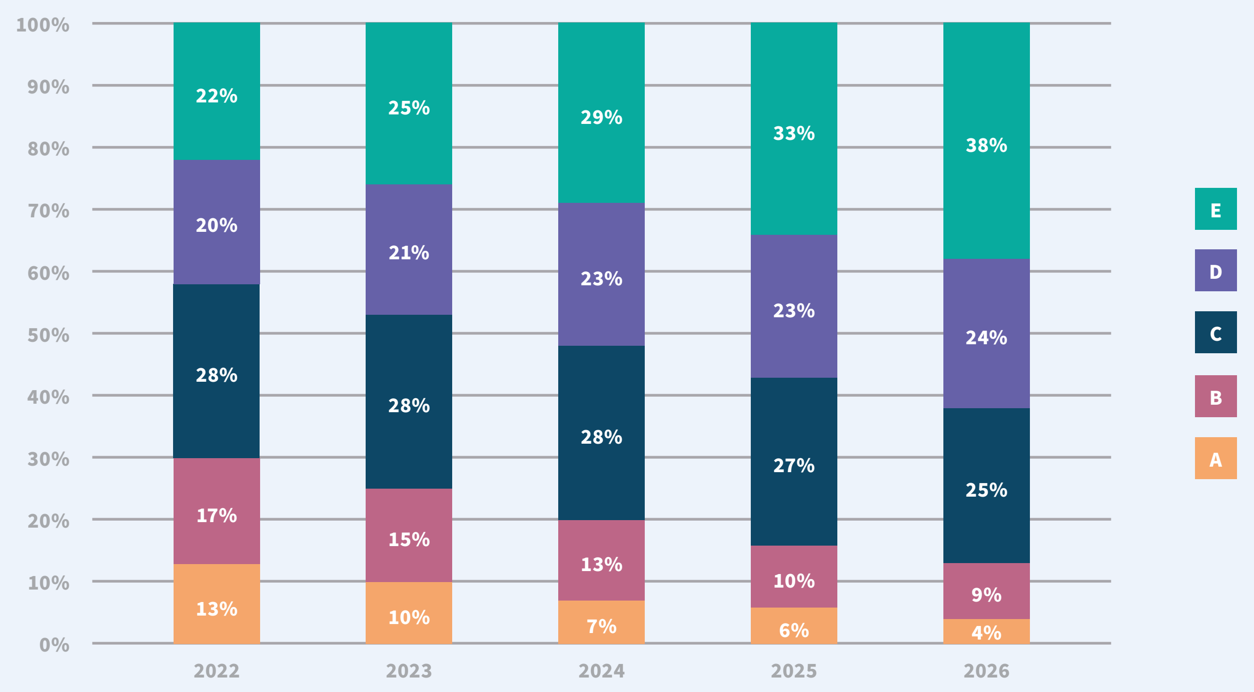
IMO Carbon Intensity Indicator

The IMO Carbon Intensity Indicator (CII) measures operational carbon intensity through fuel consumption reported under the Fuel Oil Data Collection System (DCS), grouping efficiency of operation into discrete bands (A to E) and requiring stepped improvements in the rating. As a WAPS-enabled vessel will likely have lower fuel consumption than a conventionally-powered ship at the same speed, effective deployment of wind power will improve CII performance.

CII could have a dramatic impact on the uptake of EETs particularly for existing vessels aiming to extend compliance – i.e., by prolonging their operation in a better CII band. Based on an LR analysis of the global bulk carrier fleet, the proportion of vessels attaining CII bands A-C is expected to drop from 58% to 35% between 2022 and 2026 unless significant improvements are made. This equates to around 3,000 vessels that will need to improve efficiency.

Evolution in CII rating of global bulk carrier fleet, 2022-2026

Source: LR



Starting from an initial required reduction of 5% in 2023 and adding subsequent 2% annual reductions to 2026, operators are faced with the decision of making minor enhancements at frequent intervals or adopting solutions such as WAPS that can be capable of making multi-year impact from a one-off intervention – and potentially adding five years or more compliant trading for a vessel.

However, the IMO's forthcoming decision on CII stepped reductions beyond 2026 could have an impact on the uptake of EET. Depending on measures taken to align regulations with IMO's new ambitions – particularly the target of 5-10% zero- or near-zero emission energy use and the indicative checkpoint of a 20-30% reduction in GHG emissions by 2030 (see below) – it is conceivable that more ship operators might prefer to switch to alternative fuels. Although potentially a more expensive retrofit and fuel cost, these would deliver, in principle, greater long-term emission reduction potential than WAPS.

However, the higher operational costs for alternative fuels will likely make return on investment for WAPS, and all EETs, much more attractive, reducing the barrier to their uptake. A middle way of WAPS/EET with alternative fuels is also foreseeable, with enhanced energy efficiency and lower engine power demand reducing spend on alternative fuels.

IMO revised GHG strategy

Following the adoption of IMO's revised strategy on the reduction of GHG emissions from ships in 2023, the organisation's Marine Environment Protection Committee (MEPC) and the subordinate Intersessional Working Group on Reduction of Greenhouse Gas (GHG) Emissions from Ships (ISWG-GHG) are tasked with developing technical and economic measures towards reducing emissions in line with the new ambition, reaching net-zero emissions by or around 2050.

By reducing fuel use, WAPS can contribute to compliance with the IMO revised strategy, notably its ambition that "uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources to represent at least 5%, striving for 10%, of the energy used by international shipping by 2030"[v]. The extent to which WAPS will be deployed with a view to meeting those longer term targets – including the 2030 and 2040 indicative checkpoints – is less clear. The GHG emission reductions required by those dates, 20-30% and 70-80% respectively based on 2008 levels, would need to combine multiple energy efficiency or zero-emission power solutions alongside wind.

The impact of wind propulsion on the mid-term technical measure (a global-based fuel standard) and economic measure (a pricing mechanism on GHG emissions) will also be driven by its fuel-saving potential, but cannot be assessed while those measures are under development. Wind propulsion has been included in IMO Lifecycle Analysis Guidance of Marine Fuels (LCA Guidelines), which are expected to be used in any new measure, as a zero-emissions pathway. But putting that into effect will require a standardised formula for calculating performance that has yet to be developed. A suggested approach from the International Towing Tank Conference is expected in 2024.

