INTERNATIONAL
MARITIME
ORGANIZATION

MARINE ENVIRONMENT PROTECTION COMMITTEE
81st session
Agenda item 7

MEPC 81/INF.39
12 January 2024
ENGLISH ONLY
Pre-session public release: ☒

REDUCTION OF GHG EMISSIONS FROM SHIPS

White paper on wind propulsion

Submitted by Comoros, France, Solomon Islands and IWSA

SUMMARY

Executive summary:	This document presents the IWSA wind propulsion white paper compiled in the light of the recently adopted *2023 IMO strategy on reduction of GHG emissions from ships* and the work underway on mid-term measures. The white paper delivers a detailed baseline assessment of wind propulsion technology (WPT) systems and outlines pathways underway for the dissemination and scaling of this technology segment. The content builds on the summary document MEPC 79/INF.21 (Comoros et al.) giving additional technology and policy context and a detailed macro and micro economic analysis of the benefits of following a wind-hybrid decarbonization pathway. These are supplemented by an updated market analysis and case studies covering numerous wind propulsion solutions. The report also delivers results from an IWSA initiated survey of industry stakeholder perspectives relating to wind propulsion uptake along with a detailed summary of barriers and drivers in the industry which help to inform the regulatory gap analysis and recommendations for further action.
Strategic direction, if applicable:	3
Output:	3.2
Action to be taken:	Paragraph 27
Related documents:	Resolutions MEPC.304(72), MEPC.377(80); MEPC.1/Circ.896, MEPC.1/Circ.815; MEPC 62/INF.34; MEPC 74/5/30, MEPC 74/INF.39; MEPC 75/INF.26; MEPC 76/6/2, MEPC 76/6/6, MEPC 76/6/7, MEPC 76/6/8, MEPC 76/6/10, MEPC 76/7/31, MEPC 76/INF.30; MEPC 77/6; MEPC 79/INF.21 and MEPC 80/INF.33

Introduction

1 MEPC 72 adopted resolution MEPC.304(72) on the *Initial IMO Strategy on reduction of GHG emissions from ships* and this was designated as the first milestone set out in the *Roadmap for developing a comprehensive IMO Strategy on reduction of GHG emissions from*

ships approved at MEPC 70. The roadmap identified that a revised Strategy was to be adopted in MEPC 80 in 2023 and MEPC 80 (July 2023) adopted the *2023 IMO strategy on reduction of GHG emissions from ships* (2023 IMO GHG Strategy) through resolution MEPC.377(80).

2 Resolution MEPC.377(80) tightened the IMO decarbonization goals, with GHG emissions from international shipping to peak as soon as possible and to reach net-zero by or around, (i.e. close to), 2050, taking into account different national circumstances. The uptake of zero- or near-zero GHG emission technologies, fuels and/or energy sources is to represent at least 5%, striving for 10% of the energy used by 2030. Interim indicative checkpoints were introduced for 2030, when all GHG emissions should be reduced by 20%, striving for 30% and by 2040, reduced by 70%, striving for 80%.

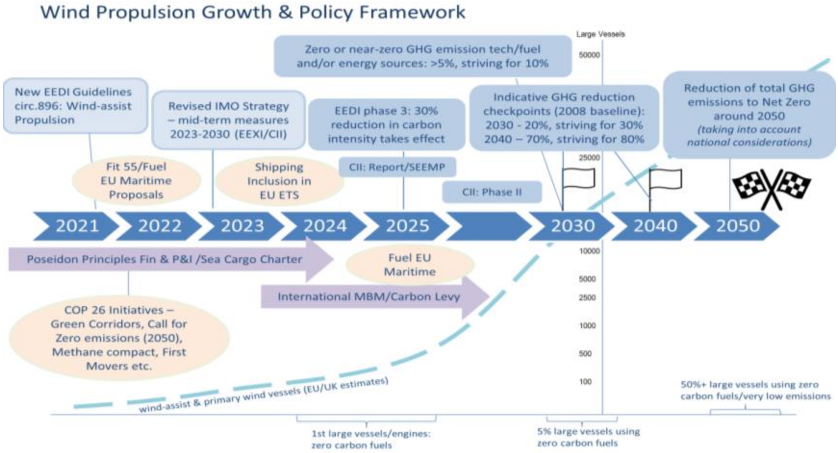

Figure 1: Wind propulsion growth and policy framework (IWSA, 2023)

3 In light of this challenging set of decarbonization goals and the ongoing work to deliver mid-term measures within a tight framework, the provision of this wind propulsion white paper, contributes further detail and analysis to assist with the full inclusion of wind propulsion technologies into the models and structures being prepared at the Organization.

4 Many previous assessments and decarbonization pathway reports have significantly underestimated the potential for wind propulsion or excluded the technology segment entirely. This situation has been improving recently, partly in response to the updated *2021 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI and EEXI* (MEPC.1/Circ.896) and earlier wind propulsion submissions culminating in document MEPC 79/INF.21 (Comoros et al.).

5 Most past assessments of wind propulsion technology (WPT) solutions have either not taken into account the optimization factors that enhance wind propulsion solutions, such as weather routing for wind, voyage, etc. or have solely focused on retrofit wind-assist without adequate emphasis on new build design optimization for wind-assist or primary wind ships. There has also been an underestimation of the number of ships that can utilize wind systems (most of the fleet), the size and scale potential of WPT solutions, the improvement in materials and support systems, automation and the innovative approaches in dealing with air draft and operational constraints (movable, hinged, retractable, modular), etc.

6 The optimization of WPT solutions and their integration into a holistic approach to ship design, full fleet deployment and operations has the potential to deliver substantially on the targets enshrined in the 2023 IMO GHG Strategy. This contribution is highlighted in the report *Shipping GHG emissions 2030: Analysis of the maximum technical abatement potential* that

was released during MEPC 80 from CE Delft (June 2023)* which indicates that: "significant reductions in GHG emissions of between 28-47% can be realized with a combination of wind-assisted propulsion option with the largest efficiency improvement (which may vary per ship); — 20 or 30% speed reduction relative to 2018 (for those ship types where such a speed reduction results in a reduction of GHG emissions, after taking into account that the fleet will need to increase to provide the same amount of transport work as in BAU); and — 5-10% of the energy is derived from zero-GHG fuels. This amounts to approximately 175–350 Mt CO2e on a well-to-wake (WtW) basis per annum, depending on the Business-As-Usual (BAU) emissions in 2030. When introduced gradually from 2025, the measures could avoid cumulative emissions of 500–1,000 Mt CO2e. About half of the emission reductions result from lower speeds and other operational measures, a quarter from wind-assisted propulsion and other technical measures and another quarter from using zero and near-zero-GHG fuels, however the report does not look deeper at the combined additional benefits that could be delivered from wind-propulsion in combination with the reduction in speed for example. Implementing these measures would only increase shipping costs by 6-14% on average, relative to BAU which is well within the standard annual fluctuations in bunker costs."

7 The report presented in full in the annex to this document covers the following areas: (1) key policy issues; (2) summary and application of wind propulsion systems; (3) assessment of wind propulsion – approaches, challenges; (4) current installations and market potential; (5) economic benefits, business models and finance and case studies; (6) barriers and drivers for wind propulsion; and (7) regulatory gaps, recommendations and work underway.

Key policy issues

8 Adopting a holistic energy-focused approach as opposed to a narrow fuel-centric one is key to the delivery of the IMO 2030, 2040 and 2050 levels of ambition and indicative checkpoints on decarbonization as well as other non-GHG emission reduction targets. This requires the development of a level playing field for all energy sources, including wind propulsion, throughout the policy deliberations at the IMO (and elsewhere), including but not exclusively: the comprehensive impact assessment of mid-term measures, the fuel life cycle analysis, the GHG fuel standard and so forth. This holistic approach acknowledges the inclusion of all climate impacting and non-climate related emissions and will facilitate 'Total Cost of Ownership' (TCO) assessments.

Summary of wind propulsion systems

9 The report covers the main wind propulsion technologies in the market and under development along with a focus on the separation of 'wind-assist' and 'primary wind' deployments, noting that at lower speeds a nominally 'wind-assist' system could be providing most or all of the propulsive power to the ship under certain weather conditions.

Application of wind propulsion

10 Well-to-tank (WtT), the energy source used by WPT (the wind) is a zero-rated emissions energy source. It could also constitute a reference for comparing emissions from all energy sources in complement or in alternative of using HFO as a reference as is often the case today. WtT benefits of this energy source include: (1) no embedded energy from existing and new infrastructure; (2) no risk of pollution/accidental discharge or fugitive emissions risk; (3) no fuel safety considerations – there are no risks of contamination, fire, explosion, exposure etc. in WtT delivery of wind energy to the ship; (4) supply risk can be factored into supply chain assessment; (5) low risk of restriction of supply/usage in vulnerable areas (Arctic, MPAs etc); and (6) no risk from regulatory or criteria change as it is zero-rated for all emissions.

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* https://cedelft.eu/wp-content/uploads/sites/2/2023/06/CE_Delft_230208_Shipping_GHG_emissions_2030_Def.pdf

11 Tank-to-wake (TtW), the energy delivered remains the same. Even if some WPT require some energy to operate, all will be net zero-emission in operation. Manual passive systems require no additional power whereas automated passive systems require a small amount to lower/raise and adjust the system to maximize thrust. (<1%). Active systems such as rotor sails/suction wings require electric motors to generate additional thrust (<10%) but the energy required can be provided by the system itself and will vary between WPT.

Assessment of wind propulsion – approaches, challenges

12 The need for a standardized approach to the assessment of WPT systems is very important as the type and sizes of WPT continue to proliferate and robust calculations are required for regulation going forward. This section discusses the means for validating WPT performance and how WPT interact with the ship and one another.

13 Safety is a key consideration and the recent European Maritime Safety Agency (EMSA) report on *Potential of wind-assisted propulsion for shipping* (November 2023) includes a comprehensive gap analysis on safety regulations and recommendations for action.

14 As larger WPT systems are introduced and primary wind ships enter service, sea trial standards, the need for review and updating of *2021 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI and EEXI* (MEPC.1/Circ.896) along with further updating of current classification society guidelines for WPT installations will be increasingly important too.

Current installations

15 The fleet of wind propulsion installed ships continues to grow. As of August 2023, there were 30 large WPT equipped commercial ships in operation across a range of segments and sizes, from VLCC/VLOC, other tanker and bulker sizes, ro-ro, ferry/cruise, general cargo and fisheries along with eight ships that have received a notation of 'wind ready'. These ships have a total of 63 rigs installed and account for over 1.8 million tonnes of shipping (DWT for cargo, GT for ro-ro/passenger ship) along with 445,000 DWT 'wind-ready' and a further 16 ships (1.7 million DWT) awaiting installation and delivery by the end of Q1 2024.

16 There also 20+ smaller sail cargo and traditional rigged cruise ships in operation and this is likely to rise 25 to 50% in the coming 2 to 3 years. There are also surviving pockets of small traditional commercial craft, most notably operating in lesser developed regions such as the dhow trades in the Indian Ocean, South-East Asia and the Pacific islands.

Market potential

17 An IWSA survey (June 2023) questioned over 80 policy makers and industry stakeholders on the market potential of wind-assist and primary wind uptake in 2030 and 2050 alongside other fuel options. The results clearly indicate that 'wind-assist' was seen as a very significant contributor to the energy mix in 2030, and both primary wind and wind-assist combined would be on a par with other low and zero-emission fuel choices by 2050.

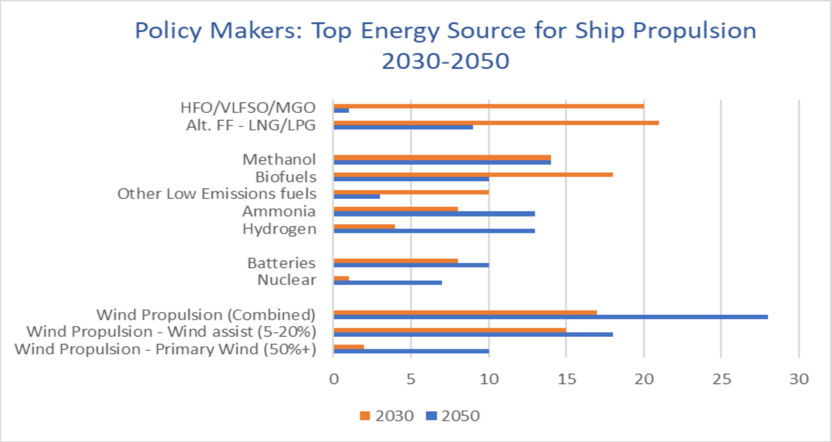

Figure 2: Policy makers: top five energy sources for ship propulsion 2030 to 2050 (25 respondents) (IWSA Survey 2023)

18 The EU market analysis (CE Delft 2016/7) forecast up to 10,700 installed systems until 2030 on bulk carriers, tankers and container ships, equivalent to savings of up to 7.5 Mt CO_2 in 2030 and around 20,000 jobs, however this study did not include general cargo, ro-ro, ro-ro passenger ships, fishing ships or cruise segments. The current trend of roughly doubling installations each year aligns with this forecast, however further acceleration in these additional markets could significantly boost those numbers if conditions are right.

19 The UK Government Clean Maritime Plan (July 2019) gives a global market projection for WPT systems growing from a conservative £300 million/year ($360 million) in the 2020s to around £2 billion/year ($2.4 billion) by the 2050s worldwide. Added research indicated 37,000 to 40,000 ships with wind propulsion installations by 2050 or 40 to 45% of the global fleet.

20 Major ship owners, ship charterers and cargo owners are already involved in WPT projects including: Berge Bulk, Cargill, CMA-CGM, Compagnie Maritime Nantaise, Hapag Lloyd, "K"-lines, Louis Dreyfus Company, Louis Dreyfus Armateurs, Marubeni, Mitsubishi, Mitsui O.S.K. Lines, Odfjell, Oldendorff, Ponant, Scandlines, Shell, Vale, WWL, etc. along with shipbuilders Chantiers de l'Atlantique, CSSC, DCIS, DSME, Hyundai Heavy Industries, Oshima Shipyards, Samsung Heavy Industries, Sumitomo Heavy Industries, etc.

Economic benefits, business models and finance

21 Making the case financially is critical for both technology vendors and shipowners. Wind propulsion is the only alternative propulsion system that will use a fuel that is cheaper than existing energy sources and thus secure an ROI which will improve as carbon levies are imposed and lower costs from economies of scale and 10% learning curve for WPTs are factored in. Growing options for alternative WPT financing with modular installations and leasing moves the segment away from heavy CAPEX to more of an OPEX approach.

22 The wind propulsion sector is showing signs of scaling activity with investment levels increasing markedly and growing merger/partnership activity. The potential benefits from this activity are highlighted by an example of the wind propulsion cluster forming in France, and on the potential for LDCs and SIDS to introduce, operate and fabricate WPT in the future.

Case studies

23 To add context there are over 20 selected case studies of installations, technology assessments and economic models included that have been chosen to create a three-dimensional snapshot of ongoing projects and current commercial operations.

Barriers and drivers for wind propulsion

24 The combination of IWSA survey results (Jun 2023) and findings from an expert roundtable of 30+ leading industry stakeholders (September 2023) deliver a detailed analysis of the barriers to WPT uptake and the drivers and enablers that are in place tackling these issues.

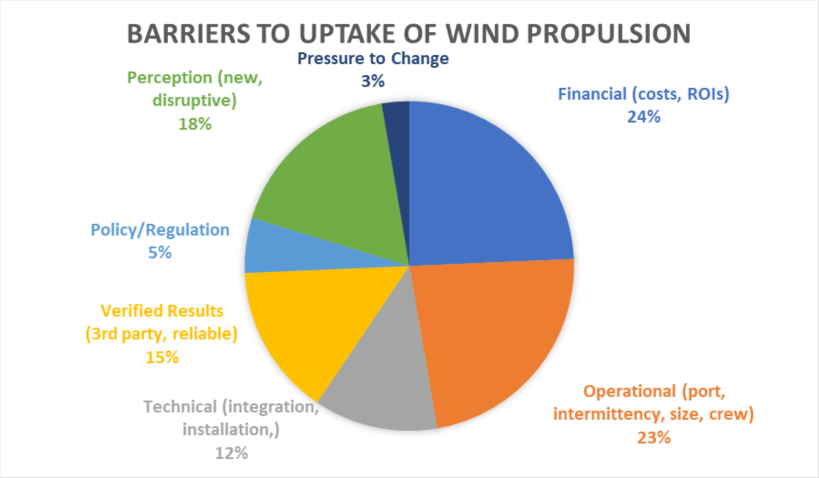

Figure 3: Barriers to the uptake of wind propulsion (IWSA Survey 2023)

25 With an increase in the number of demonstrator installations in operation and larger shipping stakeholders becoming actively involved, the technical and policy areas are now moving in the right direction, though much work still remains to be done. The market and finance sector however need to move more robustly in order for WPT to scale quickly.

Regulatory gaps, recommendations and work underway

26 The report concludes with regulatory gaps and recommendations, and these are presented as discussion points and not formal recommendations to the Organization at this stage:

.1 level playing field assessment: the adoption of an integrated, holistic energy approach, instead of a narrower 'fuel-centric' one;

.2 full emissions calculation: assess and compare wind propulsion with other fuel pathway options on a full life cycle assessment of emissions (not only TtW GHG emissions);

.3 finance and subsidies: adoption of a "Total Cost of Ownership" (TCO) approach is needed if business models, returns on investment and the full impact of WPT's are to be appreciated; and

.4 safety and technical – the current regulatory model does not adequately incorporate wind-assist technologies and primary wind ships.

Action requested of the Committee

27 The Committee is invited to note the information contained in this document.

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ANNEX

Wind Propulsion:
Zero-Emissions Energy Solution for Shipping

Compiled by: International Windship Association (IWSA), January 2024

Wind Propulsion:
Zero-Emissions Energy Solution for Shipping

Executive Summary

This report on wind propulsion technologies is delivered in light of the challenging set of decarbonisation goals set at IMO MEPC80 and the ongoing work there to deliver mid-term measures within a tight timeframe of making those operational in 2027/28. It is also presented with the backdrop of the EU inclusion of shipping into the EU ETS as of 01 January 2024 and the pending implementation of the FuelEU Maritime regulations at the beginning of 2025. This report is intended to contribute further detail and analysis for the full inclusion of wind propulsion technologies (WPT) into the decarbonisation pathways, regulatory models and structures being prepared at IMO.

2024/5 is slated to be a period of substantial growth for the wind propulsion segment. This report aims to create a baseline against which these developments can be measured. After introducing a brief summary of the key unique points relating to wind propulsion and a cursory look at the technologies in development and in the market it moves on to tackle the key questions around the assessment of wind propulsion technologies, their inclusion in the design and operations of vessels, and the opportunity to optimise the use of the systems and ships through state-of-the-art satellite weather forecasting, cutting edge weather routing software, sensors/LiDAR and voyage optimisation measures.

As a standalone technology cluster, wind propulsion could easily deliver 20%+ fuel and emissions reductions across the fleet in a combination of retrofitting existing ships and the delivery of optimised new build and primary wind vessels by the 2030s if the resources, finance models and a level playing field in regulation, decarbonisation pathways and subsidies are delivered on.

Wind energy is the only alternative energy source that will not only pay for itself but will deliver a pure zero-emissions energy (not just zero-GHG emissions) from well-to-wake for the lifetime of the vessel at no charge.

This report takes a snapshot of confirmed WPT developments up to the end of Q3 2023 with 30 large commercial vessels in operation with WPT installed, a further eight wind-ready ships and 16 more large vessels installations pending (by the end of Q1 2024), altogether accounting for over 2.2 million dwt of shipping operational, with another 1.7 million dwt pending.

The report then delivers the overview of results from the recent IWSA survey of shipping industry stakeholders and policy makers (June 2023), indicating wind propulsion as a key component of the energy mix both in 2030, especially wind assist, and again in 2050 as a mix of wind-assist and primary wind ships. These findings align with the EU report forecasts of 10-15% of the global fleet (mainly tankers and bulkers) installed with WPT in 2030 (CE Delft 2016-17) and the UK Clean Maritime Plan (2019) analysis of future markets for WPT, with 40-45% of the global fleet installed by 2050. The IWSA inhouse near-term pipeline assessment of installations aligns with these forecasts, however, the technology segment is showing signs of approaching an inflection point with the potential for having virtually all ships outfitted with wind propulsion systems at far earlier dates being a real option, but that will require bold market and policy choices to be made in the next few years.

The current installations and forecasts outlined in the report are supported by a collection of 20+ case studies that present operational vessels, designs and potential market development.

There are of course barriers in place to upscaling and disseminating WPT at a global fleet level and findings from the aforementioned survey and an expert roundtable held in September highlight that while technical and design issues are still pertinent, these are being tackled systematically, whereas the availability of validated performance data for the market, financial sector alignment and other business related obstacles are where the majority of work needs to be done to assure scaling of WPT and primary wind vessels in the market.

The report concludes with a focus on regulatory gaps and a raft of recommendations of how to reduce or eliminate these. These are clustered together under four main categories; the need for a level playing field assessment of WPT and its potential in policy pathways, a full emissions calculation to comprehensively assess and compare wind propulsion with other fuel pathway options, a finance and subsidy model that incorporates a holistic 'Total Cost of Ownership (TCO)' model and the need for WPT safety & technical measures for both wind-assist and primary wind ship to be fully integrated into the regulatory model framework.

Related Documents (IMO)
Resolution MEPC.304(72), MEPC.1/Circ.896, MEPC.1/Circ.815; MEPC 62/INF.34; MEPC 74/5/30, MEPC 74/INF.39; MEPC 75/INF.26, MEPC 76/6/2, MEPC 76/6/6, MEPC 76/6/7, MEPC 76/6/8, MEPC 76/6/10, MEPC 76/7/31 and MEPC 76/INF.30, MEPC 77/6, MEPC 79/INF.21, MEPC.377(80), MEPC 80/INF.33

Related Documents (EU)
EU ETS, FuelEU Maritime, REDIII, Net Zero Infrastructure,

Other Related Documents & Approaches
Total Cost of Operation (TCO), Life Cycle Assessment (LCA), Clydebank Declaration: Green Corridors, Methane Declaration, Net-Zero Commitments, Paris Agreement, UNFCCC AR6 Report.

Overview of Wind Propulsion Systems

Contents

1) Introduction & Key Policy Issues

> **“The pessimist complains about the wind; the optimist expects it to change; the realist adjusts the sails.” - W.A. Ward**

Introduction

The shipping industry has unique access to an abundant, globally available, pure zero-emissions energy source that is delivered directly to the ship at the point of use without the need for mining, refining, transporting, bunkering or storing the energy onboard. This free energy source is of course the wind, and the modern technologies used to harvest this directly for ship propulsion have been under development for many years utilising decades of knowledge. These wind propulsion technologies (WPT) are now being demonstrated extensively across the fleet with over 30 large commercial vessels from bulkers to tankers and general cargo through to RoPax and RoRos in operation worldwide.

Industry stakeholders and policy makers are increasingly understanding that wind propulsion provides a robust and readily available decarbonisation option, that also has co-benefits that can also help future proof the fleet when it comes to providing; energy security, regulatory compliance for all emissions (not only GHG emissions) and one that has a strong business case as it remains a free of charge energy source for the lifetime of the vessel and beyond.

As a standalone technology cluster, wind propulsion could easily deliver 20%+ fuel and emissions reductions across the fleet in a combination of retrofitting existing ships and the delivery of optimised new build and primary wind vessels by the 2030s if the resources, finance models and a level playing field in regulation, decarbonisation pathways and subsidies are available.

There is a rapidly increasing body of information on this new technology segment and how it can be applied fleet wide and therefore this report was conceived in an effort to draw together the key sources of information, highlight the work underway but also to identify areas for further investigation and continued barriers that need to be challenged.

The growing momentum in the deployment of both retrofit and newbuild optimised wind propulsion systems is a timely development in the light of the recent decarbonisation strategy passed by IMO and the regulations coming into force in the EU in 2024/25. The creation of a wind hybrid decarbonisation pathway is a great opportunity for shipping, for investment, for coastal communities and for lesser developed regions and small island developing states. The following chapters will help map out that opportunity and guide us through how that deployment will look across the global fleet in the 2020s and beyond.

1-1 General Overview of Policy

MEPC 72 adopted resolution MEPC.304(72) on Initial IMO Strategy on reduction of GHG emissions from ships and this is designated as the first milestone set out in the Roadmap for developing a comprehensive IMO Strategy on reduction of GHG emissions from ships (the Roadmap) approved at MEPC 70. The Roadmap identified that a revised Strategy was to be adopted in MEPC 80 in 2023 and in July last year the IMO adopted the revised IMO GHG strategy. https://www.imo.org/en/MediaCentre/PressBriefings/pages/Revised-GHG-reduction-strategy-for-global-shipping-adopted-.aspx

This strategy outlines the following:
1. Level of Ambition - GHG emissions from international shipping to reach net zero - to peak GHG emissions from international shipping as soon as possible and to reach net-zero GHG emissions by or around, i.e. close to 2050, taking into account different national circumstances.

2. 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. (*underlining added)

3. No binding interim targets for 2030/2040 but rather indicative checkpoints:

(3-1) 2030, all greenhouse gas (GHG) emissions should be reduced by 20 percent, striving for 30 percent.

(3-2) 2040, all greenhouse gas (GHG) emissions should be reduced by 70 percent, striving for 80 percent.

Mid-term measures – there was an agreement to move forward with a (i) technical element, namely a form of goal-based marine fuel standard regulating the phased reduction of the marine fuel’s GHG intensity [likely a Global Fuel Standard or Global Fuel & Energy Standard] (ii) economic element, on the basis of a maritime GHG emissions pricing mechanism with a basket of measures that is still undecided but will undergo a Comprehensive Impact Assessment (CIA) led by UNCTAD to judge their impacts of these measures especially on LDCs/SIDs [but also on other developing countries.]

IMO draft schedule: The basket of mid-term GHG reduction measures should be finalized and agreed by the IMO Committee by 2025, however no dates are set for establishing the delivery mechanisms or for these coming into force, the earliest will be 16 months after the adoption.

2024 - MEPC 81 (spring 2024) - Interim CIA report // Finalization of basket of mid-term measures

2024 - MEPC 82 (autumn 2024) - Finalized CIA report

2025 - MEPC 83 (spring 2025) - Approval of mid-term measures

2025 - Extraordinary 1-2 day MEPC (six months after MEPC 83 – autumn 2025) - Adoption of mid-term measures

2027 - 16 months after adoption - Earliest date of entry into force for mid-term measure

- The European Union (EU) has moved forward with the ‘Fit for 55’ program with maritime elements included; the technical elements being the FuelEU Maritime regulation along with the Renewable Energy Directive (RED) III and the economic element being shipping’s inclusion in the EU ETS from the beginning of this year. There are also significant elements in infrastructure and fuel provision legislation that will also impact shipping. [Note: A white paper regarding EU regulation impacts on wind propulsion will be released shortly.]

- This report covers only these international policy implications, however it is noted that there are numerous national decarbonisation initiatives that will also impact the industry collectively and individual shipping companies operating in or out of those countries.

1-2 Overview of Impacts and Implications for Wind Propulsion

These policy developments at IMO and the EU acknowledge explicitly or implicitly the role of wind propulsion in the delivery of the targets set and there is movement to fully integrate the use of wind as a direct propulsive energy source however that is still a work in progress.

(i) IMO Targets - In 1-1 General Overview of Policy section above, the inclusion of ”technologies” and ”energy source” into the 5% and striving for 10% target for the uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources is significant as it implicitly includes the use of wind propulsion in meeting these targets.

(ii) IMO Fuel Lifecycle Assessment – wind propulsion energy has been included in the fuel designation list, and designated as a zero-rated pathway. The provision of wind propulsion is included in the fuel listing as pathway/fuel 128 and this will require a standardised formula to calculate wind propulsion performance which is under development by the ITTC and the suggested approach will be delivered to IMO in mid-2024.

(iii) Well-to-Wake Assessment of Fuels – there is strong support for the adoption of Well-to-Wake assessment for all fuels, and IBIA, the bunkering association assured IMO that they can provide standardised certification for fuels within the next 12-18 months. This is a key issue for a level playing field assessment with wind propulsion energy. The LCA guidelines adopted in July 2023 state that;

”NOTING FURTHER that the 2023 IMO Strategy provides that the levels of ambition and indicative checkpoints should take into account the well-to-wake GHG emissions of marine fuels as addressed in the guidelines on life cycle GHG intensity of marine fuels developed by the Organization,” IMO Resolution MEPC.376(80)

(iv) Global Fuel Standard – there is support from a number of key delegations to either having wind propulsion included as a fuel in this or for the GFS to be amended to a Global Fuel & Energy Standard. Further work is underway by ITTC on how to assess wind contribution with revised, standardised Key Performance Indicator (KPI’s) as noted above.

- It is vital that all promising energy efficiency, alternative fuels and alternative means of propulsion be considered equitably and with the latest and best information at hand.

- Short-term measures based on EEXI and CII are now in force since January 01, 2023 and these are expected to have profound effects on the decarbonisation of shipping operations in the mid- to long-term, especially after the review of these measures culminating in 2026 and the potential to include firm enforcement or penalty clauses. It is also likely that regional and national regulation, such as the inclusion of shipping into the EU ETS (01 Jan 2024, fully implemented in 2026) and the FuelEU Maritime regulations (01 Jan 2025).

- Existing bunker fuel cost rises, the volatility and risk profile of fuel markets have all been starkly evidenced over the last two years. Linking these with the uncertainty over decarbonisation and energy transition pathways along with associated compliance burdens and costs for new fuels and technologies leave many in the industry with challenging and risky decisions to be made. The introduction of carbon pricing will also add further price pressure to fossil fuels and fossil fuel derived transitional fuels in the foreseeable future. Wind propulsion solutions are however currently available and generate a level of compliance support and de-risking going forward.

The message being delivered to the shipping industry is a clear one, that some form of global carbon levy is on the way, and ever tightening regulation will make it increasingly expensive to be compliant and that early adopters of lower emissions technologies and practices will be in a strong market position going forward. In light of this we have seen a growth in the industry interest in wind-assist and primary wind propulsion systems across a range of vessel segments and there has also been a noted upsurge in research, technology projects and market installations of these systems. This growth pattern is starting to follow the pattern of a classic 'S-curve', with installations from 2014-2021 being 15 ships in total. While in 2022 this number grew by eight installations and projections are for 24 system installations and wind ready vessels to be delivered in 2023 (or early 2024).

The need to improve the guidance and provisions for wind propulsion technologies was reflected in the multiple submissions made at MEPC 76 (MEPC 76/6/2, MEPC 76/6/6, MEPC 76/6/7, MEPC 76/6/8, MEPC 76/6/10, MEPC 76/7/31 and MEPC 76/INF.30) proposing updates to the 2013 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI (MEPC.1/Circ.815). An informal working group was assembled to work on a single submission, MEPC 77/6 submitted by Comoros, Finland, France, Germany, Japan, Spain, Netherlands and RINA which was adopted as MEPC.1/Circ.896, effectively updating the provisions for wind-assist technologies in EEDI/EEXI calculations but these still require refinements and more provision for primary wind vessels.

This increase of engagement with wind propulsion solutions has also been evidenced by the granting of IMO Consultative status to the International Windship Association (IWSA) by the IMO Council in late 2021, with the IWSA growing to over 150 members worldwide, including 50+ technology provider and ship project development members. The European Sustainable Shipping Forum (ESSF) Ship Efficiency sub-group also initiated a broad workstream on wind propulsion in April 2022.

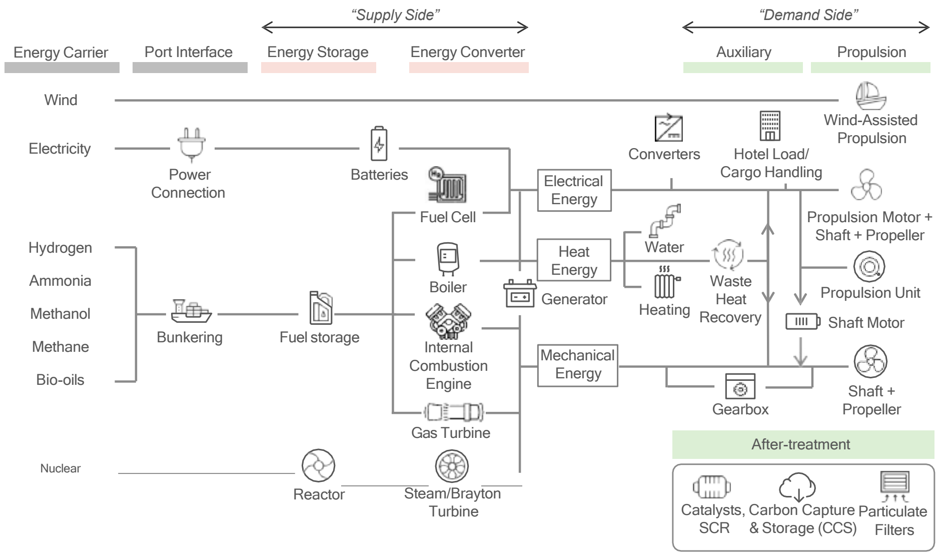
Many previous assessments and decarbonisation pathway reports have substantially underestimated the potential for wind propulsion or excluded the technology segment entirely. This situation has been improving recently (see Graphic 1-1) however, generally the assessments of WPT solutions to date have made the following miscalculations or omissions;

(i) Not taken into account the optimisation factors that enhance wind propulsion solutions, such as weather routing for wind, speed optimisation etc.

(ii) Have solely focused on retrofit wind-assist without adequate emphasis on new build design optimisation for wind-assist or primary wind vessels.

(iii) Underestimated the number of vessels that can utilise wind systems (most of the fleet) and the size and scaled potential for energy provision from WPT.

(iv) Undervalued or understated the continued improvement in materials and support systems for WPT, automation and the innovative approaches in dealing with air draft and operational constraints (movable, hinged, retractable, modular etc.)



Graphic 1-1: Industry Transition report, MMMCZCS 2021, page 20 https://cms.zerocarbonshipping.com/media/uploads/documents/MMMCZCS_Industry-Transition-Strategy_Oct_2021.pdf

The ongoing policy debate covering proposed mid-term measures such as the adoption of carbon pricing, market-based measures, makes it increasingly important that a level playing field is developed that fully recognises and incorporates wind propulsion and other forms of non-commoditised energy sources (such as wave) into those mechanisms. Such tools as 'Contracts for Difference' should be carefully considered, rather than adopting a simplistic fuel-centric approach as proposed in the influential report; 'Zero-Emissions Shipping: Contracts-for-difference as incentives for the decarbonisation of international shipping' (Clark et al 2021), the more detailed and holistic 'Total Cost of Ownership' (TCO) model would be key to incorporating the assessment of all energy sources along with full lifecycle analysis (LCA) of the fuel and the embedded energy and cost required for the equipment and vessels.

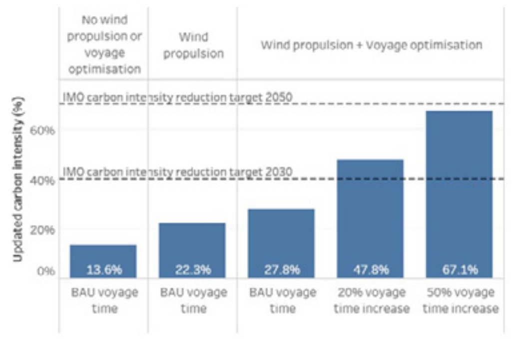
This paper aims to update and expand upon the general information on wind propulsion that was submitted by Union of Comoros in 2020 (MEPC75/INF.26) and the MEPC 79/INF.21 document submitted by Finland, France, Saudi Arabia, Solomon Islands, Spain, Union of Comoros, RINA and the International Windship Association (IWSA) in 2022, after consideration by the European Sustainable Shipping Forum (ESSF) wind propulsion workstream. This is done in the light of the further developments in the sector, along with policy advancements and provides additional insights into the technologies, their assessment, market readiness and current market penetration and level of energy provision, while also highlighting the continued barriers to uptake of the technology.

The optimisation of WPT solutions and the integration of these systems into a holistic approach to ship design, full fleet deployment and operations has the potential to deliver substantially on the new IMO GHG Reduction Strategy. The recent report 'Shipping GHG emissions 2030: Analysis of the maximum technical abatement potential' from CE Delft (June 2023) indicates that;

> "significant reductions in GHG emissions of between 28-47% can be realised with a combination of wind-assisted propulsion option with the largest efficiency improvement (which may vary per ship); — 20 or 30% speed reduction relative to 2018 (for those ship types where such a speed reduction results in a reduction of GHG emissions, after taking into account that the fleet will need to increase to provide the same amount of transport work as in BAU); and — 5-10% of the energy is derived from zero-GHG fuels. This amounts to approximately 175–350 Mt CO2e on a Well-to-Wake (WtW) basis per annum, depending on the Business-As-Usual (BAU) emissions in 2030. When introduced gradually from 2025, the measures could avoid cumulative emissions of 500–1,000 Mt CO2e. About half of the emission reductions result from lower speeds and other operational measures, a quarter from wind-assisted propulsion and other technical measures and another quarter from using zero and near-zero-GHG fuels, however the report doesn't look deeper at the combined additional benefits that could be delivered from wind-propulsion in combination with the reduction in speed for example. Implementing these measures would only increase shipping costs by 6-14% on average, relative to BAU which is well within the standard annual fluctuations in bunker costs."

Source: https://cedelft.eu/wp-content/uploads/sites/2/2023/06/CE_Delft_230208_Shipping_GHG_emissions_2030_Def.pdf

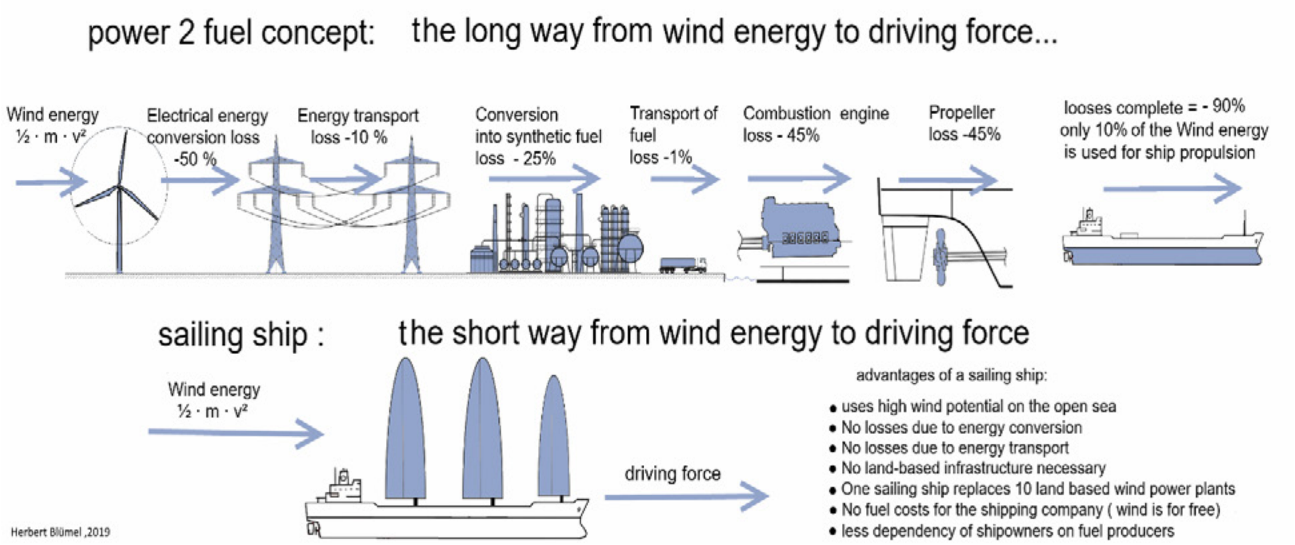
The conclusion of this report concurs with other research done on wind propulsion and voyage optimisation. WPT can strongly contribute to the meeting of the decarbonisation targets being set by IMO and the EU.
The comparison used in Graphic 1-2 (as introduced in MEPC79/INF.21) with IMO Carbon Intensity reduction targets is only indicative as these are fleet targets and individual ship savings do not translate 1:1 to fleet savings. From a single ship perspective, Graphic 1-2 therefore indicates that adding WPT alone could deliver 22.3% reduction in carbon intensity in conjunction with the speed reductions and other measures already instituted from 2008 onwards (based on a wind-assist Panamax bulk carrier with 4 rotor sails installed), in comparison with a Business-As-Usual (BAU) voyage from the ship without WPT of 13.6% (Mason 2021). Note: These findings would likely be comparable for other similar size/power WPT solution options. Add in voyage optimisation which will be a combination of weather routing for wind and some speed modification but maintaining the ship ETA, then that jumps to 27.8%, but then by using a wider range of weather routing and speed changes thus increasing voyage time by 20%, the IMO 2030, 40% reduction in carbon intensity target is surpassed (for this single ship simulation). Increasing voyage time by 50%, then the IMO 2050, 70% reduction target is already in sight. (Mason 2021)



Graphic 1-2: Annual CO2 savings relative to IMO 2030 & 2050 CI targets. [All cases are compared to operational practices of the sector in 2008, with a speed of 13kn. Business-As-Usual (BAU) - no change to current arrival times] Quantifying voyage optimisation with wind-assisted ship propulsion: a new climate mitigation strategy for shipping, p.246, Mason 2021
https://www.research.manchester.ac.uk/portal/files/209787529/FULL_TEXT.PDF

1-3 Key Points in Relation to Direct Wind Energy

- Wind energy itself is an abundant, renewable, zero-emissions energy source delivered free of charge to the point of use onboard the ship without the need for production, transport or bunkering infrastructure, nor does it require any storage onboard.



advantages of a sailing ship:

- uses high wind potential on the open sea
- No losses due to energy conversion
- No losses due to energy transport
- No land-based infrastructure necessary
- One sailing ship replaces 10 land based wind power plants
- No fuel costs for the shipping company (wind is for free)
- less dependency of shipowners on fuel producers

Graphic 1-3: Comparing the Wind energy Pathways for Shipping Source: Becker Marine, Herbert Blumel, 2019

- This energy source is uniquely available to shipping and to maximise it's efficacy should be viewed as a significant propulsive energy source, not solely through the lens of fuel efficiency, with the cost of that energy fixed at zero for the lifetime of the vessel and WPT systems.

- Graphic 1-3 clearly demonstrates that the harnessing of wind directly by WPT systems is simply the most effective way of utilising renewable energy, with anything up to a ratio of 1:10 with all of the losses and lack of efficiency and leakage in the system to deliver the same energy as a commoditised unit of fuel.

- It should be noted that wind-energy delivered directly to the ship is free of all emissions, not only those direct GHG's that are dealt with in the upcoming EU and IMO regulations. This means all climate impactors such as Black Carbon (BC), fugitive H2 emissions, Volatile Organic Compounds (VOC) and Underwater Radiated Noise (URN) etc.

- There are no spill or leakage risks along with the corresponding pollution abatement issues inherent with the direct use of wind and this de-risking also extends to security of supply.

- As the propulsive energy delivered by the wind is zero-rated for all emissions to air and water it could be argued that this energy source should be adopted as the benchmark that we measure all other energy sources, rather than the current use of IFO380.

- Supply of this wind energy is nonetheless intermittent and dependent upon route, time of year and weather systems, however, through the use of weather prediction modelling and voyage optimisation software coupled with state-of-the-art weather forecasting data, the energy resources can be mapped and are increasingly predictable.

1-4 Key Points in Relation to Direct Wind Propulsion Technology (WPT) Solutions

Graphic 1-4 below is taken from the MEPC79/INF.21 submission that was generated from the work undertaken in the ESSF wind propulsion workstream and it summarises many of the key considerations pertaining to the direct use of wind energy for propulsion and the technologies used to harness that.

Direct Wind Energy Use	
Propulsion vs Fuel Efficiency	A direct propulsive energy source that can be used as a partial or main propulsion system.
Emissions	An efficient zero-emissions energy source requiring no conversion thus avoiding power loss of up to 90% for alternative fuels based on a Well-to-Wake (WtW) calculation.
Infrastructure	Requires no ongoing mining, refining, bunkering or transport – delivered directly to the point of use.
Storage	Requires no storage tanks onboard the ship, though requires installation space on deck. Wind solutions also reduce propulsion energy requirements, therefore can also reduce other energy storage systems requirements, such as batteries.
Energy Cost	Cost of direct wind energy is zero and tax free for the lifetime of the ship without competition for supply.
Energy Availability	Abundant and freely available worldwide today. Wind is however intermittent and irregular and this variability is route specific with some routes having more wind resources than others.
Predictability	Increasingly predictable with modern forecasting technologies, a century of wind data and onboard weather stations/sensors, LiDAR etc.
Facilitation	With this free energy source integrated into an energy efficiency strategy, the use of WPT reduces the amount needed of new alternative fuels/ technologies, thus helping to facilitate their deployment in a cost-efficient way.
Wind Propulsion Technologies & Ships	
Wind-assist	5-20% of the propulsive energy requirement delivered as a retrofit based on motor ship profiles with the potential to optimise these operationally up to 30%.
Primary Wind	50%+ of propulsive energy requirement (potential for 100%) especially on newbuild ships & using wind optimisation techniques.
Viability	WPT are already demonstrating their viability as a technology on 30 large commercial ships (as of Q3 2023) and 20+ small and traditionally rigged vessels across six fleet segments.
Safety	All systems and ship designs are certified by class and comply with SOLAS/ COLREGS. WPT have the potential to also add to safety as a secondary propulsion system in case of engine failure in certain conditions. Certain wind systems can also improve the stability and comfort onboard, as they can dampen rolling, etc.
Operations	Air draft and port operations are key issues solved with folding/retracting/ movable systems + modular possible.
Availability	Available now with 13+ companies supplying varied size/power WPT already into the market. 10+ more are in pre-market, 20+ in R&D pipeline.
Compatibility	WPT are compatible with all other fuel and technology choices and various types can be deployed in all fleet segments.
Integration	Integrating WPT into Energy Management Systems (EMS) will further optimise systems and fuel savings.
Speed	While speed is primarily determined by market factors, if ships do reduce speed, then the ratio of the power delivered by WPT rises. However, WPT can also be used to maintain higher speeds with lower fuel consumption.
Routing for Wind	Increasingly sophisticated wind-routing software is available, enabling operators to maximise wind/minimise fuel and/or maintain schedules.
Range	Using this free energy source, WPTs can increase ship range for the same fuel usage,
Onboard Energy Production	Surplus wind power can be harvested and used to produce electricity/ alternative fuels through onboard turbines or by other means.
Autonomous Shipping	Wind gives a large degree of energy autonomy to ships aligning with development of autonomous ships.
Lifecycle Analysis	The energy used in the production and operation of the WPT is minimal and recouped quickly. Materials will increase in recyclability as production processes develop.
Training & Crew	Highly automated + Remote sensors help with predictive maintenance. No extra crew required but some training is necessary.
Underwater Radiated Noise (URN)	Additional benefit of WPT is the reduction of underwater noise with the option to be fully silent when in sensitive marine areas.

Graphic 1-4 - Updated MEPC 79/INF21 Table 1 – Key considerations for direct wind energy, WPT and ships (October 2022)

- Wind propulsion systems can be installed as retrofits or integrated on optimised new build vessels. As retrofits, WPT's can deliver 5-20% of the propulsive energy required (and the fuel and associated emissions savings) with no change in the vessel operational profiles, with the potential to be optimised and reach 30%.

- WPT's are compatible with all existing and new alternative fuel options currently available or proposed for deployment. The uptake of these alternative and low carbon fuels will likely be expensive, especially this decade and the lower fuel requirement for vessels, reduction of storage space required and potentially the lowering the ships installed/operational power requirement could help to increase the diffusion of these new fuels.

- WPT systems integrated into optimised new builds offer substantially higher savings with designs that offer well above 50% of the propulsive energy required for the ship. These primary wind propulsion vessels with auxiliary engines are options for various sizes and designs of vessel across the fleet.

- Note that the fuel and emissions saving estimates stated above are calculated using motor vessel operational profiles, without adjustments to speed, route or other operational changes to enhance the wind energy component onboard the vessel. Thus, these numbers can be further increased by adopting those measures and supporting technologies. Longer, ocean going routes with fewer port calls will likely increase the deployment time of the wind energy units.

- WPT systems add additional operational benefits such as extended range, allowing ships to operate for longer periods of time, on longer, less used routes or enabling the selection of lower cost bunkering options.

- There is potential for supplementary onboard zero carbon fuel generation on wind-powered vessels as there is often more wind energy delivered to the vessel than can be utilised through direct propulsion. Thus, using feathered propellors, drag generators or deck mounted turbines to harness that energy have the potential to add further fuel autonomy.

- As the technology segment has continued to grow, so has the development of standards and validation research. All major class societies have published or are in the process of developing wind-assist guidelines including Bureau Veritas, Lloyds Register, ABS, ClassNK, RINA and DNV. These have recently been joined by the classification societies from China and Russia. The development of further guidelines for validating energy provision, standardised sea trial procedures and assessing primary wind vessels are also underway as these vessels will be increasingly entering the market. Work is underway as part of the WiSP 2 Joint Industry Project, the International Towing Tank Conference (ITTC) has established a wind propulsion working group and through a number of EU-funded projects including WASP, CHEK Optiwise, Retrofit55 and Zhenit (see Section 11).

1-5 Key Points in Relation to WPT Market & Market Forecasts

- Wind propulsion technologies (WPT) are available in the market today, especially in the wind-assist category and there is a significant pipeline of viable and certified systems in late R&D and pre-market stages.

- As of August 2023, there were 30 large WPT equipped commercial vessels in operation across a range of segments and sizes, from VLCC/VLOC, other tanker & bulker sizes, RoRo, Ferry/Cruise, General Cargo & Fisheries along with eight ships that have received a notation of 'wind ready'. These vessels have a total of 63 rigs installed.

- These 30 vessels account for over 1.8 million tonnes of shipping (dwt for cargo, GT for RoRo/pax) with 445,000dwt 'wind-ready' and a further 16 ships (1.7 million dwt) awaiting installation and delivery by the end of Q1 2024.

- The pipeline of orders is also strengthening with 30+ additional vessels slated for delivery in 2024/25 though this is only taken from the currently announced projects and this number includes five 400GT+ primary wind vessels already under construction (Source: IWSA & Clarksons)

- There are also 20+ smaller sail cargo & traditional rigged cruise vessels in operation and this number is likely to also rise 25-50% in the coming 2-3 years. There are also surviving pockets of small traditional commercial craft, most notably operating in lesser developed regions such as the dhow trades in the Indian ocean, South-East Asia and the Pacific islands.

- EU market analysis (CE Delft 2016/17) forecast up to 10,700 installed systems until 2030 on bulk carriers, tankers and container vessels, equivalent to savings of up to 7.5 Mt CO2 in 2030 & c. 20,000 jobs, however this study only looked at four WPT systems and didn't include the general cargo, RoRo, RoPax, fishing or cruise vessel segments

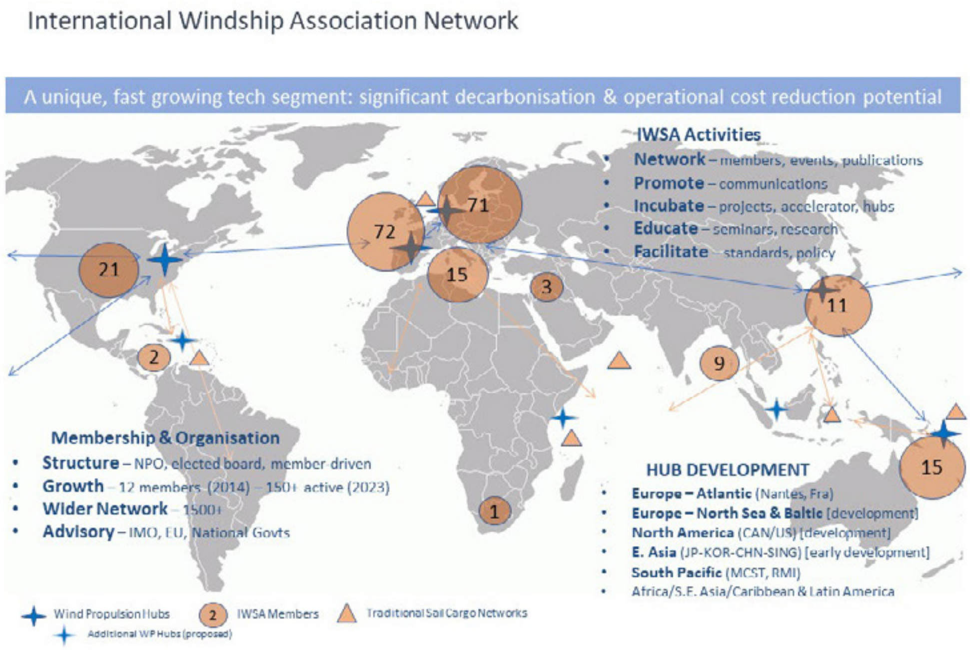
- UK Govt Clean Maritime Plan (July 2019) - global market projection for WPT systems estimated it to grow from a conservative £300mill/year in the 2020s to around £2bill/year by the 2050s worldwide. Added research indicated 37,000-40,000 vessels with wind propulsion installations by 2050 (assuming 50-100% GHG abatement) or 40-45% of the global fleet.

- Major ship owners, ship charterers and cargo owners are already involved in WPT projects including; Mitsui O.S.K. Lines, Odfjell, Louis Dreyfus Armateurs, "K"-lines, Oldendorff, Scandlines, Cargill, Vale, Marubeni, Hapag Lloyd, Shell, CMA-CGM, Compagnie Maritime Nantaise, Louis Dreyfus Company, Ponant etc. along with shipbuilders Chantiers de l'Atlantique, DCIS, Oshima Shipyards, Sumitomo Heavy Industries, Samsung Heavy Industries, Hyundai Heavy Industries, DSME, CSSC Chengxi Shipbuilding and non-shipping companies active either as cargo providers, investors or co-owners including: Renault group, Michelin, Airbus, the European Space Agency, Drax, Hennessey, EIC etc.

- Collaboration and joint development projects are increasingly being seen in these early stages of growth, with shipyards, production facilitators and OEMs combining to deliver technologies to market. This trend is expected to accelerate further.

- The growth in investment in the sector is following these trends according to the IWSA. Publicly announced finance commitments are already in the hundreds of millions (US$) for plant and production line development both in Europe and Asia and there have been a number of innovation projects funded by EU announced this year too.

- Graphic 1-5 gives a fairly broad outline of where the IWSA members are clustered and where the development of wind propulsion hubs is underway. This graphic only indicates the direct membership of IWSA and doesn't indicate the whole commercial network involved with wind propulsion development including engineering companies, fabrication facilities, many of the shipyards and suppliers involved etc.



Graphic 1-5: Global Overview of the International Windship Association Membership [150+ active members of which 70%+ are based in Europe]

Table of Terms

Air draft	The distance from the surface of the water to the highest point on a vessel.	MGO	Marine gasoil - a high quality marine fuel that consists exclusively of distillates.
Anemometer	A device that measures wind speed and direction.	MPA	Marine Protected Area
AWS	Apparent Wind Speed - Apparent wind is the wind you feel when you're moving.	OEM	Original Equipment Manufacturer
BC	Black carbon	Pitch	The up and down motion of a vessel. Characterized by the rising and falling of the bow and stern
Beaufort scale (Beaufort Wind Force Scale)	A scale from 0-9 indicating wind speed based on a visual estimation of the wind's effects.	Primary renewable energy	Where renewable energy is used directly without conversion to a storage medium (i.e. passive solar, wind propulsion etc.)
Bilge Keel	An external device used in pairs deployed on either side of keel to reduce a ship's tendency to roll.	Primary Wind	Wind propulsion is the primary propulsion energy for that ship. NOTE: There is a minimum power requirement (unless exempted as a traditional, non-mechanical vessel)
Centre Boards	A retractable hull appendage used to provide lift to counter the lateral force from sails.	Rig	A type of wind propulsion system
CII	Carbon Intensity Indicator – measures CO2 emissions per ton/mile rating from A-E	Roll	The tilting motion of the ship from side to side. Wind/waves push against the ship and cause it to rock back and forth.
Dagger Boards	A retractable hull appendage used to provide lift to counter the lateral force from sails.	Rotor sail (Flettner Rotor)	Rotating cylinder operated by low power motors that use the Magnus effect (difference in air pressure on different sides of a spinning object) to generate thrust.
DWT	Deadweight tonnage - a measure of how much weight a ship can carry.	Secondary renewable energy	Where a medium/fuel stores renewable energy (i.e. hydrogen, batteries, methanol etc.)
EEDI	Energy Efficiency Design Index (New build ships)	SIDS	Small Island Developing States
EEXI	Energy Efficiency eXisting ship Index	Skegs	Sternward extension of the keel with rudder mounted on the centre line.
Embedded Energy	The sum of all the energy required to produce any goods or services.	SOG	Speed-over-ground
ESG	Environmental, social, and governance.	STW	Speed-through-water
EU ETS	European system of GHG Emissions Trading System.	Suction wing/Suction sail	Non-rotating wing with vents and internal fan (or other device) that use boundary layer suction for maximum effect.
Flatrack	A specialised cut down container with walls only at the short ends of the container.	Surge	Wave action produces forces that accelerates/decelerates the ship forwards or backwards.
FuelEU Maritime	The European Union regulation as part of the Fit for 55 package directed at shipping.	Sway	Sliding motion occurring when the ship's hull is pushed by the wind or current.
GHG	Green House Gas	TWA	True Wind Angle - The direction of the true wind relative to the heading of the vessel.
GPS	Global Positioning System	TWS	True Wind Speed - True wind is the actual wind that is blowing.
GRP	Glass Reinforced Plastic. It is also called fibreglass, composite plastic or FRP.	VOC	Volatile organic compounds - a variety of chemicals often with climate and health impacts.
GT	Gross tonnage - the volume of all the space within a ship.	WAPS	Wind-Assisted Propulsion Systems
GWP	Global Warming Potential - a measure of the impact of a given emission relative to CO2	WASP	Wind-Assisted Ship Propulsion
Heave	Up and down motion of a ship generated by large swells.	Weather routing	Optimising a ship's voyage taking into consideration weather conditions (wind, wave, current)
Heel	A temporary inclination of the ship caused by wind pressure on sails or other influences.	Well-to-Tank	The process from fuel production, and delivery prior to the use onboard the ship and all emissions produced therein.
IMO	International Maritime Organization – UN specialised agency with responsibility for safety, security and prevention of pollution from ships.	Well-to-Wake	The entire process from fuel production, and delivery to using onboard ships and all emissions produced therein.
LCA	Life Cycle Assessment	Wind-assist	Wind propulsion system delivers on average less than 50% of the propulsive power to the ship at a given commercial speed
LDC	Least Developed Countries	Wingsail	A rigid or hard sail
Leeway	The amount of drift motion caused by wind vector perpendicular to forward motion of ship.	WPT	Wind Propulsion Technology
LiDAR	A remote sensing method using the light from a laser to collect measurements.	Yaw	Movement of spinning a ship on a middle line.
LNG	Liquefied Natural Gas		

3) Summary of Wind Propulsion Systems

3-1 Categories of Wind Propulsion System
3-2 Primary Wind vs Wind-Assist
3-3 Considerations When Assessing WPT
3-4 Classification Societies & Guidelines
3-5 IMO Guidelines for EEDI & EEXI
3-6 Materials & Production Techniques

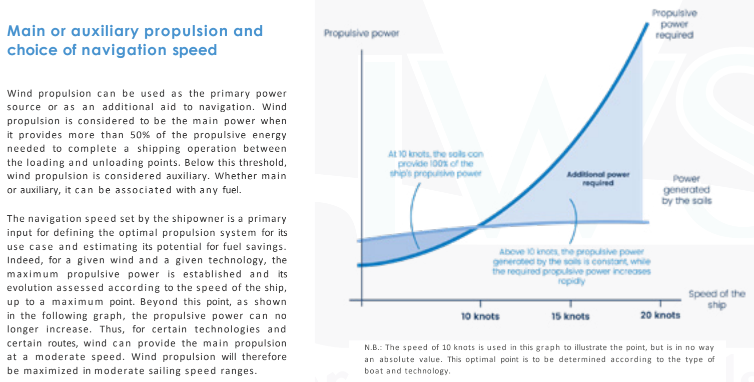
3-1 Categories of Wind Propulsion System

Wind Propulsion Technology Type	Description	Graphic
Soft Sail	Both traditional sail and new designs of dynarig, etc.	Graphic 3-3
Hard Sail	Wing sails, foils and JAMDA style rigs. Some rigs have solar panels for added ancillary power generation.	Graphic 3-4
Flettner Rotor or Rotor Sails	Rotating cylinders operated by low power motors that use the Magnus effect (difference in air pressure on different sides of a spinning object) to generate thrust.	Graphic 3-5
Suction Wings/Suction Sails (eSAIL, Ventofoil, Turbosail)	Non-rotating wing with vents and an internal fan (or other device) that uses boundary layer suction for maximum effect.	Graphic 3-6
Kites	Dynamic or passive kites off the bow of the vessel that can be deployed to assist propulsion or to generate a mixture of thrust and electrical energy.	Graphic 3-7
Turbines	Marine-adapted wind turbines to either generate electrical energy or a combination of electrical energy and thrust.	Graphic 3-8
Hull Form	The redesign of the ship's hull to capture the power of the wind to generate thrust.	Graphic 3-8

3-2 Primary Wind vs Wind-Assist

As noted in previous sections, we can, in principle, separate the application of WPT systems into two main categories; 'wind-assist' and 'primary wind'. However, at lower speeds, a nominally wind-assist system could be providing most or all of the propulsive power to the ship under certain weather conditions, as noted in Graphic 3-1.

Source: Association Windship White Paper [English version] (2022)



Main or auxiliary propulsion and choice of navigation speed

Wind propulsion can be used as the primary power source or as an additional aid to navigation. Wind propulsion is considered to be the main power when it provides more than 50% of the propulsive energy needed to complete a shipping operation between the loading and unloading points. Below this threshold, wind propulsion is considered auxiliary. Whether main or auxiliary, it can be associated with any fuel.

The navigation speed set by the shipowner is a primary input for defining the optimal propulsion system for its use case and estimating its potential for fuel savings. Indeed, for a given wind and a given technology, the maximum propulsive power is established and its evolution assessed according to the speed of the ship, up to a maximum point. Beyond this point, as shown in the following graph, the propulsive power can no longer increase. Thus, for certain technologies and certain routes, wind can provide the main propulsion at a moderate speed. Wind propulsion will therefore be maximized in moderate sailing speed ranges.

N.B.: The speed of 10 knots is used in this graph to illustrate the point, but is in no way an absolute value. This optimal point is to be determined according to the type of boat and technology.

Graphic 3-1: Main or Auxilliary (Wind-assist) Propulsion

3-3 Considerations When Assessing WPT

There are some key considerations to take into account when assessing WPT systems.These are primarily (but not restricted to) whether you are installing the systems as a retrofit to an existing hull configuration, or if you are integrating the WPT into an optimised newbuild. Naturally, when a WPT system is installed onto a motor vessel design, there will be issues with the amount of deckspace and positioning, the interaction between the WPT and the freeboard, drag from the hull design and issues with rudder and drive train efficiencies. As WPT systems are increasingly intergrated into the energy management systems onboard, these effects can be mitigated to a degree. Each ship type will have variations on these themes.

When WPT systems are fully integrated into a vessel'sdesign from the outset, many of these aforementioned issues will be reduced or eliminated completely. There will also be options to look at onboard energy harvesting when wind loads are high and there is excess energy generated that can be converted to electricity and processed into alternative fuels for use when operating in less ideal wind conditions. See Graphic 3-2.

3-4 Classification Societies & Guidelines

The installation and deployment of WPT systems is fully supported by Classification Societies, and there are increasingly standardised approaches to wind-assist installations. These classification guidelines cover installation, safety, operation, materials and SOLAS compliance issues.

There is still a level of flexibility and the need for further development of these guidelines as new system variations, innovations and integration are introduced to the market. The increase in the number of demonstrator wind-assist vessels and installations is providing a positive feedback loop, thus increasing the data available and the refinement and review of vessel classification procedures is already underway.