EU Emissions Trading System

Shipping was included in the EU Emissions Trading System (ETS) on 1 January 2024. Tank-to-wake (TtW) CO2 emissions from cargo and passenger ships of 5,000GT and above, reported under the MRV system in 2024, will be subject to the ETS in 2025. For offshore ships and general cargo ships of 400GT to 5000GT, and for offshore ships of 5000GT and above, MRV reporting will be applicable from 2025. A review of the subsequent inclusion of offshore ships of 5,000GT and above is intended by December 2026, for inclusion in the ETS from 2027.

Shipping companies operating those vessels will need to buy and surrender EU Allowances (EUA) to cover half of their GHG (CO_2, CH_4 and N_2O) emissions to and from EEA (EU plus Norwegian and Icelandic) ports, and all emissions for intra-EEA voyages and while at berth at EEA ports. Initially companies will be required to surrender sufficient EUAs to cover 40% of emissions released in 2024, raising to 100% of emissions released in 2026 and subsequent years

The EU has not considered a further reward for WAPS users in the inclusion of shipping in EU ETS, but it will offer a greater incentive in its forthcoming FuelEU Maritime regulation.

FuelEU Maritime

The FuelEU regulation was passed into law on 25 July 2023 and applies from 1 January 2025, with the exception of articles related to the required monitoring plan, which apply from 31 August 2024.

To incentivise the use of renewable and low-carbon fuels on ships over 5,000GT, FuelEU sets targets that reduce the GHG intensity of energy used on ships, based on 2020 reference levels. The energy use within the scope of FuelEU is similar to the scope of emissions covered under the EU ETS: half of energy use on voyages to and from EEA ports, and all emissions for intra-EEA voyages and while at berth at EEA ports.

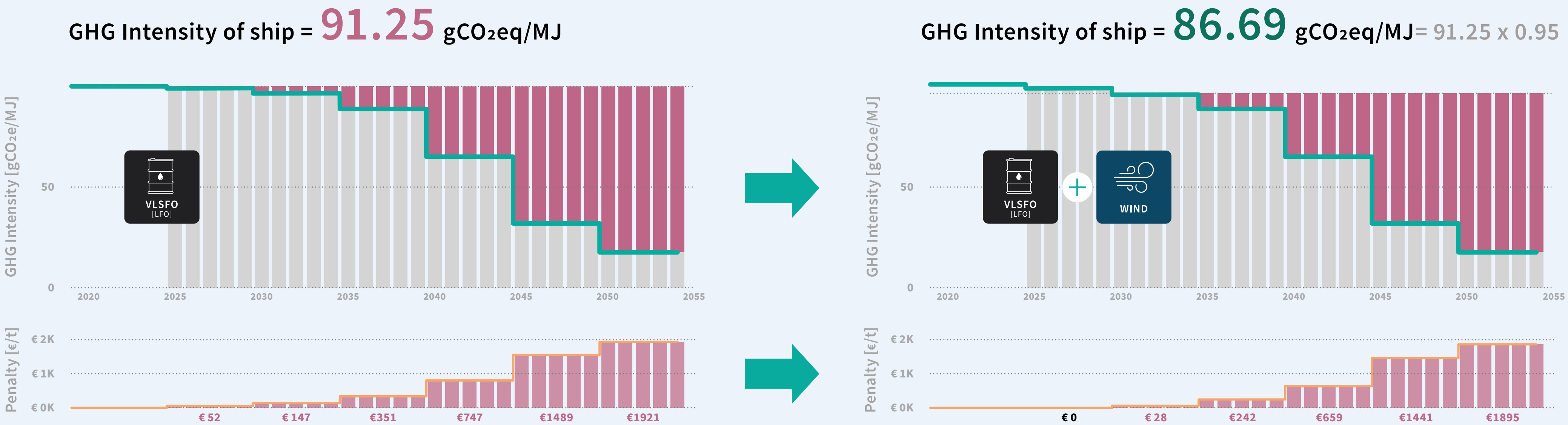
The reduction required in the lifecycle GHG intensity of fuels under FuelEU – measured based on reported fuel consumption similar to EU MRV and the emission factors of the fuels used on a well-to-wake basis – will gradually increase over time, starting at a 2% GHG intensity reduction in 2025 to an 80% reduction by 2050. There will be a financial penalty for each quantum of energy used above the reference level.

FuelEU Maritime also grants up to a 5% reduction on the GHG intensity calculation of energy used onboard for those vessels where wind assisted propulsion accounts for 15% or more of the energy used for propulsion. A reward factor is available for vessels with a minimum of 5% of propulsion energy from wind, offering a 1% discount on the GHG intensity calculation. These reward factors are ‘subject to the availability of a verifiable method for monitoring and accounting of wind propulsion energy’ – again highlighting the need for development of standardisation in how energy savings from wind propulsion are quantified.

The example below illustrates how a vessel deploying WAPS systems could reduce its FuelEU Maritime penalties – and extend the period until its energy intensity reaches the penalty level. In this case, the vessel achieves a surplus energy intensity until 2030. Under FuelEU rules this surplus can be banked for the following year or used to offset excess energy intensity in other vessels operated in the same pool. After 2030, wind assist continues to pay dividends, saving penalties amounting to more than €100 per tonne of fuel until at least 2035.

WAPS impact on FuelEU penalties, example vessel

Source: LR



4 Market forecast

Source: Anemoi Marine Technologies

Overall demand

Only two significant attempts have been made to size the future WAPS market. As part of the UK government's Clean Maritime Plan in July 2019, a study was commissioned to assess the annual global market for wind propulsion systems alongside other technologies and fuels. This was estimated to grow from a conservative £300 million a year in the 2020s to around £2 billion a year by the 2050s.

In this analysis, wind technologies – which here include both WAPS and primary wind propulsion vessels, is rated as the second most important propulsion technology field behind alternative fuels (at £8-11 billion per year in the 2050s), representing around 15% of the market potential for propulsion systems.

Another study, undertaken by CE Delft for the European Commission in 2017 , predates both the post-2018 surge in uptake and the commercial maturation of some leading technologies, notably suction sails. The report concludes that, 'should some wind propulsion technologies for ships reach marketability in 2020', the maximum market for bulk carriers, tankers and container vessels is estimated at around 3,700–10,700 installed systems by 2030, including both retrofits and newbuild installations depending on the bunker fuel price, the speed of the vessels, and the discount rate applied.

Although some WAPS technologies did reach maturity before 2020, and while greater clarity on emissions legislation has emerged since 2017, the early years of uptake forecasted by the CE Delft study do not match with the observed reality: by the end of 2023, there were just 29 WAPS installations rather than the several hundred projected in the report.