Large, newbuild, primary wind vessels will also require more standardised classification approaches as these come into the fleet from 2024 onwards and work is underway by class and also through ITTC to standardise these approaches and ways of trialling and validating the system performances.

In the list below, examples of classification documentation on wind propulsion systems are presented:

ABS Guidelines: Download
Bureau Veritas Guidelines: Download
ClassNK Guidelines: downloadable from www.classnk.com
DNV Guidelines: Download
Lloyds Register Guidelines: Flettner Rotors // Masts, Spars & Standing Rigging
China Ship Classification Society: Guidelines for Survey of Marine Wind-Rotor Assisted Propulsion System 2023 Download

Note: Further safety assessments have also been undertaken in the recent European Maritime Safety Agency (EMSA) report - Potential of wind-assisted propulsion for shipping (Nov 2023).
https://www.emsa.europa.eu/publications/reports/download/7664/5078/23.html

3-5 IMO Guidelines for EEDI & EEXI

In 2021, IMO adopted the "Guidance on Treatment of Innovative Energy Efficiency Technologies for Calculation and Verification of the Attained EEDI and EEXI"
https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.1-Circ.896.pdf

This guidance document improved on the previous circular 815 in its assessment of WPT and their contribution to EEDI and EEXI. The guidance takes into account a lot of the issues with assigning performance for WPT and enables the assessment to be completed using the best 50% of wind performance data, which improves the overall performance recognition for WPT bringing that closer to the actual operational experience. However, IMO guidance requires improvements, especially where it comes to equal treatment of all WPT systems under this formula and also the need to develop more robust KPI's and calculations for the assessment of the primary wind ships that will enter the fleet from 2024 onwards.

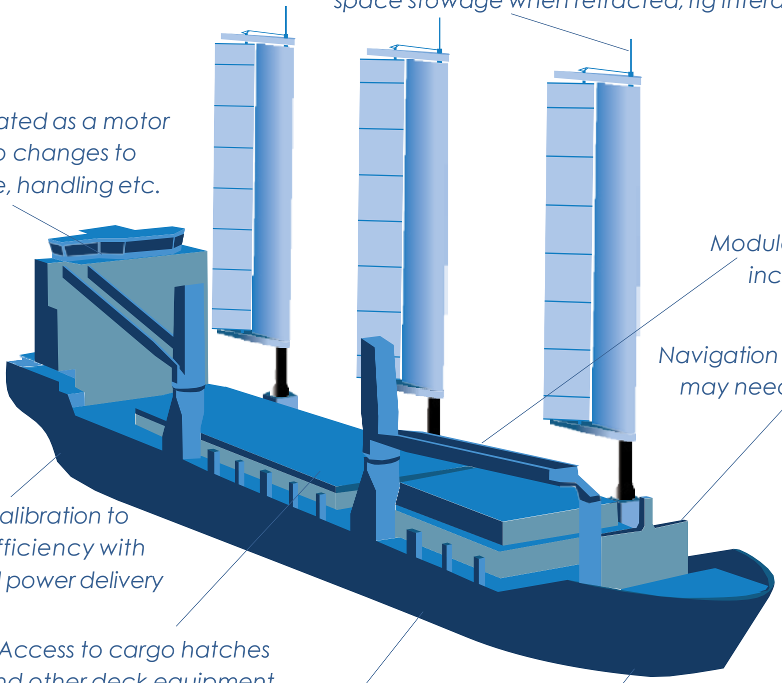
3-6 Materials & Production Techniques

As wind propulsion systems have developed, they have benefitted from the improvement in materials and their application, whether that has been learning from the leisure and racing sail sector, offshore wind turbine developments or internal innovation programs. Composite, lightweight and robust materials are already helping to improve performance and enable design adjustments in the WPT systems that use these more advanced materials.

A selection of the advances in materials used for WPTs were covered in the paper 1.18 High Performance Composite Materials for Wind Propulsion Technologies: Challenges & Opportunities, (Hexcel Corporation) in MEPC 80/INF.33 https://www.wind-ship.org/wp-content/uploads/2023/05/MEPC-80-INF.33-Wind-propulsion-technologies-as-a-key-enabler-RINA-and-IWSA-1.pdf. As these materials and production processes are standardised, we are likely to see significant improvements, optimisation and the further scaling of the size of WPT. Lowering embedded carbon, improved recyclability and efforts to make process and materials fully circular are continuing across the sector. (Source: IWSA questionnaires & interviews 2021-22).

Some Key Considerations Assessing WPT

Wind-Assist



Size limitation & location – air draft, deck space stowage when retracted, rig interaction

Often operated as a motor vessel – no changes to speed, route, handling etc.

Modularisation possible to increase flexibility

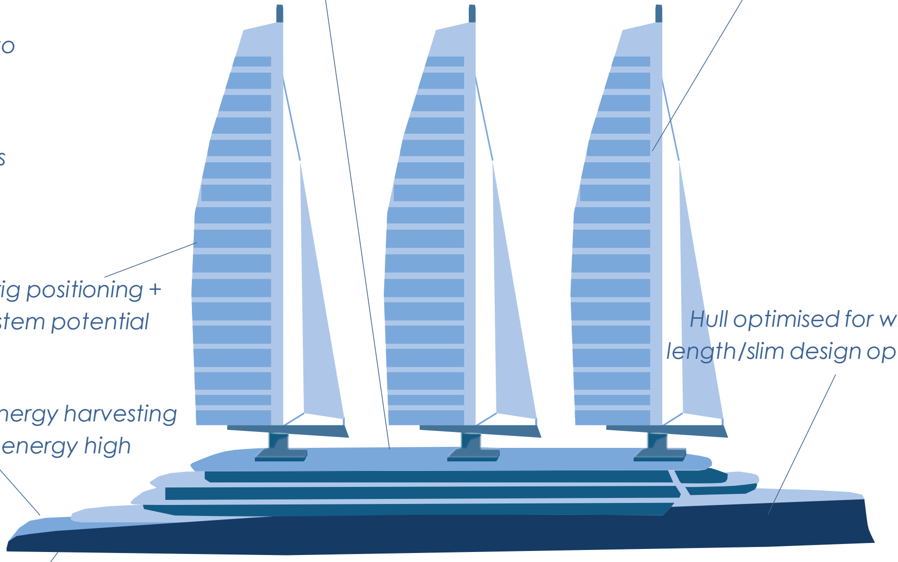
Navigation and other systems may need reconfiguring

Engine calibration to maintain efficiency with variable wind power delivery

Access to cargo hatches and other deck equipment

Freeboard Interaction

Standard Hull Design



Integrated design elements – access, stability, ballast, cargo/passenger configurations etc.

Weather routing for wind and voyag optimisation lead to substantial increased performance

Optimal rig positioning + hybrid system potential

Hull optimised for wind, length/slim design options

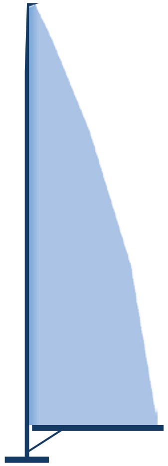
Potential for energy harvesting when wind energy high

Full integration wind/engines. Hybrid/electric options.

Primary Wind & Newbuild Wind-Assist

Graphic 3-2: Key Considerations When Assessing WPT

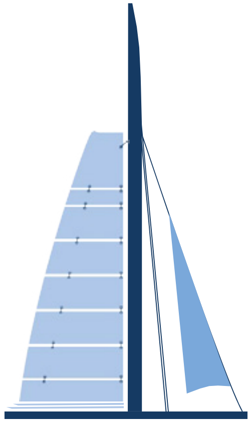
Source: International Windship Association / Association Windship



Soft sail & Hybrid sail

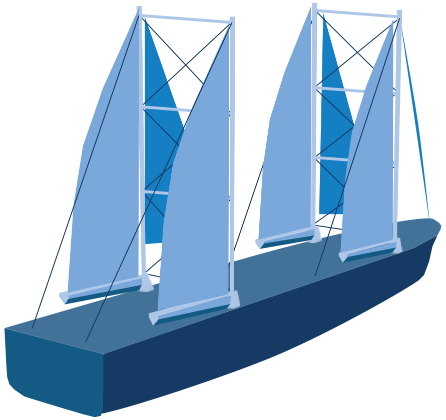
Soft sails come in a wide variety of configurations and these include both traditional sail rigs and new designs such as the dynarig system. Many of these systems are well-tested and their use has been extensive throughout the world both commercially and more prevalently in leisure sailing recently.

New robust materials & production techniques are lengthening their usability/lifespan and automated furling systems and control systems reduce the need for additional crew for large installations (smaller rigs can still be handled manually). Commercial applications require masts to be either retractable or foldable.



Hybrid rig design using furlable rigid panels and soft sail combo

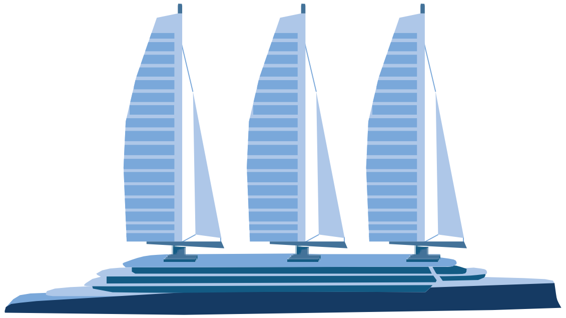
Auto-furling systems are configured for large traditional soft sail installations

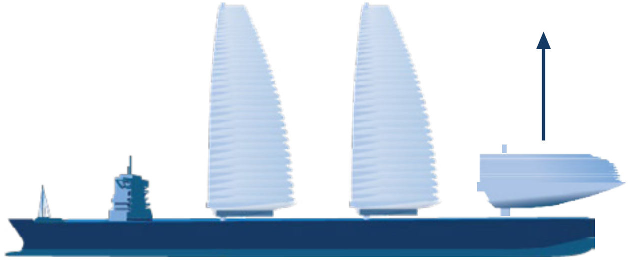


Considerations

Deck space
Retractability
Navigation/Line of Sight
Windage/Stability
Material longevity

Sizes
highly variable/flexible





One of many new designs, this one is using an inflatable sail system

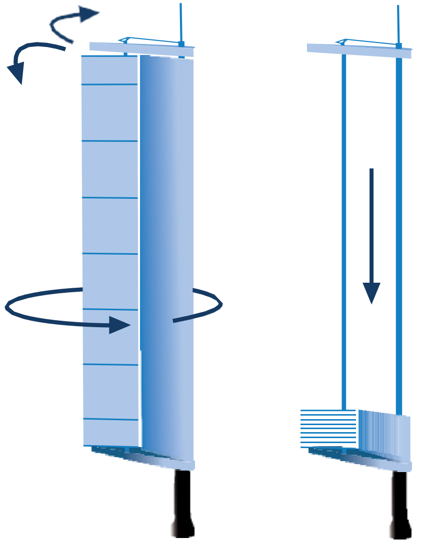
Graphic 3-3: Soft sail and hybrid sail WPT

Source: International Windship Association / Association Windship

Hard sail

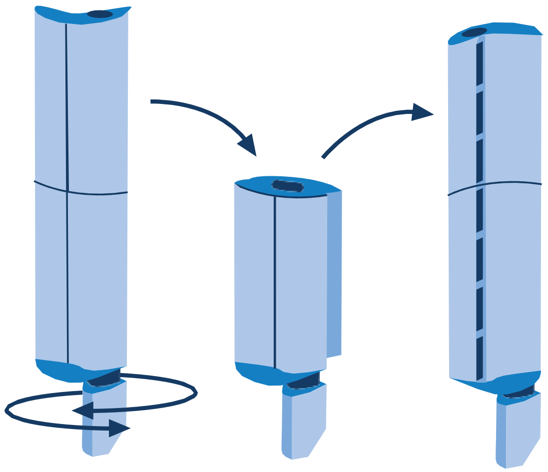
Hard or rigid sails are defined by the use of a rigid materials and design and these types of system have been used extensively in the racing world. There are quite a variety of different systems from wing sails, foils and JAMDA style rigs, some with single or multiple foils, others deploying movable flaps and some segmented. Some rig designs have solar panels for added ancillary power generation.

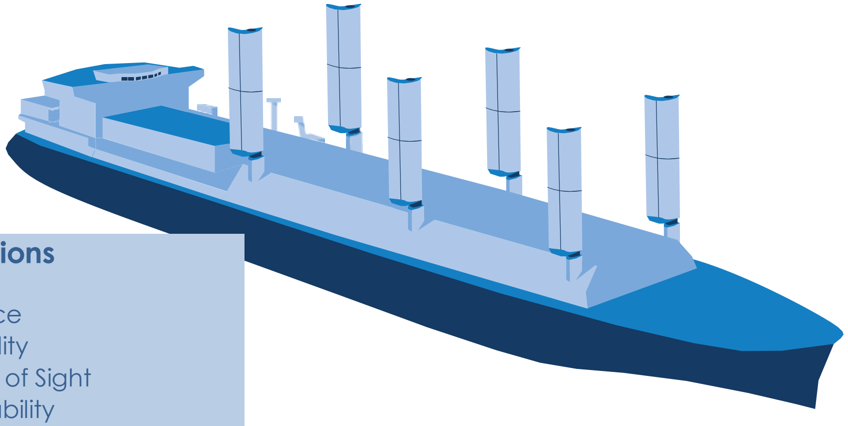
Note: There are also hybrid wing sails developed that have a rigid frame, but flexible soft coverings. Rigid sails were first deployed on modern commercial vessels in the 1970s and 1980's.



Hybrid wing sail with flap with soft membrane

Single wing sail with flap and retractability





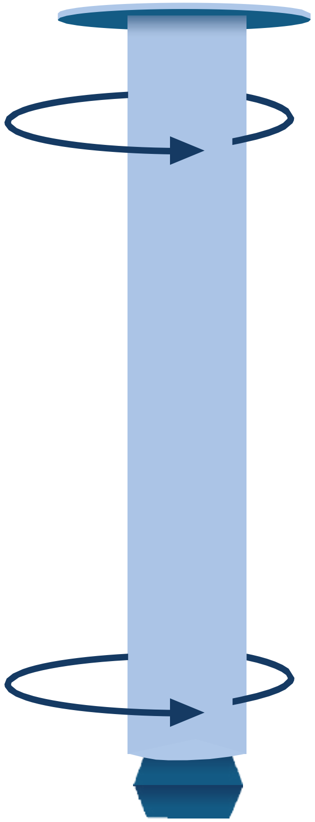
Considerations

Deck space
Retractability
Navigation/Line of Sight
Windage/Stability

Installed Sizes (to date)
2m x 9m -15m x 35m

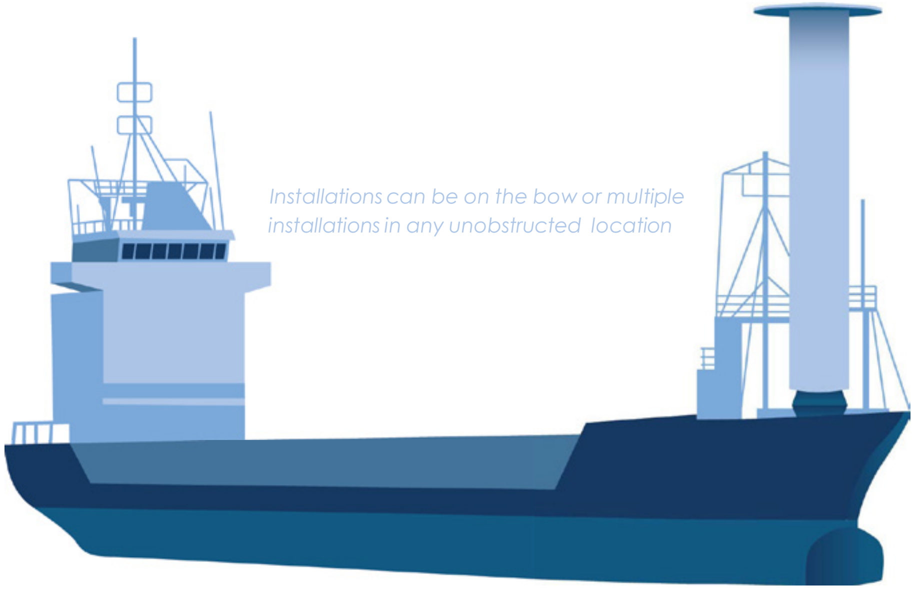
Graphic 3-4: Hard sail WPT

Source: International Windship Association / Association Windship



Rotor sail

Flettner Rotor or Rotor Sails are rotating composite cylinders with a top disc and possibly a bottom disc that are rotated at up to 300 rpm (dependent on size/application) by low power motors and as the wind catches the rig, they use the Magnus effect (difference in air pressure on different sides of a spinning object) to generate thrust. Systems already designed include ones deployed on rail systems, hinged and telescopic versions. The original concept was developed in the 1920's with a small number of installations, however the modern, upgraded version of these sails were first installed on modern vessels in 2010's.



Considerations

Deck space
Retractability
Navigation/Line of Sight
Beam/Head Wind Performance
Vibration/Motor

Installed Sizes (to date)
1m x 18m – 5m x 35m

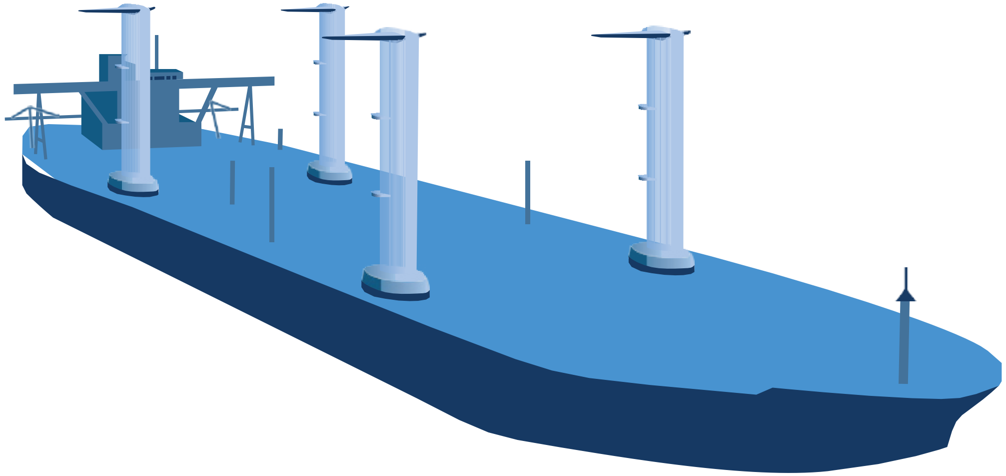
Graphic 3-5: Rotor sail WPT

Source: International Windship Association / Association Windship

Suction wing/sail

Suction Wings/Sails (Ventifoil, Turbosail, eSAIL) are stubby, non-rotating wing sails with vents and an internal fan (or other device) that creates suction which pulls in the boundary layer around the wing generating enhanced effect. Installations to date have been deployed on the bow, stern and as deck containers and flatrack.

The system was originally designed and deployed in the 1980's



Considerations

Deck space
Retractability
Navigation/Line of Sight
Suction device

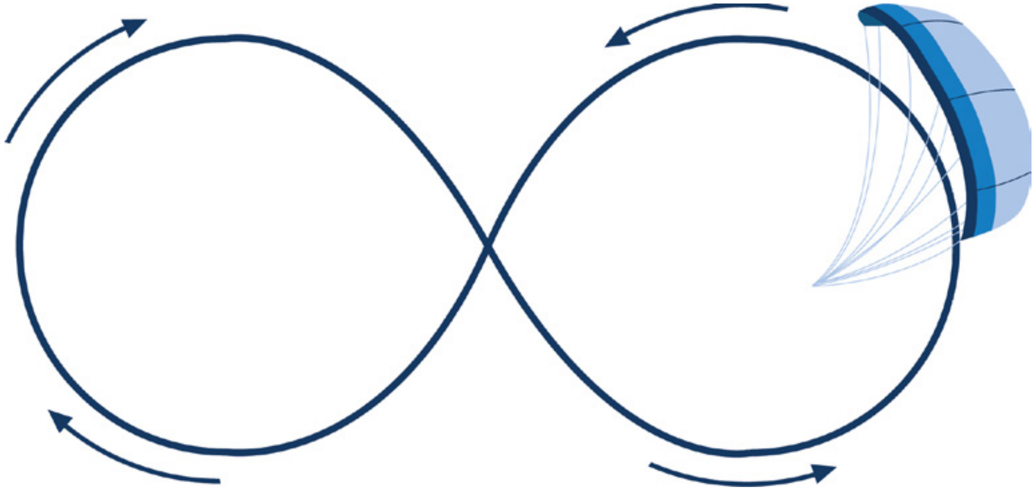
Sizes

(deployed/designed)
10m-36m

Graphic 3-6: Suction wing/sail WPT

Source: International Windship Association / Association Windship

Dynamic kite example with a figure of eight deployment to enhance power delivered



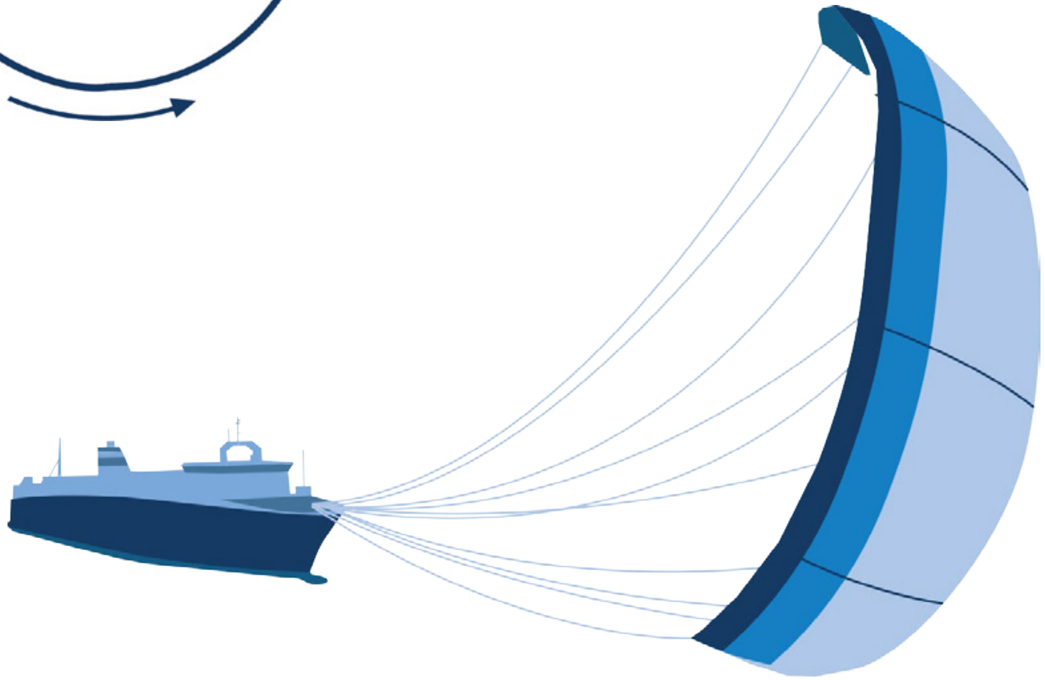
Considerations

Wind Resources/Direction
Deployment/Retrieval
Control systems
Material longevity

Sizes
(deployed/designed)
500m2 – 1000m2

Kite

Kites are deployed at over 200m above the vessel with a tether attached to the bow of the vessel (or assisting tug) to assist with propulsion. The kites take advantage of constant winds at those high elevations and can either be passive (maintain a single position) or dynamic (controlled deployment in a figure of eight or other configuration to maximise thrust). Kites are primarily generating thrust however the tether could also be used to generate electrical energy. First generation towing kites were first deployed in the 2010's.



Graphic 3-7: Kite WPT

Source: International Windship Association / Association Windship

Turbine

Turbines using marine adapted wind turbines to either generate electrical energy or a combination of electrical energy and thrust. Turbine systems are being designed that are both vertical and horizontal configurations.

Considerations

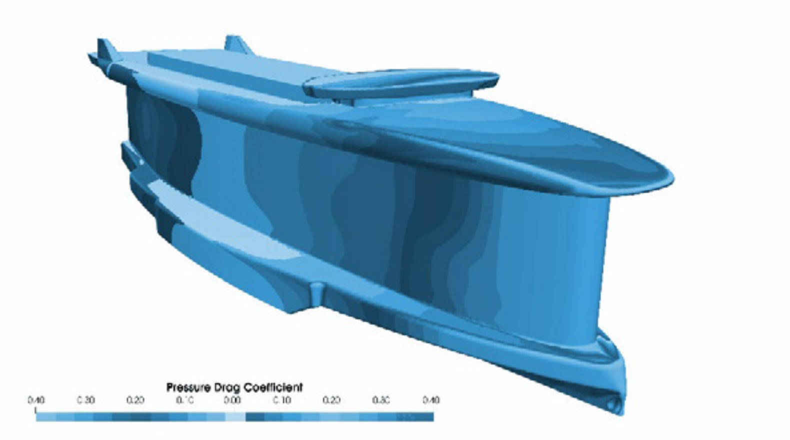
Wind Resources/Direction
Mountings/Forces
Vibration/Stability
Material longevity

Sizes
Containerised or Free Standing

Considerations

Stability / Ballast
Extreme Weather Performance
Ship Type / Adaptation

Sizes
Vessel Size



Hull Form

Hull Form designs take the whole of the vessel and adapt the ship's hull itself so that it functions as a large 'sail', capturing the power of the wind to generate thrust. Applicable primarily to newbuilds.

Graphic 3-8: Turbine WPT and Hull form adaptation

Source: International Windship Association / Association Windship

4) Application of Wind Propulsion

4-1 Overview

The installation of a wind propulsion system, or the design of a primary wind propulsion vessel, is at its heart a hybrid solution, where the wind power component functions either as an assist to or is assisted by engines. Currently most decarbonisation pathways still treat wind propulsion as an 'energy efficiency measure' or 'fuel saving device', rather than categorising WPT systems as the significant propulsor that they are. This appears to stem partly from a lack of 'fuel' commodification which can reduce interest from bunker and investment interests. The need to adopt a 'hybrid' or 'holistic' view of a vessel's energy and propulsion system is a necessary step to fully utilise and realise the contribution that wind energy can bring and enable direct comparisons of propulsive energy provision pathways. Therefore, viewing a vessel as an 'energy management system' with power supplied from various sources.

4-2 Wind as a Direct Propulsion Energy Source

The IMO Life Cycle Analysis guidelines presented at MEPC80 in July 2023, as outlined in MEPC 80/7/4 - REDUCTION OF GHG EMISSIONS FROM SHIPS: Final report of the Correspondence Group on Marine Fuel Life Cycle GHG Analysis https://docs.imo.org/Shared/Download.aspx?did=142399, designate wind propulsion as a propulsive energy source with a designated 'fuel' pathway number 128. The revised MEPC1 Circ.896 also takes a more integrated view of the delivery of wind https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.1-Circ.896.pdf and the newly approved FuelEU Maritime regulation also recognises that wind energy is an important contributor to the vessel energy mix. https://data.consilium.europa.eu/doc/document/PE-26-2023-INIT/en/pdf

According to the Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure, the current definition states; "Alternative fuels are those fuels or power sources which serve, at least partly, as a substitute for fossil oil sources in the transport sector. According to the European Commission's 2050 Long-term Climate Strategy, there is no single fuel solution for the future of low-emission mobility - all main alternative fuel options are likely to be required, but to a different extent in each of the transport modes." Source: EU Alternative Fuels https://alternative-fuels-observatory.ec.europa.eu/general-information/alternative-fuels

4-3 Life Cycle Assessment

The lifecycle assessment of fuels (LCA) and the inclusion of wind in this process is being undertaken to create a foundation for the policy design and development at IMO and upon which both a Global Fuel Standard (GFS) [Preferably a Global Fuel and Energy Standard] and Mid-/Long-term measures will be based upon. It is very important that all energy sources or 'fuels' are included in this assessment that are used to propel ships. If any alternative energy sources are excluded, that would effectively undermine the validity of the assessment and creates a selective listing of energy sources rather than a neutral approach. This, in turn, would create an un-level playing field when it comes to regulation design, Market Based Measures (MBM's) and other measures.

4-3-1 Well-to-Tank - Zero Emissions

The energy source used by WPT is a zero-rated energy source that could, and perhaps should, be used as the baseline when calculating all other energy sources rather than the current approach of using HFO as the baseline. The Well-to-Tank (WtT) benefits of harnessing this energy source also include (but are not restricted to);

(i) No embedded energy from infrastructure – this includes new infrastructure, but also includes the use of 'historic' or 'legacy' infrastructure where energy, pollution impact and costs have already been amortised and thus don't appear on comparative analysis of energy sources. There are also no decommissioning, waste or circular economy considerations to take into account.

(ii) No risk of pollution/accidental discharge or fugitive emissions risk – all other energy sources if they are not produced on board the vessel themselves have inherent issues with these emissions. Not all emissions are GHG's but many of them will have climate and local pollution implications such as VOC's, PM, fugitive H2 etc.

(iii) No safety considerations – there are no risks of contamination, fire, explosion, exposure etc. in WtT delivery of wind energy to the vessel.

(iv) Supply risk to be factored into supply chain assessment – while wind is intermittent it is also free at the point of delivery and the wind is delivered directly to the ship at the point of use. There is no competition for this energy source and the predictability of wind resources around the world is fairly robust. However, standard fuel supply lines are at risk of a large number of factors including refinery issues, land transportation delays or technical disruptions, bunkering issues, conflict, price spikes etc.

(v) Low risk of restriction of supply/usage in vulnerable areas (Arctic, MPAs etc.) – there is growing concern about the impact of localised emissions in vulnerable areas and further restrictions on the transport, bunkering and use of fossil fuels and possibly for alternative low carbon fuels is increasingly likely, not so for wind.

(vi) No risk from regulatory or criteria change – currently Life Cycle Assessment (LCA) activity focuses only on direct GHG assessments from fuels, however adjustments and the widening of the regulatory spectrum to include all climate impacting emissions are certainly being discussed. These include;

- leakage rates reassessment (differ greatly from country to country and have historically been underplayed),
- adoption of a 20-year Global Warming Potential (GWP) alongside the 100-year GWP in assessing fuel emissions, especially methane. This has already been highlighted and adopted at IPCC level but not yet considered in maritime regulation. (IPCC AR6 2022),
- feedstock reappraisal – many alternative fuels require fossil fuel or non-sustainable feedstocks for a substantial period of 'transition'. These fuels are potentially higher emitters during this transition period as they require cracking or other energy intensive chemical processes to be refined,
- new science of climate impacts – the science of climate change and emissions impacts is constantly evolving and new understanding of the GHG and non-GHG interactions with the atmosphere will likely lead to enhanced restrictions,
- all emissions inclusion – it is likely that ultimately all direct and indirect climate impact emissions will be included in regulatory control. These include black carbon, PM, VOC's, fugitive H2, Underwater noise etc.

As such, when wind propulsion energy source is compared to other energy sources and energy carriers, a full comparative analysis of emissions must be inclusive of all emissions and risks, at the point of use but also in their production, supply chain and disposal.

4-3-2 Tank-to-Wake – Zero or Net-Zero Emissions

Different WPT systems will require some energy to operate. [Note: there is embedded energy in the units themselves. However, this section deals with the energy source itself.]

Power requirement profiles of WPT are divided into:

(i.a) Passive systems (Manual) – if a passive system is manual then there is no need for additional power to be used, thus that would be zero-emissions (e.g. traditional soft sail, manually operated wing sails or a hull design configuration etc.).

(i.b) Passive systems (Automated) – an automated system requires a small amount of electricity to lower/raise and adjust the system to maximise thrust. (<1%).

(ii) Active systems – these would typically be rotor sails and suction wing/sail devices with active movement as part of their operation. A rotor sail requires electrical energy to run the motor that rotates the rotor to generate the magnus effect. The suction wing has an internal fan or other suction device in constant operation during deployment that enhances the suction of the boundary layer around the wing and increases lift/thrust. (<10%).

NOTE: There are numerous systems and designs available. There will be a variation of energy use between WPT types., but these will broadly fit into these three categories.

The electricity used for the operation of these systems is however, covered by the amount of propulsive energy they provide up to a multiple of 10. Therefore, the systems would be designated as 'net-zero'. However, it should also be noted that the wind energy delivered to the ship can also be harvested and thus creating a 'net-positive' contribution, see Section 4-3-3 below.

4-3-3 Key Considerations for Wind Energy

When assessing wind as a propulsive energy source there are a number of key considerations that should be incorporated;

- Direct Energy Used for Propulsion: Wind is a non-combustible direct propulsion energy source, or 'fuel', that can be used to move ships 100% as has been done for millennia. The argument around the percentage delivered or intermittency of the energy source are borne from commercial operational or business concerns (i.e. maintaining specific speeds), not from the assessment of the energy source itself.

- Comparison of Non-Commoditised vs Commoditised Fuels: If we take electricity as an example, this is rightfully included in the IMO's LCA of fuels, however this is in fact an energy carrier (as indeed are all designated fuels) that is not combusted. The only difference in this regard for direct wind use is that electricity is a commoditised form of energy that can be either used directly or stored and later released and is run through a motor to move a propellor or other propulsor. Direct wind energy is used directly and does not require a propellor but is instead run through a 'wind engine' or 'wind propulsor'.

- Hybrid or 'Dual Fuel' System: All wind vessels are hybrid vessels with primary or auxiliary engines depending on whether the vessel is primary wind or wind-assist. While wind prediction and routing software (and even LiDAR) are increasingly sophisticated and accurate, wind energy is still intermittent, thus the whole propulsion system (not the fuel itself) would be classed as a 'dual-fuel' system. NOTE: This will be similar to the treatment of onboard generation or use of electricity in a hybrid vessel.

- Onboard Energy Harvesting: Wind power is the only propulsive 'fuel' available that enables additional 'fuel' to be generated and stored onboard a vessel. This excess energy can be generated when design/hull speed (or required operational speed) is reached and would otherwise require that excess wind energy be 'spilled' from the sails. Instead, this can be harvested and used to generate electricity through hydro-generators, a reversed propellor on an electric powertrain or even deck mounted turbines or other technology options. This onboard generation of electricity can then be used to generate other forms of alternative fuel to be stored onboard and used when motors are being used.

There are quite a number of examples of the onboard energy generation throughout the mega-yacht and research vessel segments. Operational large vessel commercial examples are not yet available. However, the following two examples give an outline of what is possible and planned:

Example 1: The Sea Cargo SC Connector, a 155m, 12,251GT RoRo vessel fitted with two 35m rotors is reported to generate over 25% of its total energy requirement on North Sea routes (averaged over a year of operations, though not third party validated). However, for up to 20% of the time the vessel could be running exclusively on the wind. Estimates have been made that the ship is having twice the amount of wind propulsive energy delivered to it than it can use, which could thus be harvested while underway.
https://www.norsepower.com/post/setting-sail-onboard-sea-cargos-sc-connector-experiencing-efficiency/

Example 2: The design of the Windhunter tanker vessel by Mitsui OSK Lines (MOL) is predicated on becoming a climate positive vessel, where it generates all of its fuel component from harvested wind energy but takes that one step further and produces hydrogen to be stored in toluene in its tanks as cargo. A 60m scaled prototype will be in operation in 2024 with the full-scale vessel slated for 2030 https://www.mol.co.jp/en/bam/004/

4-4 Wind-Assist Applications

Most of the current large vessel installations fall under the designation of 'wind-assist' vessels, meaning that a percentage of the vessel's propulsive energy has been delivered from wind, delivered directly to the vessel in the form of energy harvested by a device/rig. These systems can be either retrofitted to an existing vessel or installed on the vessel during the build.

There are varied technology options (as listed in Section 3) and these typically will be able deliver up to 20% (potential to be optimised up to 30%) of the propulsive energy requirement if that is averaged out over a year of operations and this is calculated with these vessels operating on motor vessel operational profiles thus making no changes to operations to maximise wind power, i.e. speed, routing etc.

The EU-funded WASP project undertook an extensive literature review and summarised these systems with an overview of performance in the 'New Wind Propulsion Technology A Literature Review of Recent Adoptions', WASP Project Sep 2020 (Research table on page 7 and the review of technology fuel savings on page 18)
https://vb.northsearegion.eu/public/files/repository/20210111083115_WASP-WP4.D5B-NewWPTALiteratureReviewofRecentAdoptions-Final.pdf

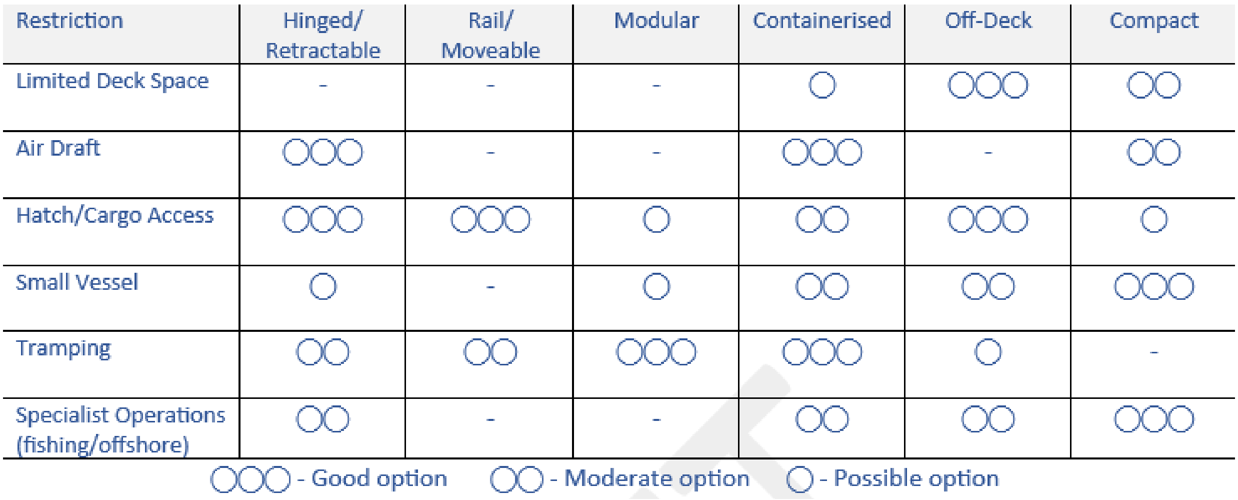
The retrofitting of wind-assist vessels may require reinforcement of the superstructure, addition of foundations and the adjustment of other navigation/safety measures and other equipment, though this is not necessarily the case. Each vessel/system configuration will have specific requirements.

As DNV states in their Maritime Impact (Feb 2022) article:
"Some ship types are better suited for WAPS than others. Smaller ships can choose from a wider range of systems. Larger ships are often more restricted (in choice) due to the air drag reducing the efficiency of sail systems. Ships carrying deck cargo require new concepts for arranging sail systems efficiently."
https://www.dnv.com/expert-story/maritime-impact/more-commercial-ships-utilize-wind-technologies-to-cut-emissions.html

Considerations relating to air draft and operational constraints are of course very important and most of the systems coming into the market are designed with these considerations integrated into their design. The DNV statement continues that a Hazard Identification Study (HAZID) is highly recommended before launching a wind propulsion project and acknowledges that the newbuild option is preferable as it:

"allows designers to include stability and efficiency considerations and electric power needs, and include the WAPS as part of a hybrid propulsion system to make the most of the investment."

With a multitude of wind propulsion systems available with a variety of sizes, configurations and ways these can be installed onboard vessels there is the potential to install some form of wind system on almost all ship types across the fleet as retrofits, see Graphic 4-1



Restriction	Hinged/ Retractable	Rail/ Moveable	Modular	Containerised	Off-Deck	Compact
Limited Deck Space	-	-	-	○	○○○	○○
Air Draft	○○○	-	-	○○○	-	○○
Hatch/Cargo Access	○○○	○○○	○	○○	○○○	○
Small Vessel	○	-	○	○○	○○	○○○
Tramping	○○	○○	○○○	○○○	○	-
Specialist Operations (fishing/offshore)	○○	-	-	○○	○○	○○○

○○○ - Good option ○○ - Moderate option ○ - Possible option

Graphic 4-1 Summary of WPT Retrofit Application Options & Restrictions (IWSA/Varied Sources)
The various system installation options also lend themselves to different business models that are discussed in Section 8.

4-5 Wind-Ready Applications

The retrofitting of WPT will be more expensive than integrating the WPT systems during the design process where all structural reinforcement and other alterations can be made at minimal or no cost (alternatively it is also possible to do this with a retrofit vessel which can be prepared and then installed later). With shipowners assessing WPT systems for new builds in particular and acknowledging that this technology package will be significant in the future, there is the option to prepare the ships to take either a specified WPT or in general prepare the vessel to take WPT installations in the future, otherwise designated as 'wind-ready'. This market option relieves the pressure to make the decision immediately on purchasing the rigs themselves, possibly awaiting a period of higher fuel prices, lower WPT costs or the reaching on a mandated regulatory compliance threshold in the future requiring further and deeper action.

There are currently eight wind-ready vessels in operation (along with three additional ships awaiting soft sail rigs). A number of OEM's are looking at this as a possible business model to ensure a steady flow of vessels passing through yards that are not restricted by the need to install additional multiple systems during that period and to also strengthen the economies of scale of mass production of WPT systems.

The 'wind-ready' designation has potential to stimulate the rollout of systems and at least one Classification society, ABS, has created a 'wind-ready' notation already applied to six delivered tankers.

4-6 Primary Wind Applications

Vessels that are powered or can be powered substantially using wind alone have auxiliary engines for use when there is little or no wind, for propulsion in very heavy sea states, for motoring in restricted channels/canals and for manoeuvring in port and elsewhere. There is the potential for this type of vessel to also harvest excess wind onboard by generating electricity or zero-emissions fuel (as noted in Section 4-3-4). With larger rigs it is challenging for any motor vessel to be retrofitted to this level, as Bureau Veritas states:

> "The masts that support the rigid and rotating sails installed onboard ships can measure up to 80 meters high, taking up significant space on deck. The space required varies with the number of masts, which may reach up to four per ship, based on current prototypes. For ship designers and shipyards this represents a challenge, particularly for smaller vessels (e.g., fishing vessels, inland navigation vessels) that cannot accommodate such large masts."
>
> Source: https://marine-offshore.bureauveritas.com/powering-marine-decarbonization-wind-assisted-propulsion

However, as new build vessels designed with optimised hulls and configured to maximise the efficiency of wind energy along with requisite stability, rudder and navigation issues addressed then the size of these systems can be significantly scaled.

These primary wind vessels will naturally perform at their best when deployed on more predictable and windier routes (as will wind-assist vessels) which is highlighted in Section 4-7

Primary Wind Projects: Larger Vessels

Name	Neoliner	Silenseas 210	Oceanbird	Wind Hunter
Size	136m x 24m 11,000GT/5,000dwt	190m x 25m 300pax 23,000GT	200m x 45m 7,000 car capacity	Not currently specified
Type	RoRo	Expedition Cruise	Car Carrier	Tanker
Wind System	Soft Sail	SolidSail: reefable rigid sail system	Rigid Wingsail: retractable	Rigid ‘Windchallenger’ Sails: retractable
Performance	Upto 80% wind power 11kn sail, 14kn engine	Upto 70% wind power. Max speed under sail 17kn	Upto 90% wind power at 10kn	100%+: capture excess wind energy – H2 fuel
Build/ Operation	2023/2025	Build ready – full scale rig testing 2022	Design 2023, first operations 2025/6	Initial system testing 2021/2, 60m test vessel 2024, full-size by 2030
Route	Initial: North Atlantic	Various	Initial: North Atlantic	Pacific+

Graphic 4-2: Examples of Proposed Large Primary Wind Vessel projects

These newbuild vessels will almost inevitably be more expensive to build with a twin (hybrid) propulsion system, however the operational costs will be significantly reduced. Most WPT systems coming onto the market have 20-25 year warranties or can be refurbished and extended for lengthy periods of operational use. There are currently five primary wind vessels under construction and a number of others are on order. There are also over 20 small traditionally rigged commercial sail cargo and small cruise vessels in operation with design plans and projects set to deliver more of the same along with these larger vessel types.

4-7 Wind-As-A-Service Applications

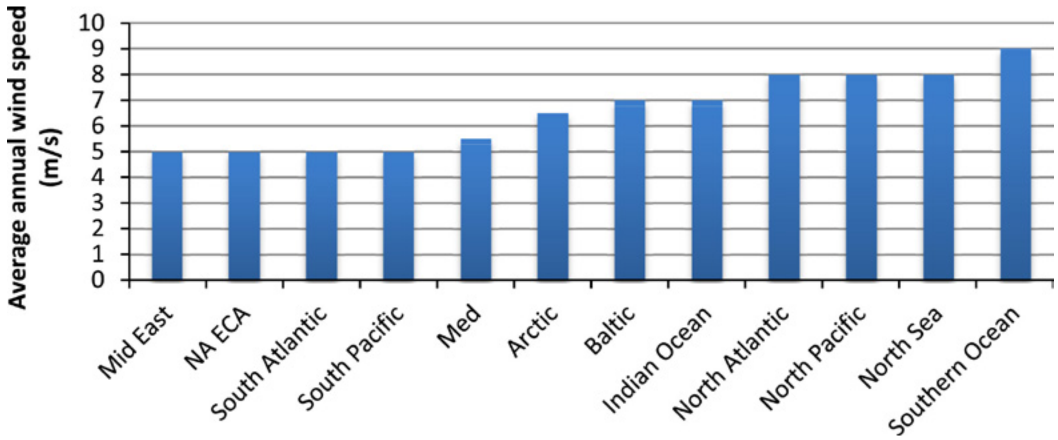
This is a small but growing area of interest, where wind propulsion energy would be delivered to the vessel via a non-vessel installed system. One option under development is for an ocean-going tug to tow the vessel and for the tug to be primarily wind powered and that would then deliver that propulsive energy as a service. Another variation of that would be the attachment of an outrigger or other external wind powered module to the vessel.

4-8 Facilitating & Supporting Technologies

Along with the development of WPT there has also been steady progress in the development of new testing procedures and performance criteria, energy management systems, weather routing, training etc. The further integration of WPT into the operations of ships from a retrofit perspective and the increased operation of ships as ‘wind ships’ as opposed to ‘motor ships’ is where significant additional benefits and optimisation can be achieved, listed below (though not exhaustive) are a number of areas that are significant to this.

4-8-1 Optimal Conditions for Wind-Assist and Primary Vessel Operations (Routes)

The understanding of how each system option works and the regions/routes where that is best deployed is an area that shipowners are rightly concerned. Each wind propulsion system’s performance differs with the wind conditions. For example, Wing sails and suction wings have better upwind performance whereas rotor sails perform better in beam and down winds. Hull form designs and turbine technologies hold the potential to operate well in head winds and kite systems utilise virtually constant wind conditions at 200m+ elevations. However, as an approximate overview of wind conditions and average wind speeds, we can see from the figure below that the wind averages in all regions are 5m/s (9-10 knots) or above, with the Baltic, Indian Ocean, North Atlantic, North Pacific, North Sea and Southern Ocean all averaging 7 m/s (15 knots +) or above.



Graphic 4-3 Average Wind speeds in Varied Ocean Regions (Source: Rehmatulla et al, Marine Policy 2017)

These regional average wind analyses only give a part of the story as within these regions there are prevailing winds, trade winds and seasonal variations that can and will provide significantly enhanced options for wind installed ships.
NOTE: As highlighted in Section 1 and Section 3, the speed of the wind doesn't necessarily indicate the amount of power or speed that can be derived from any given wind device, as the vessel is not pushed by the wind but rather pressure differentials generate lift which means that ships can go faster than the wind.

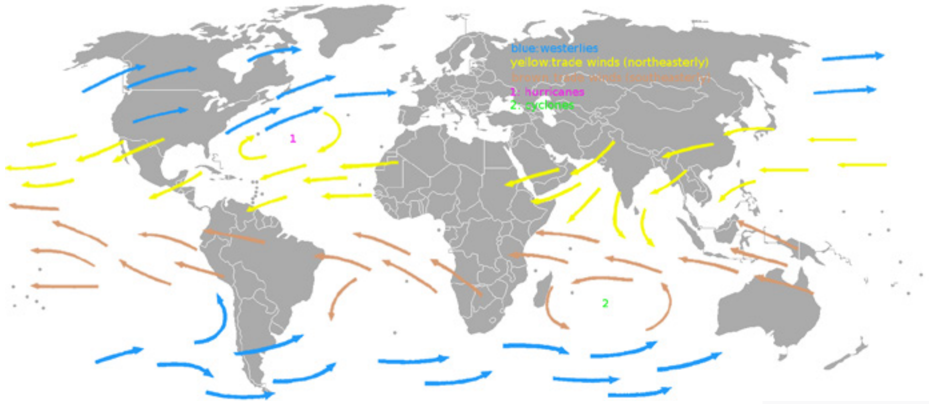
Regarding preferable routes, there was seemingly significant movement at COP26 in Nov 2021 with the signing of the Clydebank declaration by 24 countries to establish 'Green Corridors' to help facilitate the transition to zero-emissions shipping. Unfortunately, to date this declaration has been interpreted as 'fuel centric' corridors where the sole concern is to establish the infrastructure to deliver new alternative fuels, however the signatories in fact pledged:

"In supporting the establishment of green corridors, signatories recognise that fully decarbonised fuels or propulsion technologies should have the capability to not add additional GHGs to the global system through their lifecycle, including production, transport or consumption." (*underlining added)

Source: Clydebank Declaration for green shipping corridors (2021) https://www.gov.uk/government/publications/cop-26-clydebank-declaration-for-green-shipping-corridors/cop-26-clydebank-declaration-for-green-shipping-corridors

Traditional sailing routes following the 'trade winds' and other prevailing wind systems are well known and predictable and can be once again used to facilitate low-emission corridors and integrated into this approach. The driver will be to significantly reduce emissions and will require operational profile adjustments however in a carbon constrained and high fuel cost environment, these wind corridors are a significant energy conveyer.

Source: Return Journey: Call for an 'energy-centric' approach to green shipping corridors, Bunkerspot Article, G. Allwright, April 2023 https://www.bunkerspot.com/features-all/item/return-voyage

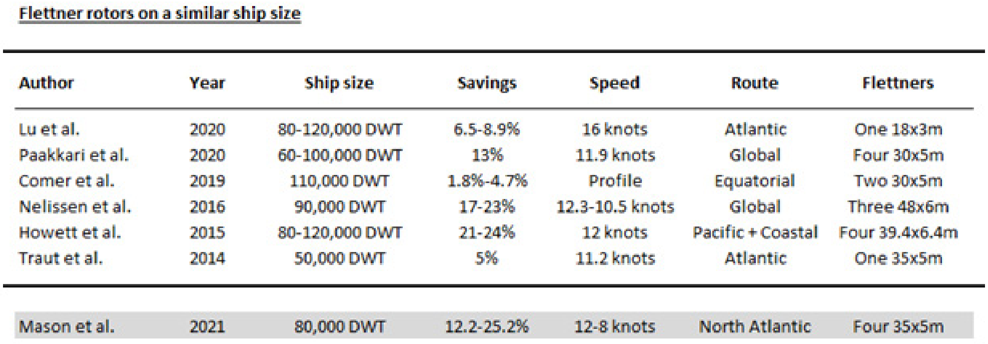


Graphic 4-4 World Map indicating Major Wind Systems (Source: Wikipedia)

4-8-2 Voyage Optimisation: Route and Speed

Weather routing has been used since the 1850's with Lt. Matthew Fontaine Maury, US Navy's work on the Oceans currents and related atmospheric phenomena, which culminated with the release of 'The Physical Geography of the Sea' (1858). Using these charts and ones that followed, sail vessels were able to shave many days off their long trade voyages and were able to plot voyage times far more accurately. Today, with increasingly sophisticated weather-routing and voyage optimisation software, ship operators are now able to maximise the gain from wind propulsion systems with far greater accuracy and can simulate many thousands of routes and any time of year with varied speed, ETA and other criteria to plot the most efficient routes for any given ship type and trade.

Using a wind-assist model of a Panamax bulk carrier with 4 x 35m rotors, (Mason 2021) a series of route and speed optimisation simulations help to indicate the level of additional savings that can be accrued, and these correlate with other studies/simulations in the table below. When speed is reduced along with speed and routing is optimised for wind then far higher results are indicated in the 3-D Optimisation curve, dependant on the voyage increase time selected, i.e. 20-45%.



Flettner rotors on a similar ship size

Author	Year	Ship size	Savings	Speed	Route	Flettners
Lu et al.	2020	80-120,000 DWT	6.5-8.9%	16 knots	Atlantic	One 18x3m
Paakkari et al.	2020	60-100,000 DWT	13%	11.9 knots	Global	Four 30x5m
Comer et al.	2019	110,000 DWT	1.8%-4.7%	Profile	Equatorial	Two 30x5m
Nelissen et al.	2016	90,000 DWT	17-23%	12.3-10.5 knots	Global	Three 48x6m
Howett et al.	2015	80-120,000 DWT	21-24%	12 knots	Pacific + Coastal	Four 39.4x6.4m
Traut et al.	2014	50,000 DWT	5%	11.2 knots	Atlantic	One 35x5m
Mason et al.	2021	80,000 DWT	12.2-25.2%	12-8 knots	North Atlantic	Four 35x5m

Graphic 4-5: Listing of various simulations on ships of a comparative size and WPT selection (Source: Mason 2021 p212)

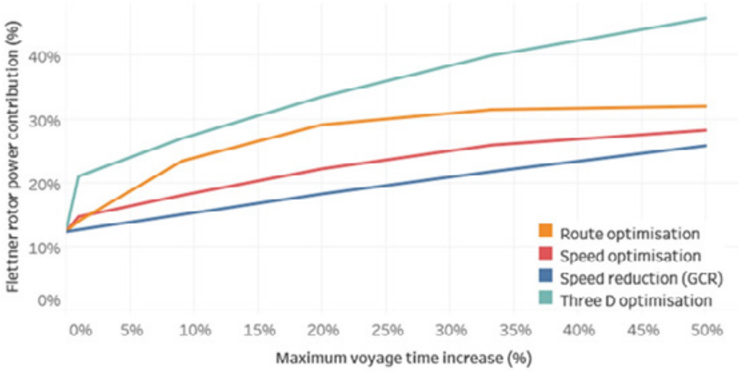


Figure 5.14: Flettner rotor power contribution for all four simulation types: route optimisation, speed optimisation, three-dimensional optimisation and speed reduction.

Graphic 4-6: Flettner rotor simulation of power contribution plotted against operational scenarios and ETA. (Source: Mason 2021, p226)

These results are not comprehensive as they only cover a single technology option, the use of wind-assist as opposed to primary wind and projections based on a narrowly selected ship type. However, they do provide a clear insight into the level of additional propulsive energy delivered to the vessel when all three options are combined and this is further enhanced when the ETA is relaxed, with just over 20% power provision when ETA's go unchanged and all three aspects are combined which is then increased to just under 35% when the ETA is relaxed by 20% and well above 40% when the ETA is lengthened by 50%.

4-8-3 Weather Tracking

All wind propelled vessels have a weather station installed onboard which assists with the optimisation of the wind system performance in real time. Overlaying that with precise satellite weather forecasting data allows for a quite accurate picture of wind and wave behaviour during operations. There is the possibility to further enhance that with the deployment of LiDAR which can map localised wind patterns very accurately out to tens of kilometres off the ship, and which is deployed on large wind turbines. This would enable larger rig systems to both further improve the performance of the installed rigs in real time, but also to inform designers on ways to improve design and providing extensive performance data to feed back into digital twins. This is also the case with datasets available to the routing software developers. Ref: https://www.sssri-marin-jv.com/measuring-3d-wind-fields-at-the-speed-of-light/

4-8-4 Automation

This has been a key area of development for OEMs and most WPT systems are now highly automated with a control box on the bridge that delivers all of the required metrics and adjusts the angle/RPM of the given device. The level of automation is of critical importance for off-deck systems such as kites to maintain altitude and safe deployment. This level of automation is a significant change from earlier phases of wind propulsion and was pioneered in the early 1980's with the systems being introduced in Japan and elsewhere. The last 50 years has seen the level of technology advance significantly and during this period we have also seen significant technical advancement in the leisure and racing sectors with the use of sensors and computerised optimisation, and this has been adopted directly and been brought into the commercial sphere. This is a significant change as commercial operators require a turnkey solution on large vessels and the need for swift action to power down and retract systems in the case of heavy weather or emergency situations is critical.

4-8-5 Integration

The further integration of WPT systems into the energy management system of wind-assist and primary wind vessels is required and this process is underway. This integration into the 'system of systems' that makes up a ship will help to improve the performance of engines that must operate with fluctuating amounts of direct energy provided to the vessel and thus can lose efficiency and negate a level of the fuel/carbon emissions reduction provided by the wind propulsion system. This is made more manageable through adjustments to the energy management power curves being developed by engine producers such as Wartsila and MAN Energy Solutions or on vessels with electric hybrid propulsion trains, where power to the drive chain is more easily controlled.

Source: Preliminary Study on the Propeller and Engine Performance Variation with Wind Propulsion Technologies, Reche-Vilanova et al 2023 https://www.researchgate.net/publication/372788453_Preliminary_Study_on_the_Propeller_and_Engine_Performance_Variation_with_Wind_Propulsion_Technologies

Source: Optimal Wind/Hybrid Propulsion systems – MAN video https://www.youtube.com/watch?v=zQZVEPgfIvQ

4-8-6 Human Element - Training

The training for seafarers operating a specific WPT or wind-powered vessel will be primarily initially the responsibility of the technology provider. However, the need for a standardised training curriculum is recognised as an important collective effort and there are some initiatives underway to create a training curriculum and a digital simulator through the two-year DIGI4MER project. That said, the high level of automation of the systems means that this training will be mainly focused on system awareness, the operational parameters of the WPT, safety and maintenance.

5) Assessment of Wind Propulsion: Approaches, Challenges

The complexity of the installation of wind propulsion systems will, of course, vary according to the following criteria (but not restricted to);

- Ship type.
- Ship size.
- Type of WPT.
- Weight/size of WPT.
- Foundation requirements.
- Movable/retracting/hinged.
- Location of the WPT unit on the vessel.
- Operational requirements of the vessel.
- Obstacles and interaction with other deck equipment (hatches, cranes, winches etc.).

Source: EU WASP Project: Best Practice Manual Best Practice Manual
https://vb.northsearegion.eu/public/files/repository/20230627094010_WASP-BPM-version5-FINAL27June2023.docx
Currently, the 30th International Towing Tank Conference (ITTC) 'Specialist Committee on Performance of Wind Powered and Wind Assisted Ships is working on many of the application elements and their guidelines will be released in 2024. The terms of reference for this workstream are available at: https://ittc.info/media/10159/tor-revised-after-conference.pdf

5-1 Performance Validation

Here we describe the present status with regard to validated performance data being available. For references to sea trial validation standards see section 5.6.

5-1-1 Standard Metrics

Although, the standard is not yet formalised, the ITTC committee referenced before has published a draft for standard performance metrics (Werner et al 2023). An excerpt from the publication is shown in Graphic 5-1. As a primary indicator, the "Power Saving Potential" (PSP) was identified. The idea of PSP is that it should reflect the best saving that can be achieved. It thus assumes perfect control of the ship. The number can be prepared for different progression levels in a project as indicated in the table. Each progressive stop requires more accurate calculations methods. Discussion has progressed and also other indicators are now considered, such as energy and fuel savings. The final standard is expected in 2024.

KPI	Unit	Usage	Power modelling*)	Weather Modelling
Rated WPU power	kW	General comparing, scanning the market	Stand-alone WPU power	EEDI
PSP-I	kW	Early idea	Level I	EEDI or the ship's intended route
KPI	kW	Early business case assessment	Level II	The ship's intended route
KPI	kW	Business case & Performance expectation	Level III	The ship's intended route
KPI	kW	Advanced Business case & Performance expectation	Level IV	The ship's intended route (incl. possible weather routeing, speed optimisation)

Graphic 5-1: Recommended Key Performance Indicators (Werner et al 2023)

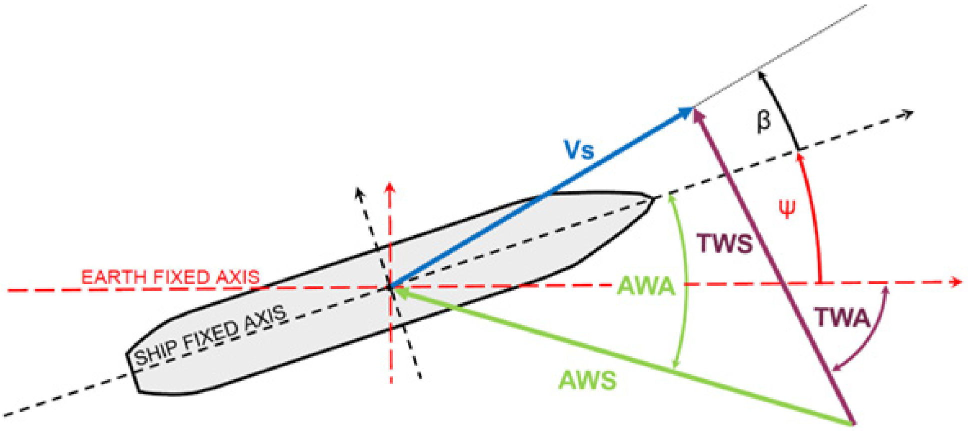
Also, IMO implemented a defacto standard with their guideline for wind propulsion in EEDI & EEXI (MEPC.1/Circ.896). The default performance metric for EEDI and EEXI is the grammes of CO2 equivalent (CO2e) GHG emission emitted divided by the product of cargo mass and ship speed.

Although not a standard, in publications it is common to see savings expressed as percentages. By many this is deemed a very easy to understand definition. As it is dimensionless, it allows easy comparison between ships. However, actual comparison between numbers from different ships should be done with great care. The percentage definition suggests it can be easily transferred between projects. However, in reality power saving is very sensitive to design aspects and operation aspects. Generally, one cannot simply transfer or compare a percentage between projects. Defining a percentage implies that the savings are also divided by a certain reference number. It then becomes important to define what is the reference performance. For instance, whether auxiliary power is included in the overall power level becomes important. It is noted that the definitions used throughout publications at the moment vary and, in some cases, they are not even mentioned.

Note: When analysing these issues we should always consider base WPT performance and weather routing separately. Different weather routing software can deliver varied results.

5-1-2 Wind Direction & Measurement

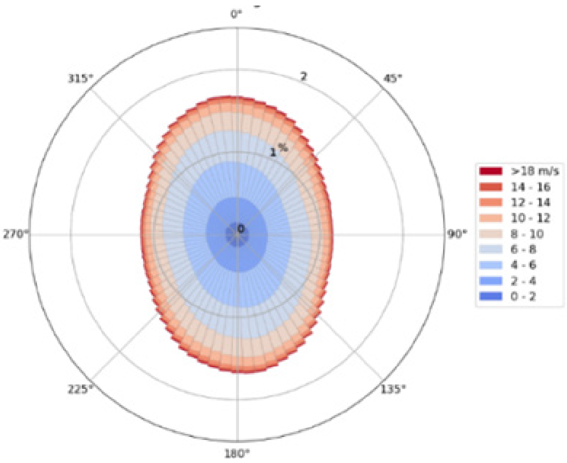
In order to understand the performance of ships with wind propulsion, it also important to know for which wind conditions these were defined. A common definition is the "undisturbed" wind speed and relative angle at 10m from the sea level. Undisturbed refers to wind that is not affected by the ship. Relative wind angle is defined relative to the track of the ship. In sailing terms these parameters are generally called "True Wind Speed" (TWS) and "True Wind Angle" (TWA). However, what is measured on board is the "Apparent Wind Speed" (AWS) and "Apparent Wind Angle" (AWA) defined relative to the ship centreline. Being on the ship means that the influence of ships speed and also leeway (the ship also sailing sideways) is embedded in the data. See these quantities illustrated in Graphic 5-2.



Graphic 5-2: Wind Definitions (source: MARIN)

The measurement on board is generally done at a position higher than 10m using anemometers. This higher position leads to higher wind speed than closer to the sea. Correcting for these effects require an assumption on the wind speed profile, knowing the disturbance that the ship causes on the measurement and the leeway. These characteristics require specific measurement or calculation. Hence, in trials and monitoring with emphasis on accuracy, it may be preferred to equip the vessel with LiDAR measurements. LiDAR allows us to measure the wind some distance from the ship directly at 10m, eliminating all corrections except leeway. At the moment LiDAR is relatively expensive, so that it is only used in selective test campaigns. However, if equipment and procedures could be standardised it would be interesting to collect more data.

When having, the wind speed and angles for a particular case, the overall statistics may be condensed in a wind matrix, such as in MEPC.1/Circ.896, describing the frequency of occurrence of specific combinations of True Wind Speed and True Wind Angle. The standard wind matrix from MEPC.1/Circ.896 is shown in Graphic 5-3.



Graphic 5-3: A Wind Matrix presented as a polar – from MEPC1. Circ.896 – wind speeds indicated with different colours in m/s – wind angle along the radius – the (cumulative) probability of occurrence is shown in percentages.

Generally, monitoring or trials will have been done at different wind conditions, which makes a direct comparison unfair. However, when predictions are calibrated to measured data, then these predictions can also be run for predefined wind statistics. The results then allow a fair comparison (at least considering wind statistics; there may still be other matters unequal between datasets, such as ship speed).

5-1-3 Third Party Verification

As described in this document, determining a power saving measure, in whatever form, for wind propulsion is not straightforward, especially when the figure is to be compared between different projects, suppliers or ship designs. There is potential scope for interpretation. It is therefore imperative the final verifications are not done by the stakeholders in the projects, but by third parties with experience in this topic. In recent years, several reports have been published with third party verified performance numbers. With standards not yet fully determined, comparing the numbers is not straightforward. However, these reports do provide the best assessment of wind propulsion performance in the world fleet to date.

5-2 Impacts on Performance

The impact of wind propulsion on the general ship performance varies widely. On the one hand, we see a large number of installations, mainly retrofits that are modest in relation to the ship. Such systems may yield average annual savings on fuel and emissions for propulsion of some 5% to 15%. The impact of these systems is generally only on some modified procedures for cargo loading and unloading and possibly stowage in bad weather (if at all). The operation of the ship is otherwise unchanged and may be considered “business as usual”. However, if WPT systems increase in size, they can progressively affect the performance of the vessel. Then it becomes important to adjust the design as well as operations. The following sub sections deal with ships with more substantial wind propulsion.

5-2-1 Ship Systems

With substantial wind propulsion, some systems may experience different issues:

- The ship will sail with heel. Up to a certain extent this may be acceptable, however, to counter larger heeling, an anti-heeling system can be fitted.
- The ship will sail with a leeway angle and needs to find a balance in yaw. Large leeway angles or large steering angles can induce an increase in resistance. To remedy that the hull shape may need adjustment. Also, a change in the rudder design and additional appendages can be considered such as additional skegs in the stern regions, enlarged bilge keels or (retractable) dagger / centre boards / anti drift fins that extend below the baseline when deployed.
- (Electric) power is required to run the wind propulsion system. “Active” systems such as Flettner rotors and Suction wings/sails require a larger power input as that is their means to achieve higher thrust per square meter. However, other systems need power for control. Note: There will be a variation of energy use between WPT types.
- The conventional propeller propulsion will run at a reduced load. Care must be taken that this is possible and achievable at good efficiency, without inducing pressure side cavitation. With very good wind propulsion levels, propellers may be stopped. In that case it is desired to have a Controllable Pitch Propeller that can be pitched out to a “feathering” position, minimising drag. While in this condition it still needs to be ensured that the steering capability is still sufficient with no propeller wash over the rudder(s).

5-2-2 Operational

If and how the operation needs to be changed to align with the WPT installation is highly dependent on the ship type and operations undertaken by the ship. If cargo operations require cranes, then substantial WPT systems may need special attention. However, various suppliers have developed systems to deal with this issue, such as:

- Tilting and rotating units
- Sliding along tracks
- Retracting into a container
- Still in development: Retracting into the ship

When in operation many systems have been developed already with substantial automation requiring little to no attention. The suppliers of some other systems have chosen a more hands on approach as they develop the technology further with the aim to further integrate these WPT. These more hands-on systems will require appropriately trained crew to handle them.

The EU funded WASP project 2019-2023 released a Best Practice Manual covering many of the operational aspects for five WPT installations on various general cargo and a RoPax vessel. (WASP 2023)

5-2-3 Logistics

Currently, most assessments of performance, including those with substantial WPT systems and primary wind applications, assume that the ship must always maintain its ETA so that a direct comparison with a motor vessel on the same route can be undertaken. These wind-assist vessels are of course hybrid in design and thus conventional propeller propulsion onboard makes sure that good speed can be maintained in bad wind conditions. Therefore, the predictability of transport work is not affected, but that doesn't allow for the full optimisation of the wind propulsion element.

However, some of the more ambitious projects do implement a lower ship speed than common for their trade to help maximise the amount of wind energy that can be deployed. This reduction in speed yields an energy saving by itself as outlined in Section 1 and explored in detail in Mason 2021 and applied to fleet decarbonisation potential by 2030 in CE Delft 2023. This speed reduction can also provide an additional benefit for wind propulsion, as the apparent wind will be less dominated by the sailing speed (thus better apparent wind angles). Also, the possibly of deviating from the shortest route to the best wind resource route is an important consideration, though obviously this will likely have a subsequent impact on the transport time.

5-3 Performance Optimisation

5-3-1 Weather Routing

Weather routing is already used extensively by ship operators and the routing software is fairly sophisticated with inputs from decades of historical data and real time feedback from voyages. Applying weather routing to wind propulsion has also been developed over many years, with very detailed datasets used in offshore racing and now utilised in the commercial field. Some ships are already using wind routing to maximise their fuel savings and as discussed in the paper 'Weather Routing Benefit for Different Wind Propulsion Systems', summarised in MEPC 80/INF.33 (full paper: D-ICE & Ecole Polytechnique 2023), there are substantial benefits for WPTs however, each system type will benefit from the application of weather routing for wind to differing degrees. As an example, this particular study took a post-Panamax bulk carrier outfitted with different WPT on a simulated Santos-Qingdao route with a large set of voyages (5 years of weekly departures). The study found average weather routing benefits with wing sails of 73.33%, 82.22% with suction wings, and 104.89% with rotor sails. These programs are becoming increasingly sophisticated as real operational data is being fed back into the models and the incorporation of machine learning will only accelerate this.

5-3-2 Speed

The default constraint on evaluating systems is that the ship should always arrive on time. However, if further zero-emissions energy provision is incentivised either through regulation or by simple economics and enabled by charter contractual adjustments, then a certain flexibility in arrival time would be beneficial. The combination of speed reduction and WPT performance can be calculated and as noted in sections 1, 3 and 8, there is considerable reduction in fuel use and emissions. However, this would obviously require some flexibility or buffer in cargo at the departure and destination port. Higher speeds do however burn more fuel thus reductions at those speeds may subsequently yield larger fuel savings.

5-3-3 Weather Forecasting & LiDAR

The use of satellite weather forecasting has dramatically improved the understanding of weather patterns and their effects on vessels and routing in real-time. The integration of this into the operations of WPT and primary wind vessels will increasingly improve performance and weather routing software. The deployment of LiDAR is also an area where systems could be further optimised as the LiDAR system can be used to map out wind systems approaching the ship giving lead time for the WPT to be adjusted to make the most of the incoming wind patterns. This technology is already deployed on large wind turbines and will likely be first used from a research perspective (as it already is) before moving to deployments on large vessels with substantial wind propulsion installations.

5-3-4 Energy Management System (EMS) & Vessel Systems Integration

Ships are a 'system of systems' and by introducing WPT with fluctuating levels of energy and forces acting on the vessel, there will likely be inefficiencies or disruption generated in other parts of the system, such as the engine performance, rudder configurations etc. There is much scope for increased integration of these systems to improve the interaction between all of these moving parts. One key area is how to maintain engine performance and efficiency and having an effective EMS that can handle varied WPT input is an area that will deliver further optimisation benefits and engine manufacturers are increasingly focused on delivering products that can adjust to these challenges. Both the CHEK and Optiwise wind propulsion projects are considering many of these optimisation issues. (see Section 11-3)

5-3-5 Wind Energy Harvesting

As mentioned in other sections, there is an opportunity to enhance performance by the utilisation of energy harvesting systems when the ship is primarily or fully underway using wind propulsion. Once the hull speed has been reached, usually the excess wind energy needs to be spilled, however, this energy can be harvested if hydro generators were deployed or propellors reversed on an electric drive vessel so as to act as generators. This excess energy can thus be harvested and stored as electricity or converted into a zero-emissions fuel onboard for later use.

5-4 Design Criteria

5-4-1 Stability

Stability is a key consideration in the design of wind propulsion vessels and for retrofits. The classification guidelines all specify that the installation of WPT on vessels must be compliant with IMO specifications, including aligning with the International Code on Intact Stability (IS Code) and the Second Generation Intact Stability Criteria. Neither of these specifically include WPT, however the European Maritime Safety Agency (EMSA) 2023 report; 'Potential of wind-assisted propulsion for shipping' calls for these to be updated as more data is now available from the wind powered demonstrator vessels in operation. While the report covers mainly the negative implications on stability, it should be noted that WPT systems also deliver positive effects. Pages 75-78 of the EMSA report deal with stability issues in detail and considerations include;

> "It is observed that the additional lateral windage area can be rather large, especially for wings and sails, and this can be detrimental to the intact stability of vessels with WAPS. WAPS that can be stowed should be differentiated from those that cannot. If both conditions are calculated in terms of stability, the situation with deployed WAPS will most probably dominate (which is worse in terms of stability). To overcome any stability issues, either the maximum windage area needs to be reduced (offering less wind-assisted propulsion) or hydrodynamically sub-optimal hulls need to be used to increase the vessel's stability."
>
> "Moreover, it is noticed that while intact stability assumes that the ship is upright, WAPS increases the probability that it will operate with a heel angle, and this may impact the criteria for the righting lever. WAPS will also increase the vertical centre of gravity of the vessel, so loading conditions may need to be adjusted accordingly to ensure the vessel can maintain her vertical centre of gravity within the limits of the stability criteria."
>
> "Icing scenarios will also need to be considered because ice accretion on the WAPS may add weight and also affect vessel's vertical centre of gravity." (EMSA 2023)

5-4-2 WPT Interaction with Ship & Between Rigs

There is a growing body of knowledge and experience regarding the interaction of WPT and the flow of wind across the ships hull and structures along with the interaction between multiple rigs. The understanding and reduction of the disruption of wind flow and turbulence generated by these is one of the key elements in improving performance and in the selection of the best WPT for any given ship. The key discussion points on multiple rig interaction are covered extensively in the 'Aerodynamics of Wind-Assisted Ships: Interaction effects on the aerodynamic performance of multiple wind-propulsion systems (Bordogna 2020) and subsequent work undertaken by the author on a performance prediction model that can incorporate these interactions. This growing body of information is being fed back into digital twins to enhance the accuracy of the vessel design models. Tillig & Ringsberg also do an extensive analysis of how WPT interact, in this case rotor sails, with the ship and between rigs in their paper; Design, operation and analysis of wind-assisted cargo ships (Tillig & Ringsberg 2020). They also detail how that information feeds into their modelling software. This theoretical work is also backed up by field data collected by the WASP project and published in the technical report on digital twins for the five vessels tested during that project.
https://vb.northsearegion.eu/public/files/repository/20230613152704_WP3deliverablestechnicalreport.pdf.

Other digital twin development is now being commercialised and will increasingly be available for shipping companies to access any given WPT.

5-4-3 WPT Siting and Foundation

The siting of WPT systems will require careful consideration bearing in mind deck and superstructure strength, cargo operations, ship and crew safety, helipad access, air-draft, navigation lights and radar coverage, bridge visibility etc. Most of the design considerations are covered in the classification society guidelines. The key issues and considerations involved with this are cited below in Section 5-5 on safe operations. The reinforcement work that is required for WPT foundations will vary between ship types, however, as a general rule the inclusion of that reinforcement during the build cycle will require minimal design adjustments and cost, whereas a retrofit will take longer and incur higher costs due to mitigating the changes to the design, access etc.

Overall, there are numerous design impact questions that will need to be answered during the design process for newbuild vessels and retrofitting of existing vessels and a detailed overview of these issues is provided in the publication; Wind Propulsion Principles: The complete guide to harvesting the ocean winds for commercial shipping (Fakiolas, M. 2022)

5-5 Safety

The European Maritime Safety Agency (EMSA) in November 2023 delivered a comprehensive safety overview of wind propulsion technology applications. The regulation gap analysis on wind propulsion forms the basis for further work to standardise and mitigate all the known hazards and safety concerns. The conclusion is that while there are areas of concern, no major risk was identified that can't be resolved.

> The issues described above may require further studies for better understanding of the risks as well as for defining the necessary safeguards that will need to be implemented to prevent or mitigate the major hazards. Based on the Hazard Identification (HAZID) studies, preventive and mitigative safeguards as well as recommendations for various ship types are presented, which may help to inform prescriptive requirements and develop inherently safer designs and arrangements. While some safeguards are regulatory requirements, many of these are considered additional safeguards due to the inherent risks of WAPS. Overall, the studies did not identify any major risk that cannot be resolved. (EMSA 2023)

5-5-1 General Safety Considerations

A list of safety considerations (though not exhaustive nor in order of priority) is provided below.

- Crew Safety
- Fire Safety
- Lightning Protection
- Stability Considerations
- Extreme Weather Procedures
- Navigation Safety (bridge visibility, radar blind sector, navigation lights.)
- Hazardous Areas of the vessel.
- Manoeuvrability.
- Changes in Air Draft.
- Mooring & Anchorage
- Component Failures
- Noise & Vibrations
- Safe WPT Stowage during port operations

5-5-2 SOLAS Considerations

WPT installations must naturally comply with all Safety of Life At Sea (SOLAS) Conventions including Part C Alternative design and arrangements contained in the Chapters II-1 Reg, 55, II-2 Reg. 17 and III, Reg. 38 and Chapter V.

> As WAPS tend to have large areas that are exposed directly to the wind, they can affect a ship's manoeuvrability and stability. Also, some types of WAPS, such as rotor sails and sails, install tall structures on vessel decks which may substantially increase air draft. Potentially, this could create additional obstacles to visibility from the bridge, radar and navigational lighting. The IMO's Maritime Safety Committee has developed several regulations governing manoeuvrability, stability and navigational safety, included in the International Convention for the Safety of Life at Sea (SOLAS), and related Codes and Standards, which are discussed in detail in this section [p73]. (EMSA 2023)

The EMSA study covers WPT SOLAS regulation issues on p73-80.

5-6 Sea Trial Standards

Standard approaches to sea trialling for wind propulsion are being developed under the auspices of the International Towing Tank Conference. One clear issue involved is the need for the wind to be blowing at a reasonable level to be able to adequately test the WPT systems and how that fits into the current sea trail standard approaches. While this issue is touched upon in MEPC.1/Circ.896, a far more detailed set of suggested approaches will be delivered by the ITTC in mid-2024 based on the work outlined in these two papers;

Werner, S., et.al, 2021, Speed Trial Verification For A Wind Assisted Ship, in the proceedings of RINA International Conference on Wind Propulsion, 15-16 September 2021, London, UK
https://vb.northsearegion.eu/public/files/repository/20211208153521_Werner2021SPEEDTRIALVERIFICATION.pdf

Werner, S., et.al, 2022, Speed trial methodology for wind assisted ships, p124-140 in the proceedings of HullPIC, May 2022, Ireland. http://data.hullpic.info/HullPIC2022_Tullamore.pdf

5-7 Classification Societies Guidelines

The installation and operational parameters for WPT are informed by classification society guidelines that are publicly available. These guidelines are undergoing regular updates and revisions will be required as the increased number of demonstrator and commercially installed systems are feeding back into the process. A further upgrade will also be forthcoming as larger scale retrofit WPT systems are introduced into the market and large primary wind vessels enter operation.

ABS Guidelines: Download
Bureau Veritas Guidelines: Download
ClassNK Guidelines: downloadable from www.classnk.com
DNV Guidelines: Download
Lloyds Register Guidelines: Flettner Rotors // Masts, Spars & Standing Rigging
China Ship Classification Society: Guidelines for Survey of Marine Wind-Rotor Assisted Propulsion System 2023 Download

5-8 EEDI/EEXI Calculations

The calculation of EEDI and EEXI for wind propulsion systems is guided by the 2021 IMO MEPC.1/Circ.896: Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI and EEXI. This guidance paper superseded the MEPC.1/Circ.815 and covers wind propulsion in the following section: Wind assisted propulsion system (Category (B-2))

Appendix 1: Method of wind tunnel model test.

Appendix 2: Global wind probability matrix.

https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.1-Circ.896.pdf

The MEPC.1/Circ.896 updated and improved upon the earlier guidance and adopted a metric to take the best 50% of wind performance data to more closely align with actual operational performance. Elements of the guidance circular are under review as there needs to be a more standardised approach to create a level playing field among all WPT systems as some perform very well at certain wind angles whereas others perform better across a whole spectrum of wind angles. There is also a need to enhance the guidelines to take into consideration far larger and more powerful WPT systems that will be able to use wind as the primary propulsive energy source.

5-9 Crew Training

For most WPT systems that are highly automated the training requirements are relatively light, with a general system overview training session undertaken with all crew members. Some WPT systems in their earlier iterations or with more traditional sail systems are more hands on and will require more specialised training. However, there is currently no standardised training package across the industry, in place of that there is training given by each WPT supplier.

Work is underway to create a standard curriculum and simulation materials. The DIGI4MER – WP2 project has been undertaken by the IWSA Europe Atlantic group, Association Windship, and this will deliver an online theoretical training in wind propulsion for seafarers.
https://www.economie.gouv.fr/plan-de-relance/digi4mer-projet-moderniser-formations-industries-mer
Further work is underway to widen this package and make that accessible as an industry backed curriculum.

With WPT systems that have further innovative aspects such as modular or movable ones then additional training may be required. In addition to training for the crew, user manuals are distributed as a reference material for the crew, however the main engagement that the crew have with the systems is through regular maintenance routines. As the systems are increasingly automated and can be distance monitored, the requirements for training in the future should be minimised, however emergency procedures in heavy weather and the capacity to cope with a system failure are important elements that require crew competency.

5-10 Maintenance & Repair

There are regular procedures that will be focused both on observing/monitoring/checking systems along with hands on maintenance activities.

Period	Typical examples of activities
Daily	Implicit check through operations by ship crew
Weekly	Visual check for damage by ship crew
Monthly	Greasing of moving parts by ship crew
Yearly	Check-up by technology provider
Occasionally	Visual checks after heavy weather

Graphic 5-4 Regular Maintenance considerations Source: EU WASP project Best Practice Manual (2023)

The process for repairing WPT systems are currently done on a bespoke basis as there are still relatively limited numbers of rigs and vessels in operation, however the feedback and data received by WPT suppliers is feeding into the upgrading and adjustment of systems to ensure that running repairs are more easily handled by crew members and the need for system downtime is kept to a minimum. As more repair cycles are undertaken, so shipyards will also gain hands-on experience.

Potential repair issues include:
- Small components
- Hydraulics issues
- Vibration issues
- Ice accumulation

Corrosion issues and material longevity are also key issues that require long-term monitoring, however these issues should be covered by contracts and long-term service agreements between the shipowner and the technology vendors.

6) Current Installations

6-1 Vessel Installations
6-2 Technology Segments
6-3 Vessel Segments & Size
6-4 Recent Market Trends
6-5 Under-Represented Segments
6-6 Small Vessel Segment

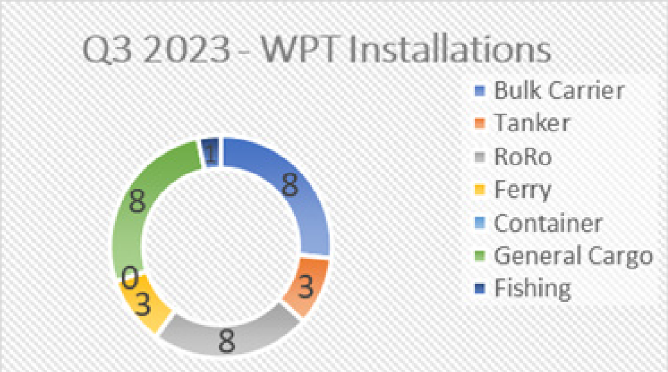
The world fleet consists of 55,000-100,000 large vessels (depending upon categorisation - >1,000gt or >100gt), with a total of over 2 billion dwt (UNCTAD 2022) and a fleet of three million+ smaller commercial cargo, domestic shipping and fishing vessels.

6-1 Vessel Installations

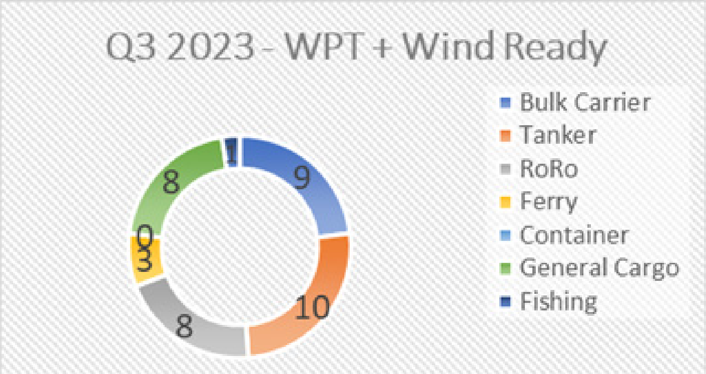
The WPT market has been gaining momentum again following the challenges of the COVID pandemic and subsequent logistical and financial turmoil that followed between 2020-2022. In 2022, there were seven additional installations of WPT, bringing the total of large commercial vessels to twenty-three along with three wind-ready vessels. In the first eight months of 2023, this number increased to thirty ships installed and eight wind-ready as of 31 August 2023. [See Graphic 6-1 & 6-2]

The near-term projection is to add a further 16 or more large vessels before the end of the first quarter of 2024 and this will include the first small feeder container ship (143m, 1036 TEU capacity Singapore owned, MV Kalamazoo), four small primary wind vessels and a number of newbuild ships underway for delivery later in 2024/25. [See Graphic 6-3]

The full list of current large vessel installations (as of 31 Aug 2023), wind-ready and traditional sail cruise vessels can be found in Annex 1.



6-1

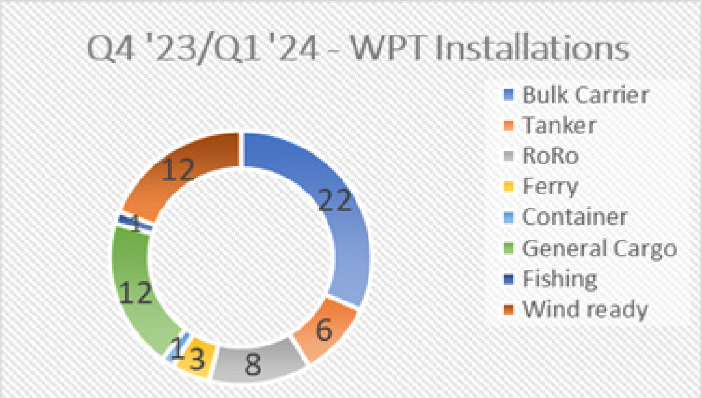


6-2

Graphic 6-1: Wind Propulsion Installations by Ship Type Q3 2023

Graphic 6-2: Wind Propulsion Installations by Ship Type – including wind-ready vessels Q3 2023

Graphic 6-3: Wind Propulsion Installation Projection by Ship Type by end of 2023/beginning 2024. Note: This graphic includes 'wind-ready' vessels in a separate section (12 ships)

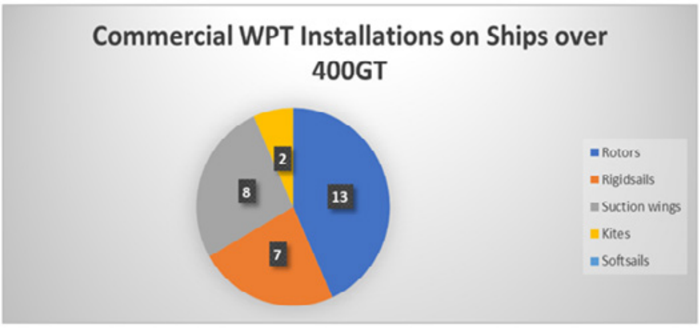


6-3

6-2 Technology Segments

The breakdown of installations via technology type is as follows; with rotor sails taking the largest share with thirty-two rotor sails installed on thirteen ships [8 x <20m, 20 x 20-29m & 8 x >30m]. Fifteen rigid/hard/wing sails have been installed on seven ships ranging in size from 12-40m in height and fourteen suction wing/sail systems have been installed on eight ships all in the 10-17m range, with 36m versions already developed for deployment. These are followed by two different sized kite installations [500m2 – 1000m2] [See Graphic 6-4]

Both the suction wing and rigid/hard wing sail systems have had a recent surge of installations and installation orders for these systems are also growing for 2024/25.



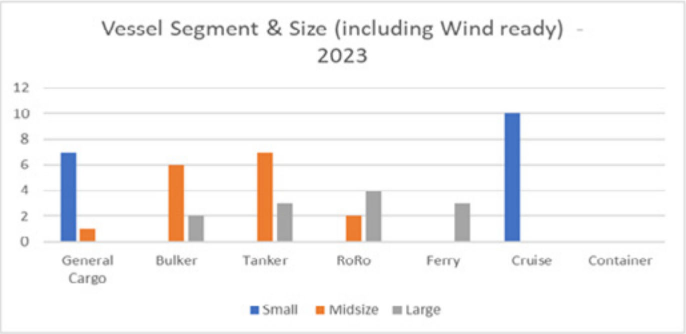
Graphic 6-4: Commercial WPT Installations by Technology Type – 31 August 2023

Note: Many ships have multiple installations of systems, so as of Q3, 2023, this amounted to 63 rigs of different types installed.

At this relatively early stage of market growth, the numbers of ships installed with each technology doesn't indicate market preference as much as both the timing of the introduction of the WPT systems into the market – rotor sails were first introduced 2010-2014, suction wings and some forms of rigid sails were introduced 2018/19 and other rigid sails and second-generation kites were first installed 2020/21. There are many theories around the diffusion of technology which will help to explain the uptake of different WPT in different segments at different times, however it is clear that those WPT and vessel segments that reach a good level of demonstrators (three to five ships) are then experiencing the growth in interest in those segments, thus the bulker, general cargo and RoRo segments are exhibiting a good level of interest and early diffusion of those technologies.

6-3 Vessel Segments & Size

As was clearly outlined in the installation overview graphics (Graphic 6-1 & 6-2), there is quite a diffusion across ship types. The general cargo vessels tend to be quite small, however this also reflects the general breakdown of that segment also. Whereas in both the bulker and tanker segments the WPT installations have included some of the largest vessels within those segments (VLCC – tankers, VLOC and Capesize – bulkers) along with various mid-sized types. The outlier in this Graphic is the inclusion of the ten small traditionally rigged (soft sail) cruise vessels.



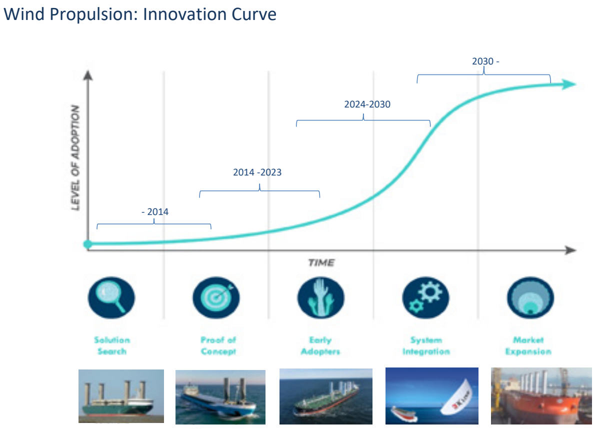
Graphic 6-5: WPT by Ship Segment and Size (31 August 2023)

In total, including the thirty vessels installed, eight wind-ready and the ten traditional rigged cruise vessels, this brings the deadweight tonnage to well over two million tonnes (Note – RoRo and Passenger vessels are calculated using their Gross tonnage (GT))

6-4 Recent Market Trends

The trend up to this point has been mainly for installing WPT on single vessels, either as retrofits (twenty-three ships or 67%) or new builds (seven ships or 23%). These demonstrator vessels have enabled the technology providers and the shipowners to gain invaluable experience, validate performance data and trial these systems in various weather and operational situations. This has been rolled out in a relatively piecemeal fashion to date, though one coordinated project was the EU Interreg WASP project that installed and validated five ships together. Nonetheless, the accumulated experience and data is enabling the movement into the next significant stage, which is multiple installations and fleet wide deployments.

Graphic 6-6 plots the classic technology/installation 'S-curve' with the path of wind propulsion developments overlayed which shows that the market is on the cusp of the upswing and movement through early adopters to the critical system integration period where wind propulsion becomes more integrated into the vessel design and operation at a micro-level and viewed as a significant technology option at a fleet level.



Graphic Template: RMI

Graphic 6-6: Wind Propulsion Innovation Curve (IWSA)

This trend has already been noted in the order and delivery of six wind-ready vessels in 2023 by the Greece-based, Capital Management and with a number of recent announcements of multiple ship build contracts for primary wind ships and fleet wide orders and options for suction wings/sails and kites.

6-5 Under-Represented Segments

However, current market trends highlighted in the Graphics 6-1 through 6-5 don't tell the whole commercial wind propulsion story. There is growing interest among cargo owners in having primary wind-propelled vessels that offer very large reductions in fuel and emissions. There are currently five vessels under construction in this category and a number of other vessels on order. The four vessels under construction for delivery in early 2024 include two 80m, 1,000+t capacity vessels that are being constructed in Romania and Vietnam for operation on Europe – US – Caribbean – Africa routes. There are two smaller sail cargo vessels (52m, 350dwt and 48m, 290dwt) that will be operating in the North Atlantic and South Pacific respectively, both likely to be in delivered in the first half of 2024 and operational soon after. The fifth one is a 136m RoRo under construction in Turkey which will operate from France on a regular route to the US and Canada and this will be delivered in 2025.

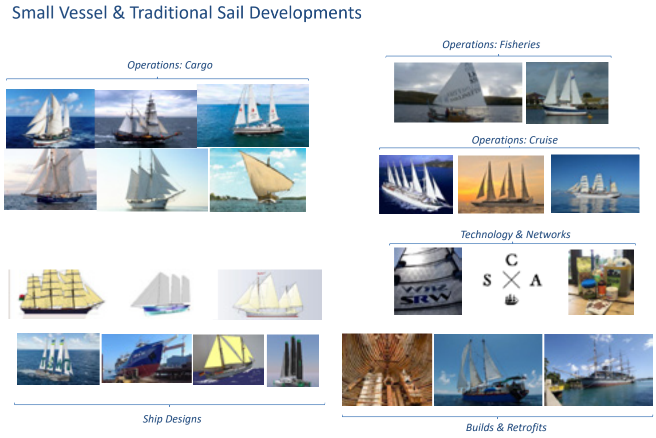
As mentioned previously, the container ship segment is a more challenging one especially with deck space restrictions for retrofitting, however the first retrofitted feeder vessel will be in operation in early 2024, and we are also seeing a number of newbuild designs and orders being finalised that will see these types of wind-assist vessels coming out of yards between 2026-27.

The cruise sector is one where there is also growing interest and there have been design, AiP awards and contract announcements for a range of relatively small, expedition type vessels that have either significant wind-assist capability or are primary wind from companies such as Hurtigruten, Ponant and the Orient Express/Accor.

6-6 Small Vessel Segment

The small vessel segment is a more challenging one to assess comprehensively as there are many small vessels that move small amounts of cargo and passengers both formally and informally around the world using wind either as their primary energy source or as wind-assist. These also include artisanal fishing boats.

In Europe, there are at least ten traditionally soft sail rigged sail cargo vessels in operation ranging in size from 19-42m and with cargo carrying capacity from under 10t to over 100t. These European based cargo vessels are mainly upgraded early 20th century vessels carrying higher value cargos such as alcohol, organic foodstuffs, coffee etc. either on routes around the European coastline or to and from the US and Caribbean countries. As these vessels are small, they operate in the main below the more stringent SOLAS requirements and can also carry up to twelve passengers which helps supplement the cargo carrying revenue. Many of the ships also provide training and volunteer crew opportunities.



Graphic 6-7 Small Vessel & Traditional Sail Developments (IWSA)

This small vessel segment holds a lot of potential, particularly on specific routes where freight costs are high, or the routes are poorly serviced. There is of course a need to expand the small vessel fleet and create a large enough network so that this will be self-sustaining and cargo owners will be offered regular and reliable transport links and trans-shipment options on those routes.

There is a wider network of traditional sail cargo vessels in operation in small island and least developed countries (LDC) maritime regions around the world and the most extensive of these until recently has been the Dhow network operating in the Indian ocean between India, Africa and the Arabian peninsula, the Pinisi and Makassar schooner vessels of Indonesia along with a scattering of small vessels in operation in the South Pacific and Caribbean, however many of these vessels now usually use only their motors or they are converted to leisure use and the commercial building, sailing and maintenance skills are in decline.

One region, the South Pacific, has been extensively researched for the potential for wind propulsion in SIDS and the vast majority of that work has been undertaken by the Micronesian Center for Sustainable Transport (MCST) https://www.mcst-rmiusp.org (which also functions as the Pacific hub for the International Windship Association). The MCST (in an earlier configuration as the Pacific Centre for Environment and Sustainable Development) along with UNCTAD released a detailed toolkit; Sustainable Sea Transport Solutions for SIDS: Pacific Island Countries Case Studies (UNCTAD 2016) which highlights the key advantages of using wind propulsion on routes in the region that are under-serviced, under-used or neglected due to long distances, high fuel costs and low cargo/passenger demand. The center has a wide-ranging archive of material covering most islands in the region.
https://www.mcst-rmiusp.org/index.php/reference-library-main

This small vessel network does, however, also offer an opportunity for developed regions to deliver a sustainable, locally engaged means of low carbon transport if the development of the fleet and port/logistics services is supported. The publication, Sail Freight Revival: Methods Of Calculating Fleet, Labor, And Cargo Needs For Supplying Cities By Sail takes a detailed look at this sector and the ability of small sailing networks to help supply a city such as New York (Woods 2021).

The small vessel market will be heavily impacted by the rising cost of fuel as carbon pricing is introduced as it always has been due to other economic drivers, however this could be compounded over the next few years with the need to swap out fossil fuels and replace those with alternative fuels and the engines/motors and infrastructure required. This could lead to substantial growth in wind-assist and primary wind vessels if the level of investment can be aligned with those needs, especially in SIDs and LDC maritime transport markets.

7) Market Potential

The world fleet consists of 55,000+ ships over 1,000gt and 100,000 ships over 100gt, including large fishing vessels. The market potential for WPT has been assessed by two, third party studies (one EU-commissioned assessment in 2016/17, the other assessment was conducted as part of the UK Clean Maritime Plan 2019). However, these assessments are often overlooked or sidelined when it comes to the development of decarbonisation pathways in shipping.

An updated comprehensive assessment of WPT market potential would be a timely undertaking in the light of the 2023 IMO GHG Strategy and EU Fit for 55 maritime package along with numerous national and industry led initiatives.

7-1 Survey of Industry and Policy Makers – Position of WPT in Energy Mix in 2030 & 2050

The International Windship Association (IWSA) conducted a survey of industry and policy maker's attitudes to decarbonisation and WPT and wind energy use in particular. These survey results help bring some counterbalance to the decarbonisation discussion that is currently framed in a 'fuel-centric' manner.

The survey covers the views of twenty-five policy makers and fifty-nine industry stakeholders (excluding IWSA members) worldwide. However, the European and Internationally operating (including EU) respondents of the policy making stakeholder group surveyed have also been sectioned off to give some additional context for this region.

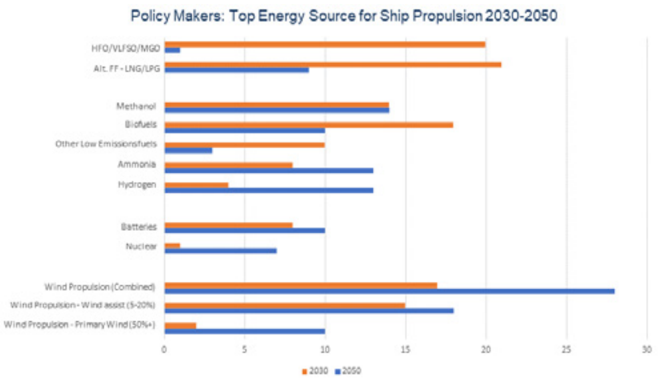
While the sample of opinions is modest and we should take these survey results as being indicative rather than comprehensive/definitive, the results do align with both observable trends in the marketplace and also anecdotal reporting from IWSA members. Ideally the survey will be followed by a well-funded, comprehensive annual tracking opinions survey in the future.

The most relevant question for this Section is where the respondents were asked to rate their awareness of wind propulsion vessels. 68% of international shipping sector policy maker respondents expressed an awareness, whereas European respondents expressed a 92% awareness. The wider maritime industry expressed an awareness level of 88%, among shipowners and charterers the awareness level was 74%.

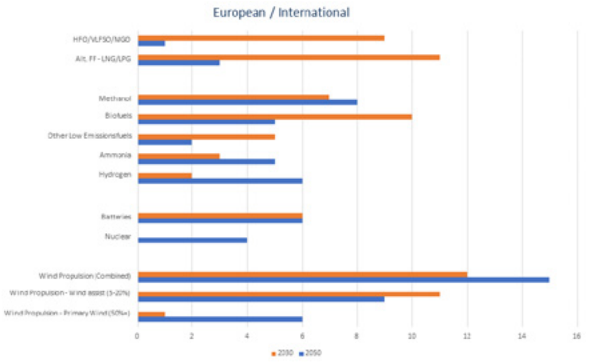
Naturally, the fact that a sizeable minority of policy makers and shipowners globally were still unaware that ships were operating with wind propulsion is concerning. Perhaps this indicates that much of the WPT development has been restricted to Europe until recently.

This number is likely to decline quickly as further demonstrator vessels enter into operation and the numbers of vessels using WPT grow in less developed segments such as container, RoPax and fisheries etc.

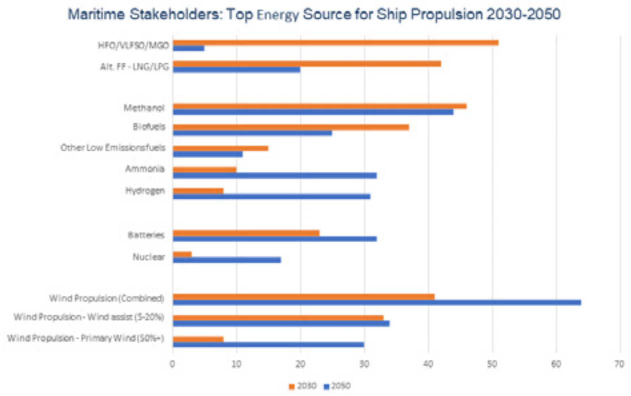
Keeping the aforementioned levels of awareness of WPT installed vessels amongst stakeholder groups surveyed in mind, the survey then asked them: "What are the top five energy sources you believe ships will use for propulsion in 2030 and 2050?"



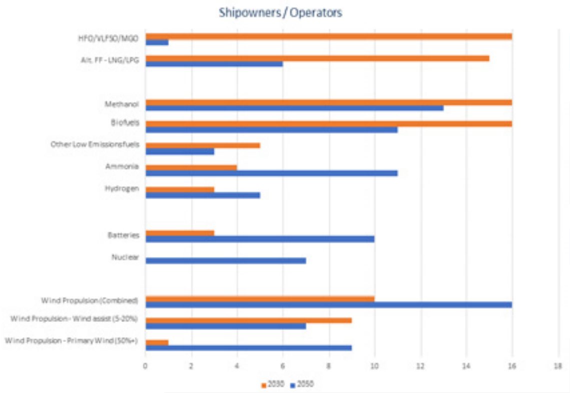
Graphic 7-1a: Policy Makers (25 respondents) – Top Energy Source for Ship Propulsion 2030-2050



Graphic 7-1b: Policy Makers (10 European based respondents) – Top Energy Source for Ship Propulsion 2030-2050
Note: This includes those operating in Europe and Internationally.



Graphic 7-2a: Maritime Stakeholders (59 respondents) - Top Energy Source for Ship Propulsion 2030-2050



Graphic 7-2b: Shipowners/Operators (19 respondents) - Top Energy Source for Ship Propulsion 2030-2050

The four Graphics (7-1a & 7.1b + 7.2a & 7.2b) give an overall picture of the energy breakdown falling into general fuel categories, although for alternative fuels it is not specified whether these fuels will be green (i.e. derived from renewable sources) or will be delivered as products from fossil fuels. However, it is safe to make the assumption that by 2030 the majority of alternative fuel will not be derived from renewable sources, whereas by 2050 this is far more likely.

The overall pattern of stakeholder responses is fairly consistent across the four groupings when it comes to the use of fossil fuels being prevalent in 2030 along with expectations that both methanol and biofuels will be the front runners as alternative energy sources. This pattern and subsequent 'mixed bag' for 2050 clearly reflects the uncertainty about energy sources by 2050 and/or the likelihood of having a wide variety of energy sources adopted in different segments and by different players in the market.

A key result from this study is the explicit inclusion of wind propulsion (both as wind-assist and primary wind) as options within the survey's energy mix. Combined (with a few anomalies aside – i.e. with some respondents identifying more than five options), wind propulsion makes a strong showing across all respondent groups, with wind-assist being more pronounced in the 2030 mix and primary wind attracting more support further out towards 2050.

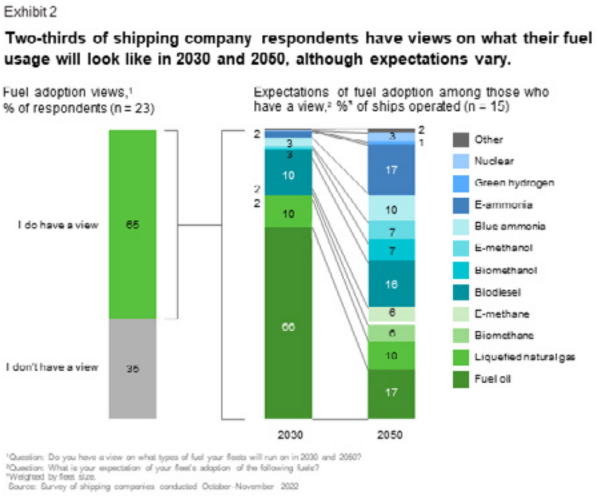
7-2 Comparison with Recent Industry Survey

As with all surveys there is a significant margin of error and a survey such as this will tend to attract more wind interested respondents. However, the 'fuel' results tend to correlate quite closely with another recent survey undertaken by the Global Centre for Maritime Decarbonisation, the Global Maritime Forum, and the Mærsk McKinney Møller Center for Zero Carbon Shipping (with analytical support provided by McKinsey) of twenty-nine shipping companies. Collectively, these shipping companies own and operate fleets—including container ships, tankers, dry bulkers, gas carriers, car carriers, cruise ships, tugs, and offshore vessels—comprising roughly 20% of the world's total shipping capacity.
https://cms.zerocarbonshipping.com/media/uploads/documents/The-Shipping-Industrys-Fuel-Choices-on-the-Path-to-Net-Zero.pdf

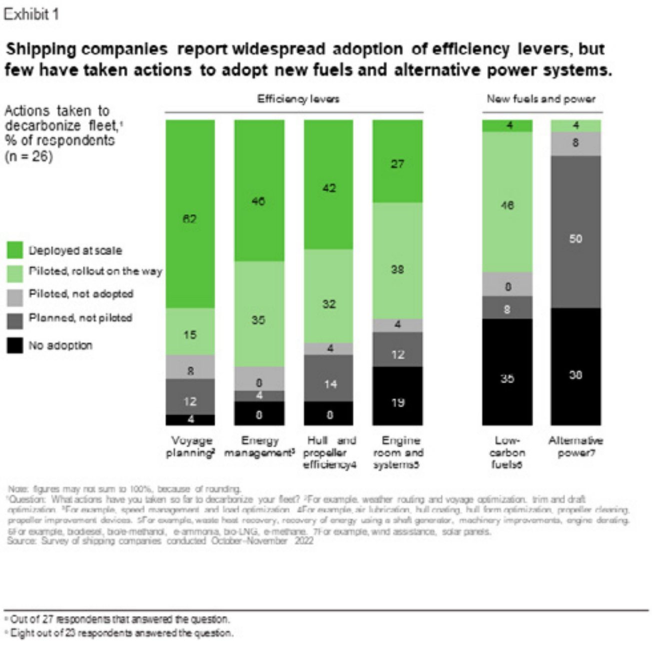
The respondents in that survey weren't given an option for wind propulsion in the energy mix question that is displayed in Graphic 7-3 below [Exhibit 2 (page 6) in the original report] which compared these alternative fuels in 2030 and 2050. However, where respondents were asked about their current development status, where it comes to fuel/power piloting etc., they were understandably less advanced in their current appreciation and application of alternative power sources, such as wind propulsion.

However, there was a comparable percentage of those shipping companies that were planning to pilot these systems as were planning to deploy low carbon fuels (62% and 65% respectively), see Graphic 7-4 [Exhibit 1 (page 5)] below. This positive, though lagging behind response, is a key finding and will likely accelerate as more validated information and the credibility of systems is proven over the coming 1-2 years.

NOTE: The survey results depicted in Graphic 7-3 & 7-4 below are mainly drawn from large shipping company respondents. As noted earlier, while there has been some investment from larger companies in direct trialling and operation of WPT systems, there is a larger contingent of smaller shipping companies that have been the main driving force behind the installation and scaling of WPT to-date.



Graphic 7-3: Fuel Usage Views – Shipowners 2030 & 2050 – Source: The shipping industry's fuel choices on the path to net zero
https://cms.zerocarbonshipping.com/media/uploads/documents/The-Shipping-Industrys-Fuel-Choices-on-the-Path-to-Net-Zero.pdf



Note: figures may not sum to 100%, because of rounding.
¹Question: What actions have you taken so far to decarbonize your fleet? ²For example, weather routing and voyage optimization, trim and draft optimization. ³For example, speed management and load optimization. 4For example, air lubrication, hull coating, hull form optimization, propeller cleaning, propeller improvement devices. 5For example, waste heat recovery, recovery of energy using a shaft generator, machinery improvements, engine derating. 6For example, biodiesel, biole-methanol, e-ammonia, bio-LNG, e-methane. 7For example, wind assistance, solar panels.
Source: Survey of shipping companies conducted October–November 2022

Out of 27 respondents that answered the question.
Eight out of 23 respondents answered the question.

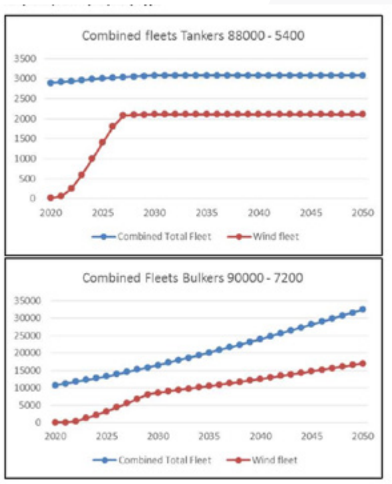
Graphic 7-4: Current Development Pathway for fuels and Alternative Power Systems - 2022

7-3 Wind Propulsion Market Size and Diffusion Rates

The EU-commissioned report produced by CE Delft and associates: 'Study on the analysis of market potentials and market barriers for wind propulsion technologies for ships' was compiled in 2016, prior to detailed deliberations on IMO2020 and well before the IMO GHG Initial Strategy adoption in April 2018, with headline findings of:

> 'Should some wind propulsion technologies for ships reach marketability in 2020, the maximum market potential for bulk carriers, tankers and container vessels is estimated to add up to around 3,700-10,700 installed systems until 2030, including both retrofits and installations on newbuilds, depending on bunker fuel price, speed of the vessels, and the discount rate applied. The use of these wind propulsion systems would lead to CO2 savings of around 3.5-7.5 Mt CO2 in 2030...' (CE Delft 2016/17)

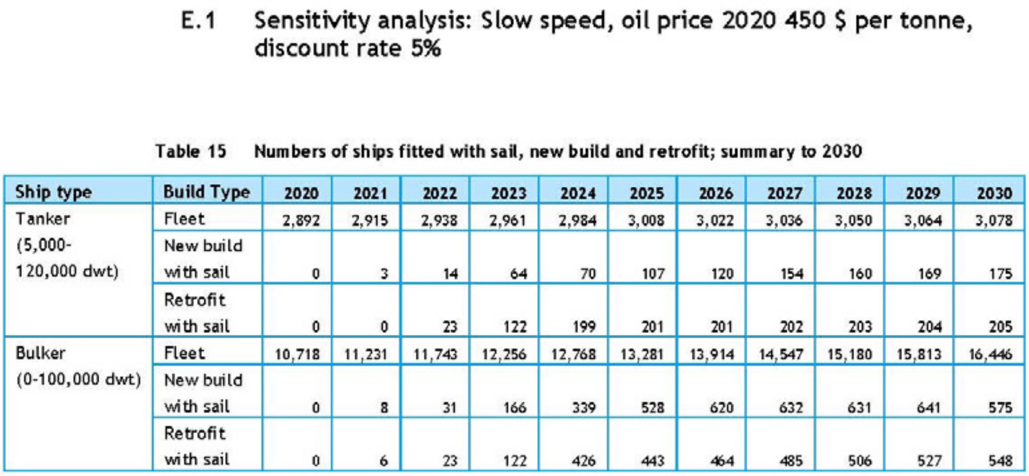
This report was constrained by capacity/funding. Therefore, the forecast was restricted to cover three key fleet segments only – bulkers, tankers and containers and it assessed only a small selection of technologies available (four WPT rig systems were selected – rotor sails, fixed wing sails, kites and turbines). The detailed report was undertaken during a period where only a small number of vessels were in operation and most data sets were collated from simulations. Therefore, the general cargo and RoRo vessel segments that have seen quite a lot of activity were excluded from the report and the container sector was not deemed to be a segment that would adopt WPT systems. Naturally the report did not factor in policy and MBM developments that have subsequently been introduced into the maritime transport market. Nonetheless, this analysis did create a baseline forecast and outlined a likely pathway to the diffusion and scaling of WPT in the marketplace.



Graphic 7.5: Maximum Potential Market Uptake for Tankers and Bulkers 2020-2050

The diffusion modelling results using US$450 per tonne of fuel shows the uptake of these four WPT in the tanker and bulker segments. This naturally does not take into account the delays concerned with the recent Covid pandemic challenges and subsequent economic, logistics and other disruption. The model does however give a clear outline for the diffusion pathway for the technology (likely with an 18–24-month lag to the numbers outlined in Graphic 7.6)

The upsurge in installations in this sensitivity analysis starts in 2022 and quickly accelerates the following year. With the time lag specified above, this natural 'S-curve' development (as shown in Graphic 6-6) will become evident within early 2024 with it gaining significant momentum in the subsequent 12-18 months, the earlier stage of which is evident in the current and near future installation pipeline outlined in Section 6.



E.1 Sensitivity analysis: Slow speed, oil price 2020 450 $ per tonne, discount rate 5%

Table 15 Numbers of ships fitted with sail, new build and retrofit; summary to 2030

Ship type	Build Type	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Tanker (5,000-120,000 dwt)	Fleet	2,892	2,915	2,938	2,961	2,984	3,008	3,022	3,036	3,050	3,064	3,078
	New build with sail	0	3	14	64	70	107	120	154	160	169	175
	Retrofit with sail	0	0	23	122	199	201	201	202	203	204	205
Bulker (0-100,000 dwt)	Fleet	10,718	11,231	11,743	12,256	12,768	13,281	13,914	14,547	15,180	15,813	16,446
	New build with sail	0	8	31	166	339	528	620	632	631	641	575
	Retrofit with sail	0	6	23	122	426	443	464	485	506	527	548

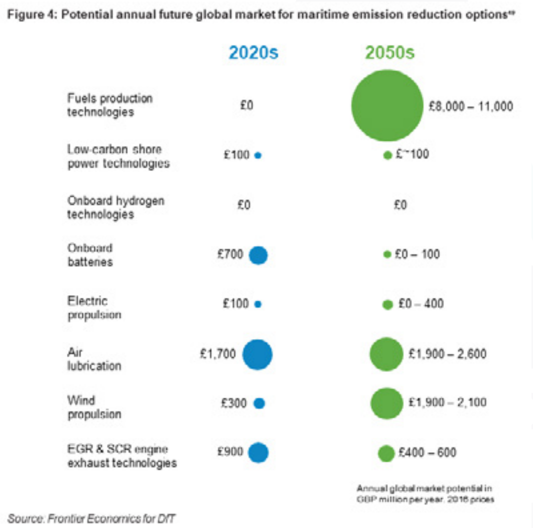
Graphic 7.6 – Table Showing Forecast Cumulative & Annual Orders of Vessels to 2030 – both newbuild and retrofit [p123 (CE Delft 2016/7)]

Another important market projection was undertaken by the UK Government in their Clean Maritime Plan (July 2019), which assessed the annual global market for wind propulsion systems alongside other technologies and fuels. This was estimated to grow from a conservative **£300 million per year in the 2020s to around £2 billion per year by the 2050s worldwide.**

An interesting note is that air lubrication technology, which is a fuel efficiency measure and not a propulsion energy provider technology and is also a far more standardised product delivered by only a couple of companies, starts from a far higher base in the 2020s leading to a similar level as wind propulsion by the 2050's. Over the last 4 years air lubrication technology has seen a good level of growth in alignment with this prediction, while WPT has been developing with multiple technology options available and a far wider provider base.

As such, in this analysis, WPT 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.

Figure 4: Potential annual future global market for maritime emission reduction options[19]



Source: Frontier Economics for DfT

Graphic 7-7: Potential Annual Future Global Market for Maritime Emission Reduction Options: UK Clean Maritime Plan 2019

The research that backed the UK Clean Maritime Plan came from the Frontier Economics report (July 2019) on Reducing the Maritime Sector's Contribution to Climate Change and Air Pollution: Economic Opportunities from Low and Zero Emission Shipping. A Report for the UK Department for Transport and it adds further detail (pages 43-44), forecasting the market size for wind propulsion by 2050 (assuming 50-100% abatement of GHG) would be **37,000 - 40,000 vessels with wind propulsion systems installed or roughly 40-45% of the global fleet.**

These reports and the IWSA-conducted survey results detailed above help to underline that there is a substantial growth forecast and an increasing understanding that WPT is an important tool in the decarbonisation toolbox. They also highlight the need to create a level playing field in regulation, economic and business approaches along with considerations around direct and indirect subsidies to fossil fuel and the new eco-fuel developments.

The need to extend a fair competition environment and an equal standing for non-fuel propulsion technologies is an important consideration for the IMO, EU and other international bodies. This will enable a more 'primary renewable friendly' environment so that all propulsion systems and alternative fuels can be effectively and objectively compared and thus generate the proper, measured decarbonisation pathways.

7-4 Market Projections and Investment Patterns

The extrapolation of long-term trends from near-term data is always challenging however, there are clear indications that the trajectory and diffusion pathways outlined in these two reports (CE Delft 2016-17/UK Clean Maritime Plan 2019) are both credible and may be conservative in their outlook. As system costs lower substantially as installations increase (see 'Learning Curves' in Section 8), yards will bring more WPT systems onto their standard equipment lists, coupled with the expected fuel price rise both due to the imposition of carbon levies and the introduction of more costly 'green fuels' will strengthen the business case for wind propulsion.

The International Windship Association (IWSA) members survey 2022/23 and public announcements of contracts and pending installations indicates a number of growing trends outlined below.

7-4-1 Market Projections

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

Graphic 7-8: Wind Propulsion Market Growth Projections - up to 2026/7 (IWSA)

Retrofit contracts have regularly been publicly announced 9-12 months in advance. However, that lead time has also been reduced over the past year, with many announcements now coming under 6 months before the installation date. Therefore, projections further than 12 months in the future are proving to be increasingly difficult unless those are contracted newbuilds which have a longer lead time and therefore a longer forecast range can be deployed.

The statistics currently received from shipyards may also not reflect the 'wind-ready' trend accurately and a more detailed analysis will likely be required. The International Windship Association (IWSA) has a relatively good overview of the market development and in 2021 forecast that there would likely be roughly a doubling of total installations from 2022 onwards as can be seen on Graphic 7-8. However, as noted 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 WPT unit onto its foundation can be completed in a matter of hours or a number of days for more complex systems.

Fleet installations are also increasingly to be expected rather than singular installations as we move towards 2024/25, as examples of this recent announcements include the confirmed build order in South Korea for five methanol and wind powered 1,200 TEU feeder container vessels for delivery in 2026 and ten 3,800dwt general cargo vessels ordered for delivery monthly starting in August 2024 which are designed as wind-assist vessels.

7-4-2 Standardisation

The move towards standardised production models and components is in full swing among the 13 companies with production models in the marketplace. This natural progression will also increasingly become evident in maintenance procedures, training and so on. This is also supported by work to standardise the ways to test, sea-trial and validate the performance of the WPT. As this standardisation gains pace, so production and installation costs and market uncertainty will continue to fall generating a virtuous circle that is evident in most other marine technology and renewable energy equipment rollouts.

7-4-3 Scaling Investment/Partnerships & Employment

Since 2021, we have seen a strong rise in joint projects and partnerships as OEMs, engineering and manufacturing companies along with their ship-owning and shipyard collaborators; examples include:

- Wallenius Marine and Alfalaval partnership, Alfawall.
- BAR Technologies, YARA Marine, Cargill and Mitsubishi
- MOL, Oshima shipyards, others
- Zephyr Boree, Neptune, AYRO, VPLP, Ariane group
- Neoline, CMA CGM, Corsica ferries, Renault Group, Hennessey & Michelin

Investment levels have been rising with significant amounts of R&D funding going into land-based testing facilities, demonstrator systems, production facilities and so on. Production expansion plans released and investments from individual companies in the EUR10-100 million range have already been implemented or announced.

A significant majority of IWSA member OEMs and other stakeholders expect to add to their workforce in the coming three years, with nearly half already hiring. In the French region around Nantes alone, which has an active wind propulsion cluster, the Nantes Economic Development group has estimated that;

> “The wind-powered transport sector currently employs 720 people directly in France in 2023, with over a third of them located in Nantes & Saint-Nazaire. By 2030, the number of jobs could increase by 5 to 10 times, with over 50% of the employment in the sector located in the region. The businesses already located here have significant growth prospects in the region by 2030: just among the equipment manufacturers, Airseas in Nantes is expected to create 1,500 jobs, CWS 500 jobs, Chantiers de l’Atlantique 200 jobs, and Wisamo 50 jobs.”
> Source: https://maritime-professionals.com/france-region-will-account-for-50-of-jobs-in-wind-sector/

7-4-4 Financial & Business Models

The use of standard ship and equipment finance models doesn’t always align well with new technology diffusion and many smaller OEM’s struggle with securing substantial financial backing to expand into the market, due to the need for investors to de-risk investments and relatively high interest rates. These instruments also require a high level of validated performance data that can only be provided once a number of installations have already been in operation over a period of at least twelve months.

However, as wind propulsion technologies harness a free energy source, there is the potential for WPT to be supplied using a variety of different approaches;

(i) Leasing system: where the savings from the fuel pay the costs of the lease.
(ii) Pay-As-You-Use model: where the CAPEX is paid for by a sharing of the fuel savings over subsequent years of operation. Schinas et al (2022)
(iii) Wind-As-A-Service: where modular WPT or containerised systems are deployed on ships working on the best routes.

These models could be very effective in reducing upfront cost barriers for shipping companies and also reducing the impact of split incentives where the CAPEX is usually the ship owner’s responsibility whereas the OPEX is the charterers, thus investment benefits accrue to the charterer rather than the shipowner that paid for the WPT.

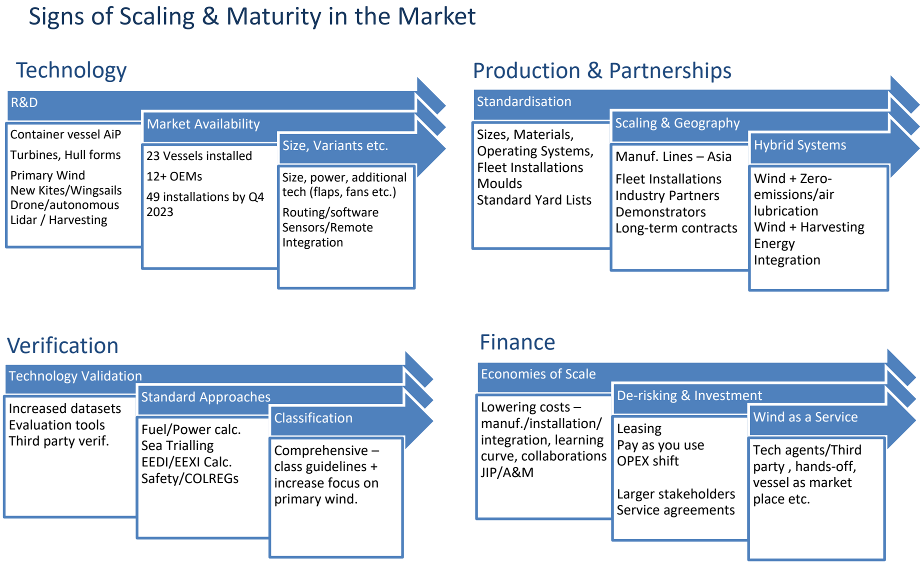
The need for clear financial and market messages from cargo owners and charterers is also a key issue when it comes to new build finance. The guarantee of long-term and favourable charter agreements for low or near zero-emissions transport vessels is a significant lever with which to enable shipping companies wanting to build primary wind vessels to secure the additional finance required to build those vessels.

7-5 Pipeline & Additional Trends

The R&D pipeline for both WPT and vessel design projects is robust. IWSA has over 20 OEMs and ship projects at various stages of pre-market development, many with technologies that are in late-stage R&D with prototypes and demonstrator rigs under testing. Naturally, there is also a lot of R&D activity underway in the 13 companies that have products already on the market as the datasets and learning cycles from those initial installations and operations are brought back into the next product iteration. Graphic 7-9 summarises the main trends underway in the WPT sector, though each are developing on different trajectories, and these are not uniform across sectors or geographical regions.

There is also a wide scope for further optimisation as WPT and other systems are increasingly integrated into ship systems or optimised through better utilisation, these include but are not limited to:

- increased integration with Energy Management System (EMS)
- weather routing for wind software
- satellite weather forecasting and LiDAR
- gate rudder system (e.g. CHEK project)
- virtual arrival systems (e.g. Blue Visby project)
- onboard energy harvesting systems utilising excess wind energy (e.g. Windhunter project)



Graphic 7-9: Pipeline, Trends, Improvement and Innovation (IWSA)

8) Economic Benefits, Business Models & Finance

The environmental benefits from the reduction of fuel use through the use of wind propulsion are clear, with no emissions at all coming from the production and utilisation of this pure zero-emissions energy source and a relatively small-embodied energy footprint in the harvesting technologies which will be returned in the first few months of operation for singular installations and in the first years for newbuild vessels.

However, the economic case is the one that is critical to the scaling and disseminating of this technology across the global fleet. This economic case needs to be made and understood at a macro level, both from a broad regional and national socio-economic level and from the industry perspective as a whole along with at a more micro-level with the clear and robust business case for shipowners, operators, charterers and cargo owners and the appropriate financial tools to deliver that.