The discrepancy could be the result of pricing assumptions – for example, a significant and permanent fuel cost increase after the introduction of IMO's 2020 sulphur cap, which never emerged.

However, the dynamics of the model remain interesting and could yet prove correct: "By the time 100+ installations have been completed, the learning effect is large enough to have brought the costs down such that all [suitable] newbuilds and retrofits make financial sense, given our cost data and the oil prices and discount rates that have been assumed."

Standing at 101 planned installations today, perhaps the short, sharp increase projected by the CE Delft model is on the verge of being realised. This 'S' shaped curve would see the majority of installations occurring in the next few years, both retrofits and newbuilds, before demand flattens out and is limited to suitable newbuilds as they are added to the fleet.

Tanker and bulker WAPS installation forecast for 2050

Source: CE Delft

Ship type	Build type	2015	2020	2025	2030	2050
Tanker (5,000- 120,000 dwt)	Fleet	2,921	2,892	3,008	3,078	3,078
	New build with sail	0	0	206	208	196
	Retrofit with sail	0	15	201	205	205
Bulker (0- 100,000 dwt)	Fleet	8,653	10,719	13,281	16,446	32,435
	New build with sail	0	0	608	662	1,257
	Retrofit with sail	0	0	443	548	1,081

Retrofit demand

The study also indicates that retrofits will continue for some years to represent between 33% and 50% of all installations. This contrasts with the shift towards newbuild projects observed in the market today. But according to IWSA, this observation is a result of shortening lead times for the announcement of retrofit projects . This leaves the prospect that, beyond the 72 planned installations for 2024 and beyond, more retrofit projects may be announced and even completed over the coming year.

IWSA has compiled a more recent, albeit less rigorous, forecast based on a 2022/23 survey of its membership of WAPS suppliers and users, combined with public project announcements. Even though that projection seems to lag behind the current status of projects, the doubling of installations beyond the 100-project milestone tallies with the earlier CE Delft analysis.

The IWSA forecast does not separate newbuild from retrofit projects but gives its assessment that retrofit projects may not be adequately represented in long-term orderbook numbers: "The market for retrofitting could expand far quicker as the installation time is relatively short , depending on the amount of deck reinforcement and foundation work that is required. The actual installation of the [WAPS] unit onto its foundation can be completed in a matter of hours or a number of days for more complex systems."

LR's own experience based on the number of pre-feasibility studies it is conducting for owners considering WAPS projects aligns with the sense from the CE Delft and IWSA analyses that the uptake of WAPS technologies is reaching, if not already at, a tipping point beyond which installation numbers will increase dramatically in the next two years.

WAPS installations, short-range forecast
Source: International Wind Ship Association

Yearly	Projected installations	Wind ready
2022	23	3
2023/4	40+	8
2024/5	70-80	15+
2025/6	100+	30+
2026/7	200+	50+

Observations

Based on the discussion above, a few very general points emerge for assessing the future WAPS market:

- **A WAPS market size of up to 10,700 bulk carriers and tankers to 2030 is potentially realistic:** While the CE Delft analysis has perhaps overestimated the pace and timing of a surge in uptake, the fundamental market dynamics it uses to assess suitable vessels is accurate. That study does not consider demand from other sectors where orders are increasing, leaving the possibility of an even larger market.
- **WAPS uptake is at or nearing a tipping point:** At more than 100 completed and planned installations, technology is sufficiently mature and installation experience broad enough to encourage greater uptake over the next couple of years. This sentiment is also backed by LR's own visibility on the number of pre-feasibility studies being conducted.
- **Retrofits will form a substantial segment of WAPS demand in the early years:** With retrofit experience already gained, the installation of systems on suitable existing ships is likely to happen fairly rapidly, alongside the first newbuild installations. This is likely to place a high demand on shipyards and technology suppliers. This will be discussed in more detail in **Section 7**.

5 Technologies

Source: bound4blue and LDC

At present WAPS technologies installed and on order can be classed into four distinct types, as described in the sections below. While the mechanisms for all four are different, each generates thrust and lift, reducing the additional propulsion power needed to move ships. Crossover technologies are also emerging as technology evolves, for example suction sails incorporating rigid sail elements. Some common observations can be made about factors affecting WAPS technologies:

- **Manoeuvrability:** All WAPS technologies can have a significant impact on vessel manoeuvrability due to both their impact on vessel weight, size and shape, as well as the conditions that need to be maintained for them to achieve the intended power savings. Size and location of installations, wind conditions, ship speed and several other factors can influence manoeuvrability and must be carefully considered before a project.
- **Deck and air space:** All technologies demand free deck space. Rigid sails potentially occupy the most deck space, followed by Flettner rotors and suction wings. While kites require less space, deck installation is still required for deployment and retrieval, and obstructions to air-space on deck during these processes needs consideration. Installations must also take account of space needed for deck operations such as loading and un-loading. Manufacturers are deploying several solutions to minimise the required deck space, including elevated, foldable or retractable designs as well as units mounted on containers or rails.
- **Air draught limitations:** As all technologies can significantly alter the height of the vessel, operational height limitations need to be taken into account. As well as avoiding interaction with operations-related structures on the vessel, the available air draught should be calculated based on routes used and ports of call to avoid interfering infrastructural barriers including cranes and bridges. WAPS providers offer tiltable bases to minimise these limitations, although these bring additional cost and complexities to installation and operation.
- **Intermittence:** The effect of all technologies will vary with the prevailing wind conditions and therefore will not be fully effective all of the time, with some conditions in which they cannot be operated.
- **Power demand:** Unlike conventional sails, WAPS devices all require some element of power to rotate, manoeuvre or deploy/retrieve – or, in the case of suction wings – to generate a boundary layer of air around the sail. This power demand needs to be accounted for in the installation and operational plan, as well as accommodated when calculating power savings.
- **Hidden costs:** Beyond the unit cost and the expense of installing the unit, all WAPS projects contain further costs associated to, for example, steelwork for foundations and engineering for compliance that need to be carefully considered before the project.

Suction sails

Suction sails are non-rotating wing-shaped sails with vents and an internal fan that creates suction, pulling in a boundary layer of air around the wing for enhanced effect. The system was originally designed and deployed in the 1980s.