8-1 General Economic Points

8-1-1 Direct Use of Renewable Energy

The use of primary renewable energy (wind) delivered directly to vessels is a critically important technology option for building a resilient, flexible and low carbon fleet, with;
(i) zero-emissions or extremely low emissions in operation (both GHG and non-GHG emissions).
(ii) a stable zero (or extremely low) fuel cost for its contribution to the propulsion requirements for the operational life of the vessel.
(iii) no need for additional infrastructure to produce or deliver the energy,
(iv) no additional energy storage facilities required onboard ships.

Moreover, wind propulsion technologies (WPT) deliver a substantial reduction in the overall demand for more costly low carbon eco-fuels, potentially reducing storage space requirements for these alternative fuels or installed power requirements and extending the vessel range, thus bringing increased flexibility for bunkering of these new fuels (reducing supply issues and potentially price).

The main economic benefit of WPT and new build primary wind vessels is in the reduction of fuel, either fossil fuel or new zero-emissions and low-carbon alternative fuels whose cost accrues to the shipowner/operator/charterers depending on the business model.

The reduction of emissions from fossil fuels through the use of WPT systems also has the indirect economic impact of reducing pollution health impacts on coastal communities, lowering ocean impacts from localised pollution and underwater radiated noise (URN) which lead to a healthier and more productive marine environment.

8-1-2 Returns on Investment (ROI) & a Level Playing Field

The installation of WPT systems and the build of primary wind propulsion vessels produces an immediate reduction in operational costs, though the selection of these systems necessarily increases the CAPEX of the vessel. However, there are approaches that can mitigate or fully remove this additional burden, for example; through leasing or adopting 'pay-as-you-use' finance models. (Section 7-4-4)

Calculations of ROI should be undertaken very carefully, especially when assessing retrofit installations, as these are currently often undertaken using only a motor-vessel operational profile. The assessment of WPT potential should include voyage optimisation, weather routing, speed etc. to attain the full benefits of wind vessel operations.

From a macro perspective, the overall global subsidy framework for energy needs to also be considered when generating comparative ROI's and in assessing fuel and non-fuel propulsion solutions. These are currently calculated using a very un-level playing field if we consider the following points;
(i) Direct Subsides – price controls on existing fuels, prospecting/R&D subsidies etc.
(ii) Indirect Subsidies – tax exemptions, externalised health and pollution costs, land-based infrastructure subsidies etc.
(iii) Historic/Embedded Energy – fossil energy used in the past and present to build and maintain infrastructure and vessels.
(iv) Policy Incentives for New/Existing Fuels – e.g. multipliers for the adoption of Renewable Fuels of Non-Biological Origin (RFNBO) in EU regulations such as Fuel EU Maritime.
(v) Additional Externalities – security costs, decommissioning costs, circular economy considerations, climate costs, impacts on employment/trade, etc.
(vi) Integrating Risk/Cost – risks of leakage, incidents/accidents, stranded assets, tipping point environmental change etc.
(vii) Measurement Parameters – use of 100-year Global Warming Potential (100 GWP) rather than 20-year GWP (20 GWP) for GHG emissions, calculation of only direct GHG gases rather than the total climate impacting emissions spectrum, need to use Total Cost of Ownership (TCO) calculations etc.

Therefore, when assessing wind propulsion's contribution to the propulsion energy mix, it should be recognised and that there is currently a very imbalanced approach to subsidies and financial support to the 'fuel' industry as opposed to direct renewable energy industry, and assessments should be modified to take these important considerations into account.

All fossil fuels are heavily subsidised either directly or indirectly making these far cheaper than should be the case, therefore the imposition of a carbon levy as introduced in 2024 through the EU ETS and measures currently being deliberated by IMO for delivery in 2027/28 is only a partial rectification of that situation. The IMF estimates that in all, the fossil fuel industry receives in the order of $7 trillion in subsidies per year (directly and indirectly), but even this number doesn't factor in all health impacts, the security costs of securing fossil fuel sources in the past and today, the cost of stranded assets, the cost of remediation and decommissioning and the opportunity costs of all of these measures. (IMF 2023)

To place that in perspective, UNCTAD estimated in 2023 that to fulfil the global commitments to the Sustainable Development Goals (SDG17) in all developing economies we would need between $6.9-$7.6 trillion annually (using the median per-capita cost for the 48 economies in the study.) (UNCTAD 2023)

In shipping, this fossil fuel issue is also compounded by the fact that these fuels are provided without any form of taxation and that some fuels burned aboard ships would not be allowed on to be used on land. As highlighted in numerous publications, including the recent Menon publication: Hydrogen Subsidies in the EU, Norway and the US, alternative, low- and zero-emissions fuels are having development and scaling activities heavily subsidized by national governments as these new fuels are used in other land-based sectors – ammonia and methanol in industrial and agricultural sectors, hydrogen across these fuels and also potential for domestic, industrial and automotive/aviation along with battery technology. (Menon 2023)

These extensive subsidy programs are used to lower costs to entry and the scaling of production infrastructure, which is understandable when fossil fuel prices are held artificially low. While these structural subsidies are concerning from a non-commoditised wind propulsion energy perspective, the more concerning measures are those that place a subsidy for per unit of consumption, including the deployment of a fuel-based rather than total cost of ownership (TCO) based 'Contract for Difference'. This out-of-sector subsidy support once again leaves wind propulsion and other non-commoditized energy sources at a serious disadvantage unless that is mitigated through the use of TCO or other measures.

From a micro, company level perspective, the economic benefits and business models for both wind-assist and primary wind development have been studied quite extensively during the SAIL project (2012-2015), EU commissioned 'Study on the analysis of market potentials and market barriers for wind propulsion technologies for ships' (2016) and during the EU Interreg WASP project (2019-2023).

In the general assessment of economic benefits from wind propulsion, the current and future cost of fuel, upcoming carbon pricing (e.g., inclusion of shipping into EU ETS, see Graphic 8-1) and the reduction in cost (learning curve, see Section 8-1-4) of WPT installations need to be factored into calculations along with technical measures such as FuelEU Maritime. Of course, any circular use of revenue generated from a carbon levy will also have an additional beneficial effect if used to support and subsidise the installation of WPTs. It is clear that any revenue being returned to the industry in support of the development and scaling of 'new energy sources' is beneficial, but this again should be applied evenly across the various energy options available, including wind propulsion and other direct renewable energy sources.

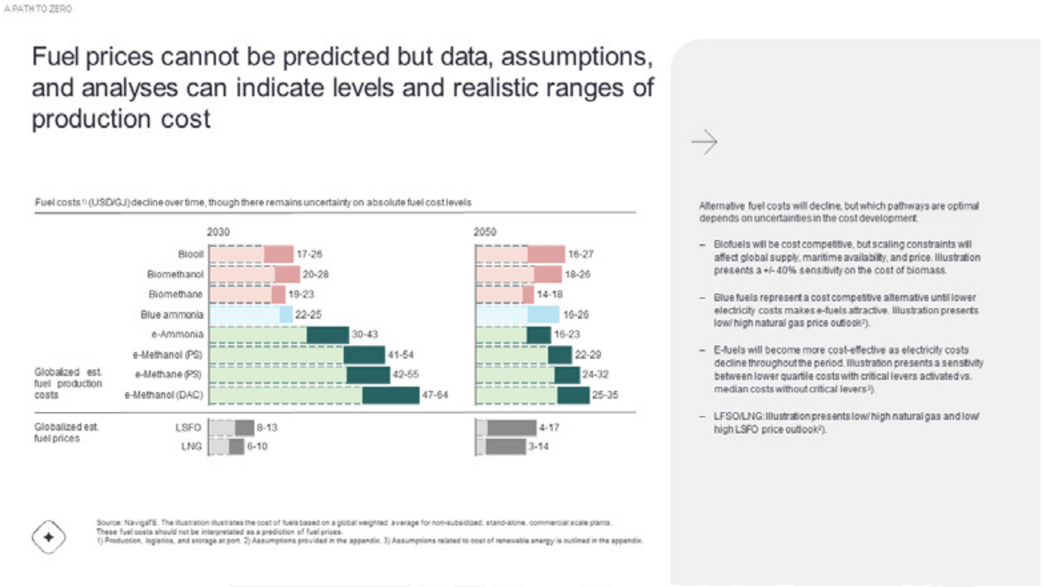
Global Average Bunker Fuel Prices			
	01 Jun 2021 (US$)	01 Jun 2022 (US$)	01 Jun 2023 (US$)
IFO 380	$413	$741	$489
VLSFO	$547	$1075	$620
MGO	$648	$1317	$807
LNG (MGOe) – Rotterdam	$567	$1372	$461
Carbon Price (EU)	$63 (€52)	$90 (€84)	$85 (€79)
EU ETS (est:$263.5/ton fuel)*	EU--EU Port / EU--Non-EU Port		
2024 (40%)	+$105 / $52.5		
2025 (70%)	+$184 / $92		
2026 (100%)	+$263.5 / $132		

*Calculation of 1t fuel = 3.1t CO2

Graphic 8-1: Table of Global Average Bunker Fuel Prices & EU ETS Carbon Pricing

Sources: https://shipandbunker.com/prices // https://shipandbunker.com/prices/emea/nwe/nl-rtm-rotterdam#LNG-MGOe // https://ember-climate.org/data/data-tools/carbon-price-viewer/

Future fuel prices and new alternative fuel prices are of course notoriously difficult to forecast, however most analysis suggests continued upward pressure, taking into account existing and proposed carbon levies and the heavy demand/ supply issues and infrastructure costs faced by the rollout of new low and zero-emissions fuels. The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS) position paper: Fuel Option Scenarios (Oct 2021, page 12) shown in Graphic 8-2 indicates that if we take the mid-point for the range of costs, for example; Methanol in comparison to the two fossil fuel options, then globalised bio-methanol costs are 2.5x higher and e-methanol is 4x in 2030, whereas the latter comes down to be more comparative in cost, but still 2x the cost of the fossil fuel alternative in 2050.



A PATH TO ZERO

Fuel prices cannot be predicted but data, assumptions, and analyses can indicate levels and realistic ranges of production cost

Source: NavigaTE. The illustration illustrates the cost of fuels based on a global weighted average for non-subsidized, stand-alone, commercial scale plants. These fuel costs should not be interpreted as a prediction of fuel prices.
1) Production, logistics, and storage at port. 2) Assumptions provided in the appendix. 3) Assumptions related to cost of renewable energy is outlined in the appendix.

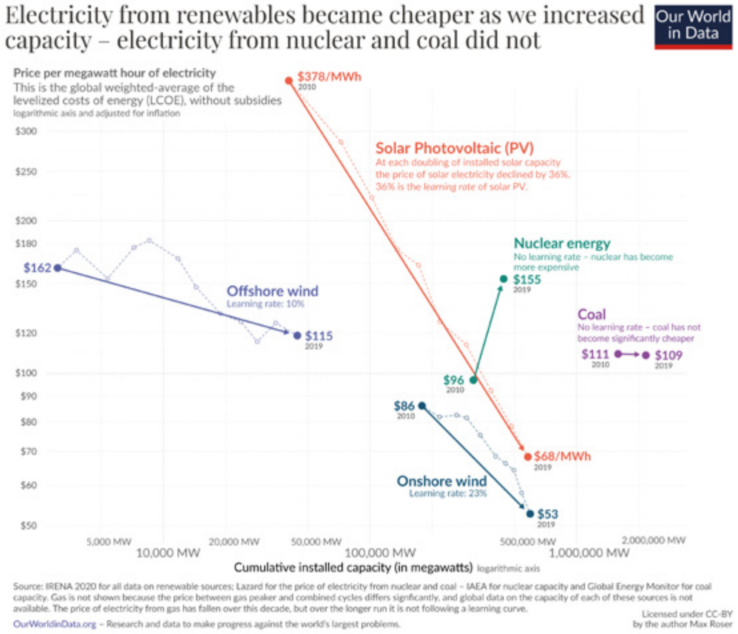
Alternative fuel costs will decline, but which pathways are optimal depends on uncertainties in the cost development:

- Biofuels will be cost competitive, but scaling constraints will affect global supply, maritime availability, and price. Illustration presents a +/- 40% sensitivity on the cost of biomass.
- Blue fuels represent a cost competitive alternative until lower electricity costs makes e-fuels attractive. Illustration presents low/ high natural gas price outlook[2]).
- E-fuels will become more cost-effective as electricity costs decline throughout the period. Illustration presents a sensitivity between lower quartile costs with critical levers activated vs. median costs without critical levers[3]).
- LFSO/LNG: Illustration presents low/ high natural gas and low/ high LSFO price outlook[2]).

Graphic 8-2: Position Paper Fuel Option Scenarios (MMMCZCS October 2021, page 12)

8-1-4 Learning Curve for Wind Propulsion Technologies (WPT)

Adopting the 10 percent learning curve for WPT identified in the previously cited EU commissioned report (CE Delft 2016-17) is a conservative but easily defended position to take. This level is comparable with other maritime equipment and a similar level observed in the offshore wind sector (See Graphic 8-3) as opposed to onshore wind (23% from 2010-2019) and solar pv (36% from 2010-2019). This means that we will observe a 10% reduction in cost for each doubling of installed capacity. Assuming there is a simple correlation between the number of 'rigs or vessels' and 'capacity' (without the consideration of the size/power delivered and avoiding the differences presented by newbuild primary wind propulsion vessels and retrofits), then we are likely to see this on a yearly cycle as current installations are roughly doubling every 12 months of so.



Graphic 8-3: Learning Rate Comparison for Renewables

Source: Why did renewables become so cheap so fast? Max Roser (2020)
www.ourworldindata.org/cheap-renewables-growth

This level of 10% reduction in cost is however, a levelized figure, and technologies can often experience steeper reduction in costs during the first few years of development and early deployment, where the optimisation of production techniques, design adjustments, standardisation of components and supply chains, early economies of scale and positive feedback learning loops from early installations are at their peak. This is already an observable trend in the WPT sector. However, even with this conservative, levelized 10% assumption in place, and taking the installations rate identified in the report, then installation costs will have dropped by c.50% from the 2020 baseline by 2025/26.

This approach is outlined in the aforementioned report:

> “Overall, these results represent an important insight: given a bunker price increases from the current (2016) historically low levels to $450 per tonne, wind technologies will be financially attractive if a few ships have demonstration wind technologies installed. Furthermore, the results are actually similar in 2030 for the different scenarios, in terms of the new installations per year. This is because after only 2-3 years, the take-up is so high that all ships in the samples with significant savings are being fitted with wind, both newbuild and retrofit. To put it another way, by the time 100+ installations have been completed, the learning effect is large enough to have brought the costs down such that all newbuilds and retrofits make financial sense, given our cost data and the oil prices and discount rates that have been assumed. If there is a significant knowledge spill over (for which we have made a fairly conservative assumption of 10% installation CAPEX reduction per doubling of cumulated installations) then the costs would decline quickly enough to make all ships for which significant savings could be expected viable.” (page 58, CE Delft 2016-17)
>
> “The literature on learning in energy technologies assumes a learning rate of 20% production cost reduction for each doubling of installed capacity. Because the installations in this case take place over a range of ship types and sizes, the learning effect is assumed to be less and a learning rate of 10% per capacity doubling was assumed. An initial level of five demonstration installations running in operational ships by 2020 was assumed to initiate the simulation.” (page 55, CE Delft 2016-17)

8-1-5 Additional Considerations

There are quite a number of additional benefits and considerations to factor into the economic calculations. With the increasing of range, less restrictions around bunkering for fuel and lower operational costs afforded to vessel operators by WPT installations, there is the opportunity to change the economic dynamics surrounding speed reductions or lowering engine power requirements at existing speeds. Also, these dynamics alter the way of approaching existing less economical routes with the potential to reopen previously uneconomical ones, possibly relieving congestion in busy areas or adding route flexibility at reduced costs during periods of disruption. Having access to a free of charge energy source can enable the opening up of additional trade opportunities, increase the volume of trade moved by the world fleet and critically enable SIDS and other developing countries to provide far more economical and sustainable shipping services both domestically and internationally.

Increased resilience, reduction in fuel insecurity, the reduction of upstream & downstream emissions and the potential for modular or leasing options for installations of WPT solutions are all important economic considerations. As a pure zero-emissions energy source, this also de-risks the future and lowers the impact from new regulations, such as restrictions on non-GHG emissions, including black carbon (BC) and under-water radiated noise (URN) (ICS & Univ. of Southampton 2023).
From simply a marketing perspective, these highly visible WPT systems are also increasingly viewed as a very public statement of intent by cargo owners and the shipowners themselves to decarbonise their operations, telling a positive shipping story to a wider audience.

8-2 Investment Level Trends + New Entrants & Merger & Acquisition (M&A) Activity

The WPT market is gaining substantial momentum as is noted in Section 6 with the current market uptake. There are a growing number of significant market players involved with installing and operating WPT systems, many in collaboration or in partnerships. The company names listed below are just a selection of larger partnerships, all investing substantial amounts in the installation and operation of WPT's and increasingly large shipbuilders are engaging as outlined in Graphic 8-4.

A number of good examples of this scale of collaboration are (but certainly not limited to):

Canopee Project - Alizés, a joint venture firm set up between Zéphyr & Borée and JIFMAR Offshore Services (France), designer VPLP and wingsail developer AYRO (France), Ariane Group, Neptune Marine Shipyard (Netherlands) https://www.offshore-energy.biz/canopee-gets-its-oceanwings/

CHEK Project (EU Horizon) - BAR Marine Technology (UK), YARA Marine (Norway), Cargill (US/Switzerland), Mitsubishi (Japan), Wartsila (Finland), Deltamarin (Finland), World Maritime University [WMU] (Sweden) https://www.projectchek.eu/

Neoliner Project (Newbuild Primary wind Vessel) - CMA CGM, ADEME Investissement, NEOLINE Développement, Corsica Ferries, Louis Hardy S.A.S, the Banque des Territoires and the Pays de la Loire Region. The share of bank financing is provided by the Crédit Industriel et Commercial (CIC) and guaranteed by the Public Bank of Investment (BPI). The ship, built by the RMK MARINE (Turkey) shipyard. The Neoliner will be the first one equipped with a SolidSail rigging system, supplied by Chantiers de l'Atlantique. https://www.neoline.eu/en/neoliner-under-construction/

Oceanbird Project - Alfawall – Alfalaval and Wallenius Marine JIP, KTH Royal Institute of Technology and SSPA, Wallenius Wilhemsen, financial support from the Swedish Transport Administration. https://www.theoceanbird.com/

Type	Example of Companies involved with WPT & Projects
Large Vessel Shipowners	Mitsui OSK Line (MOL), K-Lines, Oldendorff, Louis Dreyfus Armatueurs, Scandlines, CMES, WWL, CMA-CGM, Corsica Ferries, Mitsubishi, Hapag Lloyd, NYK lines, Berge Bulk, Capital Ship Management, Odfjell, ONE, IINO, Tufton, Socatra/Total, Nippon Marine (BHP), CLdn, Compagnie Maritime Nantaise, Louis Dreyfus Company, Ponant etc.
Small Vessel Shipowners	Blue Planet Shipping, Bore, Sea Cargo, Terntank, Boomsma shipping, Rord Braren, Van Dam Shipping, Tharsis River & Sea Shipping, Marfret, Schramm, SMT, Amasus, Vertom, Chemship, Vega Reederie, etc.
Charterers/Cargo Owners	VALE, Michelin, Cargill, Shell, YARA, Renault group, Hennessey, Enviva, DRAX, Ariane Group, Enercon, Marubeni, Accor, Pan Ocean Ship Management, etc.
Ship Builders	Chantiers de l'Atlantique, Oshima, Samsung Heavy Industries, Hyundai Heavy Industries, Dalian Shipbuilding Industry Company (DSIC), Neptune Marine, Sumitomo Heavy Industries, China State Shipbuilding Corporation (CSSC), RMK Marine, etc.

Graphic 8-4: Select List of Large and Small Shipowners, Charterers and Shipbuilders Involved with WPT projects (IWSA 2023)

8-3 Finance Approaches

As noted in Section 7-4-4, there are a number of financial approaches that can help to de-risk and kick start a wider dissemination of WPT and newbuild primary wind ships.

(i) Leasing system: where the savings from the fuel pay the costs of the lease. As deck equipment, the adoption of leasing approaches for WPT., especially as retrofit systems is an approach that a number of OEM's are proposing or currently offering to customers. This does however add cost and risk to the OEM's involved and could be a model that is developed further under an agency or licencing agreement. A recent example of a more formalised leasing system is being offered by IINO Lines and the Mizuho Leasing Company to provide leasing for rotor sails. https://www.rivieramm.com/news-content-hub/news-content-hub/rotor-sail-leasing-initiative-aims-to-improve-access-to-wind-assisted-power-78375

(ii) Pay-As-You-Use model: where the CAPEX paid is for by a sharing of the fuel savings over subsequent years of operation. The use of a proposed WPT system where the purchase of the equipment is undertaken using the fuel savings in operation is also a viable pathway to shifting the heavy CAPEX over to OPEX. One such model has been developed, in part under the WASP project - A pay-as-you-use business model for the greening of shipping. https://doi.org/10.1016/j.clscn.2022.100034

(iii) Wind-As-A-Service: where modular WPT or containerised systems are deployed on ships working on the best routes. There is also a wind powered towing tug system under development that would also function as a wind service provider.

There are an increasing number of consultants that offer to help with comparative assessments of wind propulsion systems which are vessel specific. Two early decision-making tools were developed during the EU Interreg WASP project, the tools and instruction videos can be accessed here. https://northsearegion.eu/wasp/wasp-tools/

8-4 Shipowner Business Case

There are of course a wide range of factors that go into the selection of equipment, fuel choices, retrofits and the increasing amount of validated performance data and tools such as those above help with making those decisions regarding WPT among shipowners. Financial data and the costs of systems for each ship and from each vendor are currently still rather bespoke, as systems are not fully standardised and installations are still relatively few, however by taking a look at one case study on costs and ROI can help to highlight the general pathway towards making those investment decisions. This is of course helped by things such as long-term maintenance and replacement parts service contracts and a robust longer-term financial outlook.

Case Study: Wind-Assist Vessel: 19,500dwt Asphalt Bulker in North Sea

Simulations based on a 19,500dwt asphalt bulker operating on a North Sea route with three large generic rotors installed have shown modelled fuel savings of 21.7% on the straight or shortest distance route and reduction on the fuel optimised route of 29.5%. (Kolk, Mason, Bonello, Bordogna 2019)

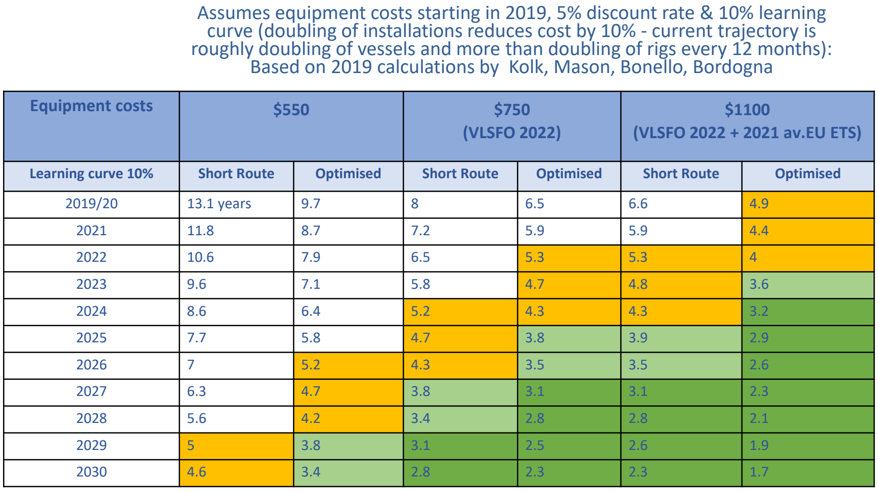
Equipment costs at the time and assuming a 5% discount rate and with a fuel cost of $550/t the ROI was found to be 13.1 and 9.7 years respectively, however if we assume an average MGO fuel cost for 2022 of $750/t (Rotterdam prices HFO - $678/t, VLSFO - $858/t, MGO - $1206/t, LNG MGOe - $1272/t https://shipandbunker.com/prices) then the ROI is 8 years and 6.5 years respectively. With a carbon price added at $100/t (mid-2022 – EU ETS €84 = $90) https://ember-climate.org/data/data-tools/carbon-price-viewer/) – then the ROI for the fuel optimised route comes down to 4 years. Higher carbon pricing or the use of more expensive alternative fuels would then naturally lower the ROI period further. These calculations utilised routing optimisation, however, speed was kept steady to reduce significant schedule/ utilisation changes on the fuel optimised route, however speed-optimisation would also likely lead to significant improvements as we saw confirmed in the recent CE Delft report outlined in Section 1. (CE Delft 2023)

The costs of the rotor sail installations in this simulation are based on 2019 prices, and as installations increase, it has been estimated in the earlier Section 8-1-4 that WPT will likely follow the average learning curve of maritime equipment of approximately 10%, thus the costs in 2019 for three rotors is set at $3.5m, by 2025/6, assuming a doubling of installations per year in line with EU/UK estimates, this will likely half in price, reducing to $1.5-1.75m, excluding any abrupt changes in material costs, step change manufacturing innovation etc., thus effectively halving the ROI in 6-7 years. See Graphic 8-5

Report: https://www.researchgate.net/publication/337858674_Wind-assisted_ship_propulsion_performance_prediction_routing_and_economic_analysis_-_a_corrected_case_study

NOTE: This is a general simulation for a specific installation of WPT systems, however the findings of this case study should be taken as indicative rather than as general findings. All WPT systems and their applications are varied, with a full range of variations around costs, performance, ship type, routes and operational profiles.

ROI Example: 19,500dwt Asphalt Tanker



Assumes equipment costs starting in 2019, 5% discount rate & 10% learning curve (doubling of installations reduces cost by 10% - current trajectory is roughly doubling of vessels and more than doubling of rigs every 12 months): Based on 2019 calculations by Kolk, Mason, Bonello, Bordogna

Equipment costs	$550		$750 (VLSFO 2022)		$1100 (VLSFO 2022 + 2021 av.EU ETS)	
Learning curve 10%	**Short Route**	**Optimised**	**Short Route**	**Optimised**	**Short Route**	**Optimised**
2019/20	13.1 years	9.7	8	6.5	6.6	4.9
2021	11.8	8.7	7.2	5.9	5.9	4.4
2022	10.6	7.9	6.5	5.3	5.3	4
2023	9.6	7.1	5.8	4.7	4.8	3.6
2024	8.6	6.4	5.2	4.3	4.3	3.2
2025	7.7	5.8	4.7	3.8	3.9	2.9
2026	7	5.2	4.3	3.5	3.5	2.6
2027	6.3	4.7	3.8	3.1	3.1	2.3
2028	5.6	4.2	3.4	2.8	2.8	2.1
2029	5	3.8	3.1	2.5	2.6	1.9
2030	4.6	3.4	2.8	2.3	2.3	1.7

Note: Green shading indicates c.3-year ROI threshold

Graphic 8-5 ROI Calculation (in years) in Various Fuel Cost Scenarios – 19,500dwt Asphalt Bulker (IWSA 2023)

8-5 Additional Trends & Market Developments

8-5-1 Modularisation

There has already been some development of modular versions of WPT including wing sail and suction wing/sail installations deployed in containers or on flatrack systems, along with interest in designs for turbines and the potential for other systems. It can also be argued that a number of existing installations could be viewed as 'modular', as the actual installation of the WPT systems only take a few hours once the foundation work has been completed. This modularisation could enable a different business model approach for smaller systems or for particular technologies and applications, facilitating fleet installations where WPT rigs are moved onto vessels on particularly beneficial, windier routes. There are also options under development and installed that use a rail system, that could be used for interchangeable installations. This modularisation approach has been adopted on a small number of vessels to date, however, in early 2024 a containerized WPT will be installed on the first container ship, the 143m, 1036 TEU capacity MV Kalamazoo feeder vessel owned by Norse and operated by Singapore-based Ocean Network Express (ONE) https://www.offshore-energy.biz/one-invests-in-wind-assist-propulsion-orders-two-containerized-units-from-econowind/

8-5-2 Wind-Ready Vessels

The development of 'wind-ready' ships entails either retrofitting structures and making adjustments to make ships capable of taking WPT or the building of vessels with a number of relatively minor changes made at the design and build stages of a vessel that can drastically reduce the costs of later retrofitting systems. Such changes as structural design and reinforcing of the superstructure and decks where WPT are likely to be installed, adjustments in the location of navigation systems or other vital equipment, electrical system modifications and so on. Up until 2023, a small number of ships had already been launched wind-ready and some other vessels had been designated 'wind-ready' for periods when they were awaiting the installation of the rigs. However, a more pertinent example of this approach are the six wind-ready 50,000dwt Chemical/Product MR tankers that have been delivered to Capital Ship Management in Greece through 2023 with an ABS 'wind-ready' notation. https://www.capitalship.gr/content/press-releases/134-capital-ship-management-corp-takes-delivery-of-m-t-039-atrotos-039-m-t-039-anikitos-039

8-5-3 Ship Builders & Building Process

As the numbers of WPTs being installed is increasing, so the experience and competencies in the shipbuilding sector are growing and a number of shipbuilders are involved in developing newbuild projects and WPT themselves (see Graphic 8-4). This development is significant in lowering costs and increasing the speed of installations and that will be further enhanced by the inclusion of WPT into yard standard equipment lists, which is a trend already underway. There is also an increased interest among WPT OEMs to shift production lines to be closer to these yards and their markets.

8-5-4 After-Sales Agreements

These agreements will be key to building long-term trust in WPT installations where guarantees and servicing agreements are extended from established third party entities that will maintain the systems and help with upgrades of new technologies. In the past two years, such agreements have been entered into by some of the early market entrant OEM's and other technologies being developed in partnership with established industry parties already have a higher degree of support.

8-5-5 Smaller Vessel Segment

The largest group of small vessels in operation that can benefit from WPT are the 2.86 million motorised fishing vessels (63% of the total), however currently there are only a small number of fisheries related projects. There are 64,000 larger vessels over 400gt worldwide. (FAO 2020)

When installing WPT on fishing vessels there are special considerations, usually these ships have limited working area on deck and challenging operational profiles, however vessels with long voyage times could make substantial fuel savings from the use of WPT. (European Commission, DG MARE 2023) Additional research and demonstrator vessels are required to assess and validate these installations. (See Section 9: Case Studies – Annex II-M: Fishing Vessels in Focus)

Small sail cargo vessels are in operation either on short sea routes or cross-ocean routes as identified in Section 6. The network of these vessels is growing, however, to achieve a level of reliability and confidence in small vessel operations there needs to be a widening of the network and a significant boost to the number of ships servicing those routes, with trans-shipment hubs and competitive transport costs. This network is developing gradually though it is hindered by high port fees, the lack of regular cargo contracts and general compliance costs.

8-5-6 SIDS/LDC Regions

There are substantial benefits for less developed regions to deploy WPT systems and primary wind ships that can offset the cost of decarbonisation, extend range and also deliver regional employment and trade benefits. Most of these regions are forced to purchase fossil fuel on international markets using limited reserves of foreign currency which multiplies costs that are already often elevated by the need to transport the fuels to their market by small tankers. This periphery experience is especially the case in smaller island states that have limited or non-existent domestic production of fossil fuels and limited scope to produce alternative, low or zero-emissions fuels. An example of this highlights just the headline price of the fuel without the added foreign exchange and comparative purchasing power included. Taking mid-2023 fuel prices (MGO/tn), the cost in Singapore stood at US$900, while in Fiji the cost was US$1,100 in the largest port of Suva, while to the north on the small island group of Wallis & Futuna, the cost was US$1,800+

If we take an assessment of WPT potential in a single region, the South Pacific, there has been extensive modelling done by the Micronesian Center for Sustainable Transport (MCST). Wind propulsion is found to have high potential in the region dependent upon application, deck space available and vessel/WPT type. Many of the findings are collated and summarised in this paper: Pacific island domestic shipping emissions abatement measures and technology transition pathways for selected ship types. (Nuttall, P et al 2021)
https://mcst-rmiusp.org/index.php/reference-library-main/download/26-usp-papers-low-carbon-shipping-pacific/598-irvin-a-et-al-2021-pacific-island-domestic-shipping-emissions-abatement-measures-and-technology-transition-pathways-for-selected-ship-types

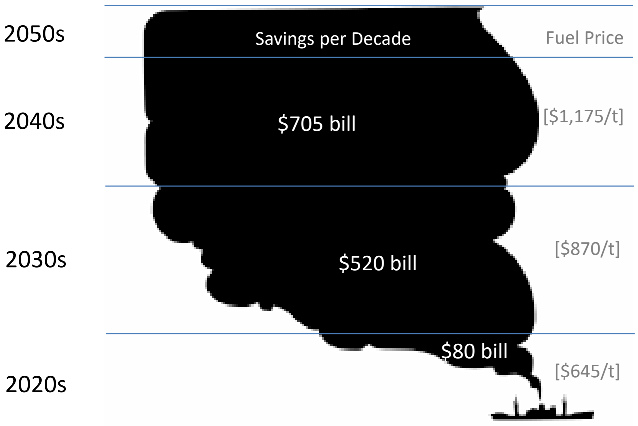
8-6 Macro Scale – Industry Scale Economic Benefits

The potential for wind propulsion to be a critical lever in delivering the full decarbonisation of the international fleet is brought into focus if we envision a scenario where all ships are mandated to install some form of wind propulsion by 2030 (retrofits for all older vessels, along with integrated wind-assist or primary wind vessels for the 1,000-2,000 new ships built each year). This level of rollout would deliver somewhere in the region of a 20% reduction in fuel usage across the fleet, as almost all ships can take some form of wind propulsion system. As carbon taxes and new costly alternative fuels are brought into the market, the savings in fuel would reach approximately $1.3 trillion by 2050 with conservative assumptions made of an 35% increase in fuel cost per decade. This would, by the calculations made by UMAS and the Energy Transitions Commission effectively cover the entire cost of decarbonisation of the international fleet, especially when factoring in a 20% lower amount of alternative fuel production capacity and infrastructure would also be required. (UMAS & ETC 2020)

Graphic 8-6 is a visual representation of these savings, based on updated statistics from an article written in 2021: Original article: https://splash247.com/could-wind-propulsion-fund-the-full-decarbonisation-of-shipping/

The Shipping Sustainable Shipping Challenge

Could Wind Propulsion Fund the Sustainable Shipping Transition of the Fleet?



UMAS/ETC Report

100% Net Zero Shipping = $1.4-$1.9 trill

[$1.4 trill = $20+mill per ship]

Ref: UMAS/ETC Report (2020)

Full Wind Propulsion Roll Out in 2020s.
Installation costs = c.**$300 bill**

+ Reduce total cost by 10-20%

[$200-300 bill = <$5 mill per ship]

- *Static fleet size*: 60,000
- *Fuel: $*300 mill t/yr / *CO2*: 1bill t/yr
- *Price*: $645/t (VLSFO Global Av./02 May'23)
- *Increase*: 35%/decade from 2030s
- *Wind*: 20% power delivery (inc. some operational changes)

NOTE: No IRR/Currency rates etc included

Ref: Updated from IWSA Article (2021)

$1.3 trillion+ savings by 2050 (+ lowers total cost to $1.1-1.7 trill)

Graphic 8-6: Scenario - Potential Savings Generated by a Full Fleet Roll-out of WPT by 2030 (updated from 2021 article: Could wind propulsion fund the full decarbonisation of shipping? https://splash247.com/could-wind-propulsion-fund-the-full-decarbonisation-of-shipping/ (Allwright, G 2021)

The scenario outlined in Graphic 8-6 makes a series of assumptions and a detailed analysis of this pathway would be required to validate this approach, however, the level of decrease in fuel use is not disputed by many in the industry. A recent Intertanko sponsored presentation at IMO ISWG13 showed that the tanker operator Odfjell was on track to deliver above 60% reductions by 2030 in fuel use through a careful program of energy efficiency measures and voyage optimisation that has already been implemented that has delivered an Annual Efficiency Ratio (AER: gram CO^2 emitted per dwt-mile) reduction of 52% for the Odfjell managed fleet compared to the average IMO baseline for their 2008 fleet with further reductions to be delivered through wind-assist systems and other measures.

Source: Towards Zero Emission Odfjell`s perspectives on decarbonization of deep-sea shipping, Odfjell SE, IMO ISWG-GHG 13, 05 December 2022, https://docs.imo.org/Shared/Download.aspx?did=139801

The CE Delft report (July 2023) also combined speed reductions with WPT and a 5-10% alternative low-carbon fuel delivery and found that this would deliver a 28-47% reduction in emissions by 2030, with only a slight increase in transport costs;

> The maximum technical abatement potential is defined as the emission reduction that could be realised if all ships in the world fleet would use all technical and operational abatement options from the CE-Ship model, including: — the wind-assisted propulsion option with the largest efficiency improvement (which may vary per ship); — 20 or 30% speed reduction relative to 2018 (for those ship types where such a speed reduction results in a reduction of GHG emissions, after taking into account that the fleet will need to increase to provide the same amount of transport work as in BAU); and — 5-10% of the energy is derived from zero-GHG fuels. The report concludes that it is technically possible to reduce shipping emissions by 28-47% by 2030, relative to 2008, under the assumptions listed above. This amounts to approximately 175–350 Mt CO2e on a WtW basis per annum, depending on the BAU emissions in 2030. When introduced gradually from 2025, the measures could avoid cumulative emissions of 500–1,000 Mt CO2e. About half of the emission reductions result from lower speeds and other operational measures, a quarter from wind-assisted propulsion and other technical measures and another quarter from using zero and near-zero-GHG fuels. Implementing these measures would increase shipping costs by 6-14% on average, relative to BAU.

Source: Shipping GHG emissions 2030: Analysis of the maximum technical abatement potential
https://cedelft.eu/wp-content/uploads/sites/2/2023/06/CE_Delft_230208_Shipping_GHG_emissions_2030_Def.pdf

Note: This report doesn't analyse the added benefits from the interaction and integration of these measures, leaving further benefits that could be factored in when considering the additional benefit of lower speeds and WPT systems. Also, the potential for further voyage optimisation through weather routing etc. (not just speed) and WPT wasn't considered.

8-7 National, Regional Development – Socio-Economic Benefits

This section is a brief overview of a selection of development benefits and should not be viewed as an exhaustive list. These benefits should be considered whenever decarbonisation impact studies are undertaken, such as the current UNCTAD-led Comprehensive Impact Assessment for the basket of IMO mid-term measures.

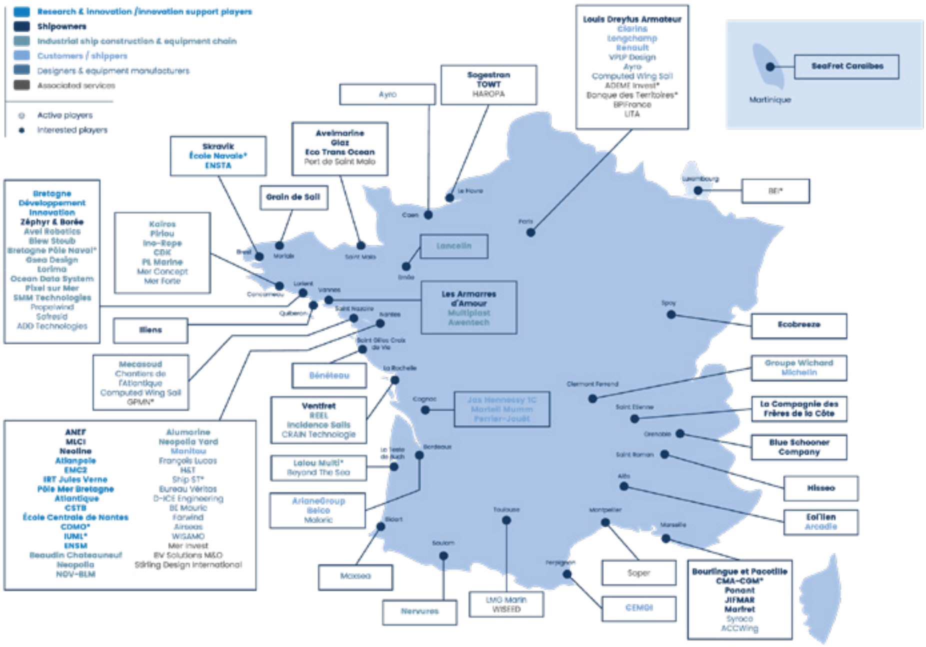
8-7-1 Employment & Investment

These two areas of benefit are naturally linked, and the economic boon of attracting significant green/blue investment will in turn generate significant numbers of jobs in the design, construction, testing, installation, training and maintenance fields. With ethical, low emissions transport increasingly on the radar for trading companies, the existence of these types of ships and a cluster of companies developing these types of technologies and ships may also factor in their wider investment decisions.

The UK Government's Clean Maritime Plan (released in July 2019), has assessed the global market for wind propulsion systems, and this is estimated to grow from a conservative £300 million (US$380 mill) per year in the 2020s to around £2 billion (US$2.5 bill) per year by the 2050s worldwide. Currently the EU and UK are the areas where the majority of wind propulsion companies and projects are located, however there is also quite strong growth in the shipbuilding countries in North Asia and elsewhere working to acquire a slice of this new market. The EU commissioned report in 2016 outlined that there would be a maximum market potential for bulk carriers, tankers and container vessels of between 3,700-10,700 installed systems by 2030, including both retrofits and installations on newbuilds, depending on the bunker fuel price, the speed of the vessels, and the discount rate applied. This in itself is approximately 50% of all tankers and 67% of all bulkers currently in operation, but other sectors such as general cargo, RoRo, RoPax, cruise and fisheries etc. were excluded from the analysis. Nonetheless, this level of development already constitutes between 5-15% of the world fleet of large commercial vessels and would account for 6,500-8,000 direct jobs and around 8,500-10,000 indirect jobs by 2030. (CE Delft 2016/7)

A good example of these developments has been covered in the white paper released by the IWSA French branch, the Association Windship in 2022, detailing developments and opportunities for the French Government as part of their Blue Maritime plan. Wind Propulsion for Ships: Technologies ready to decarbonise maritime transport. An industrial opportunity for France, October 2022
https://drive.google.com/file/d/1NOMu1kGaXvNa1CkspSYqHUOWk3xeb_eO/view?pli=1

The map on page 72 of this report clearly indicates the number and diversity of companies active in the development of wind propulsion systems in the country and each of these companies is making investments in production facilities, materials testing, R&D, prototype construction and shipbuilding.



Source: Association Windship White Paper [English version] (2022)

Graphic 8-7: Wind Propulsion Development – Case Study: France (Association Windship 2022, page 72)

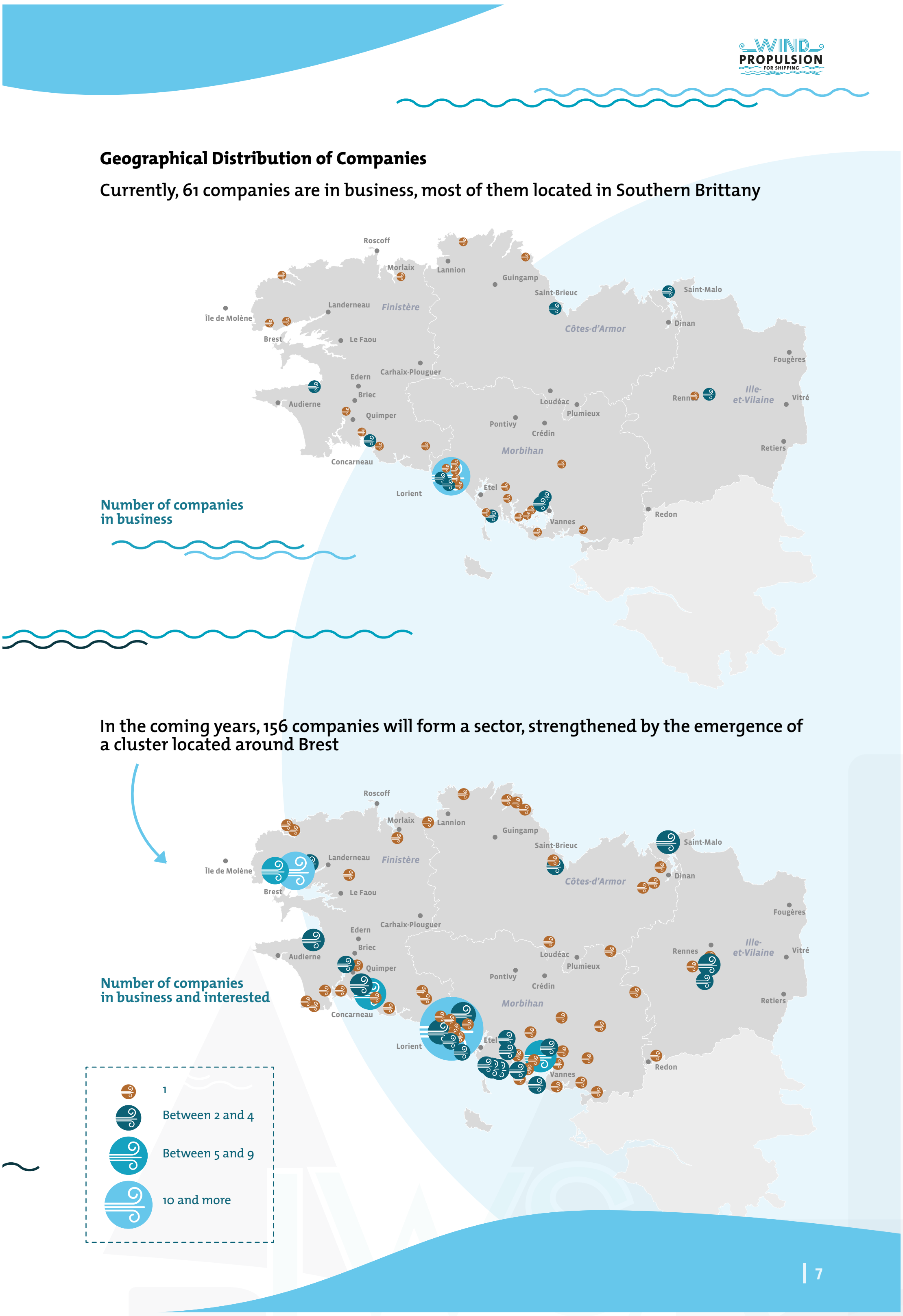
This can also be taken further, with a focus on a French regional development level, with work underway in both the Brittany and Pays De'loire regions. Brittany has compiled a directory of wind propulsion development related companies, and they released a report outlining their case to make this a key economic development focus.

In 2021, Brittany identified 61 commercial actors in the wind propulsion field, with 155 jobs specifically in wind propulsion activities and an estimated €85 million (US$94 mill) in wind propulsion related sales, including the leisure and racing sectors.

Expanding on this investment and employment opportunity, the Nantes region (Pays De'loire) believes that it will be the key hub (or one of them) and identifies the companies, investment and jobs it sees being created in that region;

> "…the wind-powered transport sector currently employs 720 people directly in France in 2023, with over a third of them located in Nantes & Saint-Nazaire. By 2030, the number of jobs could increase by 5 to 10 times, with over 50% of the employment in the sector located in the region. The businesses already located here have significant growth prospects in the region by 2030: just among the equipment manufacturers, Airseas in Nantes is expected to create 1,500 jobs, CWS 500 jobs, Chantiers de l'Atlantique 200 jobs, and Wisamo 50 jobs."

Source: Wind For Goods (2023)



WIND PROPULSION FOR SHIPPING

Geographical Distribution of Companies

Currently, 61 companies are in business, most of them located in Southern Brittany

In the coming years, 156 companies will form a sector, strengthened by the emergence of a cluster located around Brest

Graphic 8-8: Forecast Growth of Wind Propulsion Companies in Brittany (2022)

Prospective study of the Breton industrial sector wind propulsion for ships: Overview and Key Figures 2022 Edition
https://www.bdi.fr/wp-content/uploads/2022/09/2111110-BDI-Developpement-Innovation-Propulsion-par-le-vent-Brochure_en_def-1.pdf

Brittany – Wind Propulsion – Map & Directory
https://www.bdi.fr/en/publications/wind-propulsion-of-ships#map-directory/

8-7-2 Shipyards

The development of wind propulsion in general and WPT systems specifically creates an opportunity for all types of shipbuilding companies. While the opportunities are quite obvious for larger yards as part of their technology offering, there is also a significant opportunity for small to medium-sized shipyards in the building of primary wind vessels but also in the retrofitting and maintenance of WPT systems. The installation of these systems is quite manageable for these smaller sized yards and in general doesn't require any significant re-training or re-equipping of these yards or workforce. Primary wind vessels currently tend to be designed as relatively small vessels, with 18-24m, 40-80m and 120-140m vessel designs currently under construction. A general overview of the process for installing retrofitted systems is outlined in the Best Practice manual from the WASP project (WASP 2023)

As yet, this small vessel construction market and the retrofit market are relatively untapped with the focus to date being primarily on short sea cargo ships, however there is also a large number of potential fishing vessels that could benefit from WPT installations, with for example; 74,000 fishing vessels in the EU alone out of an estimated 3 million worldwide. (FAO 2020)

8-7-3 Small Regional Ports

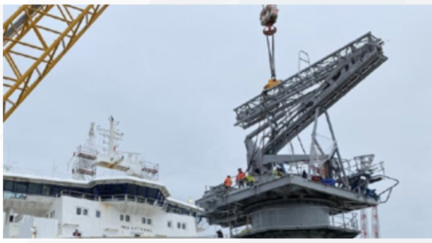
The revitalisation/regeneration of small ports and small port cities is a challenge as cargo business is frequently directed through larger ports. The development of a small vessel sail cargo network has the potential to help revitalise these smaller ports, with fuel costs substantially reduced or removed from the equation, smaller vessel operations are able to compete more effectively, even where some of those savings are transferred to additional crew members. The need to widen the network of small sail cargo vessels and help to facilitate this sector will in return deliver jobs, trading activity, port fees and other ancillary benefits to these ports and their hinterlands. The PHD Thesis - Sail Freight Revival: Methods of Calculating Fleet, Labor, and Cargo Needs for Supplying Cities by Sail, Woods, S (2021) goes into extensive detail primarily from a US/New York City case study perspective. https://www.researchgate.net/publication/354841970_Sail_Freight_Revival_Methods_Of_Calculating_Fleet_Labor_And_Cargo_Needs_For_Supplying_Cities_By_Sail

8-7-4 Health

The are additional indirect benefits for regions that embrace wind powered shipping with the reduction of harmful emissions from shipping in and around ports and of course in busy shipping channels and relatively confined maritime areas such as the English Channel, North Sea, Baltic, Malacca Strait, Red Sea and Mediterranean etc. These emissions are a key concern for coastal and port communities in particular and the installation of WPT contributes significantly and measurably to that reduction, thus reducing health issues and consequently reducing health costs to the economy as a whole.

Policy Brief: Socio-economic benefits of wind technologies for ships (EU Interreg North Sea – WASP 2021)
https://vb.northsearegion.eu/public/files/repository/20210629150330_RGO_003PolicyBrief_WEB2.pdf

Report: CLEANER SHIPPING Air pollution, climate, technical solutions and regulation (2021)
https://vb.northsearegion.eu/public/files/repository/20220502154016_20220327135716_GTD_Cleaner_shipping_2021_Final.pdf



9) Wind Propulsion Case Studies

There have been a number of case studies of simulated wind propulsion installations completed over the past few years. There are also a number of projects underway or which have recently concluded that have analysed actual vessels with installed WPT systems. Since there are quite a variety of WPT with further variations in size, ship type, installation location etc., a full-scale comparative meta-study would be required, and this is currently quite challenging as publicly available validated third party data is limited and the aggregation of results from a limited number of demonstrator vessels will be difficult to conduct and maintain anonymity of datasets. However, it is possible to provide a series of case studies in Annex II and a table of those and other case study resources are included in the table below.

Title	Description	Date	Link
Summary of bound4blue eSail Installations	Fishing Vessel (1x) 12m x 2.85m eSail, General Cargo (1x) 17m x 2.85m [tiltable] eSail and General Cargo (2x) 17m x 2.85m eSail + ongoing projects	2023	ANNEX II – A: 10-page summary
Wing sail installed on MOL Bulk Carrier	Outline of installation, technology and performance of the 231m, 100,422dwt bulk carrier MV Shofu Maru with 1 x 54m x 15m wing sail installation (operated by MOL, Japan)	2023	ANNEX II – B: 1-page summary Further information: https://www.mol-service.com/case?category=wind_challenger
Summary of Norsepower Rotorsail Installations	A summary of eight installations of various sized rotorsails on 1 x VLOC Bulk carrier, 1 x LR2 Product Tanker, 3 x Ferry, 3 x RoRo (operated by various companies)	2023	ANNEX II – C: 8-page summary
Suction wing from Econowind	Flatrack Installation on 6,477dwt MV Frisian Sea general cargo vessel.	2023	ANNEX II – D: 4-page summary
Summary of Anemoi Rotor sail installations	A summary of five installations and upcoming installations of various sized rotorsails on 1 x Ultramax bulker, 2 x Kamsarmax bulkers, 1 Newcastlemax & 1 x Valemax	2022	ANNEX II – E: 2-page summary
Primary Wind Schooner Apollonia	(Small Vessel) – 19.5m General Sail Cargo Ship	2022	ANNEX II – F: 12-page paper
Primary Wind Vessel - TOWT	General Sail Cargo Vessel - 63m, 1,200dwt	2023	ANNEX II – G: 2-page summary
Simulated study of Fastrig installations on Bulk Carrier	Simulation using the 225m, 83,611dwt MV Ultra Tiger, Panamax bulk carrier with six wingsails installed.	2023	ANNEX II – H: 2-page summary
Simulated study of Rotor installations on Bulk Carrier + Voyage optimisation	Simulation using a 225m, 80,000dwt Panamax bulk carrier fitted with five 35m rotorsails	2023	ANNEX II – I: 2-page summary
Wing Sail Simulation	Simulation of NAOS design principles and performance predictions of a Wing Sail Module system	2022	ANNEX II – J: 5-page summary
Dynarig Simulation	Progress in development and design of Dynarigs for commercial ships	2022	ANNEX II – K: 16-page paper
FastRig Digital Twin	Validation of the performance SGS FastRig solid wings, Cape Horn Engineering	2022	ANNEX II – L: 4-page paper
Fishing Vessels in Focus	Three fishing vessel examples currently in operation.	2022-2023	ANNEX II – M: 1-page summary
WASP Project	Five vessel installations covering three technologies groups – suction wing, rotor sail, wingsail.	2021-2023	Full documentation archive available: https://northsearegion.eu/wasp/output-library-publications/

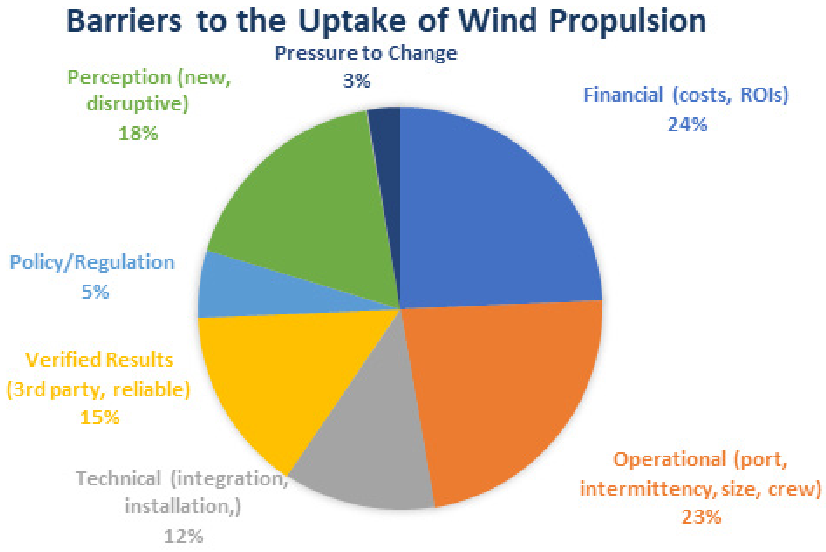
Rotor sail installed on Ferry (WASP project)	Speed trial and route analysis of 169m, 24,000gt MV Copenhagen with 1 x 30m fixed rotor sail carried out by SSPA (operated by Scandlines, Denmark)	Mar 2021	https://vb.northsearegion.eu/public/files/repository/20230505141934_RE40201042-01-revBCopenhagen.pdf
Rotor sail installed on General Cargo ship (WASP project)	Speed trial and route analysis of 85m, 5,023dwt MV Annika Braren with 1 x 18m fixed bow mounted rotor sail carried out by SSPA (operated by Rord Braren, Germany)	Sep 2022	https://vb.northsearegion.eu/public/files/repository/20220707112458_RE40201042-03-00-A.pdf
Suction wings installed on General Cargo ship (WASP project)	Speed trial and route analysis of 85m, 3,638dwt MV Ankie with 2 x 13m bow mounted retractable suction wings carried out by SSPA (Operated by Van Dam Shipping, Netherlands)	2022-2023	https://vb.northsearegion.eu/public/files/repository/20230523105108_RE40201042-04Ankie.pdf
Suction wings installed on General Cargo ship (WASP project)	Speed trial and route analysis of 118m, 6,477dwt MV Frisian Sea with 2 x 10m flatrack installed suction wings carried out by SSPA (operated by Boomsma Shipping, Netherlands)	Mar 2022	https://vb.northsearegion.eu/public/files/repository/20220728155051_RE40201042-02-00-A.pdf
Wing sails installed on General Cargo ship (WASP project)	Speed trial and route analysis of 88m, 2,300dwt MV Tharsis with 2 x 9m retractable wing sails carried out by SSPA (operated by Tharsis River and sea, Netherlands)	May 2022	https://vb.northsearegion.eu/public/files/repository/20230505142244_RE40201042-05Tharsis.pdf
Life cycle modelling of a wind powered car carrier an assessment of cost and greenhouse gas emissions	Simulation of the Primary Wind Vessel: 210m wPCC – Oceanbird Master's thesis in Maritime Management, Olsson & Carlsson	2020	https://odr.chalmers.se/server/api/core/bitstreams/464b93fc-ec75-4b25-9745-c4b04b9345ac/content
Simulation of Wind assist Bulker on North Sea routes	Simulations based on 19,500dwt asphalt bulker on a North Sea route with three rotors installed. (Kolk, Mason, Bonello, Bordogna 2019)	2019	https://www.researchgate.net/publication/335542956_Wind-Assist_for_Commercial_Ships_A_Techno-Economic_Assessment transitioningtolowcarbonshippingmodule/
UNCTAD Sustainable Freight Transport and Finance Training Toolkit: Transitioning to Low Carbon Shipping Module – Sustainable Sea Transport Solutions for SIDS: Pacific Island Countries Case Studies	Extensive package of South Pacific case studies for small vessels, including wind-assist, primary wind and alternative fuels. Includes socio-economic analysis of routes and cargo and this work is applicable to other SID's regions. (Peter Nuttall & Alison Newell, MCST)	2016	https://unctadsftportal.org/sftftoolkit/transitioningtolowcarbonshippingmodule/
Study on the analysis of market potential and market barriers for wind propulsion technologies for ships	EU DG Clima commissioned report – Historical list of technology factsheets p92-112	2016	https://cedelft.eu/wp-content/uploads/sites/2/2021/04/CE_Delft_7G92_Wind_Propulsion_Technologies_Final_report.pdf

10) Barriers & Drivers for Wind Propulsion

10-1 Identification of Barriers to the Uptake of Wind Propulsion
10-2 Drivers and Enablers for the Uptake of Wind Propulsion
10-3 Wind Propulsion: Barriers, Drivers and Perceptions Roundtable 2023 - Summary

10-1 Identification of Barriers to the Uptake of Wind Propulsion

In the maritime stakeholders survey undertaken by the International Windship Association (IWSA) in June 2023, respondents were asked an open question to help identify the main barriers they perceive to the uptake of wind propulsion and the responses were condensed into the following Graphic 10-1

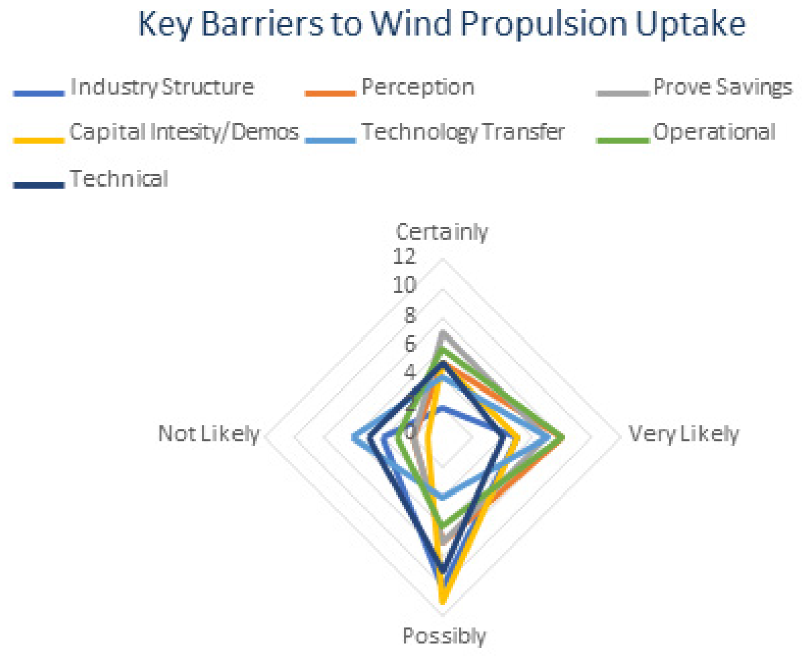


Graphic 10-1: Barriers to the Uptake of Wind Propulsion [IWSA Survey 2023 - Maritime stakeholders – 59 respondents]

There was a clear level of concern expressed around upfront costs with the expected short-term cost over mid/long-term gain and a focus on Return on Investment (ROI), whereas all other propulsion systems will be more expensive to install, which infers that these systems are still viewed as efficiency measures rather than propulsors in their own right. Operational concerns dealing with the need for systems to be manageable in port, the intermittency and predictability of wind and the need for extra training. This was followed by perception issues and the need for robust, verified results from technologies.

Policy makers were asked about the barriers, drivers and enablers in more detail, their responses on the barriers however correlate quite closely with those identified by the wider industry actors. The question was broken down into seven key barriers identified and then the likelihood of each being a significant barrier. The results outlined in Graphic 10-2 clearly indicate that proven/validated savings, operational concerns and perception are either certain or very likely barriers to the uptake of wind propulsion along with a strong showing for industry structure and the capital intensity of demonstrators (i.e. finance.)

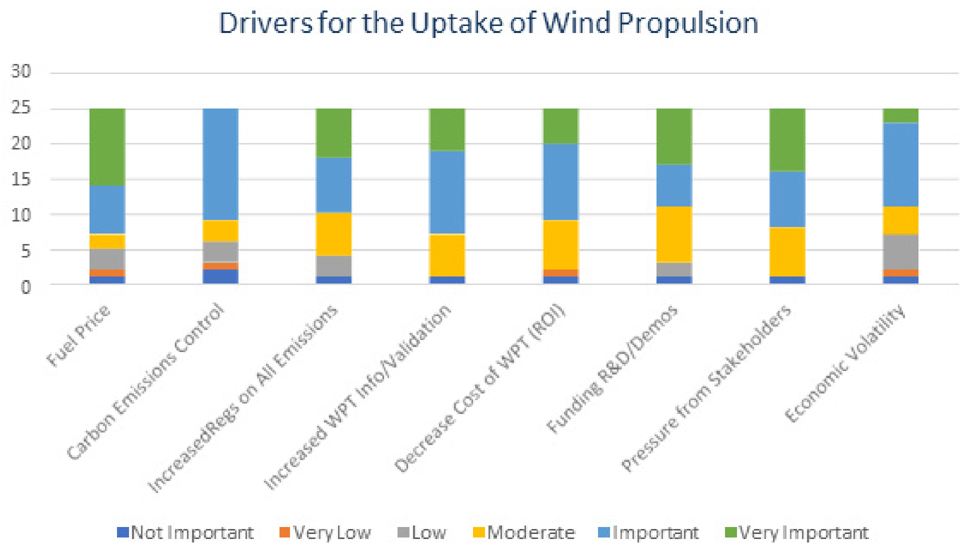
NOTE: Many of these barrier issues were discussed in the 2021 and 2023 workshop results which are outlined below in Section 10-3, along with potential enablers and solutions to mitigate these issues.