The vertical structures are mounted onto the deck like rigid sails and rotor sails. In contrast to rotor sails, their outer parts do not rotate to generate thrust. The orientation of the wings is adjusted automatically to the direction of the wind.

The sails deliver optimal thrust at beam winds, while their thrust is practically zero at head and tail winds. The current height of suction wings ranges from 10-36 m. Two or four wings per ship is common but, in some instances, only one wing is installed.

Installations to date have been deployed on the bow and stern, as well as in deck containers or on flat racks. Suction wings can cost between US$200,000 and US$900,000 per unit depending on size.

Supporting wind technology selection

Ship operator Louis Dreyfus Company (LDC) and suction wing technology company bound4blue will cooperate on the installation of four sails on LDC's chartered juice vessel, MV Atlantic Orchard, in collaboration with Wisby Tankers.

Chartered by LDC and owned by Wisby, MV Atlantic Orchard will be retrofitted with the 26-meter-high sails in 2024. Depending on vessel routing, the sails are expected to reduce annual fuel consumption and CO_2 emissions by at least 10%.

The decision to implement this technology was based on an independent assessment study carried out by LR, which evaluated a range of solutions and identified suction sails as the most promising for this use case.

LR developed a comprehensive engineering study to validate previous work done by third parties and build further evidence needed to secure class approval. This included review in structural, intact stability, and equipment number calculations alongside the field of vision report produced by WAPS manufacturers.

As part of the study, LR held the risk assessment and HAZID workshops and produced the Finite Element Analysis and structural drawings for classification approval, as well as delivering maintenance and inspection manuals and a testing plan for LDC.

The high-quality evidence and resources delivered by LR allowed LDC to be granted class approval for the WAPS installation.

Installations

Including planned installations to the end of 2024, nine vessels have been equipped with suction sails since 2020.

Flettner rotors

Rotor sails, or Flettner rotors, named after the German innovator who was the first to install them on a ship in the early 1920s, are vertical cylinders which spin and cause lift as the wind blows across them as a result of a phenomenon known as the Magnus effect. They are mechanically driven to develop lift and propulsion power, with the rotors reducing the energy consumption of a ship by providing lift and thrust.

The rotating cylinders generate thrust with force resulting in the horizontal plane, forward and sideways. To make sure the seagoing properties of the vessel remain good, it must be prepared and planned because the healing moment influencing the stability and the strength of the cylinder foot must be properly supported as it is subject to high stresses.

The range of cost for a Flettner rotor (excluding installation) is between US$500,000 and US$1 million[viii] depending on the size of the rotor. A typical delivery with multiple rotor sails ranges between US$1 million and US$3 million, although could be higher depending on the types of bases used.

Suction Wing cases

Ship name	Ship type	Year of build	Suction Wing installation
Ankie	General Cargo	2007	2020/21
Frisian Sea	General Cargo	2013	2021
Balueiro Segundo	Fishing Vessel	2001	2021
La Naumon	General Cargo	1979	2021
Ankie	General Cargo	2007	2022
Emms Traveller	General Cargo	2000	2023
Ville de Bordeaux	Ro-Ro Cargo	2004	2024
Bow Olympus	50K dwt Chemical Tanker	2019	2024
Atlantic Orchard	Fruit Juice Carrier	2014	2024
Pacific Sentinel	50K dwt Product Carrier	2019	2024

In-service validation of Flettner performance

Norsepower rotor sails were installed onboard Maersk Tankers MR2 tanker Maersk Pelican in August 2018. LR was contracted to perform in-service validation of Flettner rotor performance over a year-long period from 1 September 2018 to 1 September 2019 , confirming annual fuel savings of 8.2%.

The savings were confirmed by comparing detailed performance information to a baseline established with full scale measurements and computational analysis done for the vessel prior the rotor sail installation.

As part of the project, LR installed and managed an independent data system onboard for measuring ship performance. It then provided an independent analysis of the performance data and report on fuel savings for all project stakeholders.

The validation project was also used to build industry knowledge around the emerging technology. Using the experience gained, LR developed an online fuel savings calculator for Flettner rotors on several merchant ship types for any trade route.

Installations

Including planned installations to the end of 2024, rotor sails have been installed on 27 vessels since 2010.

Rotor Sail cases

Ship name	Ship type	Year of build	Rotor Sail installation
E-Ship 1	Ro-Ro/General Cargo	2010	2010
Estraden	Ro-Ro	1999	2014, 2015
Axios	Kamsarmax Bulk Carrier	2017	-
Viking Grace	Ro-Pax	2013	2018
Fehn Pollux	General Cargo	1996	2022
Maersk Pelican	Aframax Tanker	2008	2023
Afros	Ultramax Bulk Carrier	2018	2018
Copenhagen	Ro-Pax	2012	2020
Annika Braren	General Cargo	2020	2020
SC Connector	Ro-Ro	1997	2021
Sea Zhoushan	Very Large Ore Carrier	2021	2021
Berlin	Ro-Pax	2012	2022
Delphine	Ro-Ro	2018	2023
TR Lady	Kamsarmax Bulk Carrier	2017	2023
Chang Hang Sheng Hai	Handysize Bulk Carrier	2012	2023
Hai Yung Shi You	Module Carrier	tba	2023
Oceanus Aurora	VLGC	2023	2024
Haiyue	5K dwt Product Tanker	2024	2024
Alcyone	50K dwt Product Tanker	2022	2024
Berge Neblina	Very Large Ore Carrier	2012	2024
Dietrich Oldendorff	Bulk Carrier	2020	2024
DSIC Newbuild	LCO_2 Carrier	2024	2024
DSIC Newbuild	LCO_2 Carrier	2024	1H2024
Berge Mulhacen	Newcastlemax Bulk Carrier	2017	2H2024
Sohar Max	Very Large Ore Carrier	2012	2H2024
Yodohime	Bulk (Coal) Carrier	2016	3Q2024
Cemcommander	Cement Carrier	2024	2H2024

Rigid sails

Rigid sails can make use of wind to replace some or all of the propulsion power needed for a vessel.

Rigid sails designs to date can provide up to 1,200 kW of power per installed mast, with forward thrust reducing the power needed from the main engine. The effect will vary with the prevailing wind and therefore will not be effective all of the time. The effect and general applicability are also dependent on operating speed, with sails being most effective at lower speeds.

Unit and installation costs combined can range from US$438,000 to US$876,000[ix]. However, it should be noted that LR has observed higher costs than the range provided by EMSA. Fuel consumption reduction depends on vessel size, segment, operation profile and trading areas.