Graphic 10-2: To what extent, do you believe, the following barriers hinder the uptake of wind propulsion technologies (both retrofit and new build)? [IWSA Survey 2023 - Policy Makers – 25 respondents]

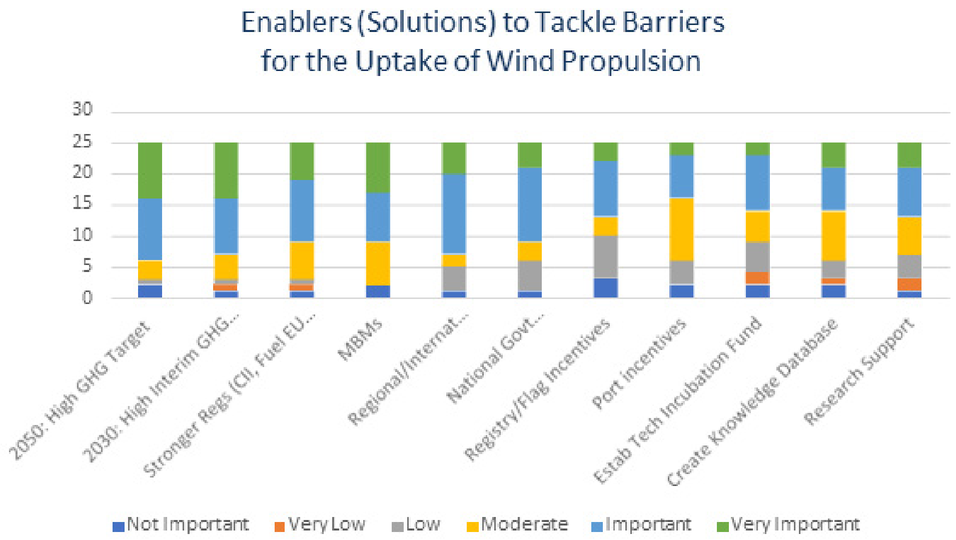
10-2 Drivers and Enablers for the Uptake of Wind Propulsion

The policy maker-specific survey then took this a further two steps, looking at drivers and key enablers. Graphic 10-3 focuses on the drivers that are required to push the uptake of WPT and financial issues (fuel price, reduction in WPT cost and increased funding for R&D and demonstrators). Naturally all scored highly as important or very important in generating momentum. The tightening of regulation and stakeholder (customer) pressure also scored highly.



Graphic 10-3: Considering the following factors, how important will each be in driving the development and uptake of wind propulsion technology in the future? [IWSA Survey 2023 - Policy Makers – 25 respondents]

The final section of the questioning focused on the more specific enablers that could be deployed as solutions to tackle those barriers. In Graphic 10-4, a wide range of opinions is indicated, the ones that garnered more than 50% important or very important were high overall and interim GHG targets, stronger regulations, market-based measures and subsidies at both national and international levels. Therefore, these results again align quite closely with policy goals and financial measures that make fossil fuels more expensive and levelling the playing field with access to funding for WPT development and deployment.

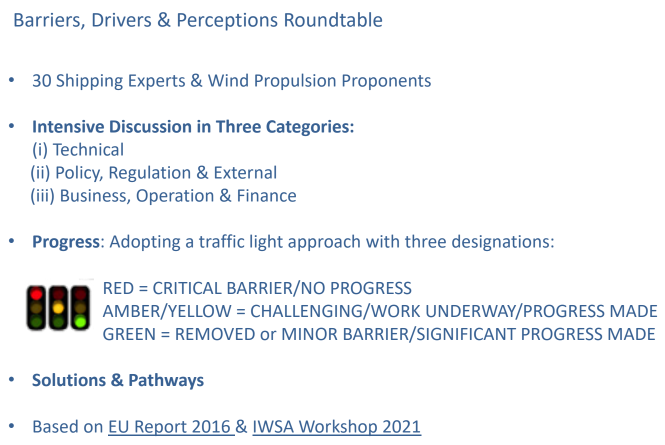


Graphic 10-4: Enablers (Solutions) to Tackle Barriers for the Uptake of Wind Propulsion [IWSA Survey 2023 - Policy Makers – 25 respondents]

10-3 Wind Propulsion: Barriers, Drivers and Perceptions Roundtable 2023 - Summary

In September 2023, over thirty key stakeholders came together for a three-hour workshop to analyse the progress being made in tackling the key barriers to the uptake of wind propulsion in the market that still require work and recommendations for actions to tackle those. This roundtable, and the additional feedback received during the open forum held at the Royal Institution of Naval Architects the following week (14th September), will enable the International Windship Association (IWSA) to identify the strategy priorities for wind propulsion development going forward. The stakeholders represented shipowners, wind propulsion technology providers, finance specialists, class and research and testing institutions. The roundtable used the 2016 EU-commissioned 'study on the analysis of market potentials and market barriers for wind propulsion technologies for ships' (CE Delft 2016/7) as the initial baseline to access progress and help to highlight areas for further development along with the results from the IWSA Wind Propulsion Strategy Workshop held in June 2021 https://www.wind-ship.org/wp-content/uploads/2021/08/Wind-Propulsion-Strategy-Workshop-June-2021.pdf which provided an update of those findings.

The workshop was broken down into three main subgroups. One focused on technical issues, one covered business, operations and financial considerations and the final one covered tackling policy, regulations and other external matters. To be able to get to the heart of the discussions quickly a traffic light system was adopted, and three main sessions covered; the progress made in the past two (seven) years, solutions for removing the remaining barriers and finally suggestions for stakeholder's engagement, next steps and the pathway forward.



Barriers, Drivers & Perceptions Roundtable

- 30 Shipping Experts & Wind Propulsion Proponents
- **Intensive Discussion in Three Categories:**
  (i) Technical
  (ii) Policy, Regulation & External
  (iii) Business, Operation & Finance
- **Progress**: Adopting a traffic light approach with three designations:

  RED = CRITICAL BARRIER/NO PROGRESS
  AMBER/YELLOW = CHALLENGING/WORK UNDERWAY/PROGRESS MADE
  GREEN = REMOVED or MINOR BARRIER/SIGNIFICANT PROGRESS MADE
- **Solutions & Pathways**
- Based on EU Report 2016 & IWSA Workshop 2021

Graphic 10-5: IWSA Barriers, Drivers and Perceptions Roundtable Criteria - September 2023

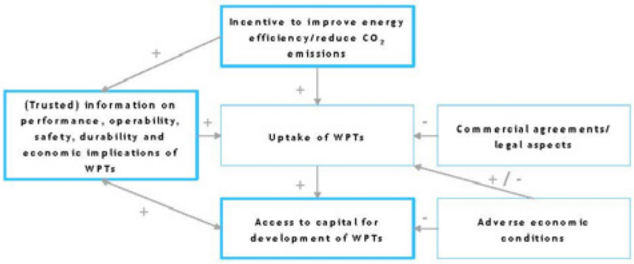
All participants agreed that in certain areas really significant progress has been made in the field and while the original EU report was limited in scope, selecting only four out of seven WPT categories to assess along with very limited actual performance data available at the time and a scope only assessing large vessels above 5,000dwt, the progress in installations aligned fairly well with the initial report, when bearing in mind the impact of the COVID pandemic and logistical challenges of the 2020-2022 period, thus delaying the uptake and scaling of the sector, with 30 large vessel installations and 8 'wind-ready' vessels in operation by September 2023 with another 10+ installations slated to be completed by the end of the year. The assumed fuel price in the initial report was US$450/ton for 2020 which was in the right ballpark and US$550/ton by 2030 which is likely to be quite conservative, especially with more expensive alternative low carbon fuels entering the market and some form of carbon pricing entering the market through the EU ETS from 01 January 2024 ratcheting up to its full level by 2026 and some form of IMO carbon pricing mechanism likely to be in place by 2028/9.

The 2016-17 report headline findings were *"Should some Wind Propulsion Technologies (WPT) reach marketability in 2020, the max. market potential for bulk carriers, tankers and container vessels is estimated to be 3,700-10,700 installed systems until 2030, including both retrofits and installations on newbuilds, depending on the fuel price, speed of the vessels, and discount rate applied. [CO2 savings of 3.5-7.5 Mt CO2 in 2030 + WPT sector: 6,500-8,000 direct & 8,500-10,000 indirect jobs]."*

The initial report identified a wide range of barriers but emphasised three key ones for the uptake of wind propulsion technologies and these formed the bedrock of much of the discussion in the workshop as elements of all three of these still persist.

1. (Trusted) information on the performance, operability, safety, durability, and economic implications.
2. Access capital for WPT development, especially building/testing of full-scale demonstrators.
3. Incentives to improve energy efficiency/reduce CO2 emissions of ships.

Figure 37 Interaction of barriers to the development and uptake of wind propulsion technologies



"These key barriers are interrelated, with the most crucial interaction being a chicken-and-egg problem between 1 & 2. In order to breach this, we see the development of a standardized method to assess WPT combined with test cases to develop this assessment method as the most important starting point for overcoming the barriers".

Overall, the three subgroups focused on nine main challenges this time (three technical, three policy/regulation/ external and three business/operations/finance), in the process identifying over 20 solutions to base their recommendations for further action upon.

10-3-1 Technical Issues

Roundtable – Technical

Barrier/Driver	2016	2021	2023	Solutions/Comments
Diffusion of Tech Knowhow	🔴	🔴🟠	🟠 + 🟢	• Green – predictions & design • Amber – crew – training/course syllabus
Class Guidelines	🔴🟠	🟠	🟠🟢	• Big progress but still many exceptions/interpretation
Third Party Verification	🔴	→	🟠	• ITTC performance standards underway • Standards needed: operability/seakeeping manoeuvring, cargo operations, etc.
Compliance & Applicability of WPT	🔴🟠	→	🔴🟠	• Need training materials • Certification development • Multistakeholder Forum
Integration & Support Systems for WPT	🔴	→	🟠	• Good progress in weather routing • Further integration – R&D
R&D Pipeline of WPT	🟠	🟠	🟠🟢	

Graphic 10-6: WPT Technical Barriers – Summary (September 2023)

The three key areas identified in the 2021 workshop that required urgent action were; further diffusion of engineering and technical knowhow, more in the way of classification WPT guidelines and the need to further boost the R&D pipeline. In all three of these, the 2023 group acknowledged that significant progress has been made in each over the last two years;

(i) Diffusion of Engineering/Design Knowhow: Red/Amber changing to Amber (among crew) and Green (among designers/naval architects) with a good understanding of WPT technologies and their application especially in Europe and North Asia.

(ii) Class Guidelines for WPT: Amber changed to Amber/Green, though there are still exceptions and interpretation issues along with the need for improved considerations around primary wind vessels. There is also increasing understanding that there is a need to standardise these guidelines further.

(iii) R&D Pipeline of WPT: Amber change to Amber/Green, as more WPT systems are in the pipeline, numerous singular and collective R&D projects are underway and increasing primary wind projects are also in development.

Compliance and Applicability of WPT [Holding at Red/Amber – since 2016]

Regarding the compliance and applicability of WPT, this was felt to be an area that has risen in importance as technology is starting to disseminate into the market and while progress has been made in the technical compliance side of the equation, the discussions centred on the increasing need for standard training and certification of procedures (regular running procedures, emergency situations, stability, colregs, passage planning, sail theory etc.) It was acknowledged that much of this material has been compiled within projects and among technology providers, however these need to be pulled together into a training program and other standardised materials. One pathway to delivering that is to establish a working group within IWSA, with outreach to Enkhuisen Zeevaartschool (EZS) to collaborate on curriculum development with other larger maritime institutes, including WMU. It was also noted that French-language training materials and simulation materials have been developed under a project led by Association Windship.

Another key issue is to involve a wider group of stakeholders in the dissemination of information on the technologies and practices, especially including seafarers, pilots, ports and cargo/logistics operators, thus setting up more dissemination. A recommendation to IWSA and other wind propulsion event organisers is to adjust venues/timing of events to accommodate these audiences.

Third Party Verification [Red changed to Amber since 2016]

Attention then moved to the issue of third-party verification of WPT but not solely with an energy/emissions focus (steady conditions) as there has been substantial progress in this area with standard appraisal KPI's under development which will be delivered as guidance from ITTC in 2024, but more focused on operability, seakeeping, manoeuvring, cargo operations and so on. More workshops, joint industry projects and EU projects will be focusing on these 'unsteady' aspects over the coming 12 months. There was a call for the ITTC wind propulsion workstream to refocus on these aspects. There were recommendations for setting up a standards committee, possibly under the auspices of IWSA and for including the analysis of the 'unsteady aspects' as obligatory aspects of the Accelerator program when that is fully established. There was also quite a bit of discussion in the group around the inclusion of wind tunnel institutes in leading positions in the JIP's/R&D projects.

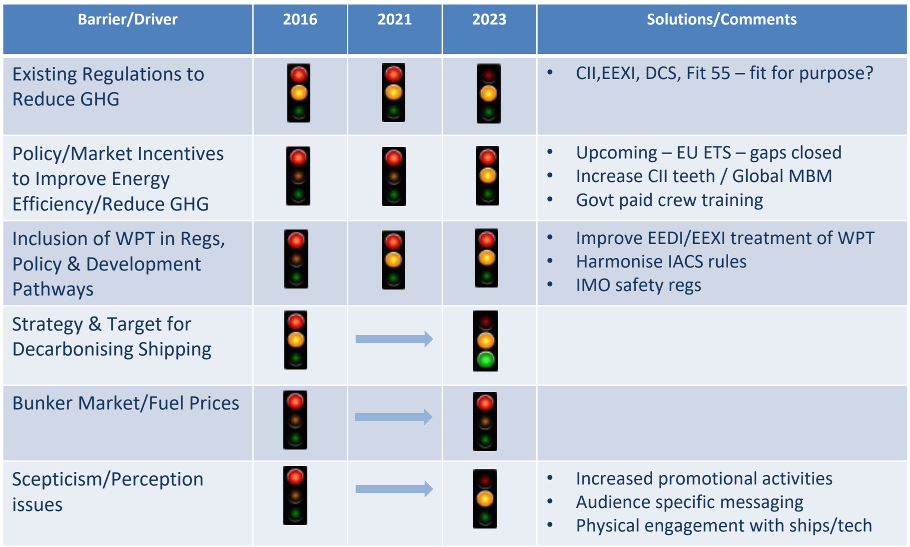
Another proposed action pathway is for the IWSA to become increasingly involved with shaping EU (and elsewhere) research programs to help shift the focus away from conventional propulsion technologies and alternative fuels. As a first step in this, it was noted that IWSA will be moving forward with joining the WaterborneEU program.

Integration and Support Systems for WPT [Red changed to Amber since 2016]

While the group only had a limited time to discuss this area, it was identified as an area that has seen an increased amount of attention, especially at the R&D level. The progress in weather routing for wind was noted. The further integration of WPT into energy management systems and improvements in how these work in conjunction with propulsion and structural components on vessels will be an increasingly important area to secure further optimisation gain and this work should be reflected more in current and future R&D projects.

10-3-2 Policy, Regulation & External Issues

Roundtable – Policy, Regulation & External



Barrier/Driver	2016	2021	2023	Solutions/Comments
Existing Regulations to Reduce GHG	🔴🟠	🔴🟠	🟠	• CII,EEXI, DCS, Fit 55 – fit for purpose?
Policy/Market Incentives to Improve Energy Efficiency/Reduce GHG	🔴	🔴	🔴🟠	• Upcoming – EU ETS – gaps closed • Increase CII teeth / Global MBM • Govt paid crew training
Inclusion of WPT in Regs, Policy & Development Pathways	🔴	🔴🟠	🔴🟠	• Improve EEDI/EEXI treatment of WPT • Harmonise IACS rules • IMO safety regs
Strategy & Target for Decarbonising Shipping	🔴🟠	→	🟠🟢	
Bunker Market/Fuel Prices	🔴	→	🔴	
Scepticism/Perception issues	🔴	→	🟠	• Increased promotional activities • Audience specific messaging • Physical engagement with ships/tech

Graphic 10-7: WPT Policy, Regulation & External Barriers – Summary (September 2023)

This was an extensive area to cover during a single short workshop, especially considering the significant movement this year. In the 2021 workshop little time was taken on assessing the **Strategy and Target for Decarbonising Shipping** as revision of the IMO initial strategy set in 2018 was not seen to likely change significantly and deliberations around the EU Fit 55 program were still in the relatively early stages. Fast forward to 2023, and development has moved from Red/Amber in 2016 through to Amber/Green in 2023. The other key external area of the **Bunker Market and Fuel Prices** was deemed to have hardly moved at all, as the shipping industry still has no carbon price in place, high volatility and very limited supplies of high-priced alternative fuels. **Scepticism and Perception** issues were deemed to have moved however, moving from Red in 2016 to Amber in 2023 in line with more ships in operation and on the back of IWSA activities in the area, however these could be boosted further with increased promotional activities, audience specific messaging and policy makers having the opportunity to physically interact with ships and the technologies installed.

Existing Regulations to Reduce GHG [Red/Amber changed to Amber]

In 2016, there were calls for the EEDI to be tightened and other measures to be brought in such as an EEOI/EEXI In 2021, there was acknowledgement that the introduction of EEXI/CII would be beneficial for wind propulsion uptake, but that CII would need to have an enforcement element. The treatment of WPT within EEDI/EEXI was under consideration in the summer of 2021 and that led to adoption in December 2021 of the MEPC.1/Circ.896, the 2021 Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI and EEXI. This featured a collaborative and compromise treatment of WPT with the use of the best 50% of wind conditions to better reflect WPT performance and still requires work to fully represent all WPT systems equally and to reflect primary wind propulsion systems. The group noted that there was substantial movement with the EU's adoption of the Fit 55 program especially with EU ETS (2024), FuelEU Maritime (2025).

Policy/Market Incentives to Improve Energy Efficiency/Reduce GHG [Red changed to Red/Amber]

Two years on from the last workshop (IWSA Wind Propulsion Strategy Workshop 2021) and there are continued calls to accelerate the uptake of Market-Based-Measures (MBM). There is no agreement on an international carbon pricing structure for the industry, however there is now a pathway to finally have an IMO structure but not in place until late 2027 at the earliest. Regionally, shipping inclusion into the EU ETS is a significant move, but will only really impact WPT uptake once that is fully implemented in 2026 and an extension made to 400-5,000gt ships. Other national government and EU programs are supplying a limited amount of funding and policy incentives for WPT; however, these need to be substantially enhanced if they are to be effective.

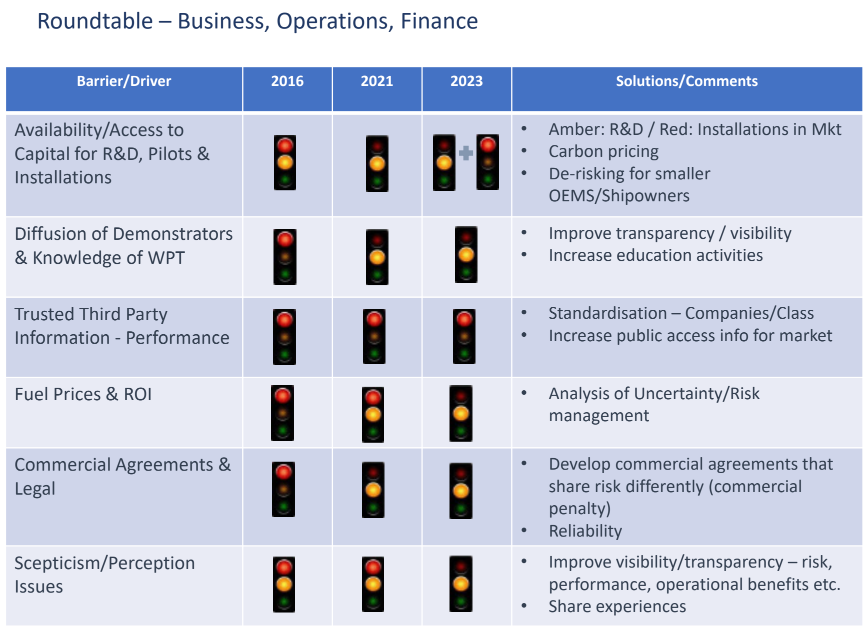
The group identified that there are a number of action areas that should be integrated in IWSA strategy. Also, IWSA should use its representation at IMO and through national delegation engagement to support efforts to create a robust global MBM with funds returned into the sector to aid with decarbonisation. A number of proposals for levies were discussed including an enhanced CII being adopted as a MBM with charges imposed on badly rated vessels also a noise levy was also floated as an option. The need for governments to shoulder any additional costs for crew training was also highlighted.

There needs to be more concerted efforts in the gathering and disseminating of WPT data whether that be the calculation of fuel savings, real case studies or technology showcases. On these matters, IWSA needs to further develop its activities including recent work on industry surveys, policy papers and whitepapers, for example the MEPC79/Inf 21 paper released in late 2022. IWSA will be releasing the reports mentioned here before the end of Q1, 2024. The measures to improve perceptions of WPT noted above will also have a significant impact as a market wide 'incentive' in its own right.

Inclusion of WPT in Regulations, Policy & Development Pathways [Holding at Red/Amber]

There has been only limited movement, with the MEPC.1/Circ.896 EEDI/EEXI issues listed above which is already embedded within the IWSA strategy/pathway and the need for IACS rules/guidelines to be more harmonised. There was a call to gather feedback on these guidelines from ships already in operation, owners, OEMs and other stakeholders to feedback on their efficacy. The group also agreed with the technical group that there is the need for standardised training and safety regulations to be put in place, with a regular five-year review cycle (like the treatment of cranes). There is also an issue with the under-estimation of the number/type of ships that can use WPT, the CII contribution and the diversity of WPT options available (for example 4th IMO GHG study, current UK Department of Transport (DofT) emissions modelling etc.), which are being increasingly engaged with by IWSA.

10-3-3 Business, Operations & Finance Issues



Roundtable – Business, Operations, Finance

Barrier/Driver	2016	2021	2023	Solutions/Comments
Availability/Access to Capital for R&D, Pilots & Installations	🔴🟡	🟡	🟡 + 🔴	• Amber: R&D / Red: Installations in Mkt • Carbon pricing • De-risking for smaller OEMS/Shipowners
Diffusion of Demonstrators & Knowledge of WPT	🔴	🟡	🟡	• Improve transparency / visibility • Increase education activities
Trusted Third Party Information - Performance	🔴	🔴	🔴	• Standardisation – Companies/Class • Increase public access info for market
Fuel Prices & ROI	🔴	🔴🟡	🟡	• Analysis of Uncertainty/Risk management
Commercial Agreements & Legal	🔴	🟡	🟡	• Develop commercial agreements that share risk differently (commercial penalty) • Reliability
Scepticism/Perception Issues	🔴🟡	🔴🟡	🟡	• Improve visibility/transparency – risk, performance, operational benefits etc. • Share experiences

Graphic 10-8: WPT Business, Operations & Finance Barriers – Summary (September 2023)

This larger subgroup broke into two teams and was able to cover a wider spread of the barriers just as the earlier 2021 workshop had. These two groups acknowledged that there had been progress across the board however that progress was not significant enough in each category from the availability and access to capital for R&D, pilots & installations, the diffusion of demonstrators and WPT knowledge and the need for trusted third party performance information, though that diverges from the points raised in the technical group. The need to update commercial agreements and revisit legal aspects that can restrict the full potential of WPT deployment, through to fuel prices, returns on investment and perception issues still persist and the two team's conclusions aligned quite closely on most of the key points raised below.

Availability/Access to Capital for R&D, Pilots & Installations [Red/Amber split with Red (general market finance) and Amber (R&D finance)]

There has been progress in the availability and access to capital for R&D in part through EU and other national funding facilities along with a number of larger companies entering the market with larger R&D budgets. This R&D funding is still patchy and doesn't compare with the levels of funding available for alternative fuel development. There needs to be an increase in the level of public funding support, especially aimed at SME's along with more of an emphasis on bringing WPT into the market and validating the technologies.

In the wider finance market, when it comes to funding installations things are more challenging. There are funds available for larger suppliers however most of the smaller suppliers' struggle. This is in part due to the usual financial risk appraisals and the need for loan security however, it is also challenging due to the lack of knowledge about the technologies among financiers and the lack of publicly available, third party validated performance data. These operational issues are compounded by the lack of carbon pricing and indirect subsidies that keep fuel costs down and thus make alternatives less attractive. When it comes to installations the groups felt that publicly supported funds that would act as security guarantees to support owners and help de-risk investments would give a significant boost.

Diffusion of Demonstrators & Knowledge of WPT [Holding at Amber]

Significant progress has been made, especially in the last 12 months, however the group participants still felt that there were too few demonstrator vessels to turn the corner to Green. There are over thirty ships in operation with WPT installed, however these feature a wide range of different designs and are spread fairly evenly across the bulker, tanker, RoRo, Ferry and general cargo segments, meaning that there isn't yet critical mass in any one of these.

More importantly it was noted that there is still much room for improved informed outreach to the market, that wider audience reach means IWSA and all of stakeholders need to be talking more to ports and terminals, cargo owners, charterers, the finance sector, to insurers and so on to spread the knowledge being garnered from these demonstrator vessels. As noted in the technical group discussion, this generic material is increasingly becoming available to designers/ naval architects but isn't being diffused as yet in the wider marketplace.

The key words highlighted under this discussion point were more transparency, more visibility and more education.

Trusted Third Party Performance Information [Holding at Red]

In the market this issue still remains a collective bottleneck. Individual suppliers do have third party performance information available for prospective clients however the collation and aggregation of this data is challenging. It was acknowledged that there have been efforts to improve the situation, notably through the EU Interreg WASP project which studied five ship installations. This lack of trusted comparative data is in part due to the complexity of that comparison with many variables at play and in part due to the relatively limited number of demonstrators in each segment and a reticence by OEM's to openly share commercially sensitive datasets, however regardless of the reasons this situation leads to a lack of trust from potential customers. The group discussed the need for standard evaluation criteria which are currently under development under the auspices of the ICCT which will make it far easier to compare WPT performance. There was also the call for all IWSA members to agree on using the same data and methodology, a standardisation agreement by classification societies and a commitment to also publicise the work and data that has been done more widely. There was also discussion of an envisioned role for the IMO to ensure that certificates are issued with caution.

Fuel Prices & ROI [Red/Amber changed to Amber]

The original report and follow up workshop in 2021 called for policy level action on MBMs, including carbon levies. In the preceding two years there has been movement in this regard with the gradual inclusion of shipping in the EU ETS system set to come into force on 01 January 2024 and with the setting of the IMO Decarbonisation Strategy in July 2023, the discussions around the basket of global MBMs and other mid-/long-term measures is now accelerating, however the earliest that will come into force is likely to be 2028. While a carbon levy will deliver upward pressure on fuel prices along with the increasing amount of more costly alternative low emissions fuels slated to grow to 5-10% of the total fuel supply by 2030, there was a high level of uncertainty about how affective a modest increase in fuel prices will have on WPT uptake. There is uncertainty across the board on bunker prices and the future regulatory framework, thus customers tend to hedge against those uncertainties.

The cost of producing WPT systems is likely to come down over the next couple of years due to economies of scale and the learning curve which will feed into improving the ROI for WPT. IWSA was urged to keep up its efforts to engage with developing a 'level playing field' when it comes to decarbonisation pathways and in the MBM development at the IMO to ensure that a robust and high ambition carbon level is introduced and that a hypothecated (or ring-fenced) tax making funding available for R&D and installations would be ideal, but that IWSA should also help more to identify additional finance opportunities.

Commercial Agreements & Legal [Holding at Amber]

This area of commercial agreements and the legal aspects of installing and operating WPT and primary wind ships has seen some movement but still remains stuck at amber. Parties are still learning how to allocate risk; the structure of commercial agreements are not standardised, and this extends to performance guarantees. Commercial agreements need to be developed that share risks differently, e.g., including penalties and shift risk between supplier and customers to customer. There have been internal IWSA discussions around this issue and the association is urged to raise the priority of these and formally engage with the appropriate stakeholders to start developing these standards and industry guidelines.

Scepticism/Perception Issues [Red/Amber to Amber]

The issue of changing perceptions continues to be a challenging area, however, there has been progress made in both policy circles and in the market. IWSA has been engaging more with market analysis and surveying attitudes towards the scaling of wind propulsion which will be ongoing and valuable as benchmarks to gauge progress going forward.

There is still a lot of scepticism though, especially among likely late adopters, however this is counterbalanced to a degree by the growing number of demonstrator ships and first mover activity. The group identified this as a priority area for action as it is multi-faceted and entrenched, thus it is deemed to be a high priority issue. Although progress has been made, especially with first movers, there is still a lot of work to be done here. There is need for the IWSA and members to widen the message/audience, including cargo owners, finance and consumers and to hone the messaging to these audiences. This needs to go in tandem with an increased visibility and transparency concerning WPT benefits including comparisons with other fuels/energy sources, reliability, operational impact and additional benefits to the ships with WPT installed. The 2021 call for IWSA to consider improving its branding and employ a specialist communications company takes on added urgency as the sector is growing. Taking that to another level, participants highlighted that IWSA should also consider bringing a large change management company onboard to improve strategy etc.

10-4-4 Concluding Comments

While there has been significant progress over the past two years and indeed the seven years since the initial EU commissioned report was published in 2016 (CE Delft 2016/17), there is still a lot of work to be done. The picture painted by the aforementioned roundtable findings is one that follows a fairly straightforward pattern of new technology dissemination. The good progress made in the technical side of things is to be expected as designers/engineers and naval architects get more familiar with the technologies and design parameters and as demonstrator vessels increase, so does the technical data and performance validation. This all feeds into the development and improvement of class guidelines and standardisation of approaches. The policy framework and inclusion of WPT into the policy realm and industry decarbonisation pathways is taking more time. Entrenched perceptions are a challenge here along with the structural inertia and caution around changing existing regulations and policy vehicles that may not now be fit for purpose. However, in the case of the wider strategy and targets, there has been substantial movement and much of that has come in the last 1-2 years (with the IMO in the last few months) and that change in focus and closer alignment to climate targets etc. takes time to filter into regulatory and policy change, however the ball is rolling in this field.

As with all new technologies, or in wind propulsion's case, 'renewed' technology, there are building blocks that are required to move the market towards scaling and full dissemination and this progress generally follows the classic 'S-curve' model. With the technical and policy areas moving in the right direction, so it comes to the market and finance to move and move robustly. Progress has been made here, but that is patchy and often due to the commercial sensitivity surrounding data sharing on performance etc. in this early stage of market uptake (with only 30 ships in operation up to the end of Q3, 2023 utilising 13 different companies WPTs) this is understandable. Nonetheless, safety, compliance, trust, confidence, operability and commercial viability are the corner stones required for that dissemination to kickstart.

The first two are in the bag, trust/confidence is growing but needs to be backed by the data so the final two can be adequately assessed and the risks mitigated – here more work needs to be done. Some of that will come from the natural growth of installations in the market, however for a step change to occur, that data and ease of assessment needs to be ramped up quickly.

Additional reference: Barriers & Overcoming Strategies for Accelerating the Uptake of WASP (December 2021)
https://vb.northsearegion.eu/public/files/repository/20220111103132_WASPWP4.D5B_Barriersandovercomingstrategiesforacceleratingtheuptakeof WASP.pdf

11) Regulatory Gaps, Recommendations & Work Underway

11-1 Regulatory Gaps

There are a number of general regulatory deficiencies that require action. These can be grouped in four general categories and recommendations for action on these are made in Section 11-2.

11-1-1 Level Playing Field Assessment

Most regulatory and policy pathway development at a National, Regional and International level to-date has neglected to include and integrate direct renewable energy sources such as wind energy used for propulsion in the structures and formula used. There is a strong tendency for policy makers to view this through a 'fuel-centric' approach and that wind propulsion technology is viewed as only an 'assist' at best or as an 'energy efficiency' measure rather than wind energy being a 'propulsive force energy source.'

The IMO Lifecycle Assessment of Fuels does recognise directly harnessed wind energy as a 'fuel', which is designated as Pathway 128 and the Fuel EU Maritime legislation that will enter into force in 2025 extends a reward factor ranging from 0.95 to 0.99 for the use of wind propulsion, however in this same formula, RFNBO fuels receive a 2x multiplier in the calculation to encourage uptake and thus incentivise the building out of the infrastructure required to produce, transport and bunker those alternative low carbon fuels.

11-1-2 Full Emissions Calculation

The full appreciation of the value of direct wind energy for the propulsion of ships is limited by the siloed approach to the reduction of emissions. The separation of emissions from fuel into their constituent parts has led to the sidelining of many of the key advantages from adopting wind propulsion as a solution.

Wind energy is a zero-rated emissions energy source and the current focus solely upon direct GHG emissions is a good example of this where non-GHG climate impacting emissions such as Black Carbon, VOCs, fugitive H2 emissions etc. are not included in the assessment of fuel pathways. The reliance on machinery and standard propellor propulsion trains also leads to high levels of Underwater Radiated Noise (URN) which can be reduced through wind-assist and effectively eliminated in primary wind vessels when using wind propulsion alone.

From a timing perspective, there is also a key consideration that wind propulsion also enables zero-emissions energy to be made available immediately, without the need for a transition period or the need to blend fuels etc.

11-1-3 Finance & Subsidies

The financial structures and subsidy framework currently in place are not well aligned with a non-commoditised energy source such as wind. An unlimited zero-emissions energy source that can't be traded or owned is once again often classed as an 'energy efficiency' measure and thus not necessarily considered as an attractive, sustainable revenue generator for investors. Wind energy for the propulsion of ships is an energy source that is confined solely within the maritime sphere whereas other fuels being considered (and the existing fossil fuel options) are also fully incorporated in other land-based markets and supply chains with uses across industrial sectors, thus easily attracting attention for subsidies and from investors.

As mentioned in Section 11-1-1, there is a lack of a level playing field assessment here too and a Total Cost of Ownership (TCO) assessment that incorporates all externalities and risks associated with each fuel pathway is either non-existent or only partially implemented.

The restrictions implemented on financial regulations can also cause issues, such as the adoption of an arbitrary lower limit of 5,000GT size in the EU ETS and Fuel EU Maritime regulations which excludes a very important smaller vessel segment where WPT can be very effective and where scaling of installations quickly could be introduced and thus generate a virtuous circle of mass production, lowering of costs and acceleration of scaling both in size and dissemination to other ship sectors.

11-1-4 Safety & Technical

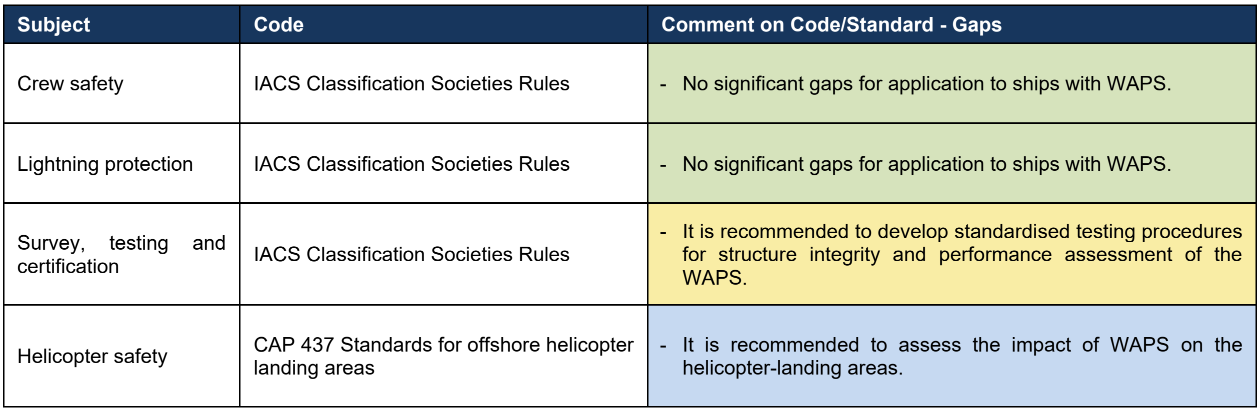
A detailed analysis of these issues has been made in the European Maritime Safety Agency (EMSA) report released in November 2023. IWSA members will be actively engaged in reviewing and refining the issues highlighted and the priority levels designated in this report. The gap analysis from p106-110 which also give comments on the focal points is presented here in the Graphic 11-1

Gap Analysis Legend

🟩 No gap or changes needed to address wind-assisted propusion
🟦 Small gaps or minor changes to address wind-assisted propulsion
🟨 Medium gaps or some challenging required to address wind-assisted propulsion
▨ Large gaps or many challenging changes required to address wind-assisted propulsion

Subject	Code	Comment on Code/Standard - Gaps
EEDI	IMO MARPOL Annex VI	🟨 - Regulation 22/23 of MARPOL Annex VI requires that the attained EEDI/EEXI shall be calculated. - Regulation 24/25 of MARPOL Annex VI provides EEDI/EEXI requirements. - Hybrid definition is unclear
	The IMO 2022 guidelines on the method of calculation of the attained EEDI for new ships, Resolution MEPC.364(79)	🟨 - Focus on the method of calculating the attained EEDI.
	The IMO 2021 Guidance on Treatment of Innovative Energy Efficiency Technologies for Calculation and Verification of the Attained EEDI and EEXI, Resolution MEPC.1/Circ 896	🟨 - Focuses on the method of treating innovative energy-efficiency technologies for calculation and verification of the attained EEDI/EEXI. - The guidance needs to be improved in several aspects to better assess the contribution of WAPS to EEDI/EEXI, such as the determination of wind-force matrix, the use of wind-probability matrix and the methods of verifying sea trials.
	The IMO 2022 Guidelines on Survey and Certification of the EEDI, Resolution MEPC.365(79)	🟦 - Focus on the survey and verification of EEDI. - Do not consider the impact of WAPS on the verification procedure.
	Ships and marine technology — Guidelines for the assessment of speed and power performance by analysis of speed-trial data, ISO 15016:2015	▨ - Focus on the procedures to be applied in the preparation, execution, analysis and reporting of speed trials for ships. - It is difficult to use the procedure to evaluate the performance of ships with WAPS during sea trials. - A standardised methodology needs to be for full-scale evaluation of ships with WAPS based on ISO standards.
Regulations for EU Member States	Fuel EU Maritime	🟦 - Focus on increasing the demand for renewable and low-carbon fuels for ships sailing to and from EU ports. - Focus is on well-to-wake emissions. - Credits are given for WAPS, based on EEDI methodology
	EU Emissions Trading System (ETS)	🟦 - Sets a limit on the yearly maximum of GHG emissions and the trading of EU emission allowances. - Only focused on tank-to-wake emissions - WAPS is considered implicitly resulting in lower fuel consumption.
	EU Energy Taxation Directive	🟩 - Maritime sector has been fully exempted so far. - Revised proposal in which maritime sector is included. - WAPS is considered implicitly due to lower fuel consumption. - Member states independently implement national policy.
	EU RED	🟨 - Divided incentives for shipowners and operators do not stimulate the deployment of renewable sources. - Wind propulsion has not been included in the list of renewable energy and power sources under RED. - Member states independently implement national policy.
Stability	IMO International Code on Intact Stability, Resolution MSC.267(85)	🟨 - Provides requirements of intact stability for several types of ships and marine vehicles. - Does not consider the impact of WAPS on the stability requirements. - The criteria in the Code may not work for ships with WAPS.
	Interim Guidelines on the Second Genration Intact Stability Criteria (MSC.1-Circ.1627).	🟨 - The criteria in the report may not work for ships with WAPS.

Subject	Code	Comment on Code/Standard - Gaps
	IMO SOLAS II-1	- Provides requirements of intact stability and damage stability for passenger ships and cargo ships. - The criteria in the Code may not work for ships with WAPS.
	IMO Resolution MSC.429 (98)	- Provides interpretation to SOLAS Chapter II-1.
Manoeuvrability and course keeping	IMO Standards for Ship Manoeuvrability, Resolution MSC 137 (76)	- Focuses on ships with conventional propulsion systems and does not consider the impact of WAPS on ship manoeuvrability and course-keeping.
MPP	IMO Guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions, Resolution MEPC Circ.850	- Focuses on the method to determine the MPP for maintaining the manoeuvrability of tankers, bulk carrier and combination carriers in adverse conditions. - It would be beneficial to develop a uniform methodology to calculate the EEDI and MPP.
Bridge visibility and safety of navigation	IMO Revised Performance Standards, Resolution MSC.192(79)	- Provide requirements of radar equipment. - Does not consider the impact of large sail areas which may cause ‘radar blind’ sectors. - It is recommended to develop specific guidelines to use alternative methods and address the larger blind sectors caused by the WAPS to radar.
	IMO SOLAS V	- Regulation 19/2.7 provides requirements regarding radar systems and blind sectors. - Reg 22 provides detailed requirements for navigation bridge visibility. - Regulation 22/3 leaves special consideration open for “unconventional design. - Does not consider the impact of large sail areas which may cause larger blind sectors than required. - It is to be demonstrated that the vessel with a WAPS satisfies the requirements under SOLAS Chapter V. - Where compliance is impractical, alternatives will be considered on a case-by-case basis in association with the Flag Administration. - It is recommended to develop specific guidelines for using alternative methods to address the larger blind sectors caused by the WAPS.
	IMO Guidelines for the Installation of Shipborne Radar Equipment, SN1/Circ.271	- Some types of WAPS which have a large sail area may affect the ships’ ability to meet the requirements in guidelines.
	IMO Convention on the International Regulations for Preventing Collisions at Sea 1972 (COLREG 72)	- Provides detailed specification for the types and locations of the navigational lights that are required to be installed on the vessel. - It is recommended to develop specific guidelines for using alternative methods to address the larger blind spots caused by the WAPS to navigation lights.
Structure	IACS Classification Societies Rules	- It is recommended to develop a comprehensive guideline to provide customised requirements for load determination of different types of WAPS.
Materials	IACS Classification Societies Rules	- It is recommended to include the certification of the materials for various types of WAPS.
Mooring equipment	IACS Classification Societies Rules	- No significant gaps for application to ships with WAPS.
Electrical systems, machinery, control systems	IACS Classification Societies Rules	- No significant gaps for application to ships with WAPS.
Fire safety and installations in hazardous areas	IACS Classification Societies Rules	- No significant gaps for application to ships with WAPS.
	SOLAS II-2	- No significant gaps for application to ships with WAPS.



Subject	Code	Comment on Code/Standard - Gaps
Crew safety	IACS Classification Societies Rules	- No significant gaps for application to ships with WAPS.
Lightning protection	IACS Classification Societies Rules	- No significant gaps for application to ships with WAPS.
Survey, testing and certification	IACS Classification Societies Rules	- It is recommended to develop standardised testing procedures for structure integrity and performance assessment of the WAPS.
Helicopter safety	CAP 437 Standards for offshore helicopter landing areas	- It is recommended to assess the impact of WAPS on the helicopter-landing areas.

Graphic 11-1 – EMSA Report - Table 25. Synopsis on Regulatory Gap Analysis for Wind-Assisted Propulsion.

11-2 Recommendations

- Raise decarbonisation target ambition and interim targets wherever possible to match the holistic potential of adopting wind propulsion, energy efficiency, voyage optimisation in combination with fuels.
- Institute and fund an updated Comprehensive Impact & Market Analysis of wind-assist and primary wind developments.
- Fund and support the development and deployment of a wind-assist and primary wind LDC/SIDs SDG17 Delivery Fleet (funded by developed countries) that will help significantly to unplug these severely climate impacted and fuel dependent regions creating a powerful symbol of commitment to ensuring a ‘Just and Equitable Transition’.
- Evaluate the application of a ‘wind-ready’ notation for all new build vessels and consider incentivising retrofit ‘wind-ready’ adaptations to existing ships.
- Launch a program of fishing vessel assessment and piloting for the installation and design of WPT equipped vessels.
- Create a regular annual survey of trends and perceptions of WPT industry wide and among policy makers.

11-2-1 Level Playing Field Assessment

- Adopt an ‘energy-centric’ approach to the decarbonisation of shipping, not solely a ‘fuel-centric’ one.
- Integrate WPT into all policy, decarbonisation pathways and business/finance structures.
- Recognition of direct wind energy use as a ‘fuel’ pathway, not simply as an ‘energy efficiency measure’ in all policy and decarbonisation pathways. Generate a standardised approach to this and disseminate that to all regulatory and financial bodies etc.
- Remove 5,000GT vessel size lower limit on all regulations to ensure fair treatment of technology scaling.
- Support the analysis and development of ‘wind-green corridors’ that combine the elements of wind propulsion, voyage optimisation and green fuels, not exclusively the latter as is the current approach.

11-2-2 Full Emissions Calculation

- Adopt a ‘holistic’ approach that includes all emissions (not GHG only), a Well-to-Wake approach with considerations of circularity, breaking and waste cycles, along with the internalisation of all external costs and impacts (health, security, climate, risk etc.) when setting policy priorities and emission reduction pathways.
- Consider the use of pure zero-rated emissions direct wind energy as the baseline for all fuel and energy assessments.
- Accurately measure WPT systems and energy provision through DCS/MRV and other policy instruments.

11-2-3 Finance & Subsidies

- Adopt a Total Cost of Ownership (TCO) approach where all costs and externalities are included in the assessment of decarbonisation pathways.
- Place wind propulsion on an equal footing with alternative fuel support/incentives and subsidies commensurate with the scale of energy provision and ease of scalability.
- Acknowledge and compensate for the support/incentives already available to alternative fuels and fossil fuels through land-based and out of sector developments.
- Initiate an in-depth assessment of the un-level playing field currently in place regarding the evaluation of energy sources for shipping, subsidy programs and national/international systems that strongly favour both fossil fuel and alternative low emissions commoditised fuels.
- Introduce adjustments to the taxation system to further incentivise wind propulsion systems due to their immediate deployability and as an abundant energy resource. (e.g. favourable multiplier, innovation & R&D credits, enhanced carbon credits, reduced tonnage taxes, port fees etc.)
- Underwrite the financial investments for early market deployment and scaling of WPT therefore ensuring installations are de-risked. Underwrite a leasing and/or ‘pay-as-you-save’ model of financing for WPT installations.
- Evaluate a tax credit system (or similar) that encourages cargo owners to issue long term (5-10 years) tenders specifying ‘ultra-low emissions and primary wind’ for new builds vessels.
- Financially support a wind propulsion ‘Innovation Accelerator Program’ to ensure that adequate resources, R&D activities and training are being undertaken in the field.
- Re-evaluate and support small scale sail cargo vessels under 400gt to facilitate the growth of local and short sea shipping zero-emission networks. Support the development of the small sail cargo and sail fishing vessel segment through tax incentives, reduction of port dues, cargo guarantees, early development subsidies and other facilitation measures.

11-2-4 Safety & Technical

- Support and help facilitate the immediate changes/updates and clarifications made wherever possible to existing regulation in relation to wind propulsion.
- Look at the regulatory framework to ensure novel approaches (tugs, wind as service, modular etc.) are not excluded.
- Establish government funding for a standardised WPT training curriculum education program for all seafarers.
- Introduce a Wind Propulsion Readiness Plan and Onboard Renewable Energy Generation Regulatory tool to match onshore energy provision stipulations for OPS.
- The EMSA report (2023) also specifies a number of recommendations and suggestions for further action. While not fully endorsed by all members of the technology segment, these are indicative of many of the areas requiring attention;

> “The installation and operation of WAPS introduces additional considerations for the safety and performance of the vessel. Many regulations, standards and guidelines do not consider the impact of WAPSs, and this imposes a barrier to their adoption. The specific impact of WAPS on ship manoeuvrability, stability, EEDI performance, MPP and helicopter-landing areas needs to be assessed. Present regulations, standards and guidelines need to be updated to consider the impact of WAPS and facilitate their adoption.”

Specifically, these are the near-term actions and regulatory gaps that need to be addressed:

- Derive a practical methodology for assessing the contribution of WAPS to the EEDI/EEXI and make correspondent updates to regulation MEPC.1/Circ. 896.
- Develop a standardised methodology for full-scale evaluation and verification of EEDI/EEXI for ships installed with WAPS.
- Develop specific guidelines for the navigation safety of ships with WAPS that allow alternative methods to be used to compensate the larger blind spots that are caused.
- Investigate if the present criteria in the IMO Code on Intact Stability and IMO's second generation of stability criteria should be adapted to ships with WAPS.
- Investigate if damage stability criteria for all ships should be adapted to ships with WAPS.
- Investigate if the present criteria in the IMO Standards for Ship Manoeuvrability are applicable to ships with WAPS.
- Develop a uniform for MPP.
- Resolve the categorisation of WAPS under non-conventional or hybrid propulsion and associated implications.
- Derive customised requirements to determine the loads of the different types of WAPS.
- Include the certification of the materials for various types of WAPS in the class rules.
- It should be evaluated whether Class Societies need to create a UR to cover some key aspects for WAPS, including loads, materials, electrical systems, crew safety, lightning protection, survey and testing, etc.
- The impact of WAPS on helicopter-landing areas needs to be assessed.

11-3 Work Underway

The continuing development of the wind propulsion sector is supported by an extensive network of companies, R&D centres, naval architects, engineers and experts, many of them are members of the International Windship Association (IWSA). This network ensures that there is a relatively strong collective approach to the policy, standards, regulatory compliance and R&D that is underway in this technology segment.

- **Technical University Delft WASP Research Program:** Multi-year and multidisciplinary research program dedicated to launched in October 2023 steered by an interfaculty collaboration between the department Maritime & Transport Technology (3mE) and the department of Flow Physics & Technology (AE) to facilitate the development of high-performing Wind Assisted Ship Propulsion (WASP). This research platform will combine the expertise of six research groups and have twelve full time postgraduate researchers. https://www.tudelft.nl/3me/over/afdelingen/maritime-and-transport-technology/research/wind-assisted-ship-propulsion
- **Wind Assist Ship Propulsion (WASP):** A three-year project launched in Oct 2019 (completed July 2023) and part funded by the Interreg North Sea Europe programme, part of the European Regional Development Fund (ERDF). The project brings together universities, WPT providers and five ship owners to research, trial and validate the operational performance of a selection of WPT solutions. https://northsearegion.eu/wasp/
- **WiSP:** This JIP (launched July 2019) led by ABS and MARIN has the objective to overcome barriers to the uptake of WPT, specifically to improve methods for transparent performance prediction, use these improved methods to provide ship owners/operators with fast low-cost predictions for their fleet and to review the regulatory perspective including status of rules and regulations, identify gaps and make recommendations, and provide examples on establishing compliance. Phase II started in October 2021 and will conclude in December 2023. https://www.marin.nl/en/jips/wisp-2 Phase III will commence in early 2024 https://www.marin.nl/en/jips/wisp-3
- **Flettner Fleet:** (01/2023 – 12/2025) - The aim of the project is to develop a scientific and technological platform to prepare the market penetration of Flettner rotors on various types of ships as a contribution to lower-emission shipping. In this context, the aim is to find an optimal configuration of the interaction of Flettner rotors with the main propulsion system and to adapt the ship design so that the Flettner rotors can be operated highly efficiently. The project has 17 academic and industrial partners https://www.mariko-leer.de/frischer-wind-fuer-die-flotte/

- **Optiwise:** The project scope involves extensive simulations where different disciplines, such as aerodynamics, hydrodynamics, routing and energy management are holistically brought together. The systems being tested include rotors sails, wing sails and a hybrid sail. Great attention will be applied to ensure realistic operational applications of the developed designs. These will be complemented with basin tests to assess manoeuvring and seakeeping, bridge simulations to assess crew operation, and land-based wind propulsion tests to verify better control. The project will deliver open guidelines for integrated system optimisation with wind propulsion and smart measurement and control for best operation. More information available here: https://www.marin.nl/en/jips/optiwise

- **RETROFIT55:** This project aims to develop a combination of energy-saving solutions that can be adopted in retrofitting aimed at achieving the 35% of GHG emissions. Two new technologies, i.e. wind assisted ship propulsion and an innovative air lubrication system, will be developed together with other solutions that, although based on already mature technologies, such as operational and hydrodynamic design optimization and ship electrification, have to be expanded to be integrated with the new solutions as well as to cope with the constraints posed by the original ship design. The final objective of RETROFIT55 is to create an advanced web-based Decision Support System (DSS), that fuses together digital twins of the different systems into an integrated digital ship model. The DSS will feature a catalogue of retrofitting solutions that are up-to-date and ready to be deployed at the end of the project and easily extendable afterward while developed and demonstrated at TRL 7-8, suitable for different ship types and operational contexts. The DSS will enable the user to configure the retrofitting by combining different options which are suitable for the specific ship type and comparing them in terms of life-cycle cost, return-of-investment and several KPIs, such as EEXI, CII. Referring to the ZEWT strategy, while primarily contributing to the Design and Retrofit, the implementation of the project will also intersect other topics, such as Use of Sustainable Alternative fuels, Energy Efficiency, Electrification and Digital Green. The consortium brings together universities and research institutions, three developers of the new technologies, a ship design office, software developers, ICT experts, a classification society, a ship-repair company, and two large ship operators. https://www.retrofit55.eu/

- **ZHENIT project:** overall objective is to promote Waste Heat Recovery (WHR) as key and "ready-to-implement" solutions to achieve 2030 IMO/EU targets for shipping sector decarbonization. ZHENIT goal is to fully untap "on-board WH potential" developing and validating WHR solutions at different temperature levels towards the exploitation of WH for different on-board services (cooling, power, desalination) thus able to valorise heat in different vessel processes like: WH-to-Trigeneration via an innovative recuperated ORC integrated with an heat pump with ejector (T>100°C); WH-to-Cooling and Desalination via an adsorption system (70<T<100°C); WH-to-Mechanical Work (e.g. for fuel compression) via an isobaric expansion (IE) engine (T<100°C). A validation campaign (TRL5) will showcase how WH-to-X if properly integrated with Digital Solutions (energy monitoring and optimized management) and wind hybrid propulsion (wingsail by BOUND4BLUE) can bring to a 25% reduction of vessel energy consumption. Validation results will drive a replication roadmap (at regulatory and economic level) towards 2027-2030 marketability of ZHENIT solutions also thanks to realization of replication feasibility studies via modelling tools and approaches already exploited for terrestrial application. The ambitious goal is to integrate all WH-to-X solutions towards a zero WH vessel. The project is driven by a consortium of 13 partners from 6 countries composed by innovative SMEs and excellent R&D Centres (expert in both WHR systems and sustainable shipping). https://www.zhenit.eu/CONCEPT.html

- **International Towing Tank Conference (ITTC):** The ITTC has established the 'Specialist Committee on Performance of Wind Powered and Wind Assisted Ships' and the terms of reference are set out below:

    1. Review technologies for wind propulsion and wind assistance. Clarify the distinction between wind powered and wind assisted ships.

    2. Review methods of ship model hydrodynamic tests, wind tunnel tests, CFD, ship dynamics simulations and routing relevant for predicting the performance and safety of wind powered and wind assisted ships at design stage with particular attention paid to higher side forces and drifting of the ship due to wind powering.

    3. Review long-term statistics of winds and waves from the point of view of applicability for the evaluation of wind assisted ships at design stage.

4. Derive a guideline for predicting the fuel consumption of a wind propulsion ship on a route at design stage with the consideration of weather-routing effects.
5. Review safety and regulatory issues related to hydro/aero dynamic testing and evaluation and recommend measures to take at design stage.
6. Derive performance indicators for comparing the performance of wind propulsion at design stage.
7. Investigate the effect on propulsive factors due to reduced propeller load arising from the use of wind power. Identify the effects of wind propulsion on the propulsion system, e.g. pressure side cavitation occurrence. Liaise with Resistance and Propulsion Committee and SC on Cavitation and Noise.
8. Derive a modified procedure for full scale trial of wind propulsion ships. Liaise with Full Scale Performance Committee.
9. Cooperate with MEPC on the continuous development of the EEDI for wind propulsion ships. Liaise with Full Scale Ship Performance Committee.
10. Liaise with the Ocean Engineering Committee regarding their work on SiL and controllable fans to model wind loads.

https://ittc.info/media/10159/tor-revised-after-conference.pdf

- **European Sustainable Shipping Forum (ESSF): Ship Efficiency Sub-Group - Wind Propulsion Workstream (2022-24)**

Terms of Reference

Task 1 – Technical Aspects of Wind (Assisted) Propulsion Systems
- Assessment of WAPS performance
- Assessment of WAPS performance
- Technical WAPS paper(s)

Task 2 – Regulatory and Policy Developments

Task 3 – Overview of Wind Propulsion Developments

Task 4 - Recommendations for Further Research (2023)

Objective: Consolidate input from Tasks 1.2, 1.3, 2 and 3 & Consider technical, operational (ship and ports), economic (finance, market barriers), legal (chartering) aspects; regulatory elements

- **International Windship Association (IWSA):** This not-for-profit membership association was established in 2014 and now with over 150 members and associates with the objective to facilitate and promote wind propulsion for commercial shipping and bring together all parties in the development of a wind ship sector. Activities include the development of wind propulsion regional hubs worldwide, communications, policy work, education program etc. along with support for specific initiatives undertaken by members.

IWSA is engaged with many of the projects underway, especially concerning communications, dissemination of results and convening working groups on policy, communications and economic assessments etc.

Developing a number of wind propulsion hubs worldwide and involved with the development of a Wind Propulsion Accelerator Program to boost the R&D pipeline of projects along with training and research.

www.wind-ship.org

Campaign Website: www.decadeofwindpropulsion.org

- **Association Windship:** The Wind Ship Association was established in 2019 as a French national cluster organisation and part of the IWSA network, also functioning as the IWSA Europe – Atlantic hub. The association brings together more than 30 players in the wind propulsion sector : equipment manufacturers, naval architects, design offices, shipyards, shipowners, consultants, etc. www.wind-ship.fr

  The NORVENT project has been working on the state-of-art needs and procedures used for WPT performance assessment to help deliver shared reliable guidelines. The DIGI4MER – WP2 project is also working to deliver an online theoretical training in wind propulsion for seafarers. The projects are led by the IWSA Europe-Atlantic hub.

- **Micronesian Center for Sustainable Transport**: MCST is a project to build and operate a Pacific country-owned and-focused world-class Centre of Excellence as a research engine to empower the long-term decarbonization of Pacific transport and the advocacy of the Pacific in related international fora and negotiations. MCST is an advanced approach to decarbonization situating country and community at the center with external experts on-tap, not on-top, prioritizing long-term capacity development based on education and research and committed to a paradigm-level transition commensurate with a 1.5-degree agenda that recognizes the need for bespoke Pacific transport solutions. MCST has done extensive work on wind-assist and primary wind propulsion systems for deployment in the Pacific region and the center is home to the IWSA - Pacific Hub. https://www.mcst-rmiusp.org/

12) References

ABS Wind Propulsion Guidelines (2022):
https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/other/315-requirements-for-wind-assisted-propulsion-system-installation/315-wind-asisted-propulsion-reqts-july22.pdf

Allwright, G (April 2023) - Return Journey: Call for an 'energy-centric' approach to green shipping corridors, Bunkerspot article, https://www.bunkerspot.com/features-all/item/return-voyage

Allwright, G, (October 2021) - Maritime fuel and other subsidies. Wind-Up or Wind Up?, The Naval Architect article, https://rina.org.uk/publications/the-naval-architect/maritime_fuel_and_other_subsidies_wind_up_or_wind_up/

Allwright, G, (March 2021) - Could wind propulsion fund the full decarbonisation of shipping?, Splash 24/7 article, https://splash247.com/could-wind-propulsion-fund-the-full-decarbonisation-of-shipping

Association Windship (2022) - WIND PROPULSION FOR SHIPS: Technologies ready to decarbonise maritime transport. An industrial opportunity for France, October 2022
https://drive.google.com/file/d/1NOMu1kGaXvNa1CkspSYqHUOWk3xeb_eO/view?pli=1

Bordogna, G (2020) – Aerodynamics of Wind-Assisted Ships: Interaction effects on the aerodynamic performance of multiple wind propulsion systems, PHD Dissertation, TU Delft.
https://doi.org/10.4233/uuid:96eda9cd-3163-4c6b-9b9f-e9fa329df071

Brittany (2022) - Prospective study of the Breton industrial sector wind propulsion for ships: Overview and Key Figures 2022 Edition https://www.bdi.fr/wp-content/uploads/2022/09/2111110-BDI-Developpement-Innovation-Propulsion-par-le-vent-Brochure_en_def-1.pdf

Brittany (2022) – Wind Propulsion – Map & Directory https://www.bdi.fr/en/publications/wind-propulsion-of-ships#map-directory/

Bureau Veritas (2022) Powering marine decarbonization with wind-assisted propulsion
https://marine-offshore.bureauveritas.com/powering-marine-decarbonization-wind-assisted-propulsion

Bureau Veritas Wind Propulsion Guidelines (2021):
https://erules.veristar.com/dy/data/bv/pdf/206-NR_2021-02.pdf

CE Delft (June 2023) - Shipping GHG emissions 2030 Analysis of the maximum technical abatement potential.
https://cedelft.eu/wp-content/uploads/sites/2/2023/06/CE_Delft_230208_Shipping_GHG_emissions_2030_Def.pdf

CE Delft (2016) - Study on the analysis of market potentials and market barriers for wind propulsion technologies for ships, Dagmar Nelissen (CE Delft) Michael Traut (Tyndall Centre) Jonathan Köhler (Fraunhofer ISI) Wengang Mao (Chalmers University) Jasper Faber (CE Delft) Saliha Ahdour (CE Delft), Nov 2016
https://cedelft.eu/wp-content/uploads/sites/2/2021/04/CE_Delft_7G92_Wind_Propulsion_Technologies_Final_report.pdf

Clark et al (2021) - Zero-Emissions Shipping: Contracts-for-difference as incentives for the decarbonisation of international shipping, Alex Clark, Matthew Ives, Byron Fay, Ronan Lambe, Johanna Schiele, Lukas Larsson, Jessica Krejcie, Leah Tillmann-Morris, Peter Barbrook Johnson, and Cameron Hepburn – Smith School of Enterprise and Environment, University of Oxford, Institute for New Economic Thinking & Pincent Masons, June 2021
https://www.inet.ox.ac.uk/files/zero-emissions-shipping-FINAL.pdf

China Ship Classification Society (2023): Guidelines for Survey of Marine Wind-Rotor Assisted Propulsion System 2023
https://www.ccs.org.cn/ccswzen/file/download?fileid=202301300953804120

Chuo, T (2020) - A Comeback of Wind Power in Shipping: An Economic and Operational Review on the Wind-Assisted Ship Propulsion Technology. Chou, T.; Kosmas, V.; Acciaro, M.; Renken, K., Sustainability 2021, 13, 1880.
https://doi.org/10.3390/su13041880

ClassNK Wind Propulsion Guidelines are downloadable from www.classnk.com

Comer, B et al (2022) - Decarbonizing Bulk carriers with Hydrogen Fuel Cells and wind-Assisted Propulsion: A Modelled Case Study Analysis , Bryan Comer, Elise Georgeff, Xiaoli Mao, Liudmila Osipova International Council on Clean Transportation & Douglas Stolz, Cross Product Atmospheric LLC
https://theicct.org/wp-content/uploads/2022/01/Hydrogen-and-propulsion-ships-jan22.pdf

D-ICE & Ecole Polytechnique (2023) - Weather Routing Benefit for Different Wind Propulsion Systems, first presented at RINA/IWSA Wind Propulsion Conference Feb 2023 – summary available in MEPC 80/INF.33 – updated paper (May 2023):
https://www.researchgate.net/publication/371957698_Weather_Routing_Benefit_for_Different_Wind_Propulsion_Systems

DNV Maritime Impact (2022) https://www.dnv.com/expert-story/maritime-impact/more-commercial-ships-utilize-wind-technologies-to-cut-emissions.html

DNV Maritime; Wind assisted Propulsion - Rules, Standards, Services and Publications WAPS - Wind Assisted Propulsion Systems - DNV
https://www.dnv.com/maritime/insights/topics/waps-wind-assisted-propulsion-systems/index.html

Ember Climate – Carbon Price Viewer – accessed 2023 https://ember-climate.org/data/data-tools/carbon-price-viewer/

European Maritime Safety Agency (EMSA) report - Potential of wind-assisted propulsion for shipping (Nov 2023).
https://www.emsa.europa.eu/publications/reports/download/7664/5078/23.html

European Commission, Directorate-General for Maritime Affairs and Fisheries [DG MARE] (2023), Possibilities and examples for energy transition of fishing and aquaculture sectors, Publications Office of the European Union, 2023, (pages 19-21) https://data.europa.eu/doi/10.2771/828897

European Union [EU] (2023) - FuelEU Maritime REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC
https://data.consilium.europa.eu/doc/document/PE-26-2023-INIT/en/pdf

FAO (2020) - The State of World Fisheries and Aquaculture 2020. Sustainability in action, Food and Agriculture Organisation of the United Nations, Rome. P41 https://doi.org/10.4060/ca9229en

Fakiolas, KM (2022) – Wind Propulsion Principles: Complete guide to harvesting the ocean winds for commercial shipping, edition 3.0 Requested hardcopy - https://www.finoceanltd.com/wind-assisted-propulsion-the-book/

Frontier Economics (2019) - Reducing the Maritime Sector's Contribution to Climate Change and air Pollution: Economic Opportunities from Low and Zero Emission Shipping. A Report for the UK Department for Transport, Frontier Economics, July 2019 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815666/economic-opportunities-low-zero-emission-shipping.pdf

GCMD et al (2023) - The shipping industry's fuel choices on the path to net zero, Global Centre for Maritime Decarbonisation, the Global Maritime Forum, and the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (with analytical support provided by McKinsey) of 29 shipping companies. https://cms.zerocarbonshipping.com/media/uploads/documents/The-Shipping-Industrys-Fuel-Choices-on-the-Path-to-Net-Zero.pdf

Green Transition Denmark (2021) - CLEANER SHIPPING Air pollution, climate, technical solutions & regulation.
https://vb.northsearegion.eu/public/files/repository/20220502154016_20220327135716_GTD_Cleaner_shipping_2021_Final.pdf

International Monetary Fund [IMF] (2023) - Fossil Fuel Subsidies
https://www.imf.org/en/Topics/climate-change/energy-subsidies

International Chamber of Shipping [ICS] & University of Southampton (2023) - The impact of shipping's energy efficiency measures on reduction of underwater radiated noise, and opportunities for co-benefit,
https://www.ics-shipping.org/wp-content/uploads/2023/11/URN-Final-report-ver-4-02-11.pdf

IPCC Sixth Assessment Report – AR6 https://www.ipcc.ch/assessment-report/ar6/

ITTC (2022) International Towing Tank Conference – Wind Propulsion Working Group Terms of Reference
https://ittc.info/media/10159/tor-revised-after-conference.pdf

IWSA (2021) - Wind Propulsion Strategy Workshop – IWSA Multi-stakeholder Group (June 2021)
https://www.wind-ship.org/wp-content/uploads/2021/08/Wind-Propulsion-Strategy-Workshop-June-2021.pdf

IWSA Newsletter: July 2023
https://www.wind-ship.org/wp-content/uploads/2023/09/IWSA-Newsletter-July-2023-General-Release.pdf

IWSA Newsletter: December 2022
https://www.wind-ship.org/wp-content/uploads/2022/12/IWSA-Newsletter-Dec-2022.pdf

IWSA Newsletter: May 2022
https://www.wind-ship.org/wp-content/uploads/2022/07/IWSA-May-2022-Newsletter.pdf

IWSA Newsletter: December 2021
https://www.wind-ship.org/wp-content/uploads/2021/12/IWSA-Newsletter-Dec-2021.pdf

IWSA Newsletter: April 2021
https://www.wind-ship.org/wp-content/uploads/2021/07/IWSA-Newsletter-April-2021.pdf

IWSA Newsletter: October 2020
https://www.wind-ship.org/wp-content/uploads/2021/02/IWSA-Newsletter-October-2020-Summary.pdf

IWSA Newsletter: April 2020
https://www.wind-ship.org/wp-content/uploads/2020/11/IWSA-April-2020-Newsletter-SUMMARY.pdf

IWSA Newsletter: December 2019
https://www.wind-ship.org/wp-content/uploads/2020/11/IWSA-Dec-2019-Newsletter-SUMMARY.pdf

IWSA Newsletter: July 2019
https://www.wind-ship.org/wp-content/uploads/2020/04/IWSA-Jul-2019-Newsletter-Summary.pdf

IWSA Newsletter: February 2019
https://www.wind-ship.org/wp-content/uploads/2020/04/IWSA-Feb-2019-Newsletter-Summary.pdf

IWSA Newsletter: October 2018
https://www.wind-ship.org/wp-content/uploads/2020/04/IWSA-Oct-2018-Newsletter-Summary.pdf

IWSA (2023): Open Letter to UNFCCC delegates at COP28
https://www.wind-ship.org/wp-content/uploads/2023/12/IWSA-Letter_COP28.pdf

Kohler, J (2020) - Zero carbon propulsion in shipping – scenarios for the development of hydrogen and wind technologies with the MATISSE-SHIP model, Kohler, Jonathan
https://content.iospress.com/articles/international-shipbuilding-progress/isp190269

Lloyds Register Wind Propulsion Guidelines (2022): (Rotors)
https://www.lr.org/en/knowledge/lloyds-register-rules/guidance-notes/guidance-notes-for-flettner-rotor-approval/
(Masts, Spars & Rigging) https://www.lr.org/en/knowledge/lloyds-register-rules/guidance-notes/guidance-notes-for-masts-spars-and-standing-rigging/

Mason, J (2021) - Quantifying voyage optimisation with wind-assisted ship propulsion: a new climate mitigation strategy for shipping, James C Mason PhD, University of Manchester 2021
https://www.research.manchester.ac.uk/portal/files/209787529/FULL_TEXT.PDF

Maury MF (1858) - The Physical Geography of the Sea, Harper & Brothers, 1858

Menon (2023) - Hydrogen Subsidies in the EU, Norway and the US, Erraia, J, Foseid, H, Śpiewanowski, P, Wahl, E.S, Menon Publication No. 48/2023
https://www.menon.no/wp-content/uploads/2023-48-Hydrogen-subsidy-regimes.pdf

MEPC.1/Circ.896 (2021) - Guidance on treatment of innovative energy efficiency technologies for calculation and verification of the attained EEDI and EEXI
https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.1-Circ.896.pdf

MEPC 75/INF. 26 IMO - REDUCTION OF GHG EMISSIONS FROM SHIPS: Wind propulsion solutions Submitted by **Union of Comoros**
https://www.wind-ship.org/wp-content/uploads/2020/02/MEPC-75-INF.26-Wind-propulsion-solutions-Comoros-1.pdf

MEPC 79/INF. 21 IMO - REDUCTION OF GHG EMISSIONS FROM SHIPS: Wind Propulsion
Submitted by Finland, France, Saudi Arabia, Solomon Islands, Spain, Union of Comoros, RINA, International Windship Association
https://www.wind-ship.org/wp-content/uploads/2022/10/MEPC-79-INF.21-Wind-Propulsion-Finland-France-Saudi-Ar....pdf

MEPC 80/INF.33 IMO - REDUCTION OF GHG EMISSIONS FROM SHIPS: Wind propulsion technologies as a key enabler, Submitted by RINA and IWSA
https://www.wind-ship.org/wp-content/uploads/2023/05/MEPC-80-INF.33-Wind-propulsion-technologies-as-a-key-enabler-RINA-and-IWSA-1.pdf

MEPC 80/7/4 IMO - REDUCTION OF GHG EMISSIONS FROM SHIPS: Final report of the Correspondence Group on Marine Fuel Life Cycle GHG Analysis
https://docs.imo.org/Shared/Download.aspx?did=142399

MEPC.376(80) (adopted on 7 July 2023) - GUIDELINES ON LIFE CYCLE GHG INTENSITY OF MARINE FUELS (LCA GUIDELINES)
https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.376(80).pdf

MMMCZCS (2021) - Position Paper Fuel Option Scenarios (October 2021), Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping
https://cms.zerocarbonshipping.com/media/uploads/documents/Fuel-Options-Position-Paper_Oct-2021_final.pdf

Nuttall, P et al (2021) - Pacific island domestic shipping emissions abatement measures and technology transition pathways for selected ship types, Marine Policy, Vol 132, 2021, P. Nuttall, A. Newell, I. Rojon, B. Milligan, A. Irvin, https://doi.org/10.1016/j.marpol.2021.104704 PDF available at https://mcst-rmiusp.org/index.php/reference-library-main?task=download.send&id=598&catid=26&m=0

Odfjell (2022) - Towards Zero Emission Odfjell`s perspectives on decarbonization of deep-sea shipping, Odfjell SE, IMO ISWG-GHG 13, 05 December 2022, https://docs.imo.org/Shared/Download.aspx?did=139801

Olsson, T et al (2020) - Life cycle modelling of a wind powered car carrier: An assessment of cost and greenhouse gas emissions Master's thesis in Maritime Management, Tobias Olsson, Josef Carlsson, Chalmers University of Technology, 2020
https://odr.chalmers.se/server/api/core/bitstreams/464b93fc-ec75-4b25-9745-c4b04b9345ac/content

Reche-Vilanova, M et al (2023) - Preliminary Study on the Propeller and Engine Performance Variation with Wind Propulsion Technologies. Reche-Vilanova, M., Bingham, H. B., Psaraftis, H. N., Fluck, M., & Morris, D. (2023). Paper presented at Wind Propulsion Conference 2023, London, United Kingdom.
https://www.researchgate.net/publication/372788453_Preliminary_Study_on_the_Propeller_and_Engine_Performance_Variation_with_Wind_Propulsion_Technologies

Rehmatulla, N (2017) - Wind technologies: Opportunities and barriers to a low carbon shipping industry, Rehmatulla, N, Parker, S, Smith, T, Stulgis, V Marine Policy, Volume 75, 2017, Pages 217-226,
https://doi.org/10.1016/j.marpol.2015.12.021

Rojon, I & Dieperink C (2014) - Blowin' in the wind? Drivers and barriers for the uptake of wind propulsion in international shipping, Energy Policy, Vol 67, 2014, Pages 394-402, https://doi.org/10.1016/j.enpol.2013.12.014

SAIL (2015) - Business Case -
https://www.nsrsail.eu/wp-content/uploads/2015/12/Roadmap-SAIL-Transport-WEB-Bonduelle-WP4.pdf

SAIL (2015a) - Health Benefits -
https://www.nsrsail.eu/wp-content/uploads/2015/10/Report-WP5-SAIL-2015-11-WEB.pdf

Schinas, O et al (2022) - A pay-as-you-use business model for the greening of shipping, Cleaner Logistics and Supply Chain, Vol 4, 2022, Orestis Schinas, Dmitriy Sonechko https://doi.org/10.1016/j.clscn.2022.100034

Ship and Bunker https://shipandbunker.com/prices

Ship and Bunker https://shipandbunker.com/prices/emea/nwe/nl-rtm-rotterdam#LNG-MGOe

SSSRI-MARIN (2021) - Measuring 3D wind fields at the speed of light! - SSSRI-MARIN Joint Venture https://www.sssri-marin-jv.com/measuring-3d-wind-fields-at-the-speed-of-light/

Tillig & Ringsberg (2020) - Design, operation and analysis of wind-assisted cargo ships, Ocean Engineering Volume 211, 1 September 2020, Tillig, F & Ringsberg, J.W. https://www.sciencedirect.com/science/article/pii/S0029801820306077

UK Clean Maritime Plan 2019 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815664/clean-maritime-plan.pdf

UNCTAD Handbook of Statistics 2022 - Maritime transport https://unctad.org/system/files/official-document/tdstat47_FS14_en.pdf

UNCTAD (2016) - Sustainable Freight Transport and Finance Training Toolkit Transitioning to Low Carbon Shipping Module – Sustainable Sea Transport Solutions for SIDS: Pacific Island Countries Case Studies (Nuttall, P & Newall, A, 2016) https://unctadsftportal.org/sftftoolkit/transitioningtolowcarbonshippingmodule/

UNCTAD (2023) - UNCTAD counts the costs of achieving sustainable development goals September 2023 https://unctad.org/news/unctad-counts-costs-achieving-sustainable-development-goals

UMAS & ETC (2020) - The scale of investment needed to decarbonize international shipping https://www.u-mas.co.uk/new-study-by-umas-shows-that-decarbonisation-of-the-shipping-sector-is-a-whole-system-challenge-and-not-something-just-for-shipping

Van der Kolk et al (2019) - Wind-Assist for Commercial Ships: A Techno-Economic Assessment. van der Kolk, Nico & Bordogna, Giovanni & Mason, James & Bonello, Jean-Marc & Vrijdag, Arthur & Broderick, John & Larkin, Alice & Smith, Tristan & Akkerman, Ido & Keuning, Jan & Huijsmans, Rene. (2019). https://www.researchgate.net/publication/335542956_Wind-Assist_for_Commercial_Ships_A_Techno-Economic_Assessment

WASP project (2023) - Technical report on digital twins for WASP https://vb.northsearegion.eu/public/files/repository/20230613152704_WP3deliverablestechnicalreport.pdf

WASP project (2023) – Best Practice Manual https://vb.northsearegion.eu/public/files/repository/20230627094010_WASP-BPM-version5-FINAL27June2023.docx

WASP project (2022) - A Comeback of Wind Power in Shipping: An Economic and Operational Review on the Wind-Assisted Ship Propulsion Technology - https://vb.northsearegion.eu/public/files/repository/20220202204237_20210310083257_01.2021._1stresearchpaper_Sustainabilityjournal.pdf

WASP project (2021) - Report Barriers and overcoming strategies for accelerating the uptake of WASP (Dec 2021) https://vb.northsearegion.eu/public/files/repository/20220111103132_WASPWP4.D5B_Barriersandovercomingstrategiesforacceleratingtheuptakeof WASP.pdf

WASP project (2021) - Policy Brief: Socio-economic benefits of wind technologies for ships https://vb.northsearegion.eu/public/files/repository/20210629150330_RGO_003PolicyBrief_WEB2.pdf

WASP project (2020) - New Wind Propulsion Technology A Literature Review of Recent Adoptions', WASP Project Sep 2020 (Research table p7 and the review of technology fuel savings p18) https://vb.northsearegion.eu/public/files/repository/20210111083115_WASP-WP4.D5B-NewWPTALiteratureReviewofRecentAdoptions-Final.pdf

Werner, Sofia. (2023) - Key Performance Indicators for Wind-Powered Ships." RINA & IWSA Wind Propulsion Conference 2023. https://vb.northsearegion.eu/public/files/repository/20230405083500_WernerGerhardtKontos-TechnicalKeyPerformanceindicators.pdf

Wind for Goods (2023) - France region will account for 50% of jobs in wind sector – Press Release published in Maritime Professionals - https://maritime-professionals.com/france-region-will-account-for-50-of-jobs-in-wind-sector/

Wind For Goods - Nantes Saint-Nazaire Développement - Nantes Regional Study (May 2023) : https://mcusercontent.com/5aa9e16dfbf4e864280d034b9/files/77e89bac-29e5-7df0-ab1a-8ba39354fabb/WindShip_Infographie_31_mai.pdf

Woods, S (2021) - Sail Freight Revival: Methods Of Calculating Fleet, Labor, And Cargo Needs For Supplying Cities By Sail, March 2021, Woods, Stephen https://www.researchgate.net/publication/354841970_Sail_Freight_Revival_Methods_Of_Calculating_Fleet_Labor_And_Cargo_Needs_For_Supplying_Cities_By_Sail

ANNEX I

Large Commercial Vessel - Wind Propulsion Propulsion Installations (Q3, 2023)

	Ship Name	Ship Type	DWT	GT	Length	Technology Installed	Installation Year	Installation Type
1	E-Ship 1	General Cargo/Ro-Lo	10,020	12,968	130	4 x 27m fixed rotor sails	2010	newbuild
2	Estraden	Ro-Ro	9,741	18,205	163	2 x 18m fixed rotor sails	2014	retrofit
3	Goldy Seven	General Cargo	4,250	2,844	90	1 x 18m fixed rotor sail	2018	retrofit
4	New Vitality	Tanker - VLCC	306,751	162,636	333	2 x 32m retractable wing sails	2018	newbuild
5	Epanastasea	Tanker - LR2 Product	109,647	61,724	245	2 x 30m fixed rotor sails	2018	retrofit
6	Afros	Bulk Carrier - Ultramax	63,223	36,452	199	4 x 16m movable rotor sails	2018	newbuild
7	Copenhagen	Ferry	5,088	24,000	169	1 x 30m fixed rotor sail	2020	retrofit
8	Ankie	General Cargo	3,638	2,528	90	2 x 13m hinged suction wings	2020	retrofit
9	Annika Braren	General Cargo	5,023	2,996	85	1 x 18m fixed rotor sail	2021	retrofit
10	SC Connector	Ro-Ro	8,843	12,251	155	2 x 35m hinged rotor sails	2021	retrofit
11	Sea Zhoushan	Bulk Carrier VLOC	324,268	173,504	340	5 x 24m hinged rotor sails	2021	newbuild
12	Ville de Bordeaux	Ro-Ro	5,200	21,528	154	1 x 500m2 dynamic kite	2021	retrofit
13	Frisian Sea	General Cargo	6,477	4,298	118	2 x 11m flatrack/hinged suction wings	2021	retrofit
14	Balueiro Segundo	Fishing Vessel	n/a	593	41	1 x 12m fixed suction wing	2021	retrofit
15	Naumon	Cargo/theatre vessel	1,006	1,057	59	1 x 17m fixed suction wing	2021	retrofit
16	GNV BRIDGE	Ferry	8,632	32,581	203	1 x 12m retractable wing sail	2021	retrofit
17	Marfret Niolon	Ro-Ro	5,282	7,395	123	2 x 12m hinged/containerised suction wings	2022	retrofit
18	Anna	General Cargo	5,097	2,993	90	2 x 16m hinged suctions wings	2022	retrofit
19	Berlin	Ferry	4,835	22,319	169	1 x 30m fixed rotor sail	2022	retrofit
20	Shofu Maru	Bulk Carrier	99,000	n/a	235	1 x 48m retractable wing sail	2022	newbuild
21	Delphine	Ro-Ro	27,687	74,273	234	2 x 35m hinged rotor sails	2022	retrofit
22	New Aden	Tanker - VLCC	306,751	162,636	333	4 x 40m retractable wing sails	2022	newbuild
23	MN Pelican	Ro-Ro	8,847	12,076	154	1 x 100m2 inflatable wing sail	2022	retrofit
24	EEMS Traveller	General Cargo	2,850	2,137	90	2 x 17m suction wing	2023	retrofit
25	Sunnanvik	Cement Carrier	9,060	7,454	124	2 x 16m suction wing	2023	retrofit
26	Chang Hang Sheng Hai	Bulk Carrier	45,542	27,629	190	4 x 24m rotor sails	2023	retrofit
27	TR Lady	Bulk Carrier	82,042	44,190	229	3 x 24m movable rotor sails	2023	retrofit
28	Cape Brolga	Bulk Carrier - Capesize	211,982	108,967	300	1 x 1,000m2 dynamic kite	2023	retrofit
29	Canopee	Ro-Ro	4,700	10,400	121	4 x 30m hybrid wing sails	2023	newbuild
30	Pyxis Ocean	Bulk Carrier	80,962	43,291	229	2 x 40m retractable wing sails	2023	retrofit

Large Commercial Vessel - Wind Propulsion Ready (Q3, 2023)

	Ship Name	Ship Type	DWT	GT	Length	Technology Installed	Build Year	Installation Year
1	Axios	Bulk carrier - Kamsarmax	81,960	44,113	229	wind ready (rotor sails)	2020	XXXX
2	MT Alkiviadis	Oil/Chemical Tanker	50,113	29,565	183	wind ready	2023	XXXX
3	M/T Avax	Oil/Chemical Tanker	50,113	29,565	183	wind ready	2023	XXXX
4	M/T Agisilao	Oil/Chemical Tanker	50,113	29,565	183	wind ready	2023	XXXX
5	M/T Anikitos	Oil/Chemical Tanker	50,113	29,565	183	wind ready	2023	XXXX
6	M/T Atrotos	Oil/Chemical Tanker	50,113	29,565	183	wind ready	2023	XXXX
7	M/T Akrisios	Oil/Chemical Tanker	50,113	29,565	183	wind ready	2023	XXXX
8	Oceanus Aurora	LPG Tanker - VLGC	62,500	54,000	230	wind ready (2 x 20m rotor sails)	2023	2024

Additonal Cruise Vessels - Traditional Soft Sail Rigged >400GT

	Ship Name	Ship Type	DWT	GT	Length	Masts	Build Year	Owner
1	Golden Horizon	Wind Auxiliary Cruise	2,120	8,784	162	5	2021	Trade Wind Voyages
2	Le Ponant	Wind Auxiliary Cruise	92	1,189	88.5	3	1991	Ponant
3	Sea Cloud	Wind Auxiliary Cruise	788	2,532	96	4	1931	Sea Cloud Cruises
4	Sea Cloud II	Wind Auxiliary Cruise	780	3,849	106	3	2000	Sea Cloud Cruises
5	Sea Cloud Spirit	Wind Auxiliary Cruise	935	4,228	136	3	2021	Sea Cloud Cruises
6	Windsurf	Wind Auxiliary Cruise	1,645	14,745	182	5	1989	Windstar Cruises
7	Windstar	Wind Auxiliary Cruise	922	5,703	134	4	1986	Windstar Cruises
8	Royal Clipper	Wind Auxiliary Cruise	1,000	4,425	134	5	2000	Star Clippers
9	Star Clipper	Wind Auxiliary Cruise	300	2,298	111.5	4	1992	Star Clippers
10	Star Flyer	Wind Auxiliary Cruise	300	2,298	111.5	4	1991	Star Clippers

Source: International Windship Association (IWSA) Members Survey 2023.

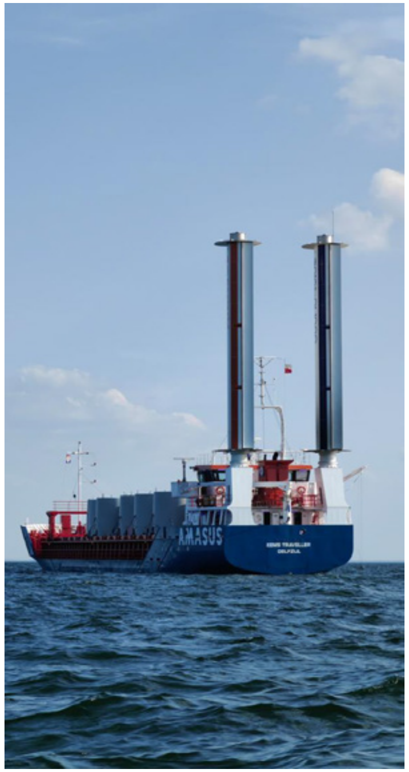
Note: This listing does not include the 10+ small traditional rigged sail cargo vessels (under 400GT) in operation in Europe, the US and Pacific or the small traditional sail cargo and fishing vessels, such as dhows in operation in developing countries and LDCS.

ANNEX II – A

POWER THE WORLD WITH WIND

Full-scale installations and on-going projects

References



Installations

Full-scale installations and on-going projects

Installations

eSAIL® projects

EXECUTED

OR.PA.GU.
ORGANIZACIÓN DE PALANGREROS GUARDESES

LA FURA DELS BAUS

AMASUS

ON-GOING

LouisDreyfus
ARMATEURS

ODFJELL

Marubeni

Executed

Balueiro II, 41m LOA

Installation
May 2021

Type
Fishing Vessel

eSAIL®
Model 1 - (1x) 12x2.85m

Approval
Spanish Flag & Bureau Veritas

Executed

La Naumon, 62m LOA

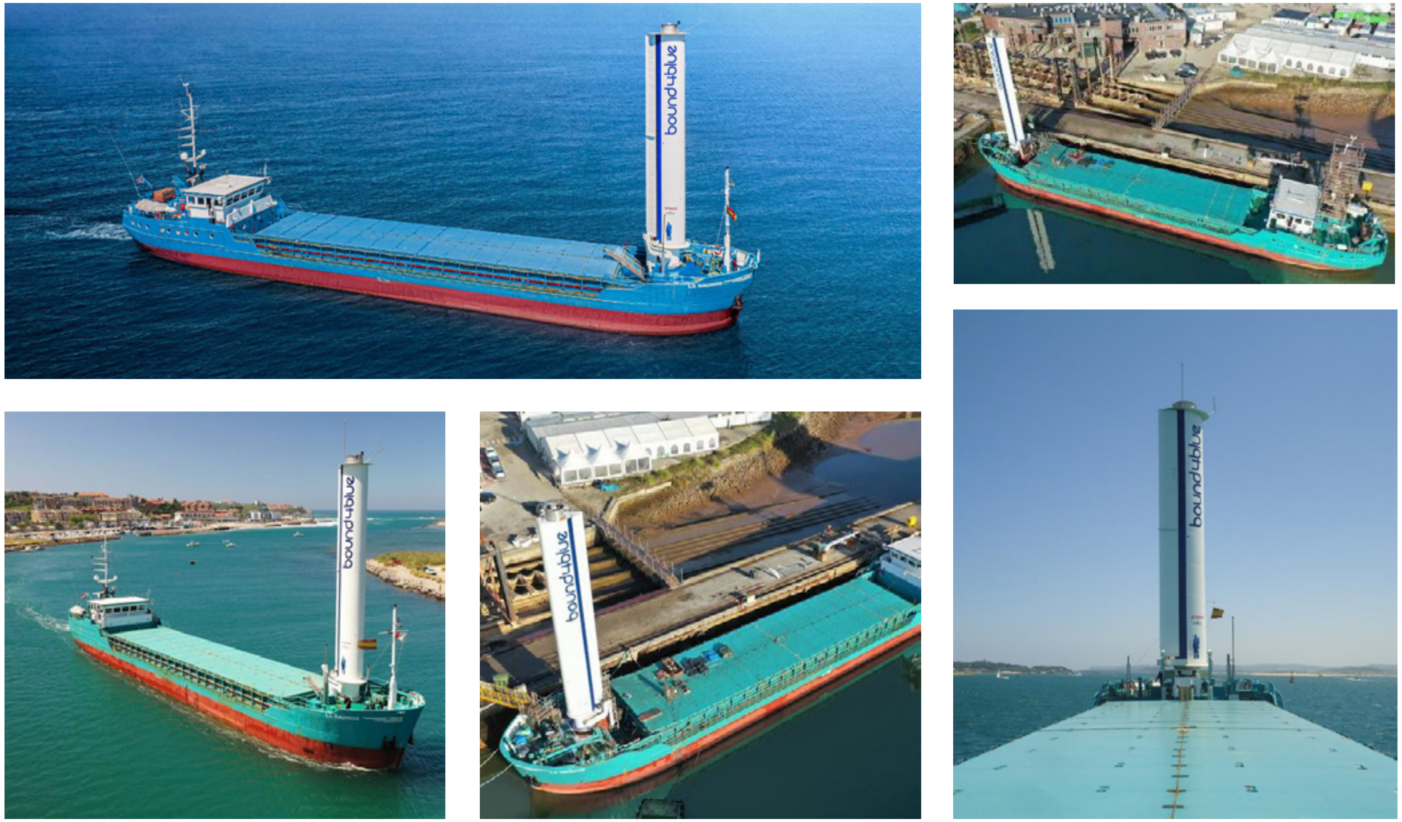
LA FURA DELS BAUS

Installation
December 2021

Type
General Cargo

eSAIL®
Model 1 - (1x) 17x2.85m (tiltable)

Approval
DNV-GL



Executed

Eems Traveller, 90m LOA

Installation
July 2023

Type
General Cargo

eSAIL®
Model 1 - (2x) 17x2.85m

Approval
Bureau Veritas

On-going

Ville de Bordeaux

Installation
n/a

Type
Ro-Ro

eSAIL®
Model 2 - (3x) 22x4,5m

Approval
Bureau Veritas

On-going

MR Tanker, 183m LOA

ODFJELL

Installation
n/a

Type
Tanker

eSAIL®
Model 2 - (4x) 22x4,5m

Approval
DNV-GL

On-going

MV Atlantic Orchard, 180m LOA

LDC.
Louis Dreyfus Company

Installation
2024

Type
Juice carrier

eSAIL®
Model 2 - (4x) 26m

Approval
DNV

On-going

Crimson Kingdom, 229m LOA

Marubeni

Installation
n/a

Type
Bulker

eSAIL®
Model 2 - (4x) 26x4,5m

Approval
Class NK

bound4blue

For more information, visit www.bound4blue.com
or contact us at enquiries@bound4blue.com

ANNEX Ⅱ – B

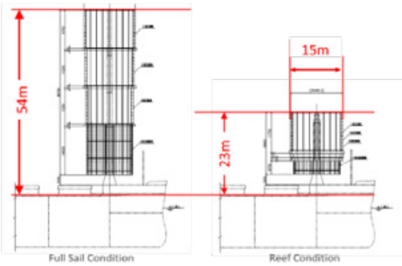
SHOFU MARU

New Build/Wind-Assisted

IMO No.	9919395
Flag	Japan
Owner	Mitsui O.S.K. Lines, Ltd. (MOL)
Type of ship	BULK CARRIER
Gross Tonnage/ Deadweight	58,209/100,422
L x B x D [m]	231.00 x 43.00 x 20.05
Main engine output	9,180 kW
Service speed	14.3kts
Delivery	5th Oct 2022
Ship builder	OSHIMA SHIPBUILDING CO., LTD.

Technology

Equipment name	Wind Challenger
Type	Rigid sail with telescopic mechanism
Sail Material	FRP panels with steel frames
Operation	Fully automated
Sail size (FULL SAIL)	Height x width = 54m x 15m

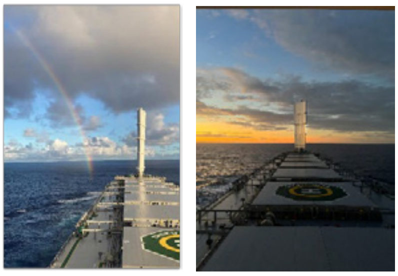


Fabrication, installation

As the first sail for this project, extensive shore tests were conducted. Manufacture of the sail took 6 months. This was a newbuild project, therefore most of the foundation work was completed during the building process. The sail installation was completed within 3 hours, with the vessel afloat condition.

Performance

The vessel completed 5 voyages in the Pacifica area so far. The sail showed good operation rate and performance, without a major technical trouble. At the sea trial, the sail recorded more than 10% fuel saving. From the long term analysis result, the sail is achieving the saving target: 8% fuel saving in annual average in Japan-US voyage for 100K BULK CARRIER with one sail.



Future plan and additional comments

After SHOFU MARU 1st sail success, commercial model is under development. The first vessel with the commercial model will be delivered in 2024 from Oshima shipbuilding. For further GHG reduction, MOL sets a milestone to install the wind challengers into total 25 vessels by 2030.

NORSEPOWER

Summary of Norsepower references

Contents

1 Reference ships

The following reference vessels are examples of Norsepower Rotor Sails™ installations and ongoing delivery projects.

1.1 RoRo ship M/V Estraden

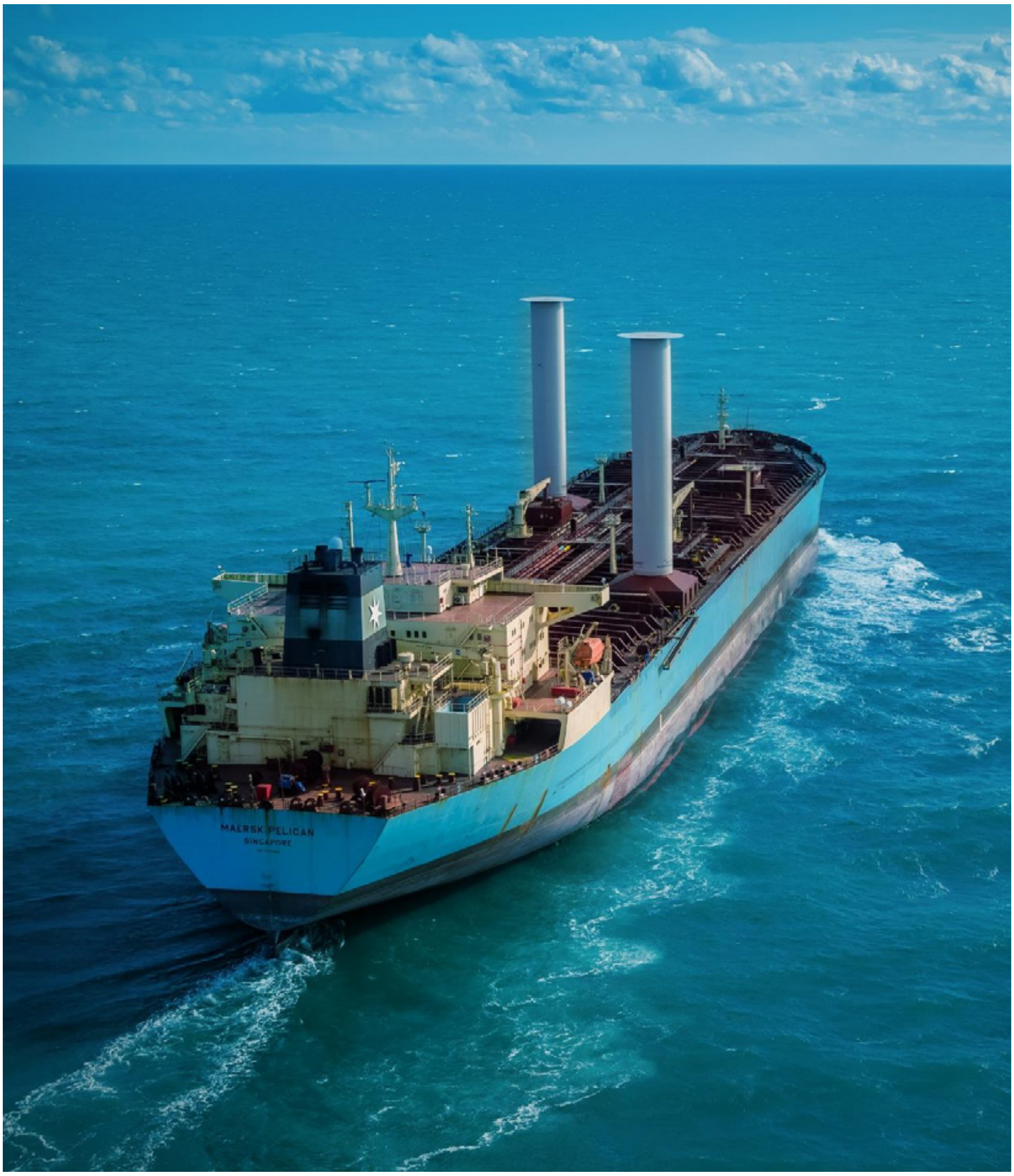
The first installation with two model 18m x 3m Norsepower Rotor Sails™ on the roro-vessel Estraden has been in operation since 2014.
www.norsepower.com/ro-ro

1.2 Cruise ferry Viking Grace

The installation of one model 24m x 4m Norsepower Rotor Sail™ on cruise ferry Viking Grace was completed in April 2018.
https://www.norsepower.com/passenger

1.3 LR2 tanker Epanastasea (ex. Maersk Pelican)

The installation of two model 30m x 5m Norsepower Rotor Sails™ was completed in the end of August 2018 on the Maersk Pelican, a 109 000 DWT LR2 tanker owned at the time by Maersk Tankers.
www.norsepower.com/tanker



1.4 Hybrid ferries M/V Copenhagen and M/V Berlin

The installation of one model 30m x 5m Norsepower Rotor Sail™ on the M/V Copenhagen, a hybrid ferry owned by Scandlines, was completed in the end of May 2020. The same model 30m x 5m was installed on the sister vessel M/V Berlin in May 2022.
https://www.norsepower.com/passenger
https://www.norsepower.com/post/norsepower-installs-rotor-sail-on-second-scandlines-hybrid-ferry

1.5 Ro-Ro vessel SC Connector

Two 35m x 5m Norsepower Rotor Sails™, fitted on tilting foundations, were installed in Dec. 2020 on the Ro-Ro vessel SC Connector, owned by Sea-Cargo. The ship's fuel consumption and emissions are estimated to be reduced by 25% on average in its operation in the North Sea region.
https://www.norsepower.com/sc-connector
https://www.norsepower.com/post/sea-cargos-tilting-rotor-sails-deliver-instant-operational-results

Photo: Sea-Cargo

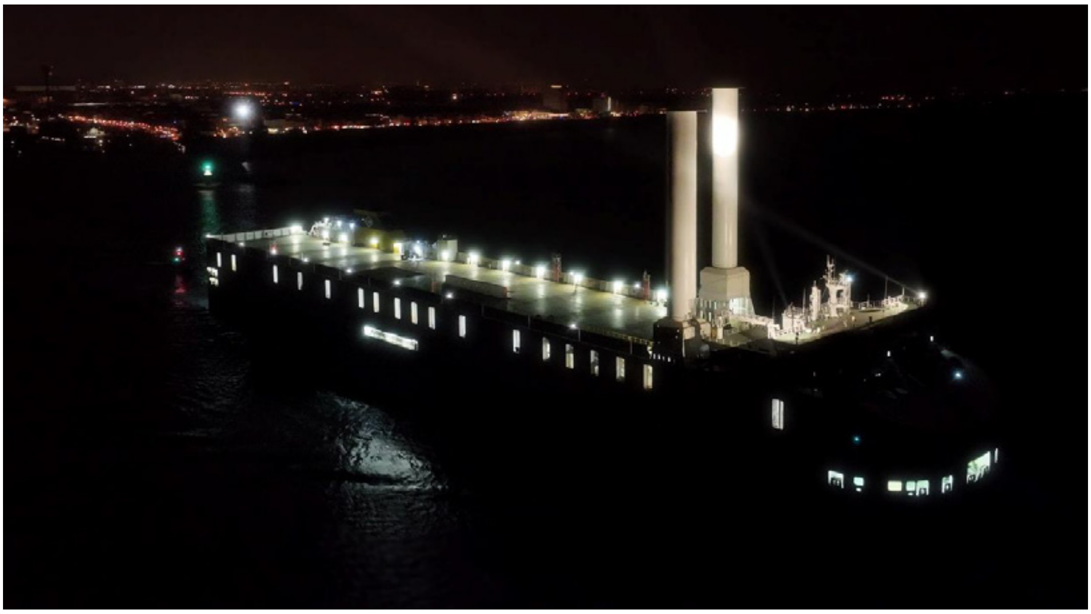
1.6 Very Large Ore Carrier (VLOC) Sea Zhoushan

Five model 24m x 4m Norsepower Rotor Sails™, fitted on tilting foundations, were installed in April 2021 on the newbuilding VLOC delivered from New Times Shipbuilding Co., Ltd. The ship's estimated average fuel savings are 8% and annual reduction of CO_2 is 3400 tons. The ship is owned by Pan Ocean Ship Management and chartered by Vale. https://www.norsepower.com/bulker

1.7 Ro-Ro vessel MV Delphine

The MV Delphine was fitted two model 35m x 5m Norsepower Rotor Sails™ on tilting foundations in Feb. 2023. Norsepower has estimated that the technology would achieve a fuel and emission reduction saving of 7 – 10% for this vessel, depending on the route.

https://www.norsepower.com/post/norsepower-announces-the-installation-of-rotor-sails-on-the-worlds-largest



2 Verified fuel saving performance results

The fuel saving performance of the Norsepower Rotor Sail™ installations on reference vessels has been measured and analysed by independent third-parties. Detailed analysis results are presented in the following table.

	Estraden	Viking Grace	Maersk Pelican	Copenhagen
Measurement party	NAPA	ABB, Chalmers, NAPA	LR	SSPA
Measurement period	Apr 2015 - Dec 2015	Jul 2018 – Mar 2019	Sep 2018 – Aug 2019	Apr 2021
Configuration	Two 18x3*	One 24x4*	Two 30x5*	One 30x5*
Average savings	450 kW	207 – 287 kW	8.2%	4-5%
Annual fuel savings	441 tons	230 – 320 tons	8.2%	4-5%
Annual CO_2 savings	1380 tons	630 - 890 tons	1400 tons	4-5%

* Norsepower Rotor Sails™ models are coded by the height (18, 24, 28, 30 or 35 m) and the diameter (3, 4 or 5 meters) of the spinning rotor.

3 Next installations

3.1 CO2-carrier newbuilding

Two liquified CO2 carriers will be equipped with one model 28m x 4m Norsepower Rotor Sail™ on each vessel. Ships are under construction at the DSIC shipyard in China.

https://www.norsepower.com/post/norsepower-signs-agreement-with-dalian-shipbuilding-industry-co-ltd-to

3.2 Combination carrier retrofit

The combination carrier M/V Koryu operated by Nippon Marine and chartered by BHP will be equipped with one model 35m x 5m Norsepower Rotor Sail™ on a tilting foundation. Installation is scheduled in 2023.

https://www.norsepower.com/post/bhp-pan-pacific-copper-and-norsepower-partner-to-harness-the-power-of-wind

3.3 MR tanker retrofit

A 50'000 dwt, 2022 built, MR tanker Alcyone is owned by Socatra and chartered by TotalEnergies. The ship will be retrofitted with two model 35m x 5m Norsepower Rotor Sails™. The installation of the units is scheduled for Q4/2023 - Q1/2024.

https://www.norsepower.com/post/norsepower-signs-agreement-with-socatra-to-install-two-rotor-sails-tm-on-mr

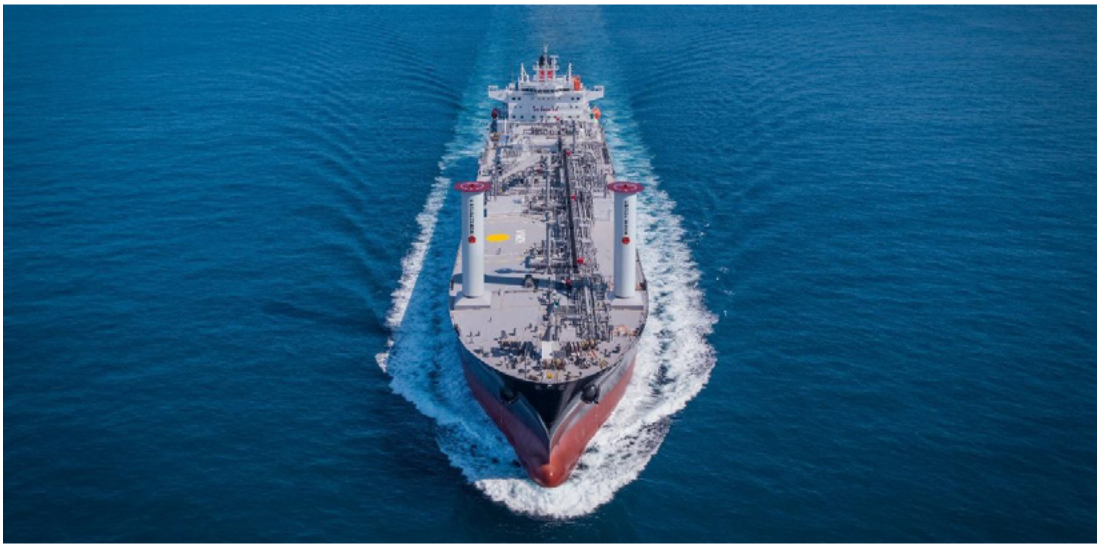
3.4 A capesize bulker retrofit

A capesize bulk carrier owned by MOL and chartered by Vale will be retrofitted with two model 35m x 5m Norsepower Rotor Sails™ on a tilting foundation. Installation is scheduled for 2024.

https://www.norsepower.com/post/mol-and-vale-agree-to-install-two-norsepower-rotor-sails-tm-to-an-in-service

3.5 A VLGC retrofit

A Very Large Gas Carrier owned by Iino Lines will be retrofitted with two model 20m x 4m Norsepower Rotor Sails™. The ship was delivered as rotor sail ready from the DSME shipyard on March 31, 2023. Installation is scheduled for 2024.



https://www.norsepower.com/post/norsepower-and-iino-lines-agree-to-install-norsepower-rotor-sails-tm-on-a

ANNEX II – D

Wind: the clean and free energy source

a white paper on wind-assisted ship propulsion

ECONOWIND


ECONOWIND
ECONOWIND
ANKIE

1. VentiFoils by Econowind

Econowind offers and provides wind assisted propulsion to seagoing ships in the shape of VentiFoils. They can be containerized inside a 40ft container or fixed to a vessel so the size of the foils are not limited to container dimensions.

The VentiFoil is a wing shaped element using modern innovations in aerodynamics creating high propelling force relative to its size. Smart suction is integrated in the wing, resulting in double the force of the VentiFoil while reefing when needed.

Folding vs. non-folding

25% to 40% of ships have unfavourable wind conditions. So, by default, VentiFoils have a folding option. This way there is never a negative drag from the wings, which non-folding versions of wind assisted ship propulsion would experience.

One investment - immediate ROI

With fuel pricing ranging between 800$ to 1.300$ dollar per ton there is a clear payback of wind assist. When financed via the ships mortgage or via a "lease construction" there is an immediate ROI. The monthly savings of fuel and potential ETS costs are higher compared to financing costs.

When compared to future renewable fuels, wind is a no brainer business case. Equivalent Ton prices of up to 2.000 to 3.000 $ per ton are no exception and the payback is immediate.

Easy to replace on other vessel

Being flexible to install is key, with the case of the Frysian Sea from Boomsma a flat rack was developed whereby the installation is done in one day. Having flexibility to place on next ships gives shipowners the freedom to operate.

Improved EU-ETS

Fuel not used lead to emissions not polluted. With the main fuels having a fuel to CO2 ratio of around 3, each ton of fuel not emitted lead to 3 ton less emission. With average sailing emission avoidance of 10% and Higher this will have a significant effect on ETS savings.

up to 20%

SAVINGS OF FUEL USE

By installing Wind Assisted Ship Propulsion high fuel savings are being accomplished resulting in an improved EEXI

Plug ‘n play - Easy Installation

Being installed in one or a couple of days there is a key integration efficiency need. This is done by a bridge control link and as such an easy installation on a ship. As the VentiFoils are considered lightweight in their design there are no large constructional changes needed for vessels.

Regulatory safe

IMO EEXI and EEDI approved there is a saving from day one. All vessels with wind installation have the capability to sail faster, due to less constraints in power limitation. This is all due to the added green power. Class adapts vessels and their green profile, ensuring a swift acceptance.

From idea to innovation

Econowind and Conoship International developed the Ventifoil as a swift deployed project. Taking the responsibility from idea of wind power to the execution.


BOOMSMASHIPPING.NL
ECONOWIND
ECONOWIND
NEWTIDE
FRISIAN SEA

1. Boomsma Shipping

Founded in 1968 in the City of Sneek, The Netherlands, Boomsma Shipping is a family-run business providing a range of shipping services including multi-purpose vessels up to 8,500 DWT.

Why Wind Assisted Ship Propulsion?

Boomsma participated in the WASP project[1] due to the climate and regulatory challenges that lie ahead. After optimizing their vessels build and trim to reduce fuel use, the next logical step for them is wind assisted ship propulsion.

Some eight months after signing the contract, Boomsma Shipping has installed its first two VentiFoil wind-assisted propulsion units. The Dutch flagged MV Frisian Sea, a 6477dwt general cargo vessel has made its maiden voyage to Vasteras, Sweden with the VentiFoils in operation,

> “We believe it is necessary and very important to meet sustainability challenges. We want to do our part to reduce our fuel consumption and CO2 emissions as soon as possible.”

Johan Boomsma, co-owner of Boomsma Shipping B.V.

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[1] The WASP (Wind Assisted Ship Propulsion) project is funded by the Interreg North Sea Europe program, part of the European Regional Development Fund (ERDF) and brings together universities and wind-assist technology providers with ship owners to research, trial and validate the operational performance of a selection of wind propulsion solutions.

The retrofit of MV Frisian Sea with Econowind Flatrack system

The requirements as stated by Boomsma for MV Frisian Sea were a perfect fit for the Econowind flatrack system: no interference with cargo operations, removeable/replaceable and easy to use. The preparations for the installation required cable routing, hatch covers to be enforced and class approval.

Navigation and safety proof

The wind assisted units are installed on Port side on this vessel. Ensuring a safe navigation and to remain in 5degree sight angle.

Operational safe

No manual interface to start sailing. At captains' choice and Econowind advisory it's time to 'go sailing'.

Stamp of approval for EEXI reduction

Lloyds Register approved the EEXI Calculation and Technical file for MV Frisian Sea of Boomsma Shipping. This approval underlines that the vessels' EEXI is lowered by installing the Econowind VentiFoils.

CONOSHIP
INTERNATIONAL

EEXI TECHNICAL FILE
"FRISIAN SEA"

A2819-1017-RevA

BOOMSMA

Freedom of placement

Being installed on a flatrack the VentiFoils are moveable by the Hatch Crane system.

The best marketing material available: a pair of Econowind VentiFoils on deck!

ANNEX II – E

Anemoi Marine Case Studies

M/V Axios, 82K DWT Kamsarmax

Owner wished to make their newly purchased vessel" wind-ready" by installing Anemoi's Rail Systems, ready to receive Anemoi Rotors in the future. After assessing the ship design, Anemoi proposed using their Transverse Rail Deployment Systems to ensure port operations would not be affected once the Rotors were installed. 4 Transverse Rail Systems were installed during vessel upgrade. To date, the Rail Systems have caused no interruption to port operations.

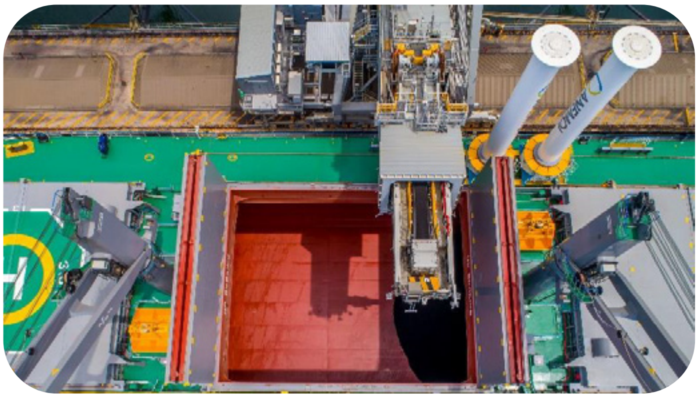
Note: A vessel is made 'wind ready' by carrying out the vessel integration (structural and electrical preparation). Once completed, the Rotor Sails can be added gradually using a 'plug and play' approach. The phased installation of Rotor Sails can be aligned to phased regulations to help maintain compliance.

M/V Afros, 64k DWT geared Ultramax

The Afros was the world's first ever Bulk Carrier to be installed with Rotor Sails in January 2018. The system configuration is four 2x16m Rotor Sails with a longitudinal Rail Deployment System to ensure they could be easily moved prior to commencing port operations.

Rotor Sails were successfully installed, avoiding clashes with deck out-fittings, ship cranes, hatch covers, shore cranes and loaders. Installation of equipment was achieved in less than 2 hours per unit. Since the installation the vessel has visited more than 80 ports worldwide with no port rejections.

Fuel and emission savings have been around 3-4% to date. Note: Anemoi's 2nd generation Rotor Sail design (to be installed on the TR Lady and Berge Bulk vessels) are much larger and therefore expected to generate much higher savings.



M/V TR Lady, 82k DWT Kamsarmax

TR Lady Shipping, a portfolio company of Tufton Investment Management, has inked an agreement with Anemoi Marine Technologies to install Rotor Sails on an 82k DWT Kamsarmax bulker.

Under the terms of the deal, the bulk carrier TR Lady will be supplied and fitted with three 5x24m Rotor Sails on Anemoi's patented Rail Deployment System, which allows the sails to be moved across the deck to minimize the impact on port operations.

M/V Berge Neblina, 388k DWT Valemax
M/V Berge Mulhacen, 210k DWT Newcastlemax

Singapore-based dry bulk owner Berge Bulk announces that it had signed agreements with Anemoi Marine Technologies Ltd – a global leader in wind-assisted propulsion for commercial vessels – to supply and fit two vessels in their dry bulk fleet with Anemoi Rotor Sails.

Both vessels will be fitted with four Rotor Sails 5x35m with Folding Deployment Systems. Rotor Sails can be lowered from the vertical to mitigate the impact on air draught and cargo handling operations.

ANNEX II – F

Operation of a sail freighter on the Hudson River: Schooner Apollonia in 2021

Steven Woods, Hudson River Maritime Museum, swoods@hrmm.org
Sam Merrett, Master of Schooner *Apollonia*

Abstract: In the discussion of sail freight worldwide, little analysis exists to illuminate the effects of sail freight vessels engaged in shipping along rivers. Even less of the literature provides meaningful, in-depth insight into the operations of such vessels. The 64-ft (19.5 m) schooner *Apollonia*, a small general cargo vessel and the only active, operational sail freighter in the United States, operates on the Hudson River and in New York Harbor. The ship's logs and other data from 2021, the *Apollonia's* first sail freight season, are examined here to gauge the performance of small sail freighters on river trade routes. The available data shows sail freight has a strong advantage over comparable trucking in fuel use per Ton-Mile.

INTRODUCTION

In the last half century, Wind Propulsion has been widely acknowledged since the Oil Crisis of the 1970s as a means of reducing fuel use in maritime transportation, and research started in that era has been resumed as climate and economic concerns force change in the maritime industry. Small sail freighters engaged in coastal or inland waterway trading with break bulk general cargo have been ignored in this discussion of working sail's revival, however. These vessels are neither bulkers carrying loose cargo such as iron ore or grain, nor do they use intermodal shipping containers. The cargo is instead loaded directly into the hold in smaller packaging, such as sacks, crates, boxes, coolers, and barrels. Analysis of logs, cargo, and fuel-use data from the schooner *Apollonia* operating on the Hudson River and New York Harbor allows for a comparison of these vessels to other methods of cargo transportation.

Sail freight is defined as "The maritime movement of cargo under primarily wind power."[1] As can be seen in the figure below, this includes sail and motor-sailing vessels which rely on their engines for less than half of their propulsive power.[2] Sail-Assist and conventional motor ships are excluded from this definition, but are by far the most-discussed in journals at this time.

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[1] Woods, Steven. "Sail Freight Revival: Methods of calculating fleet, labor, and cargo needs for supplying cities by sail." Master's Thesis. Prescott College, 2021. Pp 6. www.Researchgate.net

[2] Wind Ship Development Corporation, *Wind Propulsion For Ships Of The American Merchant Marine* Norwell, MA: WSDC, 1981. Pp II-5

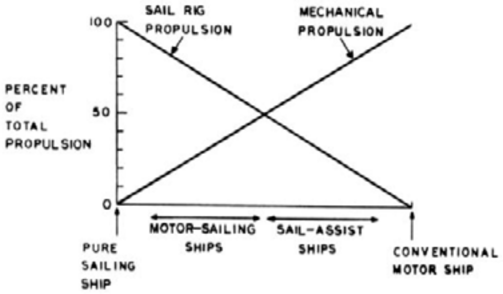

Figure 1: "Motor Sailing Propulsion Spectrum" in: Wind Ship Development Corporation, *Wind Propulsion For Ships Of The American Merchant Marine* Norwell, MA: WSDC, 1981. Pp II-5.

While there is considerable space within the sail freight continuum for high levels of engine use, the majority of coastal and inland trading under sail at this time is in small general cargo vessels which are either engineless, as with the ketch *Nordlys*,[3] or use engines only when docking or for safety reasons in crowded harbors, like the schooner *Apollonia*.

The tonnages involved in most studies of wind-assisted ship propulsion allow for comparison with conventional merchant ships. There are multiple studies which show the fuel saved from sail retrofits to existing vessels, compared to the ship's previous performance.[4] However, these are based on places where maritime shipping is the rule, such as small island states and archipelagoes, or transoceanic shipping. This is not the case when looking at inland and coastal vessels which displace rail and road transport instead of other ships.

Another element worth noting in this study is the *Apollonia*'s goals. The ship and her crew are not looking solely to reduce carbon emissions, though this is a significant part of their mission. Their goal overall is to have an environmental, economic, and social impact, the "Triple Bottom Line." This entails an extra educational bottom line, changing the way people think about the Hudson River, waterways, transportation, and supply chains. The economic mission involves paying more in labor than on fossil fuels. There is significant interaction between goals: Ecological improvements have a social impact by reducing pollution, while economic changes have social impacts on jobs and livelihoods. This multifaceted impact is outside the scope of this paper, which will be limited to assessing the comparative CO2 intensity of sail freight vessels and fossil fueled trucks.

THE SCHOONER *APOLLONIA*

The *Apollonia* is a steel J Murray Watts design from 1946, built in Baltimore, MD. Acquired in 2016, she spent 4 years in repair and retrofit before launching for a first season of relationship building and experimentation in 2020, including one circuit from Hudson, New York to New York City with a small number of cargos. 2021 was the first season of regular operations. *Apollonia* has a sail area of 122 square meters, and is equipped with a Detroit diesel engine of approximately 125 Horsepower.

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[3] "Nordlys" https://fairtransport.eu/nordlys/ Accessed 27 November 2021.

[4] R.G. MacAlister "The retrofitting of sail to two existing motor ships of the Fiji Government fleet." *Proceedings of Regional Conference on Sail-Motor Propulsion* (Manila: Asian Development Bank, 1985)

Schooner *Apollonia* Critical Data:
Length: 64 ft/19.5m Beam: 15 ft/4.5m
Rig: 2 Masted Bald-Headed Gaff Schooner.
Sail Area: 122 sq m/1320 sq ft.
Cargo Deadweight: 10 Short Tons/9.07 tonnes.
Cargo Volume: 600 Cu ft/17 Cu M/½ TEU.
Displacement: 36 tons. Draft: 7 ft
Engine: 125 HP/92 KW Detroit Diesel.
Fuel Capacity: 250 Gal/946 Liters.
Crew: 4

Fig 1: Schooner *Apollonia* under sail off Rondout Lighthouse, 24 July 2022. Courtesy, Steven Woods.

APOLLONIA'S 2021 OPERATIONS

The *Apollonia* made five circuits from Hudson, NY to New York City on the Hudson River: one per month from May through October, excepting June. Cargo was generally transported first- and last-mile by means of an electric-assist cargo bike and trailer powered by solar panels mounted on the wheelhouse of the vessel, minimizing the emissions of first- and last-mile transportation. This use of low energy intensity land transportation proves the viability of a sustainable cargo system, as well as allowing the ship to carry her own shoreside delivery capabilities. In addition, the use of a cargo bike avoids heavily congested roads. Handling of all break bulk cargo was by the “Armstrong Method” aided by ship’s gear such as block and tackle.

The typical crew of four consisted of Master, Mate, Bosun, and Deckhand. All crew served as dockers as no longshore or stevedore crews were available or hired. Sailing was by both night and day depending on wind, tide, and current conditions, which dictated the watch rotation. Due to the small crew size, there was little real differentiation of roles.

Figure 2: Map of *Apollonia*'s Port Calls.[5]

APOLLONIA'S CARGO

The *Apollonia*'s main cargo was Malted Grains moving from the Germantown, NY area to several breweries down the Hudson River and around New York Harbor. These were exclusively embarked at Hudson, NY, packed in 50 pound sacks. Many other cargos were included in the season, including solar panels, a printing press, coffee, beer, tea, mead wine, salt, a cargo of wine and chocolate cross-loaded from the French Sail Freighter *Grain de Sail* in New York Harbor, 1 ton of peppers from Milton to Hudson, hot sauce, maple syrup, yarn, honey, jam, condiments, rope, CBD, pepper flakes, soap, skincare products, and other goods. A barrel of Rye Whiskey, aging on the ship since 2020, was carried until the October run. Another cargo was 11,500 pounds of Red Oak logs from Kingston to Brooklyn for an urban mushroom farm.

TABLE 1: MALT CARGO DATA			
DESTINATION	**DIST from Hudson NY**	**WEIGHT (Lb)**	**TON-MILES**
Poughkeepsie	41.4	2,505	51.85
Beacon	56.35	3,900	109.88
Peekskill	73.6	3,600	132.48
Ossining	85.1	6,550	278.7
Yonkers	98.9	2,950	145.88
LIC, Queens	130	4,750	308.75
GBX	138	9,700	669.3
TOTALS:		33,955lb/16.98 tons	1,696.84 ton-miles

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[5] Esri *Light Gray Canvas Reference* [Basemap] Scale Not Given. February 2022. https://basemaps.arcgis.com/arcgis/rest/services/World_Basemap_v2/VectorTileServer (Accessed 1 March 2022)

TABLE 2: ADDITIONAL CARGO DATA

Origin	Destination	Cargo	Weight (Lb)	Distance	Ton-Miles
Milton	Hudson	Peppers	2,000	78.2	78.2
Poughkeepsie	South St	Flour	1,500	91.1	68.32
Kingston	GBX	Mushroom Logs	11,500	97.75	562
GBX	Ossining	Coffee	440	55.2	12.15
GBX	Kingston	Coffee	120	97.75	5.87
Hudson	Newburgh	Whiskey, Barrel	150 (est)	56.35	4.23
GBX	Kingston	Whiskey, 2 cases	50 (est)	97.75	2.44
Milton	South Street	Pumpkins	2,900	85.35	123.76
Milton	GBX	Pumpkins	500	87.4	21.85
Milton	Ossining	Pumpkins	100	39.1	1.96
Milton	South Street	Apples, 8 boxes	160(est)	85.35	6.83
Milton	South Street	Squash, Assorted	200	85.35	8.54
Milton	South Street	Grapes, 3 flats	30 (est)	85.35	1.28
Milton	South Street	Cider, 2 cases	30 (est)	85.35	1.28
GBX	Kingston	Printing Press	500 (est)	97.75	24.44
				Additional Ton Miles:	923.15
				TOTAL TON MILES:	2,619.99

ABBREVIATIONS: GBX=Gowanus Bay Terminal. **South St**= South Street Seaport Museum, Manhattan. All locations are in New York State. All distances in Statute Miles for comparison to trucking.

Small cargos included ceramic plates, books, apparel, and postcards. The ship also carried what were essentially classical “Tramping” cargos, purchased by the ship and sold on her own account.[6] This makes tracking the ton-miles involved with these cargos difficult, and these small and tramping goods have been excluded from the study. We will focus only on major cargos here, understanding the figures produced are a minimum impact.

The principal cargos and destinations for malt remained the same over the course of the season, and have been consolidated in Table 1 above. Other cargos are given in more detail in Table 2. Official river miles between ports, converted to statute miles, are used to give a uniform comparison, but the total miles covered by *Apollonia* were much greater due to tacking, jybing, and other maneuvers.[7]

FUEL USE DATA

Fuel Use for *Apollonia* over the season is estimated at 37 gallons over 38 hours of engine use.[8] Not all engine hours were recorded prior to July 2021 due to recordkeeping changes aboard ship, and

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[6] Thomas F. Tartaron, *Maritime Networks in the Mycenaean World* (New York: Cambridge University Press, 2013). Pp 30-32

[7] United States Department of Commerce, *Distances between United States Ports,* 13th ed. (Washington DC: US Department of Commerce, 2019).

[8] The *Apollonia*’s fuel tank was not full at the season’s start, and fuel purchase records from 2020 have been lost. The tank does not have a gauge, and was not “sticked” before the season began. About 40 gallons were added in 2021 and visual inspection at the end of the season shows the fuel level slightly above where it was in May. There was no plan of making these studies when the 2021 season began.

engine hours are only noted in full hours, limiting the precision of these figures. Approximately 18 hours of engine time was spent on educational programming out of Hudson, NY separate from the vessel's cargo runs. This gives an average rate of about 0.97 gallons per hour, which is reasonable for rarely exceeding clutch speed on the engine. Fuel use per voyage was calculated by the total hours of engine operation noted in the log for each voyage; total fuel used for cargo transport was about 19.47 gallons for the season.

Without the installation of costly and complicated differential fuel gauges on the ship the collection of more precise fuel use data is impossible. Such approximations are generally in line with methods used in other studies where this equipment was not available, and the data is considered sufficient for the purpose of this paper.[9] The Schooner *Apollonia* has an estimated efficiency of 134.6 Ton-Miles per gallon of diesel fuel.