Installations

Including planned installations to the end of 2024, rigid sails have been installed on 7 vessels since 2018 as seen in the chart below.

Kite sails

Kite sails can be attached to the bow of a ship to generate thrust. They need to be launched and retracted depending on the wind conditions, for which automated systems have been developed. Kites make use of the higher wind speeds found at higher altitudes available to sails positioned on the deck.

The largest kite currently operating is 1,000m², with larger kite sizes under development. These can meet the requirements of larger vessels, especially when multiple kites are deployed.

Unlike other WAPS technologie s, kites can be suitable for vessels with limited deck space. However, they could be less efficient than other technologies due to the impact of the altitude and angle to the deck affecting on drive force. The deployment and recovery of the kites also adds complexity compared to deck-mounted systems.

Kite sails can cost between US$340,000 and US$2.3 million[x] depending on the size of kite used.

Installations

There have been two performed installations of kite sails since 2018, both on bulk carriers, with a further installation planned by the end of the year.

Rigid sail cases

Ship name	Ship type	Year of build	Rigid sail installation
New Vitality	VLCC	2018	2018
New Aden	VLCC	2022	2022
Shofu Maru	Bulk (Coal) Carrier	2022	2022
Oshima 11075	Ultramax Bulk Carrier	2024	2024
Canopee	Ro-Ro/General Cargo	2022	2023
Pyxis Ocean	Kamsarmax Bulk Carrier	2017	2023
Berge Olympus	VLOC	2018	2023

6 Project planning

Source: Anemoi Marine Technologies

Planning a WAPS retrofit project entails several challenges that may be beyond the experience of a shipowner. The multiple technology options and specialist suppliers are likely to be unfamiliar to companies that have previously relied on conventional propulsion configurations. The potential fuel, saving, capital and operating costs, project timeframes and regulatory requirements will also be new. This section delivers a brief overview of the main considerations to be undertaken before embarking on a WAPS retrofit project.

Regulatory and classification issues

In December 2023, LR released Guidance Notes on Wind Assisted Propulsion Systems., replacing earlier dedicated guidance on Flettner rotors. The guidance covers class requirements for WAPS vessels, statutory regulations, safety and operational considerations and intact stability requirements. For vessels that are primarily wind-powered, LR rules related to its RIGGING notation lay out the structural requirements, and these rules can be optionally used for WAPS projects[xii].

There are several statutory requirements to be followed when deploying WAPS technologies. The main items are:

COLREG 72 –
Convention on the International Regulations for Preventing Collisions at Sea, 1972;

IMO MSC.137(76) –
Standards for Ship Manoeuvrability.

IMO MSC/Circ.1053 –
Explanatory Notes to the Standards for Ship Manoeuvrability (Adopted on 16 December 2002).

MEPC.1/Circ.850/Rev.3 –
Guidelines for Determining Minimum Propulsion Power to Maintain the Manoeuvrability of Ships in Adverse Conditions.

MEPC.1/Circ.896 –
2021 Guidance on Treatment of Innovative Energy Efficiency Technologies for Calculation and Verification of the Attained EEDI and EEXI.

SOLAS Chapter II-1, Regulation 28 –
Means of going astern.

SOLAS Chapter V, Regulation 22 –
Navigation Bridge Visibility.

IMO MSC.1/Circ.1574 –
Interim Guidelines for Use of Fibre Reinforced Plastic (FRP) Elements Within Ship Structures: Fire Safety Issues

However, the European Maritime Safety Agency (EMSA) has identified several gaps in the statutory regime that complicate the deployment of wind technologies . These mainly relate to stability, with current criteria for assessing intact stability not necessarily applicable to modern sail installations. There are further issues with regulations on bridge visibility and manoeuvrability.

While these gaps exist, it is essential that class societies support shipowners in working closely with the chosen flag state in order to deal with potential non-compliance due to a WAPS installation. At present, these issues are identified by LR and resolved during dedicated Hazard identification (HAZID) workshops specific to each project.

The table below highlights the classification requirements for vessels deploying WAPS versus primary wind propulsion solutions.

Classification requirements for wind propulsion systems

Reference to LR Rules and Regulations for the Classification of Ships Pt 3, Ch 9, Sec 11 Wind propulsion systems and Guidance Notes on Wind Assisted Propulsion Systems Ch 3 Classification	All wind propulsion systems (all ship types)	RIGGING Notation (Required when system is fitted for main propulsion, otherwise optional)	Remarks
1. General	✓	✓	
2. Rig calculation requirements	✓	✓	Wind Propulsion Systems (WPS) element and all related construction i.e. rotor, wing, main and secondary frame, standing rigging, pedestal, tilting arrangement, etc)
3. Materials and components and arrangement	3.1-Materials ✓ 3.2-Components- No 3.3-Arrangement ✓	✓	The hull foundation of the WPS is to be built under class using LR materials.
4. Rig support	✓	✓	LR to attend Harbour Acceptance Test (HAT)
5. Rig stepping	✓	✓	LR to attend HAT
6 .Rig behaviour trial	✓	✓	LR Attendance during HAT
Build under survey	No - only the WAPS base and fixtures to the vessel are to be built under class	✓	WPS element and all related construction (i.e. rotor, wing, main and secondary frame, standing rigging ,pedestal, tilting arrangement, etc)

Technical issues

Alongside regulatory requirements, there are other technical issues that need to be considered. These include the impact on cargo handling operations, which can be compromised by deck installations for some vessel types. Air draught is another crucial consideration, as infrastructure in ports and harbours – bridges and cranes, for example – could impede vessels with tall, fixed sails. Other factors include:

- **Auxiliary loads and their balance**
- **Structural strength**
- **General operational obstructions of WAPS**
- **Equipment number, anchoring, and mooring**

Many of these factors can have a significant impact on the safety of operating the vessel, yet are not fully accounted for in existing class rules and IMO regulations.

For example the vessel's equipment number calculation, which determines the type, strength and length of anchors, chains and moorings needed to secure the vessel, does not include WAPS units under IACS Unified Requirement A1. But depending on the front and side projected area, these technologies can dramatically affect the strength of equipment needed to assure safe anchoring and mooring.

LR's guidance provides full descriptions of safety and operational factors - including how to factor WAPS into equipment number calculations - that will be of value to shipowners planning a WAPS project.

Economic issues

As detailed in **Section 4**, the economics around wind technologies are far from straightforward. The fuel savings that can be generated from each solution vary widely depending on wind conditions, vessel type, speed, route and the number and positioning of WAPS units. There is as yet no single standard for comparing fuel saving claims or validating that those claims are upheld at commissioning or while the vessel is in service.

LR uses ISO Standard 19030 to validate and verify the fuel savings of WAPS installations during long-term trials. Although not a statutory procedure, this framework allows for a robust analysis of the ship performance with the WAPS, and other EETs, across time.

As WAPS systems are relatively novel, the impact on other operating costs is also unclear. This can include auxiliary power requirements for some technologies, and new demands on crew in terms of maintenance.

De-risking WAPS investments

To counter the uncertainties mentioned above and many others, LR proposes a step-by-step framework for removing the risk from WAPS installations. The process starts with a feasibility study of the fleet to assess suitable options for reducing emissions and fuel consumption, concluding with verification of actual, in-service performance.

How to assess the true Wind Assisted Propulsion Systems (WAPS) performance?

Will WAPS be an attractive option for my fleet?

Assured performance and payback

Feasibility and building the business case

1. WAPS feasibility assessment for the fleet and its operation
2. WAPS market sentiment and investment readiness research
3. Detailed techno-economic study of WAPS technologies and vendors
4. EEXI and EU regulatory instrument benefits estimation
5. Conceptual design study

Engineering

6. CFD studies and reviews
7. Detailed engineering design study

Validation and optimisation

8. Short-term sea trial
9. In-service performance verification

Supporting early Flettner rotor retrofits

A retrofit to install three Anemoi Marine Technologies (AMT) rotor sails with rail deployment to an LR-class Kamsarmax bulk carrier TR Lady was executed in two phases:

- **Retrofit to 'Wind Ready': completed in Chengxi Shipyard in November 2022**
- **Rotor sail installation: completed in June 2023**

LR provided comprehensive advisory and classification support across the project. The details of both the integration project and accompanying required compliance elements are summarised in the table below. For more details on this project, the full report can be downloaded **here**.

Source: Anemoi Marine Technologies

'TR Lady' retrofit integration and compliance requirements summary

Source: LR, Anemoi Marine Technologies

Structural and electrical integration		
Retrofit work packages	Shipyard fabrication and/or supply	
	1st Phase scope of work: 'Wind Ready'	2nd Phase scope of work: Rotor Sails installed
Scope of structural integration		
Cross-deck Rotor Sail foundations	• Structural seats arranged adjacent to centreline (For Rotor Sail in operational condition)	• Rotor Sail installation on foundation structure • Mechanical fixing of Rotor Sail to foundation
Cross-deck Rotor Sail rail systems	• Rails and rail beams • Capstan winch including foundation • Accumulator including foundation • Sheave ancillary foundations	• Rail brake unit installation and set up onto rails including link beams • Winch rope installation and set up • Hydraulic piping connection for accumulator • Hydraulic buffer installation at rail beam ends • Commissioning SAT for rail system
Minor underdeck reinforcement and cross-deck modifications	• Under cross deck reinforcement for Rotor Sail foundation and rail system • Modifications for foundation and rail system including relocation of manholes, vent/sounding pipes, access walkways etc.	
Scope of Electrical Integration		
Main deck cabling for Rotor Sails	• Cabling for Rotor Sail power and control • Main deck conduit for new cabling • Main deck cabling connection boxes	• Flexible power cables to install and connect between deck boxes and Rotor Sails
Control system for Rotor Sails Electrical system modifications	• Anemometer installations (fwd & aft masts) • Bridge Control Unit (BCU) installation • Installation of capstan winch control panel • Installation of remote I/O station to collect ship equipment/sensor signals • MSB modifications with additional circuit breakers (Rotor Sails and capstan winches)	• Commissioning SAT for Rotor Sail

Ship regulatory compliance			
Regulatory Compliance Issue	Shipyard scope of modifications, installation, and test		
	1st Phase scope of work: 'Wind Ready'	2nd Phase scope of work: Rotor Sails installed	Certificates & Manuals
Safety of Navigation			
Panama Canal steering light bridge visibility	• Foremast modification • Two blue Panama Canal steering lights installed (P&S) (NOT functioning)	• Two blue Panama Canal steering lights (P&S) installed at 1st Phase 'wired in' and functioning	-
IMO SOLAS Radar antenna blind sectors	• Foremast modification • Additional radar antenna on foremast	-	-
IMO COLREGS Aft mast head light visibility	• Main mast modification • Two aft mast head lights (P&S) installed (NOT functioning)	• Two aft mast head lights (P&S) installed at 1st Phase 'wired in' and functioning. • Existing centreline aft mast head NOT 'wired in' and functioning (or removed)	**Safety Equipment Certificate** • 2nd Phase: flag state exemption
Stability and Loading			
IMO SOLAS Lightship weight & VCG change	• Inclining experiment	• Mass and VCG of Rotor Sails to re-confirm	**Loading Manuals** • 1st Phase inclining experiment • 2nd Phase update of manuals

Key features of 'wind ready' retrofit of a Kamsarmax bulk carrier', Contopoulos et., RINA Wind Propulsion Conference 2023.

7 Supply and installation capacity

Source: Anemoi Marine Technologies

The WAPS supply chain

With 16 suppliers delivering 29 installations to date, there are serious questions to be raised about the capacity of WAPS providers to scale up production to meet anticipated demand. To meet the top range of CE Delft's estimate for 2030, around 10,700 units, would require a 100-fold increase in supply over the next six years. That level of growth would challenge any company, whether a start-up or part of a multinational conglomerate – WAPS suppliers exist at both ends of that spectrum.

There are some, albeit few, positive signals coming through. One of the biggest suppliers of Flettner rotors announced two funding deals last year, both from regional innovation funds. Another rigid sail technologist recently concluded a European manufacturing and sales agreement to complement its existing Asian partnership.

The challenge for ship operators will be to ascertain the production capabilities of their prospective partners before concluding any agreement. Scaling up may just be a temporary (and good) problem to have, but if supply chain disruptions lead to delays in delivery and postponed projects, the WAPS boom could be stymied before it reaches its potential.

In the face of high projected growth from a small base, other suppliers are turning to innovative manufacturing arrangements to allow for rapid scale-up. One suction wing supplier, for example, has secured a full production line from Europe's largest producer of wind turbines. This enables the production of one wing per week, with the potential to add lines either at the existing facility or with other manufacturers, for example to extend regional coverage.