Examining a single voyage with better records shows the October run moved 397.37 ton-miles with three engine hours, giving 136.55 ton-miles per gallon, or 51.77 tonne-kilometers per liter. Other voyages at higher percentages of the schooner's maximum load, or lower engine use will score differently, but are less well documented.

ENGINE USE STRATEGY

Apollonia's engine use strategy is quite simple: The engine is only used for safety purposes and docking where necessary. If the tide is against the vessel's course, she drops anchor or ties up in port, instead of employing the engines. If there was no wind, she would occasionally use only the tide for propulsion. This is substantially the same engine use strategy as 17th and 18th century Hudson River sloop masters,[10] and was adopted due to ecological as opposed to economic imperatives. This leads to a very low engine use figure, averaging less than 4.5% of hours under way over the season. 60% of voyages show less than 3.75% of hours underway involved engine use. As previously mentioned, the engine was rarely, if ever, brought above idle RPMs.

TABLE 3: *Apollonia* Engine Use and Sailing Data

Month	Sailing Days	Hours Sailing	Hours at Anchor	Hours at Port	Average VMC	Engine Hours	% Engine Hours
May	11	89.25	67.5	113.75	2.48	4 (est)	4.48
July	14	108.25	58.25	139.5	2.13	4	3.70
August	13	95	77.75	85.25	2.74	6	6.32
September	12	86.5	48.75	100	2.83	3	3.47
October	10	80	48.1	102.95	2.85	3	3.75

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[9] R.G. MacAlister "The retrofitting of sail to two existing motor ships of the Fiji Government fleet."

[10] Paul E Fontenoy. *The Sloops of the Hudson River: A Historical and Design Survey* (Mystic: Mystic Seaport Museum, 1994)

Apollonia used her engine less than 4.5% of the time, making her a near-pure-sail vessel. The hope for future seasons is to reduce this engine use intensity as much as possible, though with the docks available it is likely that some level of engine use will be unavoidable.

Speed and distance actually traveled by *Apollonia* is a complex calculation. Due to the inland and tidal nature of the Hudson River, it is frequently necessary to drop anchor when the tide or current is against the intended course when sailing. Due to a longer ebb than flood tide, it is easier to go South. The winds on the Hudson do not lend themselves to consistent sailing, which requires frequent tacking and gybing. There were a total of 62 days of operations over the season, with 459 hours sailing and 300.35 at Anchor. *Apollonia* made an average Velocity Made good on Course (VMC) ranging from 2.35 to 2.85 Knots while under way, with speed being higher, but unrecorded. A trend of increasing VMC through the season is noted in the logs, likely reflecting increased crew skill. Overall VMC once hours at anchor are included amounts to a seasonal average of 1.578 knots.

While the tide cycle on the Hudson River is approximately 6 hours, favorable winds cannot be scheduled so regularly. Whether the vessel's next stop would be at anchor or at dock depended on a multitude of factors and could not be reliably predicted far in advance.

When examining coastal Sail Freight, there will be different sailing characteristics in open waters, which may impact average VMC. *Apollonia* makes frequent stops, using her engine when docking frequently in comparison to a longer coastal route. As was found by Perez *et al* studying large ships, the advantages of Sail Freight are greatest on long routes with low engine use.[11] This confirms historic trends noted by Riesenberg[12] and Erikson.[13] The fewer stops or maneuvers a motor-sailer makes on their route the better expected fuel efficiency will be.

COMPARISONS TO TERRESTRIAL TRANSPORTATION

Apollonia is involved in inland waterway trading, which means she should not be compared to oceangoing cargo vessels due to the tonnages, cargos, and routes involved. The average freight-ton efficiency in the US for trucking is not a good comparison as this average is skewed by the relatively high efficiency of very large trucks moving cargo very long distances.[14]

A few other concerns arise for making a valid comparison: *Apollonia* is not capable of moving containerized cargo, making her a general cargo ship. As rail lines are not generally loaded with break bulk cargo, this means rail should also be excluded. In the case of other sail freighter designs using containerized cargo, such as those by Derek Ellard, the comparison would rightly be with large trucks or rail. In the case of his Electric Clipper 180, carrying 36 TEUs, the appropriate comparison would be rail.

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[11] Perez, S; Guan, C; Mesaros, A; Talay, A, "Economic Viability of bulk cargo merchant sailing vessels", *Journal of Merchant Ship Wind Energy*, 17 August 2021. (Accessed 3 December 2021) https://www.jmwe.org/uploads/1/0/6/4/106473271/jmwe_17_august_2021.pdf

[12] Felix Riesenberg, *Standard Seamanship For The Merchant Service* 2nd ed. (New York: D. Van Norstrand, 1936) pp 11.

[13] See: Georg Kahre, *The Last Tall Ships: Gustaf Erikson and the Aland Island Sailing Fleets, 1872-1947* Basil Greenhill, Ed. (London: Conway Maritime Press, 1990)

[14] In 2018 trucks moved 2,033,921 million ton-miles, using 28,987 million gallons of fuel, averaging 70 ton-miles per gallon. SEE: Bureau of Transportation Statistics *National Transportation Statistics* www.bts.gov/us-tonne-kilometers-freight AND www.bts.gov/content/combination-truck-fuel-consumption-and-travel (Accessed 15 Nov 2021)

Something like the Electric Clipper 100 carrying 4 TEUs would be more accurately compared to a class 8 truck.[15]

As with the 1920s when Walter Hedden studied *How Great Cities Are Fed*, it is small trucks which move most food and goods within 100 miles of major cities.[16] The cargo taken on *Apollonia* moved to its destination principally in 2½ ton box trucks before transitioning to Sail Freight in 2021. Apollonia has a similar cubic capacity to a 12 foot box truck, at about 600 cubic feet, which would be in the same class as a 2½ to three ton truck. A 2½ ton truck at 12 miles per gallon gives a maximal theoretical efficiency of 30 ton-miles per gallon, which is similar to figures given by the National Highway Safety Administration in 2006.[17] This holds for essentially all the cargos involved with *Apollonia*, excepting those likely moved by less efficient pickup trucks, and is the appropriate comparison.

COMPARISON TO BOX TRUCKS

Apollonia's Ton Miles of transport avoided the use of around 67.9 Gallons of fuel, and she has an advantage of 104.6 ton-miles per gallon against the theoretical optimum for 2½ ton trucks.[18] The *Apollonia* requires only 22.3% of comparable ideal trucking fuel use values. If account is taken of empty miles back to the malthouse or point of origin for these trucks, the advantage is immediately doubled. In this case, fuel use is less than 12% of trucking.

It should be noted this comparison contrasts real-world results aboard *Apollonia* with theoretical best-case conditions for the trucks. If the trucks are less than fully loaded, the ton-mile efficiency of the truck declines. Further, the New York Metro Area is a maze of congested roads with dozens of over-capacity *Passages Obligés* such as bridges and major intersections, leading to 335.9 million gallons of wasted fuel[19] and an economic cost of 18.26 billion dollars in 2019.[20] These figures alone bring the 30 ton mile per gallon figure for trucks into question when looking at the New York Metro Area, giving *Apollonia* a further advantage, though the effects of road congestion on truck fuel efficiency are not considered here. If there are any other disadvantages for the truck, such as steep climbs or sub-optimal maintenance, its efficiency declines. In terms of carbon impacts, the consumption of tires, lubricants, spare parts, and road wear should be included in the calculation for trucks,[21] while *Apollonia*'s inputs are essentially fuel, one tenth of a set of sails annually, and a small amount of paint.

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[15] Derek Ellard "The Electric Clippers" gosailcargo.com (accessed 1 December 2021)

[16] Walter P Hedden, *How Great Cities are Fed* (New York: D.C. Heath, 1929).

[17] NHTSA *Factors and Considerations for Establishing a Fuel Efficiency Regulatory Program for Commercial Medium- and Heavy-Duty Vehicles* (Washington, DC: NHTSA, 2010) https://www.nhtsa.gov/sites/nhtsa.gov/files/nhtsa_study_trucks.pdf (Accessed 28 November 2021) Pp 12-13. The figure given for typical ton-miles for vehicles in this study is quite clearly a multiplication of the load capacity by the average miles per gallon, not accounting for deadheading or partial loads.

[18] It is worth noting that even when compared to the optimal efficiency of 10 ton trucks, *Apollonia* retains an advantage of 22.6 tm/gal using her observed real-world efficiency. When comparing her maximum efficiency to the same 10 ton trucks, she is over 5.5 times more efficient.

[19] Bureau of Transportation Statistics "Annual Wasted Fuel Due To Congestion" *National Transportation Statistics* https://www.bts.gov/content/annual-wasted-fuel-due-congestion (Accessed 18 January 2022)

[20] Bureau of Transportation Statistics "Annual Highway Congestion Cost" *National Transportation Statistics* https://www.bts.gov/content/annual-highway-congestion-cost (Accessed 18 January 2022)

[21] David Austin, *Pricing Freight Transport to Account for External Costs* (Washington DC: Congressional Budget Office, 2015).
https://www.cbo.gov/sites/default/files/114th-congress-2015-2016/workingpaper/50049-Freight_Transport_Working_Paper-2.pdf. Pp 2 Summary.

Given better freight ton efficiency data for small trucks and historical data for the same cargo movements, a more accurate calculation of *Apollonia*'s impact could be made. This data is not readily available, and the above are the likely floor for efficiency gains from small Sail Freighters on inland routes using an auxiliary diesel engine.

Intensity as a percentage of maximum load weight for *Apollonia* is worth considering. The maximum a 10 CDWT capacity could have carried per circuit would be 2,346 ton miles. This assumes a two-way voyage from Hudson to New York City, each leg of which is 117.3 miles long, with a full hold. For five trips, this would be a maximum of 11,730 ton-miles. *Apollonia* only moved slightly over 21.5% of this maximum in 2021, as some runs were not made with a completely full hold, while others, such as a 2,000 load of peppers from Milton to Hudson, were affected by cargo density. *Apollonia*'s maximum theoretical fuel efficiency would be some 626 ton-miles per gallon of fuel (266 tkm/l), at the crew's current skill level and engine use patterns.

This maximum figure is over twenty times that of comparable trucking, nearly 9 times the average for trucking in the US, and 25% better than rail figures of around 500 ton-miles per gallon. With the time allowed by the season on the Hudson, a total of 12 voyages could be undertaken, which may result in higher realized efficiency through higher average cargo intensity or less engine use per ton-mile across the season.

The issue of cargo density as mentioned above is important for both trucks and sail freighters: It would be impossible to fit 10 tons of fresh peppers into the hold of the ship or onto most trucks, and cubic space should play into this calculation. As Malt is generally between .3-.7 tons per cubic meter in density (load factor), this is a serious concern for *Apollonia*'s main trade reaching full tonnage loads due to cargo density and the limits of storage space, meaning neither will likely reach their theoretical efficiencies in service. If fuel were allocated to vehicles based solely on their maximum theoretical fuel efficiency, no cargo moved by fossil fuels or electrified transport would ever arrive on target. This lack of clear information on average or real-world relative energy and carbon intensity for various vehicle types is a significant problem for sustainable transportation planning and research. By contrast, over 5,000 years of precedent has shown a lack of fuel does not fundamentally affect sail freighters' ability to reach their destination, though it may affect port-to-port time and scheduling.

Turning to Carbon Emissions, at 22.48 pounds of CO2 per gallon of diesel[22] *Apollonia* emitted about 437.68 pounds of CO2 in the course of her operations. A 2.5 ton truck would emit 1,963.25 pounds (890.5 kg) of CO2, assuming no deadheading and maximum efficiency loads. In the worst-case scenario, *Apollonia* avoided over 1,530 pounds (694 kg) of carbon emissions in 2021. Her impacts on particulates, SOx, NOx, and other pollutants will be proportionate, and the issue of noise pollution is not covered here.

IMPLICATIONS FOR INLAND AND COASTAL SAIL FREIGHT EFFICIENCY

There are lessons to be learned from the *Apollonia* for inland and coastal Sail Freight in small vessels. Internal Combustion Engine propulsion experiences economies of scale, and becomes more efficient the larger a vessel becomes.[23] As sail freight vessels grow in CDWT terms both important

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[22] Energy Information Administration. *Carbon Dioxide Emissions Coefficients* https://www.eia.gov/environment/emissions/co2_vol_mass.php (Accessed 8 February 2022)

[23] WSDC, *Wind Propulsion For Ships Of The American Merchant Marine* Pp X-6

efficiency metrics, Ton-Mile Fuel Efficiency and Tons Per Sailor, increase so long as engine use patterns remain the same. The application of electric engines with underway battery recharging will give further advantages against all forms of terrestrial transport. Engineless coastal vessels will have a much higher fuel efficiency in the middle legs of their voyages, but must use tugs when entering certain ports, inducing some fuel use on the terminal ends of the voyage which will be difficult to measure accurately. This will give a significant incentive in climate adaptation planning to shift cargo to coastal and inland sail-motor freighters where possible, but will need to be tested once such vessels are in service and can give real-world comparisons.

How the overall distance traveled by *Apollonia* compares to trucking routes for the same cargo has not been examined, but may conceal other difficulties in measuring efficiency by changing the relative ton miles by river or road. From Hudson Valley Malt to Sing Sing Kill brewery is 78.2 miles by truck, but 85.1 river miles from Hudson to Ossining. This makes comprehensive comparison complex, but does not affect relative fuel efficiency.

OPPORTUNITIES FOR FURTHER RESEARCH

The *Apollonia* refined her routing over the course of 2021 to optimize her circuit. This involved stopping at ports only while headed in one direction, for example. This reduces the total number of dockings per circuit, which can have a significant effect on the amount of engine time used per voyage. Less engine use translates directly to less fuel use for the same number of ton-miles. The skill of the crew and their familiarity with both the ship and the waters they sail will only grow as the operation continues, which will be worth examining when data becomes available.

No economic analysis of the *Apollonia* has been undertaken, and is outside the scope of this study. Examining the economics of coastal and inland sail freighters will have to be made based on a vessel and route pairing to make the appropriate comparison. Fuel cost and trucking rates will also play a role in making such a comparison, both of which are quite volatile at this time.

Research with small sail freighters equipped with other engine types, such as electric motors powered by batteries, propeller regeneration, and solar charging systems is worth funding once such vessels are available for study. Their ecological footprint will be significantly different than *Apollonia*'s, and their engine use strategy could be far more intensive without increasing carbon emissions or other pollution. Vessel design is outside the scope of this paper, and these vessels have yet to be commissioned, making a comparison impossible at this time.

The complete effects of *Apollonia*'s operations are difficult to quantify, such as social impact. This could be measured in the lives prolonged by a lack of pollutants released in New York City, traditional skills learned, and educational moments which changed how people think of transportation, consumption, and waterways like the Hudson River and New York Harbor. These topics are outside the scope of this study.

CONCLUSION

Schooner *Apollonia*'s cargo and fuel use records from 2021 show that the ton-mile fuel efficiency of even a very small sail freighter is far higher than comparable trucking. Operational results show a fuel efficiency of 134.6 ton-miles per gallon of diesel fuel while operating at 21.5% tonnage intensity, as compared to an average of 70 tm/gal for US trucking overall. When compared to the 2½ ton box trucks she replaces, she has an advantage of 104.6 tm/gal at the same intensity against the truck at 100% intensity. If *Apollonia* were used at full CDWT capacity with current engine use patterns, she would give 626 tm/gal, 25% better than rail, nearly 21 times better than 2½ ton trucks, and just under 9 times more efficient than the US trucking average.

Due to the engine use strategy of the ship, considerable time was spent at anchor. Over 62 days of operations, 459 hours were spent underway, with 300.35 at anchor. Velocity Made good on Course (VMC) while under way ranged from 2.35-2.85 knots, while overall VMC including time at anchor was 1.578 knots.

The nature of navigation and winds on the Hudson River make these results applicable principally to this route and engine use pattern. Predominant winds force frequent tacking and jybing, and the slightly longer ebb tide makes southbound travel easier than northbound. It is clear that larger vessels will be more efficient, and other routes which require less docking and maneuvering under power will increase efficiency, making these figures a likely floor of fuel efficiency for inland and coastal sail freighters.

Acknowledgements: Thanks are due to *Apollonia*'s Bosun Tanya Van Renesse, and Supercargo Brad Vogel for their critical assistance in collecting information on cargo weights, destinations, and origins.

Bibliography:

"Nordlys" https://fairtransport.eu/nordlys/ Accessed 27 November 2021.

Austin, David. *Pricing Freight Transport to Account for External Costs* (Washington DC: Congressional Budget Office, 2015). https://www.cbo.gov/sites/default/files/114th-congress-2015-2016/workingpaper/50049-Freight_Transport_Working_Paper-2.pdf.

Bureau of Transportation Statistics *National Transportation Statistics* www.bts.gov (Accessed 28 January 2022)

Ellard, Derek. "The Electric Clippers" gosailcargo.com (accessed 1 December 2021)

Energy Information Administration. *Carbon Dioxide Emissions Coefficients* https://www.eia.gov/environment/emissions/co2_vol_mass.php (Accessed 8 February 2022)

Esri *Light Gray Canvas Reference* [Basemap] Scale Not Given. February 2022. https://basemaps.arcgis.com/arcgis/rest/services/World_Basemap_v2/VectorTileServer (Accessed 1 March 2022)

Fontenoy, Paul E. *The Sloops of the Hudson River: A Historical and Design Survey* (Mystic: Mystic Seaport Museum, 1994)

Hedden, Walter P. *How Great Cities are Fed* New York: D.C. Heath, 1929.

Kahre, Georg. *The Last Tall Ships: Gustaf Erikson and the Aland Island Sailing Fleets, 1872-1947* Basil Greenhill, Ed. (London: Conway Maritime Press, 1990)

MacAlister, R.G. "The retrofitting of sail to two existing motor ships of the Fiji Government fleet." *Proceedings of Regional Conference on Sail-Motor Propulsion* Manila: Asian Development Bank, 1985

Merrett, Sam. "Log of Schooner *Apollonia*, 2021" Unpublished, 2021.

NHTSA. *Factors and Considerations for Establishing a Fuel Efficiency Regulatory Program for Commercial Medium- and Heavy-Duty Vehicles* Washington, DC: NHTSA, 2010. https://www.nhtsa.gov/sites/nhtsa.gov/files/nhtsa_study_trucks.pdf (Accessed 28 November 2021)

Perez, Sergio; Chang Guan, Alexander Mesaros, Atil Talay, "Economic Viability of bulk cargo merchant sailing vessels", *Journal of Merchant Ship Wind Energy*, 17 August 2021.

https://www.jmwe.org/uploads/1/0/6/4/106473271/jmwe_17_august_2021.pdf (Accessed 3 December 2021)

Riesenberg, Felix. *Standard Seamanship For The Merchant Service* 2nd ed. New York: D. Van Norstrand, 1936.

Tartaron, Thomas F. *Maritime Networks in the Mycenaean World* New York: Cambridge University Press, 2013.

United States Department of Commerce, *Distances between United States Ports*, 13th ed. Washington DC: US Department of Commerce, 2019.

Verlinghieri, Ersilia, Irena Itova, Nicolas Collignon, and Rachel Aldred. *The Promise of LowCarbon Freight: Benefits of cargo bikes in London* (London: Possible, 2021) https://www.fleeteurope.com/en/last-mile/europe/analysis/new-report-why-cargo-bikes-beat-evs-last-mile-deliveries (Accessed 30 November 2021)

Wind Ship Development Corporation. *Wind Propulsion For Ships Of The American Merchant Marine* Norwell, MA: WSDC, 1981.

Woods, Steven. “Sail Freight Revival: Methods of calculating fleet, labor, and cargo needs for supplying cities by sail.” Master’s Thesis, Prescott College, 2021. Researchgate.net

ANNEX II – G

TOWT
TRANSPORT À LA VOILE

TOWT Sailing Cargo Vessels

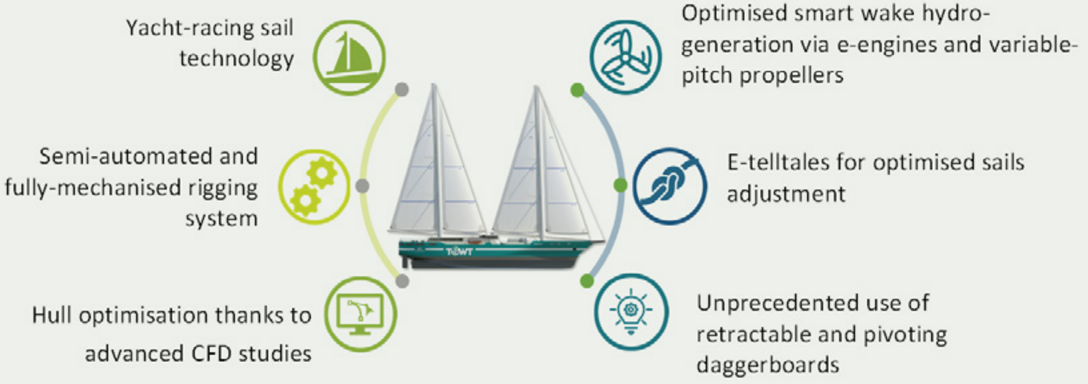
- ✓ Vessels under construction : 2 units (2024 – 03)
- ✓ Projected Fleet : 14 units by 2027

A modern, reliable and optimised logistical solution
drawing on an innovative blend of well-proven technologies

TOWT Sailing cargo Vessels, under construction

Owner :	TOWT (FR)	Gross tonnage :	Estimate 1520 UMS
Designation :	General cargo (sailing ship)	Loading capacity :	1200 t.
Classification :	Cleanship	LOA – LBP x Beam	80,5 m – 63,8 m x 12,6 m
Crew (max) : Passengers (max)	12 people 12 people	Max draft : Air draft :	4,9 m 62,5 m
Loading :	Palletized goods (1080 pallets)	Upwind sail area :	1870 m^2
		Av. speed :	10,5 knots

More than 50 Innovations



Yacht-racing sail technology

Semi-automated and fully-mechanised rigging system

Hull optimisation thanks to advanced CFD studies

Optimised smart wake hydro-generation via e-engines and variable-pitch propellers

E-telltales for optimised sails adjustment

Unprecedented use of retractable and pivoting daggerboards

TOWT – Our Impacts

Mitigating **climate change**
Mitigation of **ocean acidification**
Mitigation of **impacts on marine biodiversity**

Decarbonisation rate
>90%

< 1 g of CO_2
Per tonne and per kilometer

9 g of CO_2
Per tonne and per kilometer

1 200 t de CO_2 saved
Per year & per sailing cargo ship

TOWT – Contacts

www.towt.eu
52 quai Frissard
76600 Le Havre, France.
T : +33 (0)9 84 33 89 62 info@towt.eu

TOWT – Economics

Building
Investment
Program :
20 M€ per vessel

Massive business traction since summer 2022

Secured income to date
(signed BAs/BNs)
incl. extensions subject to good performance

36m€ over 10 years

Expected income
(signed BAs/BNs + conservative 66% conversion rate of submitted and signed LOIs
& submitted BAs/BNs)
incl. extensions and projected additional volumes

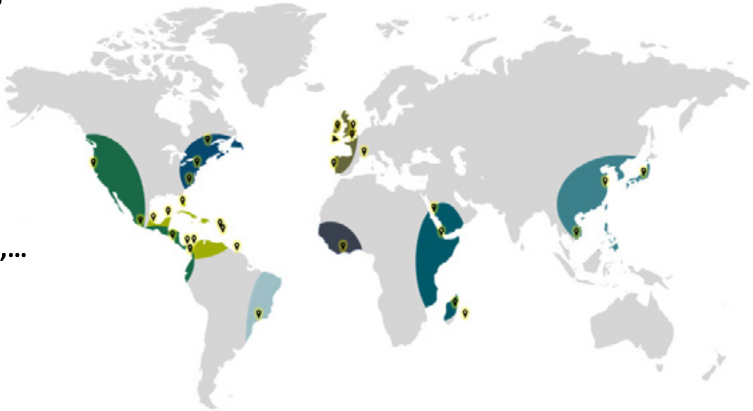
965m€ over 12 years

Our routes 2024-2025

- ● North Atlantic
- ● Central America & Caribbean
- ● West African.
- ● South America

Future routes 2026,…

- ● Europe
- ● Asia
- ● MEA and IO
- ● Pacific



ANNEX II – H

Case study

A Feasibility project was carried out to assess the potential of retrofitting FastRigs (Smart Green Shipping's (SGS) wing sail solution) on an Ultrabulk ship importing biomass into the UK for Drax to produce renewable electricity. This study's purpose was to find cost-effective ways to significantly reduce the GHG emissions from the ocean transport required in the biomass supply chain.

Vessel details: Ultra Tiger, IMO No: 9414149, Panamax bulk carrier, built 2009, operated by Ultrabulk, DWT 83611, LOA 225m, Beam 32.8m.

The study mainly focused on calculating fuel and GHG savings achievable for Ultra Tiger by installing FastRigs. This included:

- Modelling the Ultra Tiger for computational fluid dynamics (CFD) analysis
- FastRigs modelled in a 3D system and 'fitted' on the virtual Ultra Tiger
- Using CFD code to generate force and moment data to input in to the WinDesign 4 Velocity Prediction Program (VPP). We then **analysed performance and fuel/GHG saving potential across of all combinations of wind speed and angle, and with varying degrees of engine propulsive thrust.**
- Dr Graeme Winn, pioneering designer of custom-built tactical route optimisation for Americas Cup teams, created our proof-of-concept wind-assistance routing tool, for commercial shipping to optimise fuel savings to wind-fitted ships.
- Using NOAA meteorological data sets covering three decades of statistical likelihood of wind speed and direction we modelled the UltraTiger's route serving the Drax power plant - Baton Rouge - Liverpool
- Applying Ultrabulk's normal operational speeds at four start dates within each season, i.e., sixteen voyages in total.
- Measuring the ship fuel consumption along the route, for each of these voyages for the ship with and without FastRigs, to and quantifying the difference.
- Aggregating large volumes of data to produce a 20% average annual fuel saving across all seasons at normal operating speeds.
- 'Playing' with speeds and route optimisation to explore potentially greater savings. Ships can either go faster for the same fuel consumption or save even more fuel by slow steaming (going slower).

Technology

Product: **FastRig**

Type: Wing Sail with flaps – Adjustable orientation for maximum utilisation of available wind and efficient thrust production - Foldable horizontally, parallel to the deck, when not in use

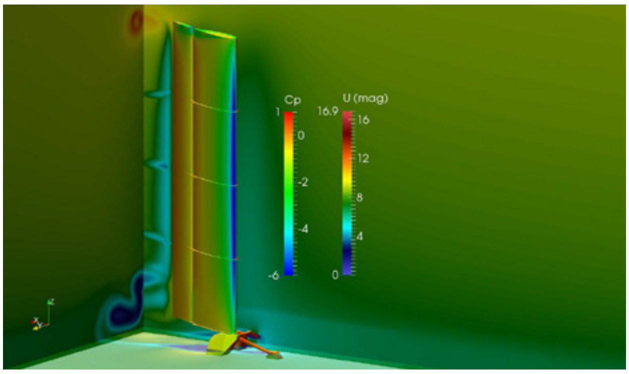
Materials: Aluminium and composite wing, and steel base

Main components: Wing with flaps, drive motors for flaps, base with HPU and luffing cylinder, slew ring, slewing motors.

Operation: Full or semi-automatic and manual remote controlled. Emergency manual control available

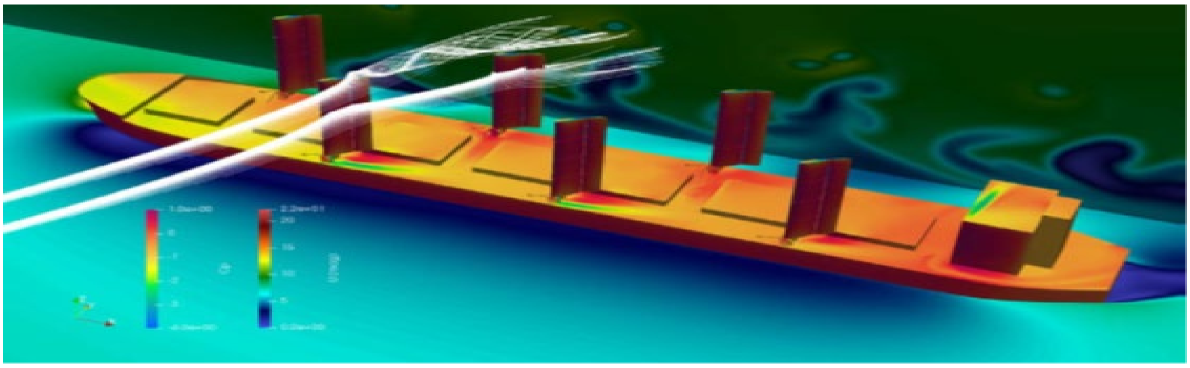
Computational methods used for case study: All simulations were conducted on the Iridis 5 supercomputer at the University of Southampton using the OpenFOAM CFD solver.

Aerodynamic CFD modelling was done for single FastRig in isolation, single FastRig on a ship, and a combination of six FastRigs on the ship.



Single FastRig in isolation

Single FastRig installed on the vessel



Six FastRigs installed on the vessel

Results:

Working with the Wolfson Unit for Marine Technology and Industrial Architecture we verified that the Ultra Tiger, could **save at least 20% fuel every year** on the route from Baton Rouge to Liverpool whilst carrying biomass for Drax at usual operating speeds.

Moreover, the design and engineering solutions were tested in collaboration with a wider group of stakeholders, including ship-owners, cargo-owners, port-owners and crews. FastRigs met the following operational criteria:

- Minimal structural or cargo capacity impact on vessels.
- FastRig technology requires no additional crew to operate it.
- No port-side infrastructure changes required. FastRigs fold to allow standard loading and unloading processes.
- From a safety perspective, all the sail area can be dropped in a moment should the need arise.

SGS is now building a land-based test FastRig, will be installing on a ship next year and is investing in latest production technologies and processes to produce the wings at scale and minimise production costs.

ANNEX II – I

Route optimization for wind-assisted ships

Route optimization for wind-assisted ships is a uniquely synergistic combination that can move the ship out of a detrimental prevailing weather pattern and into a beneficial weather pattern. In this example, a voyage from Cape Town to Djakarta is examined and 15% additional fuel/CO_2 savings are obtained while respecting a fixed arrival time.

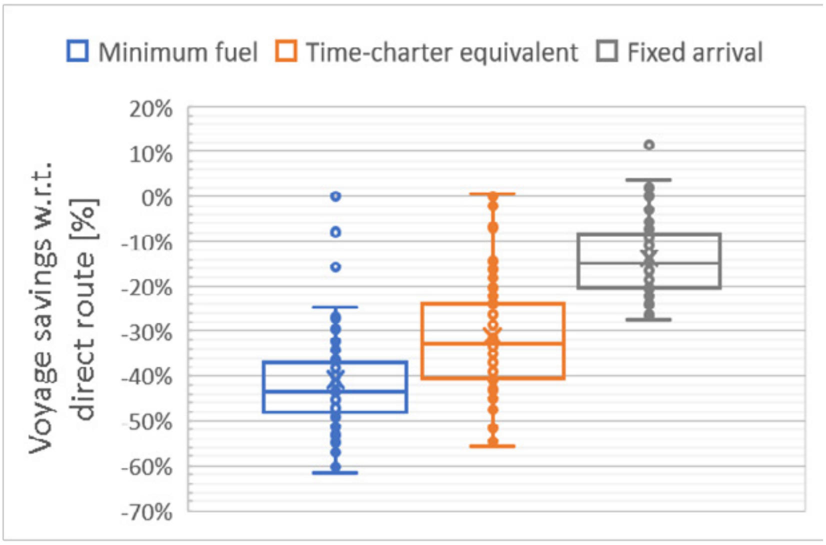


Fig. 1 Presentation of 400 best voyages based on Minimum fuel, Time-charter equivalent, and Fixed arrival consideration, benchmarked to the WASP vessel on direct route.

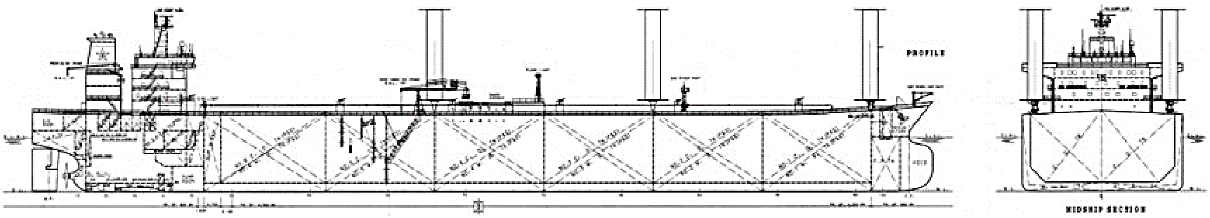


Fig. 2 A schematic diagram of the Panamax bulk carrier ship. Four Flettner rotors are installed, with three positioned on the starboard side and one at the front port side.

Panamax main particulars	
Length overall (LOA)	225 metres
Length between perpendiculars (LPP)	211 metres
Beam	32.2 metres
Draft (fully loaded)	14 metres
Specified Maximum Continuous Rating (SMRC)	9.5 MW
Size	80,000 DWT
Charter rate	15,000 USD/day

Wind assist installation	
WASP Type	Flettner Rotor
Number of rotors	4
Height of rotors	35 metres
Diameter of rotors	5 metres

Route: Cape Town – Djakarta	
Great circle distance	5,182 nm
Direct route duration (12 Knots)	18d 12h

Description of Blue Wasp technology: PELICAN

Pelican Software offers a versatile toolkit for independent WASP evaluation and best-in-class ship models. Its modular framework, ranging from quasi-static equilibrium to dynamic operations and fleet-level assessment, underscores its ability to address multifaceted maritime scenarios—a testament to Blue Wasp's forward-thinking approach. This versatile wind- ship modeling suite is underpinned by customizability, meticulous research, and a corporate vision to decarbonize maritime operations.

The Pelican ship model generated for this case study comprises more than 400,000 solutions to the vessel operational state, considering ship speed, wind condition, and wave conditions. This database fully defines the vessel behavior for possible engine and Flettner rotor settings.

Description of Theyr technology: T-VOS

The T-VOS algorithm, designed for multi-objective optimization, integrates the Multi-Level Selection Genetic Algorithm. This synergy produces multiple optimal route alternatives, each emphasizing distinct factors like fuel consumption, time-charter rate, and voyage duration. Importantly, all safety prerequisites are rigorously met during this process.

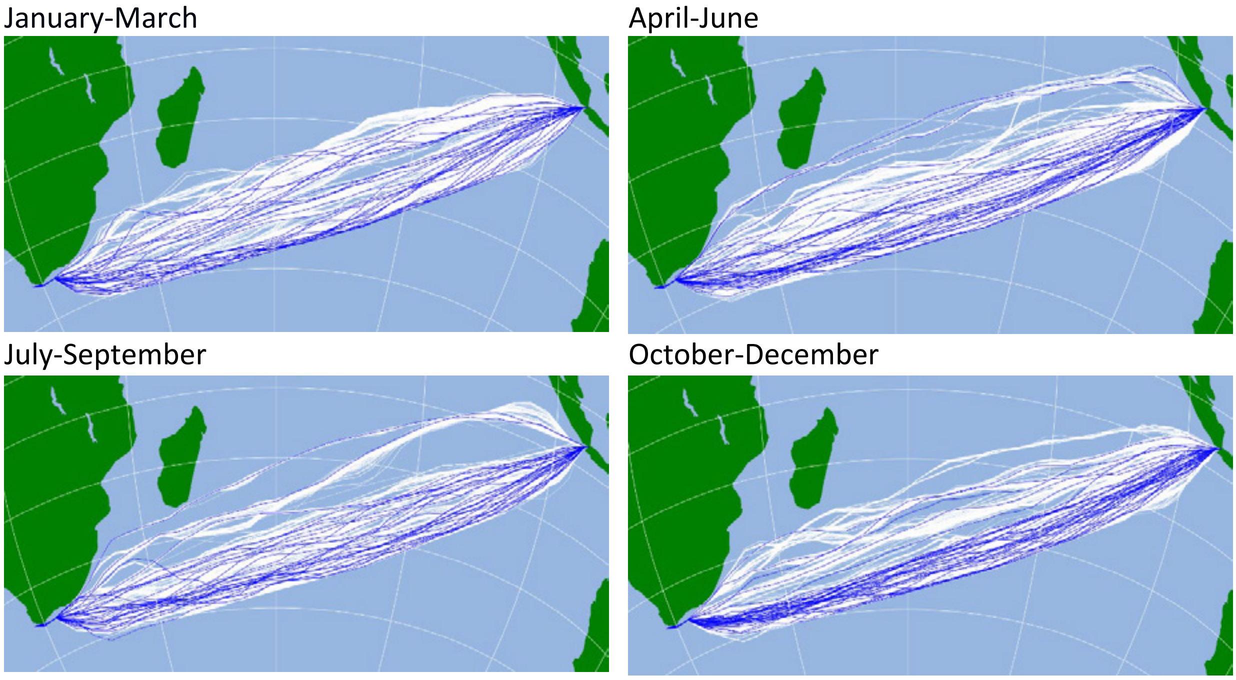
More than 19,200 voyages have been evaluated during the past five years using the Blue Wasp ship model and T-VOS algorithm with Spire weather. The percentage additional reduction in fuel burn and carbon emissions, compared with the WASP vessel on direct route, is presented below:

Minimum fuel	Time-charter equivalent	Fixed arrival
-43.3%	-33.0%	-14.9%

Description of Spire Technology

Spire is a pioneer in advancing weather forecasting through its deployment of a constellation exceeding 100 nanosatellites in low-Earth orbit, harnessing Radio Occultation (RO) technology to analyze signals emitted by the Global Navigation Satellite System. The outcome is a meticulous measurement of atmospheric vertical profiles globally, which significantly elevates the precision of weather predictions. Entities such as ECMWF, NOAA, UKMO, and NCAR rely on Spire's RO measurements. These measurements play a pivotal role in the refinement of global weather models and the advancement of climate studies.

Spire's expertise lies in the integration of RO data with both satellite-derived and publicly available information, forming the basis for their commercial global weather models and 15-day forecasts. These best-in-class forecasts hold intrinsic value for maritime operations, especially for wind-assisted ships that rely on weather forecasts to plan their routes.



January-March

April-June

July-September

October-December

Fig. 3 Presentation of seasonal variation for all voyages (white) and Fixed arrival (blue).

Spire Maritime Bundle

Wind speed	Significant Wind Wave Height	Ocean Surface Current
Wind gust speed	Mean Wind Wave Direction	Sea Surface Temperature
	Mean Wind Wave Period	Ocean Salinity
	Significant Total Swell Wave Height	
	Mean Total Swell Wave Direction	
	Mean Total Swell Wave Period	

Contact: nvanderkolk@bluewaspmarine.com

Blue WASP Wind Assist Specialists Theyr spire | weather

ANNEX II – J

NAOS
SHIP AND BOAT DESIGN

A brief overview of design principles and performance predictions of a Wing Sail Module® system

Date	July 20th, 2022
Issued by	E. Tescaroli

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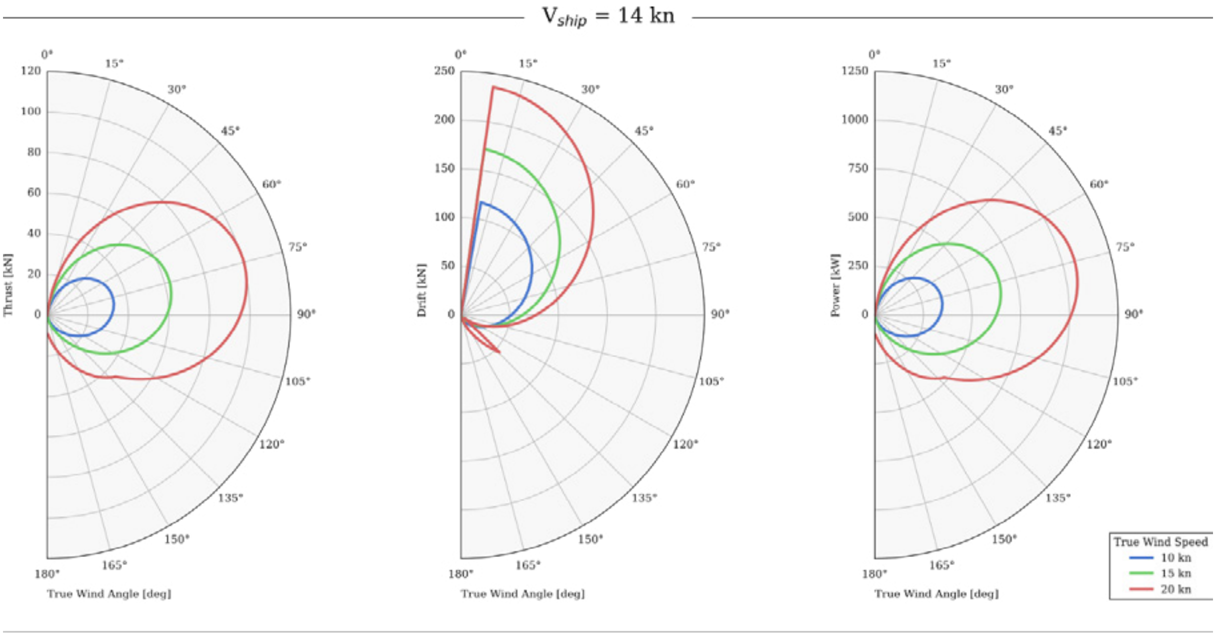
The WSM (Wing-Sail Module) is a foldable, unibody rigid sail designed to emphasize the role of efficiency in wind propulsion beside the mere thrust generation.

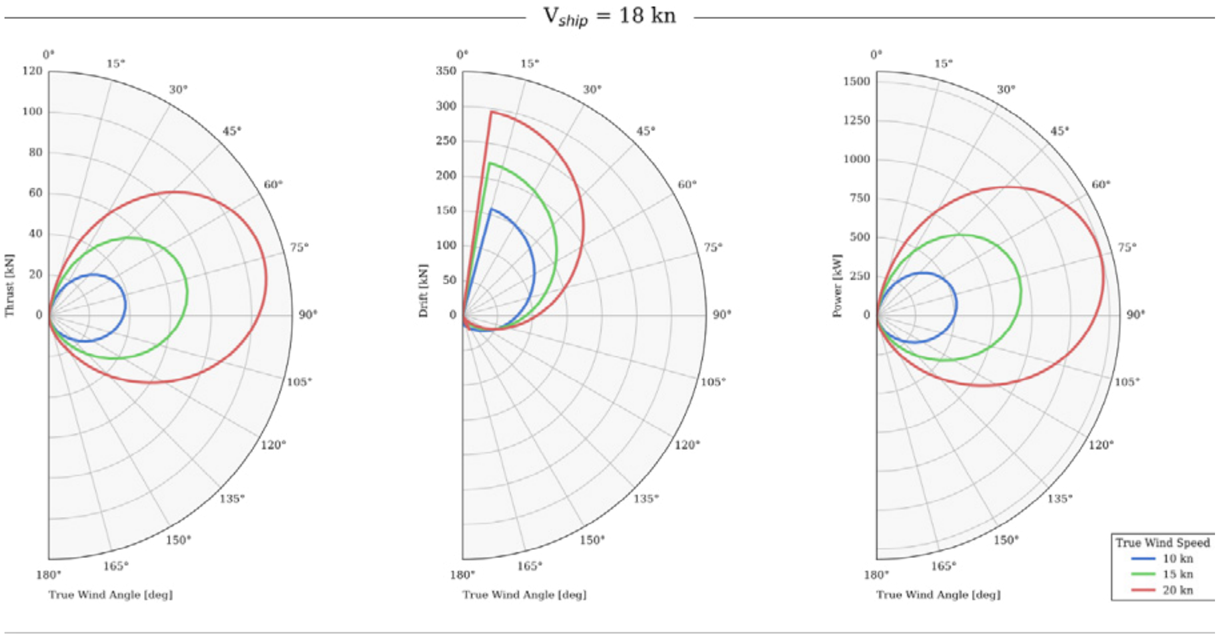
Indeed, sail's efficiency (thrust-to-drift ratio) is a key factor that should be treated on par with the delivered thrust given the impact it has on the overall power balance. Specifically: the lower the efficiency, the greater the rudder deflection required to compensate for the additional drift on the ship, translating into drag penalty and reduced net power savings.

In a WSM these two design objectives (thrust, efficiency) are met with an optimized wing section profile and a high aspect-ratio planform (relation between span and chord), leading to a rather compact design capable of extending the operational range of an average rigid sail to close-hauled sailing conditions.

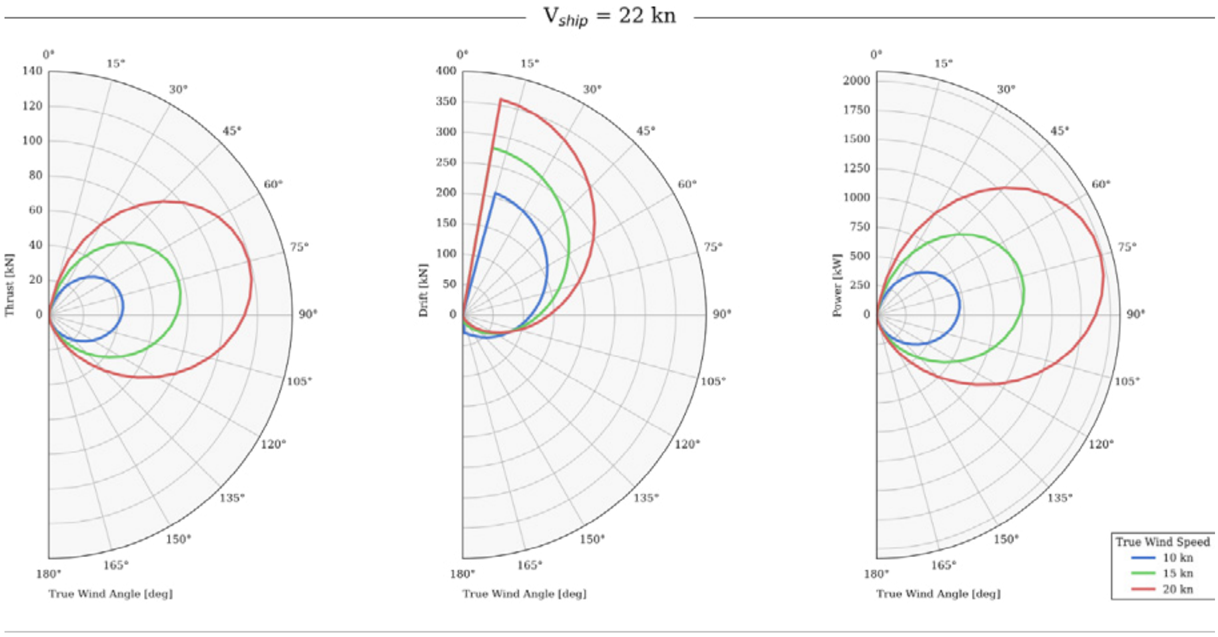
In the following charts, thrust, drift and propulsive power (ηD = 0.68) are presented for 3 different ship velocities (14, 18, 22 knots) and 3 different true wind speeds (10, 15, 20 knots). Shown data represent average values achieved with a typical 4 WSM200 units installation and originate from statistics over a large CFD dataset built on different classes of vessels. The WSM200 model features a 5m root chord extended over a 44m span, reaching an overall planform surface of 200 sqm.

Corrections are applied to account for interferences from the superstructure, with arrangement and trimming optimization in place. Data for the single sail received validation from a 1:3 scale prototype in sea trial tests.





V_{ship} = 18 kn



V_{ship} = 22 kn

Average and maximum values for thrust and propulsive power are summarized in the tables below.

Average Thrust - 4x WSM200 [kN]			
	TWS [kn]		
Vs [kn]	10	15	20
14	16.8	31.2	53.2
18	20.0	35.2	55.2
22	22.8	39.2	59.6

Maximum Thrust - 4x WSM200 [kN]			
	TWS [kn]		
Vs [kn]	10	15	20
14	33.2	61.6	98.4
18	38.4	68.8	107.6
22	43.6	76.4	117.6

Average Drift - 4x WSM200 [kN]			
	TWS [kn]		
Vs [kn]	10	15	20
14	50.2	67.6	91.1
18	70.1	90.6	115.5
22	98.9	121.1	143.4

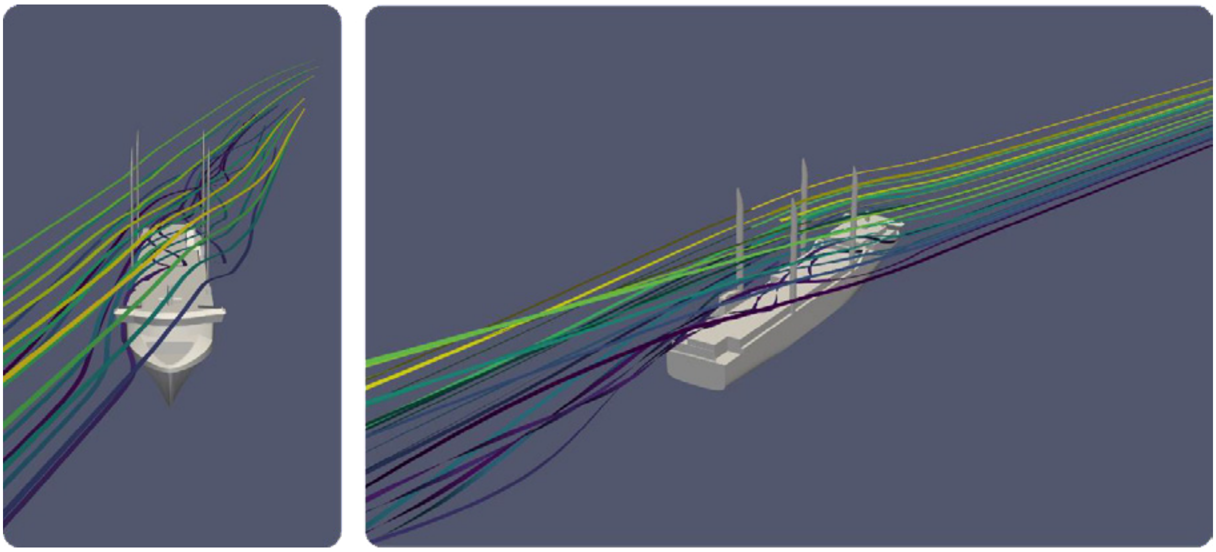
Maximum Drift - 4x WSM200 [kN]			
	TWS [kn]		
Vs [kn]	10	15	20
14	117.5	172.1	236.5
18	158.6	222.2	295.4
22	207.4	279.4	359.9

Average Propulsive Power - 4x WSM200 [kW]			
	TWS [kn]		
Vs [kn]	10	15	20
14	180	332	560
18	260	476	752
22	376	652	992

Maximum Propulsive Power - 4x WSM200 [kW]			
	TWS [kn]		
Vs [kn]	10	15	20
14	352	652	1040
18	524	940	1468
22	724	1272	1956

For simplicity, values in charts and tables assume an uniformly distributed wind in the entire 0-180° range. However, wind conditions are far from being constant around the globe, with winds to the bow or the stern occurring more often than those to the sides. This factor further tips the scale towards the adoption of the WSM technology, capable of delivering great performance even at low wind angles.

Thanks to its slenderness, the WSM has also a small footprint which gives a great level of flexibility on the arrangement on board and allows for a balanced and rational installation to keep mutual interferences to a minimum. With such a low space requirement the modules can be located as in figure close to the edges, leaving the payload essentially unaltered.



The best propulsive power for every wind condition is guaranteed by a smooth trimming of the sail, achieved through a small, low power motor which is easily fitted below each sail and has an almost negligible impact on the overall power balance.

In case of adverse weather conditions (strong gusts, heavy winds), during loading/unloading operations in port or when the wind intensity is simply not strong enough, each sail can be folded independently to a resting position where it will not interfere with normal ship operations.

The control is completely AI-based, meaning that no user intervention is required during ordinary operation. Procedures are implemented to manage extreme events, feathering the sails to the wind or folding them even in case of complete power loss. It is understood that the crew can intervene and supersede the autonomous control at any time, on-demand.

ANNEX II – K

THE 24TH CHESAPEAKE SAILING YACHT SYMPOSIUM
ANNAPOLIS, MARYLAND, MARCH 2022

Progress in development and design of DynaRigs for commercial ships

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ABSTRACT

For most of the past century sailing was (besides very few exceptions) associated with pleasure and racing only. Recently, however, this is changing as the commercial maritime transport sector becomes increasingly interested in direct wind propulsion systems. The reasons are obvious: increasing fuel cost (direct or though emission penalties) and environmental awareness (intrinsic or driven by customer demands). In this paper differences between the design requirements in the commercial market and the pleasure or racing yacht industry are discussed and enhancements to the existing design tools relevant for commercial studies are presented. Sailing yacht studies have repeatedly shown how important it is to design and optimize the aero and the hydro aspects of the vessel in synchrony. This is equally or even more important for commercial ships, where part of the thrust might still come from the engine. Thus, the engine together with economic objectives of the shipping operations enter into the design space. With DynaRigs already having proved highly successful in the pleasure yacht market and possessing key features which are attractive for the commercial shipping, it serves as a good case-study. A few select results are first presented when analyzing the aerodynamic design space alone. Detailed results from several performance analyses via our Performance Prediction Program (PPP) are then discussed as well as some outcomes from the structural analysis to show the importance of combined aero, structure, hydro, and potentially engine as well as economic design decisions. The paper concludes with an outlook on future work.

NOTATION

A	(Sail) Area
AMI	Arbitrary Mesh Interface
AOA	Angle of Attack
BS	Boat Speed
ETA	Estimated Time of Arrival
l_{ref}	Reference Length
AWA	Apparent Wind Angle
AWS	Apparent Wind Speed
CAM	Computer Aided Manufacturing
CAPEX	Capital Expenditure
CFD	Computational Fluid Dynamics
CSYS	Chesapeake Sailing Yacht Symposium
CWA	Course Wind Angle
DES	Direct Eddy Simulation
DoF	Degree of Freedom
E	Young's Modulus
FEA	Finite Element Analysis

F_i	Force along i-axis
FSI	Fluid Structure Interaction
M_i	Moment about i-axis
OPEX	Operational Expenditure
PBO	Polybenzoxazole
P_e	Effective Power
PPP	Performance Prediction Program
RANS	Reynolds Averaged Navier Stokes
T_h	Hydrodynamic Thrust
TWA	True Wind Angle
WASP	Wind Assisted Ship Propulsion
VMG	Velocity Made Good
VPP	Velocity Prediction Program
ρ	Density of air

1. INTRODUCTION

Commercial (maritime) shipping plays a key role in our economy and thus directly effects our daily lives. 90% of global trade is transported on cargo ships which consume 4 million barrels of oil per day – 4% of the global oil production (International Chamber of Shipping, 2020). Thus, decarbonizing commercial shipping is key in achieving the world's climate stability ambitions as stated in the Paris Agreement. Currently, different ways of how to decarbonize maritime shipping are being explored. While many of these have merits, using wind energy directly to power ships has three clear advantages: (A) the primary energy source (the wind power) is directly available to harvest. Thus, energy conversion, transport and storage losses are minimized. (B) harvesting wind energy directly on board involves modifications to the vessels systems and its immediate environment only. It does not require the transformation of adjacent and/ or upstream industries. This results in a much more compact technological (and regulatory) challenge. This is in contrast to any alternative fuel solution which will require the creation of a new fuel production industry, as well as modified transportation and storage infrastructure. And finally (C) using wind as a power source for marine transportation has a unique business case advantage: the cost of wind power is, and will stay at, zero. Future fuel prices, which are inherently volatile and largely unknown, introduce a significant degree of investment risk to any fuel powered project – conventional or alternative. Hence, the less a project relies on fuel for its propulsion (i.e., the more propulsive force can be generated directly form the wind), the lower the risk exposure to rising fuel prices.

The DynaRig, one of many means of harvesting wind power for ship propulsion, was conceived in the 1970's for commercial shipping by Wilhelm Prölß as a potential offset against rising fuel costs. The key features of this concept are crew safety with no loaded lines on deck, incremental reefing ability and easy and automated handling of furled sails, as well as easy and automated trimming of the sails using only mast rotation to set the sails correctly. Due to the subsequent drop in fuel prices in the early 80's, this concept never progressed past early wind-tunnel testing (Wagner, 1966), until, aided by the enhancement of modern materials, it was successfully introduced to large sailing vessels by Dykstra Naval Architects, e.g. 89m Maltese Falcon (Perkins et al, 2004) and 106m Black Pearl and followed by extensive load measurements (Roberts and Dijkstra, 2004; Wilkinson, and Robert, 2016). Over the last decade North Sails, the Wolfson Unit, and Southern Spars have conducted several studies on these kinds of propulsion systems. While all three companies come from a background of (racing) yachts, they have recently expanded their expertise into the commercial shipping world. There, North Sails' unique capacity for numerical modelling of rigs and sails as well as investigating and optimizing the complex interaction of the ship with the "engine above deck" has put them in a key position of bringing the essential sail engineering perspective into these commercial studies. After all, sails are not just a motor that produces thrust, but an aerodynamic system which requires the ships hydrodynamic design to balance forces and moments (most notably side force, roll and yaw moments) in order to create thrust. The Wolfson Unit's extensive expertise in a range of techniques for both testing and performance evaluation of hydrodynamics and aerodynamics, combined with its technical background in yacht research further enhances this position and transfers well to the assessment of wind assisted technologies on commercial ships. Southern Spars complements the group's know-how by adding leading expertise on spar and composite design specifically geared to the marine industry.

The core driver of commercial vessels (in contrast to many yacht studies) is cost. That is the need to transport the cargo as efficiently as possible in terms of financial cost and within particular time schedules. Commercial shipping operators have always been aware of wind propulsion, but wind fell out of favor with the lower costs and increased reliability of engines. The balance is now swinging back towards wind propulsion with emission limits, carbon taxes and an overall awareness of the influence of shipping upon climate change. In this paper the tools developed, and some recent results from work on wind powered solutions for commercial shipping, are presented.

2. AERODYNAMIC EFFICIENCY VERSUS COMPLEXITY OF CONCEPT

Before going into the details of DynaRigs for commercial shipping it is important to understand the basic design requirements for commercial ships, trade-offs, and pitfalls, first. Hence a brief introduction of the design considerations around aerodynamic efficiency and design complexity is given in this section.

2.1. Aerodynamic concept

There are currently a variety of different wind assisted shipping concepts, all with their own proponents, at various different stages of technical development and real-world implementation (Chou at al., 2021). Broadly speaking one can distinguish four groups:

- Relatively bluff bodies with manipulation of air flow via power input (e.g. Flettner rotors or Ventifoil)
- Solid wing sails (e.g. WindWings, WindShip or FastRig)
- Soft wing sails with rigid frame mast (e.g. DynaRig or ADD Technologies)
- Soft sails or kites (e.g. SkySails GmbH, Airseas SAS)

The companies listed above are only examples of specific concepts; there are a large number in each category. While it may be thought that one concept will gradually become the clear favorite and dominate the market, much like the Bermudan rig for sailing yachts, the choices and technical challenges are more likely to require different concepts for different tasks. Operational height restrictions and structural implications quickly create the necessity of multiple rigs. This in turn necessitates more integration of the superstructure and the need to operate the rigs such that adverse interactions are minimised - a complex task with apparent wind angles from any direction.

The concept of Flettner rotors for example is both an elegant use of fundamental fluid dynamics and a simple concept to control by altering the rotational speed to change the thrust for a given set of conditions without changing the physical positioning of elements. The aerodynamic efficiency of a rotor in isolation is good (Jones et al, 2019), with significantly higher lift coefficients than other devices. Consequently, there are currently a number of commercial shipping vessels employing Flettner rotors on the water or in planning, such as Norsepower. However, when multiple rotors are placed in close proximity, or next to superstructure, the thrust developed by the rotors drops, and the interaction becomes complex and non-linear. The effect of separation in two dimensions of a pair of rotors is presented in Figure 1, while the effect of a hullform and apparent wind angle upon lift, drag and power can be observed in Figure 2. This interaction between hull and rotor is visualised in Figure 3, where the windward deck edge separation and the extent of the recirculation zone become clear. The effect of the ship is to introduce a secondary flow pattern which interacts with the flow around the rotor causing reductions in efficiency (Figure 2), most dominant at +/- 90 deg and -135 deg (wind over the opposite deck edge to the rotor), which is where the ship form creates the largest wake over the rotor. These are large changes in relative performance with apparent wind angle.

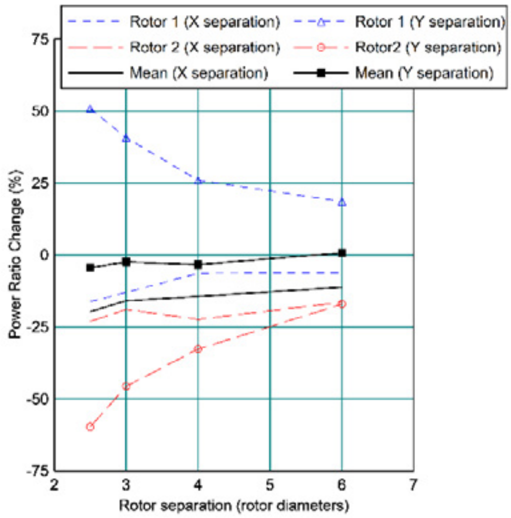


Figure 1 - Change in power ratio for two Flettner rotors, separated in streamwise (x, squares) and transverse (y, circle) direction.

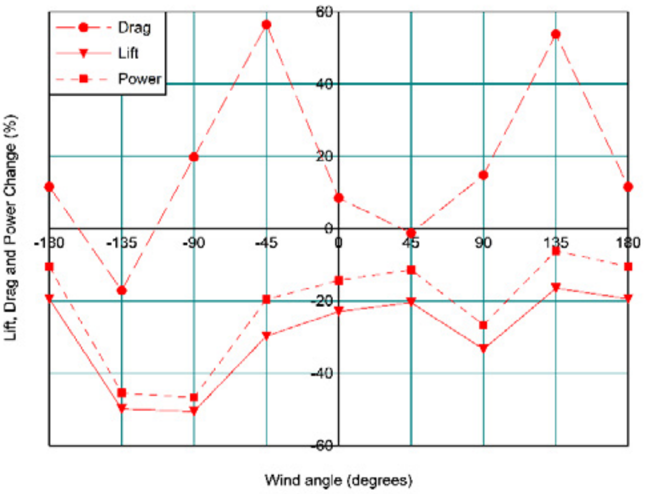


Figure 2 - Change in lift, drag and power for Flettner rotor next to superstructure.

A similar flow visualisation, but with a twin DynaRig instead of a Flettner rotor is presented in Figure 4. The differences in the fundamental flow structure are clear, with the deck separation zone suppressed by the rigs and a larger separation zone to the lee of the ship. Figure 5 shows the flow from the same simulation as that from in Figure 4 but with superstructure blocks added at the bow and for the bridge. While on first viewing there is little difference between these cases (Figure 4 versus Figure 5), careful inspection of the wake structure shows the influence of the superstructure is propagated even half a ship length aft, i.e. in the flow separation between the rigs.

In general, it can be observed that thrust generating components near the deck are of low efficiency, and there are good aerodynamic justifications for keeping them higher, both to keep them clear of the deck recirculation zone, but also to get them into higher wind speeds. However, changes in wind speed with height, as is normal in an atmospheric boundary layer, are a concern for optimising aerodynamic efficiency. Flettner rotors, where the entire device rotates at one speed, become significantly more complex if attempting to optimise for the apparent wind gradient observed when combining ship speed and the atmospheric boundary layer. Wing sails don't need to adjust (from an aerodynamic efficiency perspective) for a change in apparent wind speed, and much like for the Flettner rotor, the effect of deck edge created recirculation zone affects the effectiveness of those sections near the deck. Raising a lifting surface away from the deck is hence beneficial, and also because it transfers moving parts (booms, sails etc.) away from the deck and crew operations.