Conversion capacity

Alongside supply challenges, the rapid growth in demand for WAPS installations also poses challenges for shipyards tasked with carrying out retrofits. The current crop of 22 completed WAPS retrofits have been conducted by no more than 20 yards, with sixteen yards named and four projects unassigned to a yard. The next round of planned retrofits, totalling just 11, will bring at least a further three yards into play, extending expertise. But more will be needed to avoid slot scarcity as demand evolves.

Chinese and European yards dominate the early retrofits, and that too will need to change as the market expands. There is a notable absence of Middle Eastern and American (bar one) yards on the list to date. Global diffusion of retrofit experience will help to ensure that shipowners can secure their WAPS projects in a timely and cost effective fashion.

To counter that concern, it is likely that as WAPS technology becomes more widely accepted, vessels will be designated 'wind-ready', potentially with hull structure and mast foundations prepare from newbuild. That will ease any congestion by dramatically simplifying repair yard work, as for many technologies.

WAPS retrofits by shipyard

Source: Clarksons, LR

Yard	2018-2023	Plans 2024+
Chengxi Shipyard	2	
Shanhaiguan SB	1	
Yiu Lian (Zhoushan)	1	
COSCO Shpg (Nantong)	1	
PaxOcean Zhoushan	1	
Ferus Smit Leer	2	
Tsuneishi Zosen		1
Western Shiprepair	1	
Stocznia Szczecinska	1	
Sasebo HI	1	
Yiu Lian (Zhoushan)	1	
COSCO HI (Dalian)	1	
Damen Dunkerque	1	
Niestern Sander	1	
Damen Harlingen		1
MEC Balboa Shipyard	1	
Remontowa Repair		1
PGZ Stocznia Wojenna	1	
Astander	1	
Unknown	4	8

8 Voyage optimisation

Source: Anemoi Marine Technologies

Voyage optimisation

Aside from operating considerations discussed in previous sections, the role of voyage optimisation in effective WAPS deployment cannot be understated. In LR's experience, while most technology providers offer optimisation solutions (and crew familiarisation with them), this is not universal. Shipowners preparing to introduce WAPS technologies should take as much care over optimisation as they do over the technology itself.

As a second thought, the complementarity of WAPS and voyage should be quite clear: technologies that depend on weather can improve their performance when vessels adapt their route to find the best weather. The scale of the impact, though, is more surprising, and is confirmed in multiple academic research papers:

- **An Improved Ship Weather Routing Framework for CII Reduction Accounting for Wind-Assisted Rotors:** Weather routing, speed optimisation and wind-assisted rotors produced 4.61%, 10.61% and 4.41% reductions in total fuel consumption respectively on a single route from China to the Middle East, with a similar reduction in the attained Carbon Intensity Indicator (CII).
- **A New Routing Optimization Tool - Influence of Wind and Waves on Fuel Consumption of Ships with and without Wind Assisted Propulsion Systems:** A new software tool showed around 4% savings on its own, but 50% when combined with WAPS.
- **Minimal Time Route for Wind-Assisted Ships:** A 76,000DWT wind-assisted cargo ship achieved a shorter crossing time, with lower fuel consumption and emissions, despite the longer optimised route planned by a weather algorithm.
- **Weather Routing Benefit for Different Wind Propulsion Systems:** Higher benefits from weather routing were found first for rotor sails, then for suction wings, and finally for wing sails.

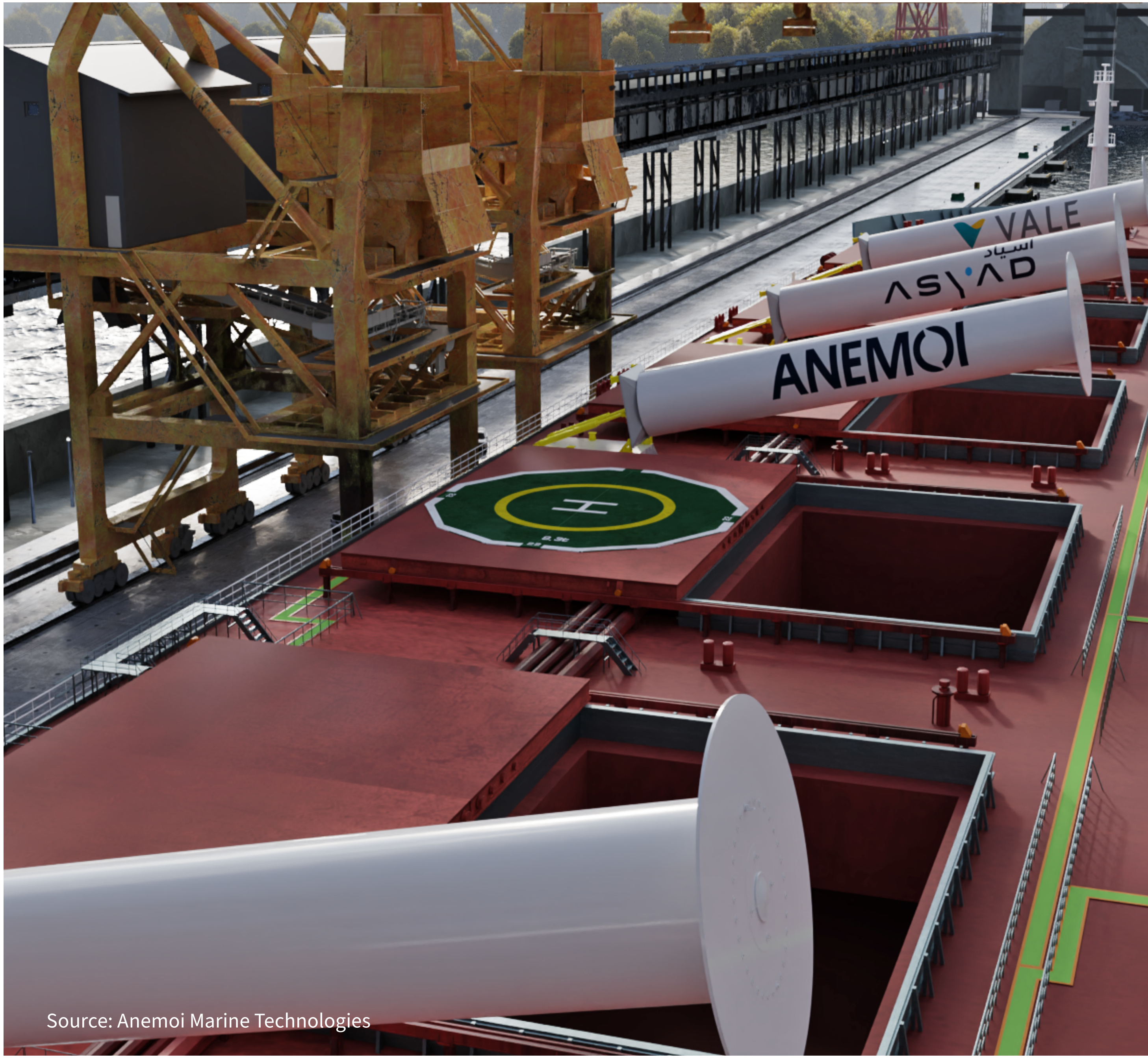
9 Conclusion

Wind assisted propulsion systems is in its late childhood and due to a significant growth spurt. The associated growing pains are inevitable. Lack of familiarity with the technology – not necessarily helped by multiple suppliers promoting many different systems – is one obstacle, both for shipowners hoping to retrofit WAPS technology and for the majority of shipyards that will be needed to perform those installations. Lack of standardisation of fuel-saving claims and methodologies for verifying them is another. Both are in hand but will remain a challenge for early adopters.

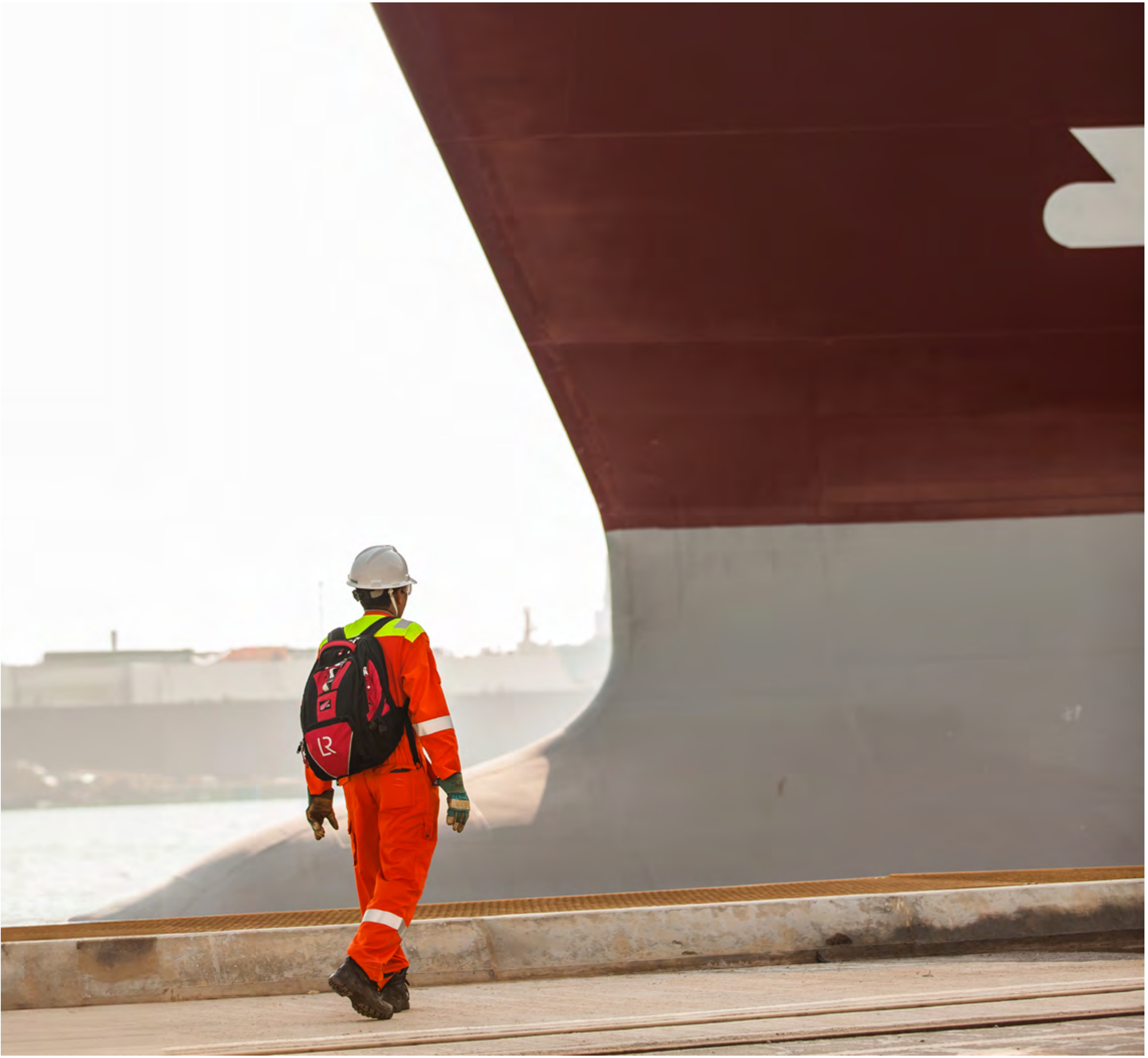
Despite those challenges, the significant impact of harnessing the wind – on fuel cost, carbon cost exposure and environmental compliance – should not be ignored. And the indications are that it will not be. Projections are hard to ascertain but based on the best available analyses and the volume of feasibility studies being requested from LR, uptake of both retrofit and newbuild installations is poised for a sharp upward tick within the next two years.

For retrofit projects, the scaling up of technology supply will be a particularly acute consideration. Taking ships out of service to find components not waiting for installation adds to the already extra expense of such conversions. Choosing the right supplier and the right yard will be vital. So too will navigating the potential pitfalls of new technologies – costs not predicted, operational constraints unanticipated and regulatory regimes unknown or incomplete.

LR has undertaken expert services for shipowners, shipyards and technology suppliers preparing to capitalise on wind technology. From approvals in principle of new technologies and feasibility studies to complex computational fluid dynamics (CFD) calculations and in-service performance verifications, LR has the breadth of experience and expertise to support stakeholders through adopting new technologies, securing confidence that WAPS retrofits can be safely and optimally deployed.



Source: Anemoi Marine Technologies



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vii. See iii

viii. See iii

ix. See iii

x. See iii

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xiii. See iii

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