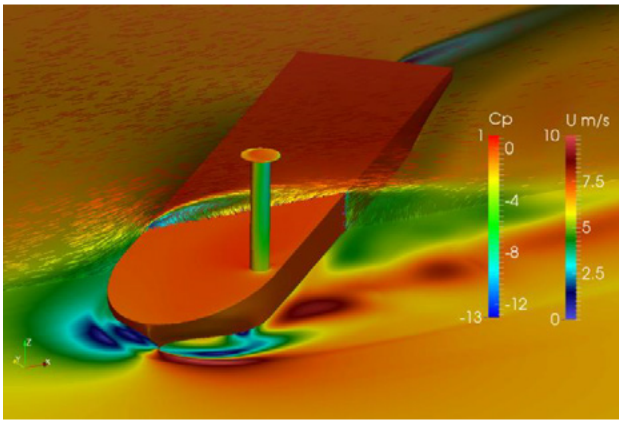


Figure 3 - Simple ship hull form with Flettner rotor (AWA = 45 deg).

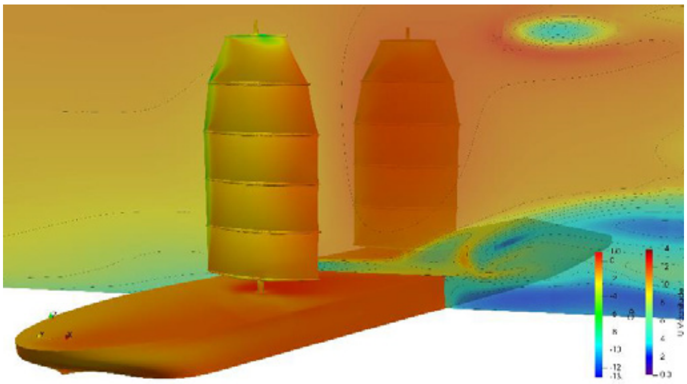


Figure 4 - Simple ship hull form with twin DynaRig (AWA = 45 deg).

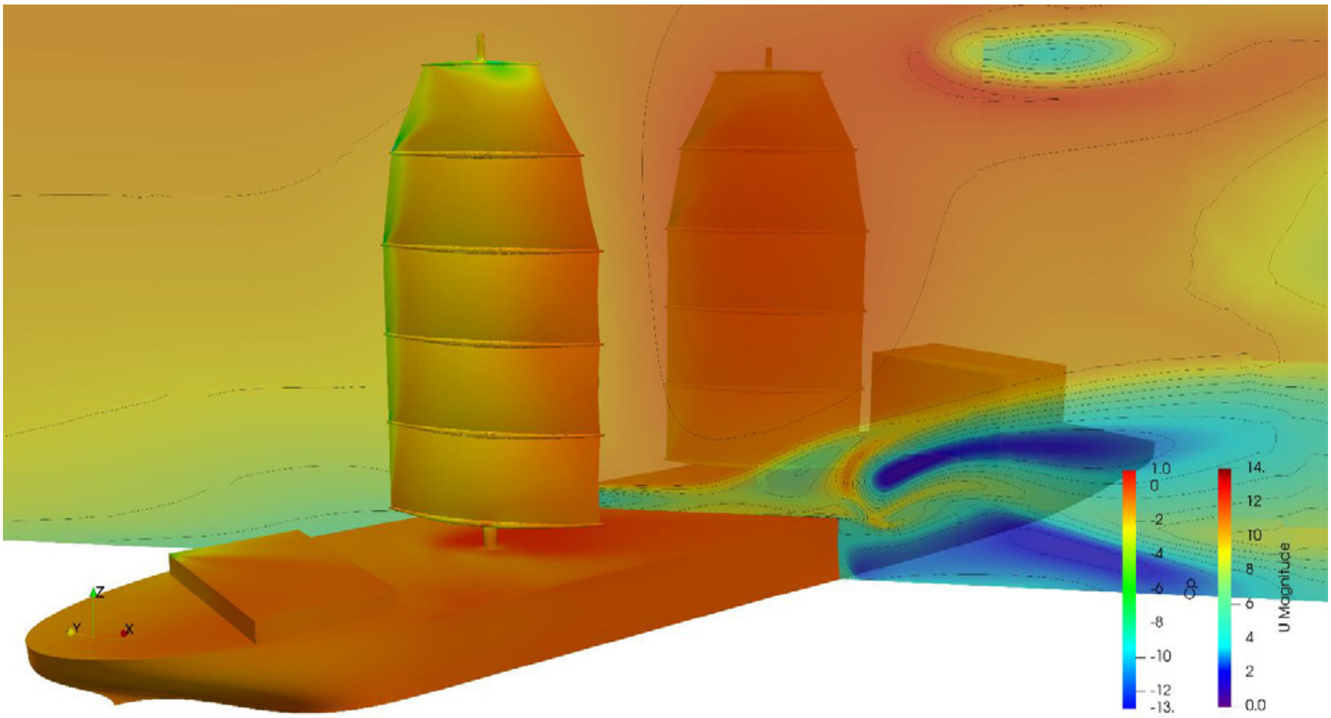


Figure 5 - Twin DynaRig on ship form including superstructure (AWA = 45 deg).

These simple case studies show a divide in functionality of different concepts (lifting wing versus rotating bluff body) from an aerodynamic perspective. In addition, it is clear the interaction of the hull form and superstructure with the propulsive device must be considered to correctly predict performance, all of which requires the use of suitable fluid dynamics tools and techniques which will then allow the balancing with hydrodynamic and engine loads to predict speed. Of course, correct modelling of all aspects, as well as an understanding of their interaction, is required in order to correctly predict performance. However, while the performance of a vessel on the water can thus be characterized, this alone does not yield a full assessment of the design; correct modelling of the structure, understanding of wear, maintenance and operational constrains are also needed in order to correctly assess trade-offs between manufacturing and maintenance costs on the one side and vessel efficiency (speed and payload capacity) on the other.

3. CHALLENGES OF WIND ASSISTED SHIPPING

The traditional approach to modelling a sailing vessel is to balance the aerodynamic forces with the hydrodynamic forces (Figure 6), usually via a VPP, either as a 3 DoF or more often now for racing yachts, 6 DoF problem. While it may appear initially that wind assisted ship propulsion (WASP) poses the same problem, there are a number of design features that make the process more complex. Although some yacht design features are irrelevant for commercial vessels, there is also a set that are unique to the WASP design challenge. For example, one of the most essential aspects to the design of a sailing vessel, that of displacement and stability, is no longer a major driver for the commercial sail propulsion system(s). Design features that are present in sailing vessels already, but are more complex, include leeway, yaw balance, structural requirements, routing and aerodynamic modelling. Engine loading, propeller efficiency, CAPEX and OPEX costs, while already known, are not typically integrally involved in the design of a sailing vessel.

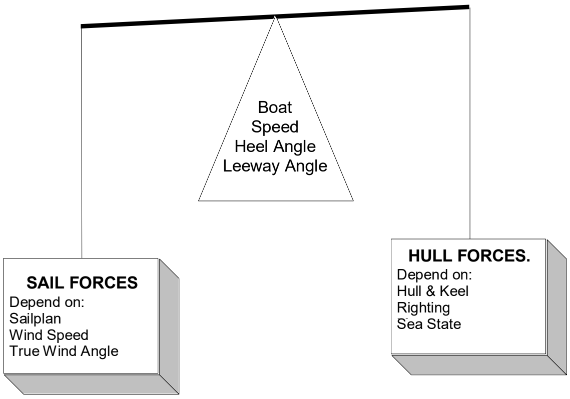


Figure 6 - Sailing yacht design via VPP as a force balance

3.1. Design features with increased complexity

Retrofitted vessels, but usually also new designs, do not have a fin keel. Hence the side force has to be resisted by the hullform, bilge keels and rudders, all of which are low aspect ratio and thus relatively inefficient. The location and size of bilge vortices can be significant in determining of vessel resistance and behavior. Fluid flow modelling of low aspect ratio foils and accurate tracing of vortices is complex, and normally requires higher order solutions such as RANS CFD or tank testing.

Hydrodynamic control of the yaw balance falls usually upon the rudder. As noted above these are typically low aspect ratio, relatively small and in disturbed flow on cargo vessels, resulting in very large rudder angles required to move the longitudinal center of resistance. As well as being inefficient, such large angles induce large and unsteady structural loads. With inconsiderately placed WASP devices, it is thus easy to find oneself in an area of the design space with highly loaded inefficient hydrodynamic appendages – a poor design solution.

Already for a typical sailing vessel we notice that the modelling of the rig(s) in isolation is only adequate in special cases to generate the main aerodynamic behavior, but that the hull generally has a significant influence on the sails. For commercial ships the superstructure is significantly larger, more bluff in shape, and it interacts even more with the propulsion device(s) than already on sailing yachts. A comparison of Figure 7 and Figure 8 shows this. In addition to this change in the relative size of the rig, the shape of the hull exacerbates flow features such as deck edge flow separation (cf. Figure 3). These all combine to require the entire geometry to be aerodynamically modelled by a higher order method capable of dealing with differing Reynolds number scales, bluff body flow and large wake structures as well as the streamline bodies of the lifting surfaces.

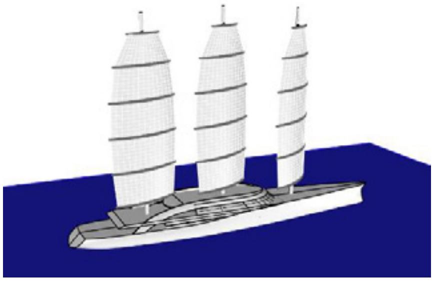


Figure 7 - SY Black Pearl Emulation

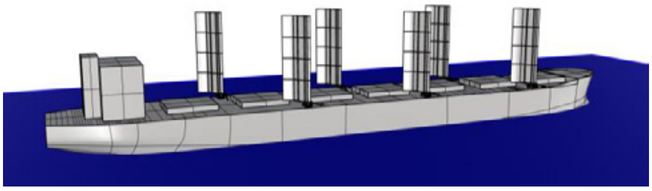


Figure 8 - Bulk carrier with solid wing rigs. image SGS

Routing is a subject well known to the yachting community, and the tools available have increased in power and capabilities over recent years. Today routing studies influence the design of racing yachts (e.g. Vendee Globe entries), but they do not dictate whether a vessel is even built or not as can be the case when assessing a wind assisted cargo vessel. In addition, the number of variables for the route optimization is increased due to the commercial sensitivity and cost/ profit implications of transit time influencing the relative level of dependency upon wind power compared to fossil fuels. Moreover, port operations and schedules required to meet contractual targets can exert an overriding influence.

3.2. Unique design features

Wind assisted shipping currently requires the engine still to provide some of the propulsive force for significant parts of the voyage. Traditionally, with the engine the sole source of power, it is an understood design process to determine the resistance, effective power and then engine power and thus fuel consumption. For a given design speed (dictated by the market forces briefly commented upon above) the engine and drive train can then be optimized for peak efficiency. Off design powering, such as light load and heavy fouling, are given consideration and may alter the peak power location but at a known percentage of time due to knowledge of routes, cargo etc. In the case of wind assisted shipping the engine power for a given speed depends upon the wind speed and direction, both of which can be statistically determined for a given route (and modelled to different levels of accuracy over different time scales), but they are not fixed. This results in a range of engine power requirements, making the optimization process more difficult and, when routing options are incorporated, highly non-linear. All of this requires the design tools to be accurate and capable of processing large datasets. Cascading from the non-unique engine powering 'design case' is the requirement for the propeller(s) to maximize efficiency over a broader range of advance ratio and thrust. This 'detuning' of the propellers away from one specific advance ratio and thrust can greatly diminish gains nominally obtained by the addition of the rig. One solution is to utilize a controllable pitch propeller. However, this is expensive for large vessels.

Harbor operations are not typically considered in the design of a sailing vessel. Yet, for commercial vessels they are a critical part of the vessel's reason for existence. Minimizing loading and offloading times and complexities determine a vessels profitability, a partial reason for the rise in containerization. The deck operations for a bulk carrier are fundamentally different to those of a car carrier, and equally different to those of a tanker. Such operations affect whether overhead gantries or cranes are required, relative placement of vessel and dock, what deck-based equipment is needed and even what port facilities can be accessed (e.g. bridge air draught restrictions). This in turn dictates if the wind propulsive device needs to be moved or laid flat on the deck, whether it can be located at the deck edge, and so on. For example, there are concept designs for Flettner rotors on rails (Anemoi Marine) to allow their movement around the deck; this would not be possible with a DynaRig, but DynaRigs can be folded away for greatly reduced windage and increased visibility.

The core reason wind assisted shipping sail technology for commercial vessels has not been previously exploited is the absence of drivers for adoption providing a viable market. That has changed with the requirement for decarbonization, primarily via the imposition of IMO's Greenhouse Gas Strategy and the Energy Efficiency Existing Ship Index (EEXI) technical measures, which raises the topic which is the final arbitrator: money, and more specifically capital and operational expenditure, or CAPEX and OPEX. The challenge currently is that relatively few wind propulsion devices have been built full scale for modern commercial shipping and those that have do not disclose costs readily. Moreover, the wind propulsive device is normally installed in addition to the engine, so CAPEX will be higher. Voyaging costs, and hence total operational costs, will be lower due to lower energy use (Schinas & Metzger, 2019) and "there is a lack of sufficient performance data for both discussed technologies". This is not unusual with a "new" technology that is embryonic and expensive; over time it becomes cheaper as production and thus efficiencies of scale increase. Against this is solid data for the installation, running and maintenance of engines and drive trains. As a consequence, the successful implementation of wind assisted shipping is dependent upon outside influences such as regulation and government incentives – just like the drivers behind increasing adoption of green technologies in other sectors and applications.

Most of the topics described above are large enough to be the topics of multiple technical papers in their own right, but will not be discussed further here. They are highlighted only to indicate the range of challenges facing wind assisted shipping, and the fact that end solutions can be counter-intuitive, depending on constrains not normally considered by yacht designers. The skill of balancing forces as per Figure 6 has become a lot more complex, leading to something like Figure 9, with costs moving the balance point between the physical forces present. To date, the economic model has been such that the balance point has made aerodynamic forces & propulsion effectively irrelevant, but the costs, tabled by the IMO (and possibly soon other bodies), are moving the balance point rapidly.

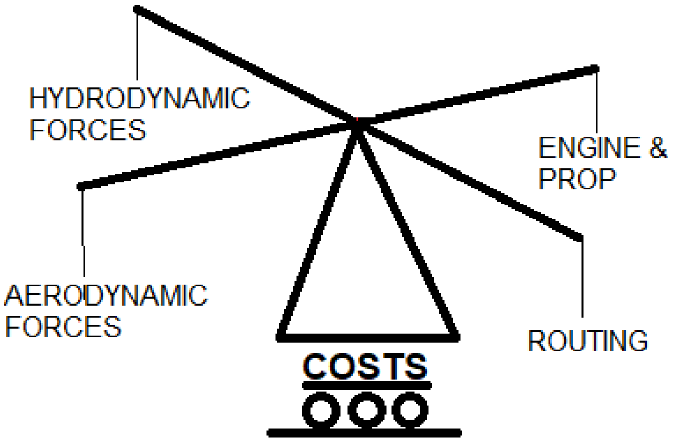


Figure 9 - Design balance for commercial wind assisted vessel

The optimal solution for one type of vessel on a specific route will more than likely be different to the solution determined for a different vessel. Changes in operational requirements or routing can quickly lead to different solutions, but what is critical to addressing the problem is a set of tools capable of correctly assessing the parameters present, and a team with expertise from all disciplines involved: naval architecture, logistics, marine operations, sailing, structural design and materials, …

4. THE NORTH DESIGN SUITE – ADAPTED FOR COMMERCIAL SHIPPING

The authors (and/or their respective departments) have been collaborating for over a decade to develop the North Design Suite, a family of 14 specialized software modules dedicated to modelling a sailing vessel's behavior on the water. The results obtained have been helping both architects and sail designers optimizing their respective products. While requirements and design challenges for DynaRigs and for commercial vessel in general are different to those for yachts (as explained above and highlighted in Figure 6 vs. Figure 9), the relevant physics are the same. Hence the authors have advanced the Design Suite to correctly model and optimize DynaRigs and are currently working to expand it to other wind propulsion systems.

Figure 10 shows of a typical workflow with the Design Suite. The remainder of this section will provide a brief summary of the core software tools. The necessity of each step in the workflow of this figure will become apparent in the next section, where a set of the most interesting results from recent DynaRig studies is presented.

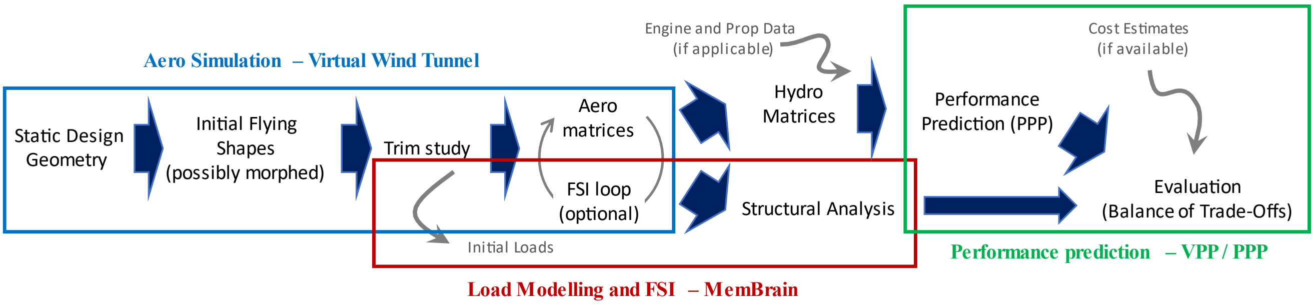


Figure 10 - The North Workflow for Performance Prediction of Commercial Sailing Ships

4.1. Aero Simulation via the Virtual Wind Tunnel

The Virtual Wind Tunnel is a scripted version of OpenFOAM, using a RANS (Reynolds-averaged Navier–Stokes) solver. The RANS equations are time-averaged equations of motion for fluid flow, and while the presence of bluff bodies (e.g. ship superstructure) may be better modelled via DES or equivalent approaches, the computational requirements of DES make RANS the most appropriate approach in an applied design environment. Meshing is unstructured, with a typical full rig plan on a hullform being 20 –25M cells. Boundary conditions incorporate wind profile, vessel speed and leeway to give twisted flow inlets, with pressure and symmetry outflows. The solver is simpleFOAM with kappa-omega (κ-ω) SST turbulence model and 'lookup' wall functions (Kalitzen et al. 2005) that have been found to provide acceptable results at relatively high y+

values. The CFD process is fully automated, with the designer submitting a case and receiving results via an FTP portal. All CFD simulations are run on the Iridis computer cluster at the University of Southampton, with Iridis 4 having 12,200 processors and Iridis 5 over 18,000 processors, allowing many simulations to be run concurrently, while maintaining high fidelity solutions, and correctly modelling complex interactions of different flow regimes (e.g. bluff body flow off a superstructure with the lift dominated flow off twin DynaRigs).

The first step in creating an aero simulation is to generate flying shapes appropriate for the given sail plan and righting moment. For conventional yachts flying shapes are obtained either from previous (similar) studies, or through bespoke FSI simulations for the sailplan in question. For a cost-efficient analysis of DynaRigs North Design Services has developed a unique DynaRig flying shape emulation tool in parametric CAD which can be adapted to match any DynaRig sailplan. Using this tool, full sailsets can be created based on observations from DynaRig yachts in service and/ or from a fully coupled MemBrain FEA simulations model for similar studies. These sailsets can then be tested in the Virtual Wind Tunnel without the need of a complete structural model as would be required for the FSI loop. This way, initial design loads can be calculated relatively quickly and validated against the initial design. The influence of realistic flying shapes will be discussed in the results section.

4.2. Load Modelling and Fluid-Structure interaction via MemBrain

MemBrain is a non-linear FEA software specifically written to model yacht sails and rigs adapted for sailing yacht external aerodynamic simulations. This software interfaces directly with the CAM software that North Sails has written for use in their lofts, meaning the input of sail geometry and structure is as close to reality as possible. Supplied with the pressure field on the sails obtained from the Virtual Wind Tunnel, MemBrain calculates the loads on sails and rig, as well as the deformations. The deformed geometries can then be fed back into the Virtual Wind Tunnel to close the FSI loop. This way, realistic loads, as generated from realistic flying shapes, can be obtained and the rig and sail design can be adjusted to these loads.

Over a number of years MemBrain has been enhanced considerably to be able to model all structural and sail control elements of a DynaRig. Today it directly reports the variables relevant to DynaRig designers, variables that would be impossible to extract from any scale-model wind tunnel testing, such as the chordwise load distribution of the sail on to the yard. This extension allows complex, high-fidelity modeling of a DynaRig, where no simplifications or load assumptions are necessary. Moreover, it has increased confidence in the simulation, and consequently has led to design improvements that would previously (with a lower fidelity tool) not have been possible (see section 5.3).

4.3. Performance prediction via the VPP / PPP

The North Sails Velocity Prediction Program (VPP) is powered by high fidelity RANS CFD force models to capture the unique aero and hydro features of the design(s) under consideration. As with most yacht VPP's the program solves for equilibrium between an aerodynamic and a hydrodynamic force, taking into account other factors such as available righting moment, maximum rudder angles, etc. (Braun and Richelson 2017). Unlike most generic VPPs, the North VPP includes custom / bespoke aero and hydro force models specific to the design in question. This enables the North VPP to capture all of the detailed aero and hydro characteristics that define the character and performance of the vessel to a level of detail not possible using lower fidelity generic VPPs.

Here as well, the situation becomes more complex when concerned with DynaRigs for commercial shipping. Now one is not only concerned about the ship's velocity, but needs to predict and optimize its performance on broader metrics: engine efficiency and fuel consumption, leeway influencing hull drag, stability and cargo holding capacity, ... (cf. section 3). Hence, for WASP studies the general performance rather than “just” the velocity is of interest. Thus, it becomes more accurate to be talking about Performance Prediction Programs (PPPs vs VPPs for yachts).

To turn the existing VPP into a PPP and address the questions specific to commercial shipping, allowances were made not only for windage (e.g. of superstructure not included in the aero models, standing rigging, comms domes and furled headsails if relevant) but also an empirical drag model for exposed propellers, shafts, etc. which were not included in the hydro geometry. The latter includes a drag force and moment which depend on the vessel's speed and operation conditions, with the ability to manipulate the individual propeller contributions to thrust or drag and yaw moment. Since the course stability (the rudder load) can be critical for WASP studies, this resolution of the influence of the propellers on the ship balance is vital for an accurate performance analysis.

5. RESULTS

In this section a summary of results from recent work on DynaRigs is presented. The wind angle is given relative to the course (course wind angle - CWA) which includes leeway as opposed to the true wind angle (TWA) which excludes leeway in the nomenclature. True Wind Speed (TWS) and angle (TWA) are measured at 10 m above waterline.

While this work is all based on the tools described above it has been collected from different studies, hence results from two and three-masted vessels are interspersed. The physics, however, are always the same, as are the principles and general conclusions.

5.1. Influences of the Sail Shape Fidelity

Just as "normal" sails, DynaRig sails pressurized by the wind assume a two-dimensionally curved shape – as a function of sail cut and membrane stretch. One metric to characterize the curvature is the Miter Normal, which is the ratio of the camber at the mid-section of the sail to the chord length at that same section. The results of Figure 11 are based on our parametric sail shape model where we varied the vertical Miter Normal between 0% (flat sail, tight between the yards – green lines in left insert), to 10% (i.e. 10% vertical camber at the mid-section – red lines). All five geometries were run in the Virtual Wind Tunnel. Drive and side forces as well as center of effort (COE) were compared relative to the zero-camber case. Figure 11 shows the results at AWA = 60 deg together with the linear (least RMS) fit for both force components. From the figure it can be seen that for this case higher Miter Normal correlates directly with the aerodynamic forces and most importantly that a good estimate of the flying shape is needed for a realistic force analysis. Note also the change in CoE, which has a direct impact not only on the ship balance (rudder angles) but also on the rig's torsional loads.

Since more vertical camber also means more horizontal camber, the results from Figure 11 could be interpreted as an indication that the yards for this vessel were too straight. However, one must note that these are results for one wind angle only. A robust design optimization should be based on a routing analysis, with the most probable wind angles, to find the best overall design for the whole operations envelope.

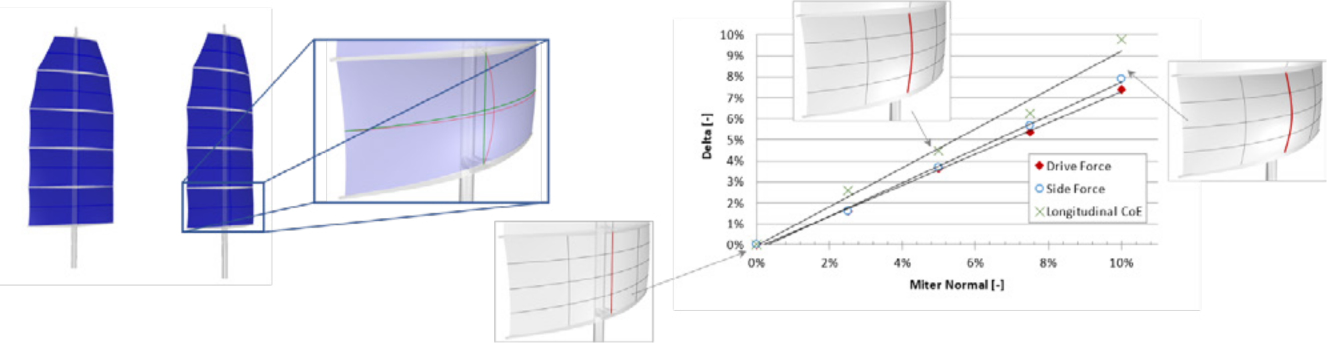


Figure 11 - Evolution of sail forces with increasingly realistic sail shapes (add camber to sails).

5.2. Influence of Rig Trim (Mast Rotation Angles)

Once reasonable sail flying shapes are obtained, "good" sail trims need to be found. Here "good" is determined by the ship's performance (e.g. speed), but also by operating limitations (e.g. heel limits; dynamic stability of the sails, i.e. luff stability to avoid excessive aging from flutter). For this an initial trim study was performed for each apparent wind angle (AWA). The study was conducted from 30 to 150 degrees of AWA. The true wind speed was increased from TWS = 12 kt at 30 degrees AWA to TWS = 25 kt at 150 degrees AWA. Heel and speed were set such that realistic sailing conditions resulted for each AWA. TWA was adjusted accordingly.

Figure 12 gives an example of a trim study: the abscissa shows the evolution of different trims for the different AWAs as indicated by the gray line (right ordinate in the top graph). The resulting drive forces are shown on the left ordinate (top graph); The lower graph shows the roll (left ordinate) and yaw (right ordinate) moments respectively. Here, a three-masted ship was studied and blue, orange, green bars indicate the force and moment contributions from the forward, mid, and aft mast respectively. Forces and moments are non-dimensionalized by $cF_i = F_i/(0.5A\rho \cdot AWS^2)$ and $cM_i = M_i/(0.5A\rho \cdot AWS^2 \cdot l_{ref})$ respectively, with F_i and M_i the respective forces and moments under consideration, A the sail area, and $l_{ref} = 10$ m a reference length. Note that the way the study was setup allowed investigation of sail trims at realistic sailing conditions. However, it led to a variation in dynamic head between the AWA blocks, which means the forces are not directly comparable between blocks. E.g., comparing $AWA = 30$ (green box, in Figure 12) to comparing $AWA = 60$ (brown box) and inferring that at $AWA = 60$ one obtains roughly double the drive force is not fair, because these two blocks are based on different AWSs.

For $AWA = 30$ deg Figure 12 shows that the first trim case (label A) leads to the highest drive forces. However, for this case the Mizzen Mast is rotated only by 3 deg. Close inspection shows that this low rotation leads to detached flow at the sail's leading edge. While this produces high overall forces in the simulation, in reality it also means an instable, potentially flapping luff. This might deteriorate the real forces, but what is even worse, it will lead to excessive sail wear and early failure. Hence, the PPP rotation angles were limited to AOAs no smaller than six degrees for the subsequent performance study.

Runs #7-9 (label B) effectively show why an aerodynamic analysis alone is not sufficient: these three trim cases all produce roughly the same drive force, however yaw and roll moments are vastly different. Therefore, in a comprehensive PPP case #8 might result in a better performance (less rudder load, less leeway, thus potentially less hydro drag) than its two neighbors (#7 and #9), even though it might have been discarded in a purely aerodynamic study for causing more roll without gain in drive force. In addition, when the increased maintenance costs of highly loaded components are considered the gains of #8 can become even greater.

At $AWA = 120$ deg (blue box) we see that what we would intuitively consider the "perfect" trim (label C, with both rigs just at the verge of stall) leads to sub-optimal drive force and even negative heel – at state that could be very unstable in real life! For good speed and stable sailing, we would want to trim the sails already at this reaching angle well into the stalled regime with considerable suction side separation (label D). As before we again find a very flat peak for drive forces with even the heel moment not changing much (cases #30-33). And again, it will be up to the PPP analysis to eventually pick the trim with the ideal performance, possibly again influenced largely by the vessel's yaw balance.

At $AWA = 150$ deg these same trends intensify: relatively "well" trimmed sails (attached flow, label E) lead to negative heel and sub-maximum drive force while rotating the sails more (cases #44-46) increases the drive force and stabilizes heel. However, these angles now also push the limits of our steady state RANS simulations. Here, conditions are reached, where the ideal trims are found well into the fully stalled flow regime, where typically large vortex structures are shed periodically. Hence, the steady state solver will no longer converge. To get a rough estimate of forces and moments, the results were averaged over several oscillation periods. Obviously, this is a crude and questionable approach but since sailing at these angles is not the most common condition this approach was deemed suitable for the time being. Employing an unsteady solver, or higher order methods such as DES (Wright, 2013) is on the list for future work.

In conclusion it can be noted that this kind of trim study provides an idea of *likely regions* of best trims. A conclusive decision can only be made with a full PPP analysis. One should also note that for this study we manually navigated the trim space. Wrapping an optimization routine around this process to automatically and reliably find the best trims would be an interesting future feature.

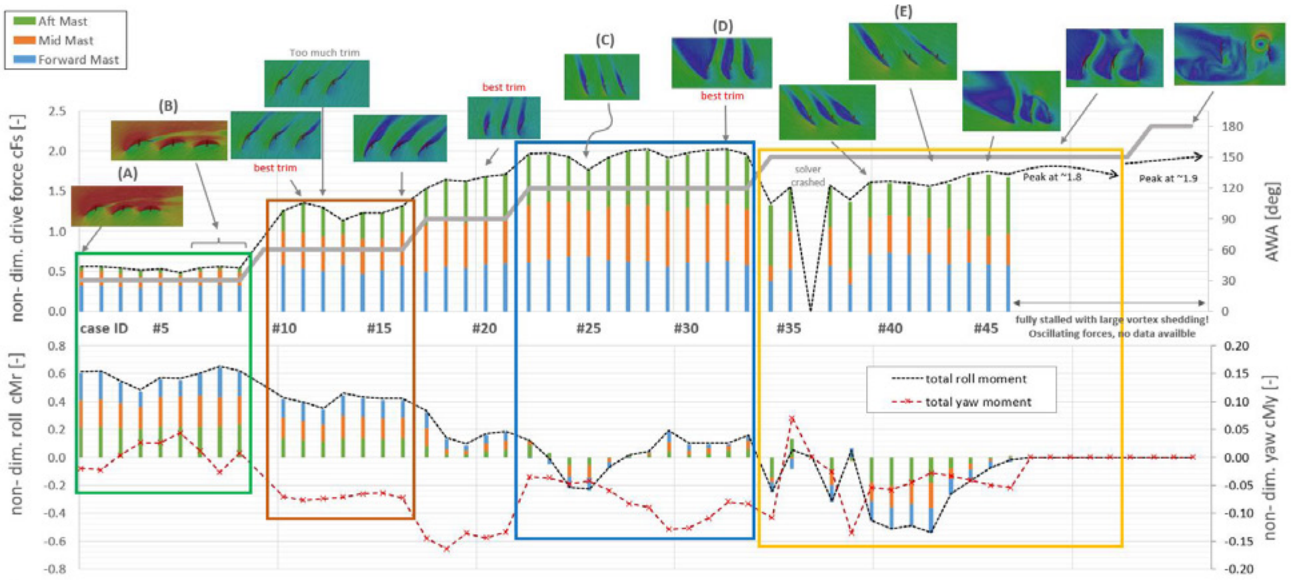
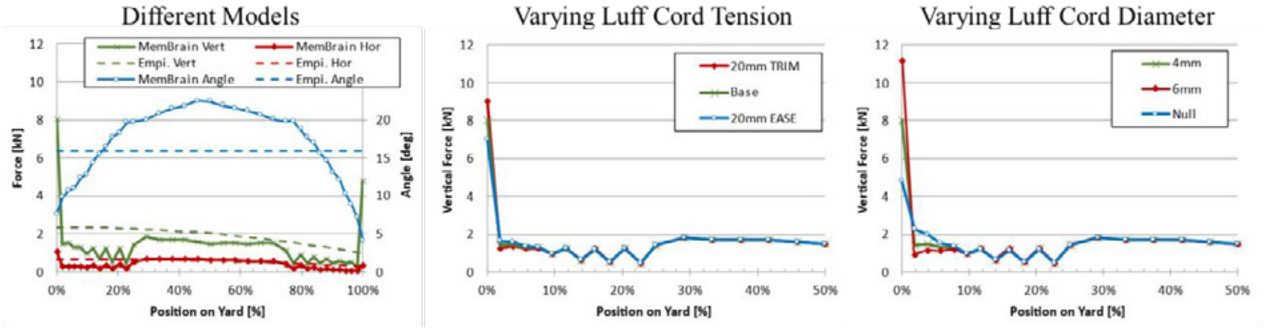


Figure 12 - Example of DynaRig trim study.

5.3. Structural Analysis via MemBrain

The trim study presented in the preceding section provides the base from which the scenarios for a subsequent load case analysis can be extracted. With these initial loads the design can be adjusted and refined early on. In this section some examples are given on results from this analysis and how it has benefited the overall design.

Figure 13a shows the force distribution along the interface between the sail and the yard obtained from the new MemBrain (FEA) simulation vs. the previously used empirical model. Both vertical and horizontal loads, as well as the resultant angle between these forces are shown. Dashed lines show empiric results from the previously used model based on extensive wind tunnel testing. The empirical method, while accurately predicting the overall load across the yard, misses the large force spike at the leading and trailing edge. The fact that on the existing rigs the highest wear the of the sails was found at the clew, where the FEA shows the load spike, confirms the superiority of the FEA model over the purely empiric data. Moreover, the angle was simply assumed to be constant in the empirical model – a rough simplification as we see from the FEA results. Considering, however, that this angle is important for proper sail furling and to avoid the sails chafing at the connection to the yard, this has direct design implications.



(a) **(b)** **(c)**

Figure 13 - Force & Resultant Angle Distribution along Yard.

With the results from this analysis, the sail structural design as well as the yard design can be adjusted to ideally match the existing loads – and in turn the new load distribution as caused by the new structural design can be validated. As a first step in that direction, further studies were conducted to determine the sensitivity of this force depending on multiple parameters. This was possible in high detail, because the MemBrain model contained all sail control elements (cf. section 4.2), including the small luff cord that is fitted on all DynaRig sails to prevent luff and leach flutter. Figure 13b and c show results from sensitivity studies conducted on the luff cord trim and size respectively. Both figures show the vertical force component along the leading half of the yard. The trim of the luff cord has a large effect on the peak force (within ±13% for a 20 mm adjustment). Adjusting the cord size, however, resulted in a much larger variation. The standard cord size for this vessel would be a 4 mm diameter PBO line (modulus: EA ≈ 900 kN). Variations either side of this were assessed with a 6 mm cord (EA ≈ 2800kN) and no cord, designated as "Null". This resulted in ±40% force variation on the baseline 4 mm cord.

5.4. Performance Prediction and Design Enhancement via the PPP

In this study the PPP was run in four Degrees of Freedom (4-DOF). This means the PPP finds an equilibrium between forces in the forward and lateral directions, and moments about the roll and yaw axes. The PPP then finds the "best" sail trim (i.e. the best mast rotations) for achieving maximum speed in the specified sailing conditions while solving for the remaining parameters in the model and observing user-defined constraints (e.g. maximum heel, rudder angle, leeway). The remaining 2-DOF (vertical forces and pitch moments) are pre-balanced in the 2-DOF hydro CFD so they do not need to be solved in the PPP. This approach is appropriate and cost effective for a fixed displacement analysis, i.e. when the aero downforces and pitching moment are a small proportion of overall displacement and do not have a notable effect.

The aerodynamic loads were generated around nominal trim points for each AWA extracted from a trim study similar to the one presented in section 5.2. Here, nominal trims for each AWA were chosen as those which give maximum aerodynamic drive force independent of any constraints. To give the PPP the required freedom to actually find the real best trims, a trim matrix was created, where each mast was rotated by ±5 degrees from its nominal (aero only "best") position. This gives three different positions for each mast, therefore there are nine different trim combinations at each AWA of this two-masted study. In addition, heel variations are tested for each AWA with three different trims (nominal and ±5 degrees). This adds six more points, so a total of 15 different points per AWA, giving a total of 105 aero CFD runs for the 7 AWAs considered. These 105 runs were then solved for each geometry (i.e. each sailset, rig position, mast height, etc.) in the Virtual Wind Tunnel to obtain the aerodynamic forces. Each CFD run took approximately three hours to solve on 32 cores in the Iridis HPC cluster (96 CPU hours per simulation, or 10080 CPU hours for the full data set). This is already a considerable effort and highlights why this approach of a variation around a set of central points was necessary: while ideally a square matrix of all reasonable trims would be simulated to give the PPP full freedom to chose any trim configuration, this is simply too computationally demanding. With the chosen approach, only a limited subset is calculated. By verifying that the PPP does not drive towards trim points which are not included in the data set, and assuming that the performance surface within design space is smooth (which seems reasonable given the physics at hand), one can assure that potential optima are not neglected in uncharted corners of the design.

5.4.1. Finding the "best" trim

While section 5.2 discussed sail trims (i.e. mast rotations) purely from an aerodynamic perspective, the complete system is now considered: that is the mast trims which actually lead to the highest speed under a certain set of constraints. Therefor the PPP was run at 4-DOF as described in section 4.3 for a sweep of course angles from 50 to 150 degrees at constant wind speed of 12 kt TWS.

Figure 14 shows the resulting AWA at 10 m height and the corresponding boat speed (Figure 14b), together with the mast rotations chosen by the PPP for maximum speed (Figure 14c) and the geometric angles of attack (AOA, Figure 14d). The latter are calculated as the angle between the apparent wind vector at 10 m height and the yards' chord line. Note that this is only a geometric estimate, as (i) the AWA varies with height and (ii) the influence of one mast on the other (i.e., induced velocities) are not considered. Yet, Figure 14d shows how the ideal AOA varies as a function of the course angle. The reason is that the two rigs interact differently on different CWA and with increasing CWA the aerodynamic drag component becomes increasingly rotated towards the thrust vector. This highlights the importance of actually simulating the rings in interaction versus simply scaling the data of one rig to model the effects of multiple rigs.

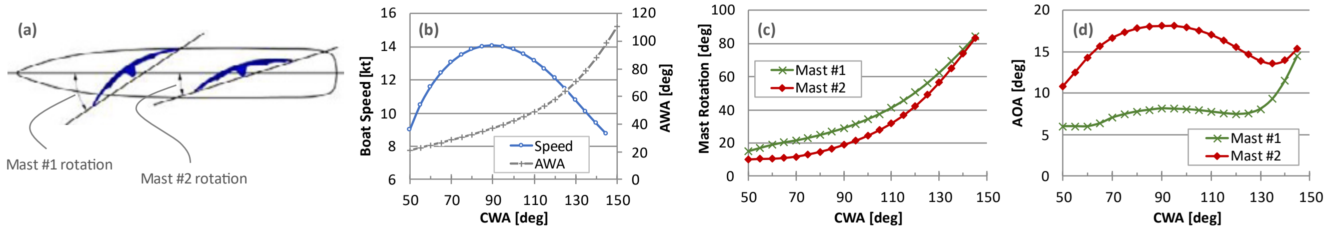


Figure 14 - The PPP finds the ideal mast rotation for the specific hull characteristics for a sweep of course wind angles (CWA).

Particularly interesting is the region of CWA ≤ 60 deg. Here, the unconstraint PPP would push towards very small angles of attack for maximum speed (AOA = 1.6 deg for Mast #1 at CWA=50 deg). This is the case we encountered during the trim study (Section 5.2, discussion of $AWA = 30$): While these low angles might theoretically be fast and consistent with CFD results, in reality they result in an instable, flapping luff. This would deteriorate the real-life forces and diminish speed. Moreover, it would lead to excessive sail wear and early failure – not ideal when overall (life time) cost is considered. Therefore, the PPP was limited to a minimum AOA of six degrees.

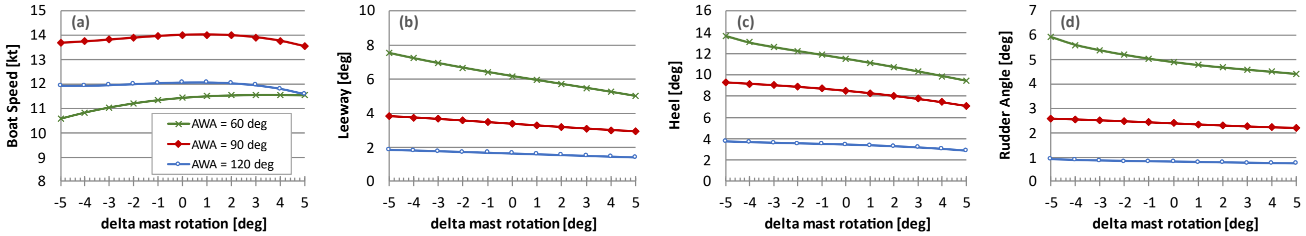


Figure 15 - Ship performance with varying mast rotations.

Figure 15 gives an insight of the variation of the ship's performance with varying mast rotations. On the abscissa, rotation deltas around the nominal trim are reported. The plots show four performance metrics (speed, leeway, heel, and rudder angle) for three different wind angles. We see that the speed exhibits a relatively flat maximum, while leeway, heel and rudder angle change considerably particularly for the close-hauled course (AWA = 60 deg). For this study – a ship with a rather yacht like hull, relatively long and slender with a prismatic coefficient just over 0.6 and under wind only propulsion – this is consistent with previous experience. However, when these rigs are installed on a dedicated cargo ship with a much higher hull prismatic coefficient, and operated in a wind assisted propulsion mode, the results of this analysis are likely to change substantially. In that case, hull drag, propeller drag and also propeller efficiency will degrade rapidly with leeway. Moreover, rudder efficiencies and drag will strongly depend on heel and leeway. Hence, the optima are expected to be very different.

5.4.2. Sailing at constant speed

Here the PPP is used to assess the engine power requirement when sailing at different course angles with different wind speeds. For the study at hand the specifics of engine, drive train, and prop were not yet defined. Hence, the power reported is the effective power $P_e = T_h \cdot BS$, with T_h the thrust delivered by the propeller and BS the boat speed.

Figure 16 shows the results for CWAs of 60, 100 and 150 degrees respectively. A target speed of 13.5 kt was set for this project. For CWA = 100 deg (Figure 16b) it can be seen that at 12 kt TWS and above the target speed is exceeded at zero engine power. For 10 kt TWS and below the engine has to be used to achieve the target speed. At around 5 kt TWS, the AWA becomes too narrow for the sails to fly efficiently and the sails will be furled (100% engine power). There are indications that there is a region around 5 kt TWS where it might be beneficial to keep the sails on one mast but furl the sails on the other (see inserts in Figure 16, left). This is because the fore mast deflects the wind on the aft mast. Thus, while the AOA at the fore mast is still sufficiently large, the (deflected) AOA on the aft mast is too tight to fly sails. For a decent yaw balance sails on both masts might furled partially. The partial furl needs to be investigated in detail and was not included in the aero models yet. Hence, the results of Figure 16 for the area around 5 kt TWS might be somewhat inaccurate.

At 150 deg CWA (Figure 16c) even at 16 kt TWS the target speed cannot be achieved under wind propulsion only. As expected, the required engine power increases with decreasing wind speed. At around 6 kt a partial furl might become beneficial again (not included in the models). For TWS ≤ 6 kt the ship will rely on 100% engine power to travel at 13.5 kt.

At 60 CWA (Figure 16a), the target speed of BS = 13.5 kt will be achieved without engine at wind speeds over 13.6 kt (true). For wind speeds under 13.6 kt the engine needs to be used to achieve the target speed, which quickly moves the (already narrow) AWA further forward. Already at 12.0 kt TWS motor sailing at BS = 13.5 kt will already become unfeasible because the AWA becomes too small to allow the sails to fly without flapping. Hence for TWS ≤ 12 kt the sails will be furled and 100% engine power must be used to keep the speed at 13.5 kt. As discussed before, there will likely be a transition area with a partially furled rig which remains to be investigated.

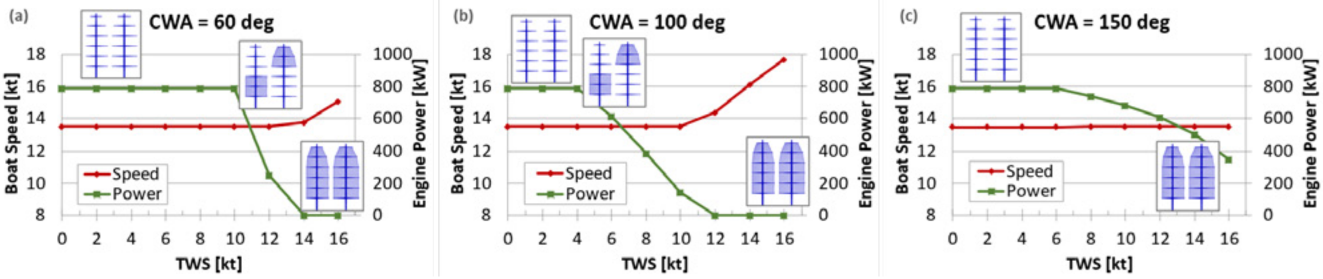


Figure 16 – Motor sailing for minimum passage speed at two different wind angles.

This section presents an initial discussion of required engine power to retain a certain speed. As such, it is meant as an example to show how the PPP can be used to analyze ship power requirements. Obviously, effective power then has to be combined with propeller efficiencies of various thrust and advance ratios as well as with engine efficiency maps to obtain fuel consumption projections. Combining this, further on, with weather and routing statistics will allow a qualified estimate of fuel savings, i.e. OPEX reductions, and thus qualify a potential business case.

5.4.3. Geometry modifications for performance enhancements

In this section results are presented that show how the PPP is used to support the design improvement process and guide decision making. Starting from a baseline hull and rig (blue in Figure 17), the hull was first enlarged and with it the rig moved forward (red); then the rig was enlarged as well (green).

Figure 17 shows the results of a performance analysis for the three hull and rig configurations used to quantify and discuss trade offs between speed and heel on a fact-based level with all stake holders. The data for 12 kt TWS is presented, based on 315 RANS simulations for the aero data for the various rig trims. The 4-DOF PPP was run as described in section 4.3. The PPP was free to find the best mast rotations (within the minimum AOA constraint from above); resulting leeway, heel, and rudder angles were calculated from the force and moment balance together with the associated hydrodynamic drag. The hydro CFD data was provided by Cape Horn Engineering (cape-horn-eng.com).

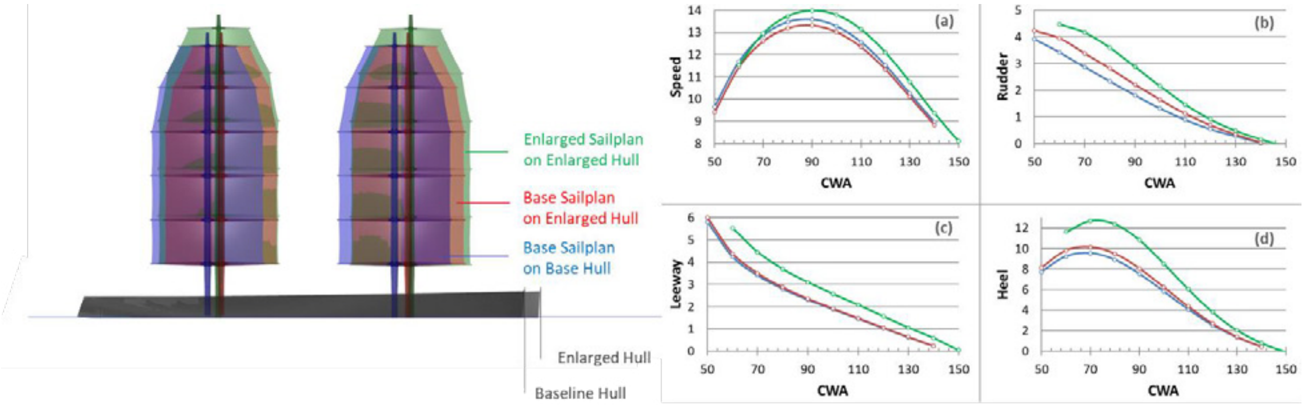
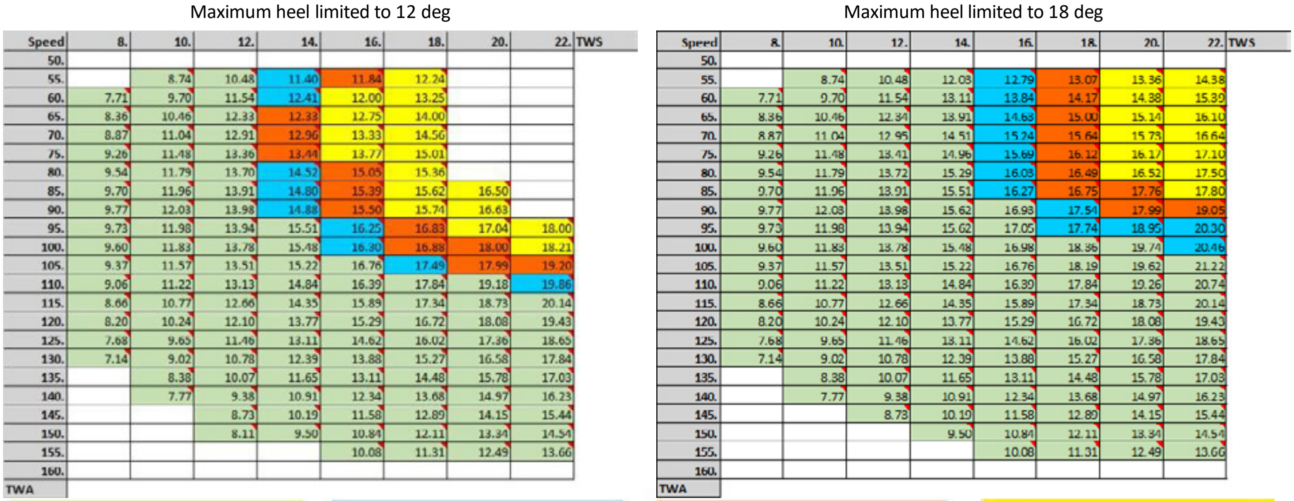


Figure 17 - Performance analysis for different hull and rig configurations at 12 kt TWS.

As expected, enlarging the hull (3.5% longer) while keeping the same rig height (i.e., same sail area) decreases the ship's speed particularly in reaching and upwind conditions (blue vs. red). This reflects the fact that the hydrodynamic resistance is predominantly caused by skin friction drag, with only a relatively small proportion of pressure (wave) resistance. Enlarging the rig (green, 16% more sail area) then over-compensates the losses through the larger hull (red) and leads to a speed above the one initially achieved by the baseline design. This comes, however, at the cost of increased heel.

For a racing yacht, the red option would be a clear loser, while green could be a winner if allowed by class rules and/or the speed gains exceed any rating penalty. For a commercial ship, however, the trade-offs are more complex: Here, a larger hull (red) can mean more payload capacity, which could offset the reduced voyage speed. Moreover, a passage route analysis could reveal that the ship will be mainly operating in downwind conditions where the differences between blue and red design are smaller (roughly 0.15 kt at CWA=130 and even less for higher CWA). While the speed of the green design is higher, it will most likely be also more expensive to build. Moreover, as can be seen from Figure 17 bottom right, the larger rig considerably increases the ship's heel, which has stability implications. For commercial operations it might have an impact on payload capacity, hence reduced revenue potential. With a viable PPP and a specific business model, these questions can now be addressed on a case-specific basis.



Maximum heel limited to 12 deg

Speed	8.	10.	12.	14.	16.	18.	20.	22.	TWS
50.									
55.		8.74	10.48	11.40	11.84	12.24			
60.	7.71	9.70	11.54	12.41	12.00	13.25			
65.	8.36	10.46	12.33	12.33	12.75	14.00			
70.	8.87	11.04	12.91	12.96	13.33	14.56			
75.	9.26	11.48	13.36	13.44	13.77	15.01			
80.	9.54	11.79	13.70	14.52	15.05	15.36			
85.	9.70	11.96	13.91	14.80	15.39	15.62	16.50		
90.	9.77	12.03	13.98	14.88	15.50	15.74	16.63		
95.	9.73	11.98	13.94	15.51	16.25	16.83	17.04	18.00	
100.	9.60	11.83	13.78	15.48	16.30	16.88	18.00	18.21	
105.	9.37	11.57	13.51	15.22	16.76	17.49	17.99	19.20	
110.	9.06	11.22	13.13	14.84	16.39	17.84	19.18	19.86	
115.	8.66	10.77	12.66	14.35	15.89	17.34	18.73	20.14	
120.	8.20	10.24	12.10	13.77	15.29	16.72	18.08	19.43	
125.	7.68	9.65	11.46	13.11	14.62	16.02	17.36	18.65	
130.	7.14	9.02	10.78	12.39	13.88	15.27	16.58	17.84	
135.		8.38	10.07	11.65	13.11	14.48	15.78	17.03	
140.		7.77	9.38	10.91	12.34	13.68	14.97	16.23	
145.			8.73	10.19	11.58	12.89	14.15	15.44	
150.			8.11	9.50	10.84	12.11	13.34	14.54	
155.					10.08	11.31	12.49	13.66	
160.									
TWA									

Maximum heel limited to 18 deg

Speed	8.	10.	12.	14.	16.	18.	20.	22.	TWS
50.									
55.		8.74	10.48	12.03	12.79	13.07	13.36	14.38	
60.	7.71	9.70	11.54	13.11	13.84	14.17	14.38	15.39	
65.	8.36	10.46	12.34	13.91	14.63	15.00	15.14	16.10	
70.	8.87	11.04	12.95	14.51	15.24	15.64	15.73	16.64	
75.	9.26	11.48	13.41	14.96	15.69	16.12	16.17	17.10	
80.	9.54	11.79	13.72	15.29	16.03	16.49	16.52	17.50	
85.	9.70	11.96	13.91	15.51	16.27	16.75	17.76	17.80	
90.	9.77	12.03	13.98	15.62	16.93	17.54	17.99	19.05	
95.	9.73	11.98	13.94	15.62	17.05	17.74	18.95	20.30	
100.	9.60	11.83	13.78	15.48	16.98	18.36	19.74	20.46	
105.	9.37	11.57	13.51	15.22	16.76	18.19	19.62	21.22	
110.	9.06	11.22	13.13	14.84	16.39	17.84	19.26	20.74	
115.	8.66	10.77	12.66	14.35	15.89	17.34	18.73	20.14	
120.	8.20	10.24	12.10	13.77	15.29	16.72	18.08	19.43	
125.	7.68	9.65	11.46	13.11	14.62	16.02	17.36	18.65	
130.	7.14	9.02	10.78	12.39	13.88	15.27	16.58	17.84	
135.		8.38	10.07	11.65	13.11	14.48	15.78	17.03	
140.		7.77	9.38	10.91	12.34	13.68	14.97	16.23	
145.			8.73	10.19	11.58	12.89	14.15	15.44	
150.				9.50	10.84	12.11	13.34	14.54	
155.					10.08	11.31	12.49	13.66	
160.									
TWA									

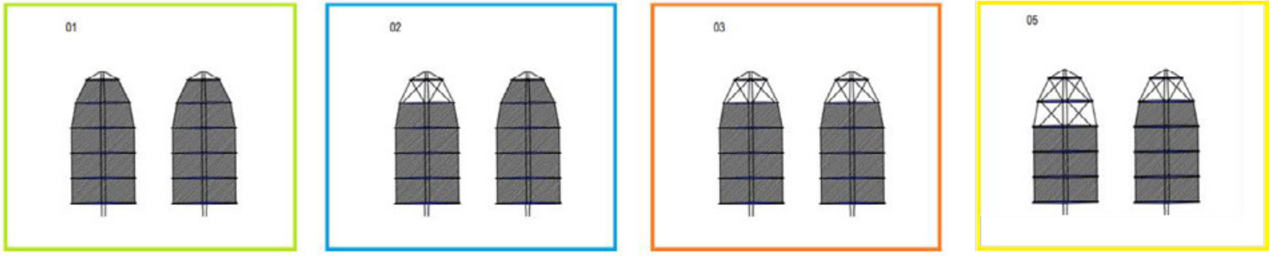


Figure 18 - PPP results: attainable speed polars and required reefing sequence for two different heel limits.

5.4.4. Crossover chart and reefing sequence

Figure 18 shows another example how the PPP can be used for navigating design trade-offs. For this study new VPP aero powering models were run in the Virtual Wind Tunnel for the reefed sailsets. Figure 18 presents best speeds and sailset crossovers for maximum heel angles of 12 (left) and 18 degrees (right). It should be noted that these heel angles may be considered more appropriate to a sailing vessel rather than a modern commercial vessel, but the same principle applies. Colours represent the various sailsets corresponding to the sketches in the lower part of the figure. White/ empty cells in the crossover charts are non-optimal conditions outside of the best VMG limits, or conditions which cannot be sailed with these sail combinations at the imposed heel limit. The polar chart for the 12-degree heel limits could be expanded with the addition of deeper reefed sailsets. This was, however, not relevant for this study.

In a subsequent step these polar tables can now be coupled with route information and expected wind speed and angle probabilities to obtain estimates for the most likely passage time. Then, combining this with cost models for payload capacities at different heel angles, engine efficiencies (how does the propeller efficiency and hull drag evolve with increasing heel?), and structural/ cost considerations, this will lead to a concrete business model. Considering that a higher heel allowance requires a design for a higher maximum righting moment, thus higher rig loads, which in turn lead to increased CAPEX to be able to meet now increased structural demands the question becomes: Does the gain of one or two knots of speed in the high AWS/ low AWA region offsets the additional CAPEX? Or, in the case of wind assisted propulsion: Do the expected OPEX savings from reduced engine power requirements offset the increased CAPEX? Again, these questions are non-trivial. They need to be answered for each ship and its operational schedule individually based on a viable PPP.

6. FUTURE WORK

This paper presents work that is very much in progress and future work has already been alluded to throughout the text. In summary there are currently a number of areas being investigated for further development. The underlying objective is always to either provide greater accuracy to the modelling undertaken and hence to support design improvements and/ or business decisions, or to assess a greater number of parameters, which represent diametrically opposing requirements (i.e. trade-offs) for design decisions, early in the design process. One of these objectives means pushing for greater complexity and more encompassing model boundaries; the other requires simplification in order to process a greater number of cases.

Approaches that will allow greater numbers of parameters to be assessed include:

- The use of a nonlinear Lifting Line model for quick assessment of diverse rig configurations to supply basic aerodynamic data for a performance comparison of different routes;
- An integrated design optimization framework which will vary basic design parameters (rig height and breadth, position, trim) automatically to identify (cost/ revenue?) pareto fronts thus allowing the user to compare a “good” design vs. another “good” one, and not e.g. a badly adjusted Fettner rotor vs. a perfectly tuned wing sail.

More accurate modelling is being achieved via:

- Incorporation of DES and AMI from research investigation into the ‘design process’ CFD to better resolve bluff body flows and the unsteady aerodynamics of large downwind AWAs;
- Extending the PPP to fully include drivetrain parameters to allow fuel consumption to be a design objective. This will include a model of propeller performance curves including impact of leeway angle and propeller and rudder interactions on powering and yaw balance, and could go as far as adding a power generation module for times when wind propulsion provides excess thrust for a given ETA.

7. CONCLUSIONS

With the North Design Suite, notably containing the Virtual Wind Tunnel, MemBrain FSI and structural analysis, and the VPP/ PPP, North Sails, Wolfson Unit and Southern Spars have been well positioned for analysing and optimizing yacht design. Recently the tools have been advanced to meet the growing need for Wind Assisted Ship Propulsion (WASP) studies. It has been discussed that, while similar, the requirements, constraints, and objectives for commercial WASP studies are considerably different from the “traditional” sailing yacht studies. Examples are the trade-off between speed (voyage time) on the one side and CAPEX, and/ or payload capacity (i.e. revenue potential) on the other. By the example of some key results from several recent DynaRig studies we showed how the North Design Suite can be used to navigate these trade-offs. In particular it was highlighted how any analysis which considers the aerodynamic performance only can supply an initial baseline for a design, but that it can not replace a full PPP study of sufficient fidelity to balance the aero and hydro forces. Only such a PPP analysis forms a viable base of a cost/ revenue analysis. The reason identified is that the real optima are largely influenced by the hydrodynamics of the hull (e.g. drag vs leeway), the efficiency map of the drive train (e.g. engine efficiency vs power, propeller efficiency vs advance ratio) and cost models (speed vs. payload capacity). The presented results show the aero vs. hydrodynamic trade-offs in detail and give an impression how and engine model can be incorporated. A detailed engine and propeller model as well as any cost model are going to be specific to any commercial study and will be implemented in future work.

8. ACKNOWLEDGMENTS

Thanks to Gerry Dijkstra, Damon Roberts, John Brickwood and Andy Shaw for their past efforts in bringing these novel rigs to reality, and especially to Damon, John and Andy for sharing their early work, as well as their ongoing efforts in expanding this fleet under the Southern Spars brand.

9. REFERENCES

Chou, T., Kosmas, V., Acciaro, M. and Renken, K., "A Comeback of Wind Power in Shipping: An Economic and Operational Review on the Wind-Assisted Ship Propulsion Technology." Sustainability 13, no. 4 (2021)

Braun J.B. and Richelson M. “Performance Prediction Program - CFD Modeling Options for Hull & Sails, Phase I” Sailing Yacht Research Foundation Report, 2017

Kalitzen G., Medic G, Iaccarino I. and Durbin P., “Near-wall behaviour of RANS turbulence models and implications for wall functions” Journal of Computational Physics, 204 (2005), 261—291

International Chamber of Shipping, “Catalysing the fourth propulsion revolution”, Marisec Publications, UK, 2020

Jones, L., Prince, M., Hudson, D. and Cocks, J., “Predicted Fuel Savings For a Flettner Rotor Assisted Tanker Using Computational Fluid Dynamics, RINA Wind Propulsion , London UK, 2019

Perkins, T., Dijkstra G., and Roberts D., “The Maltese Falcon: the realization”, The International HISWA Symposium on Yacht Design and Yacht Construction, 2004

Roberts, D. and Dijkstra, G., “The use of fibre optic strain monitoring systems in the design, testing and performance monitoring of the novel freestanding DynaRigs on a 87m super yacht by Perini Navi, Design Gerard Dijkstra”, The International HISWA Symposium on Yacht Design and Yacht Construction, 2004.

Schinas O. and Metzger D. “Financing ships with wind assisted propulsion Technologies”, RINA Wind Propulsion, London UK, 2019

Wagner B. “Windkanalversuche mit gewölbten Plattensegeln, mit Einzelmasten sowie mit Plattensegeln bei Mehrmast-anordnung”, Institut für Schiffbau der Universität Hamburg, Bericht Nr. 171, 1966

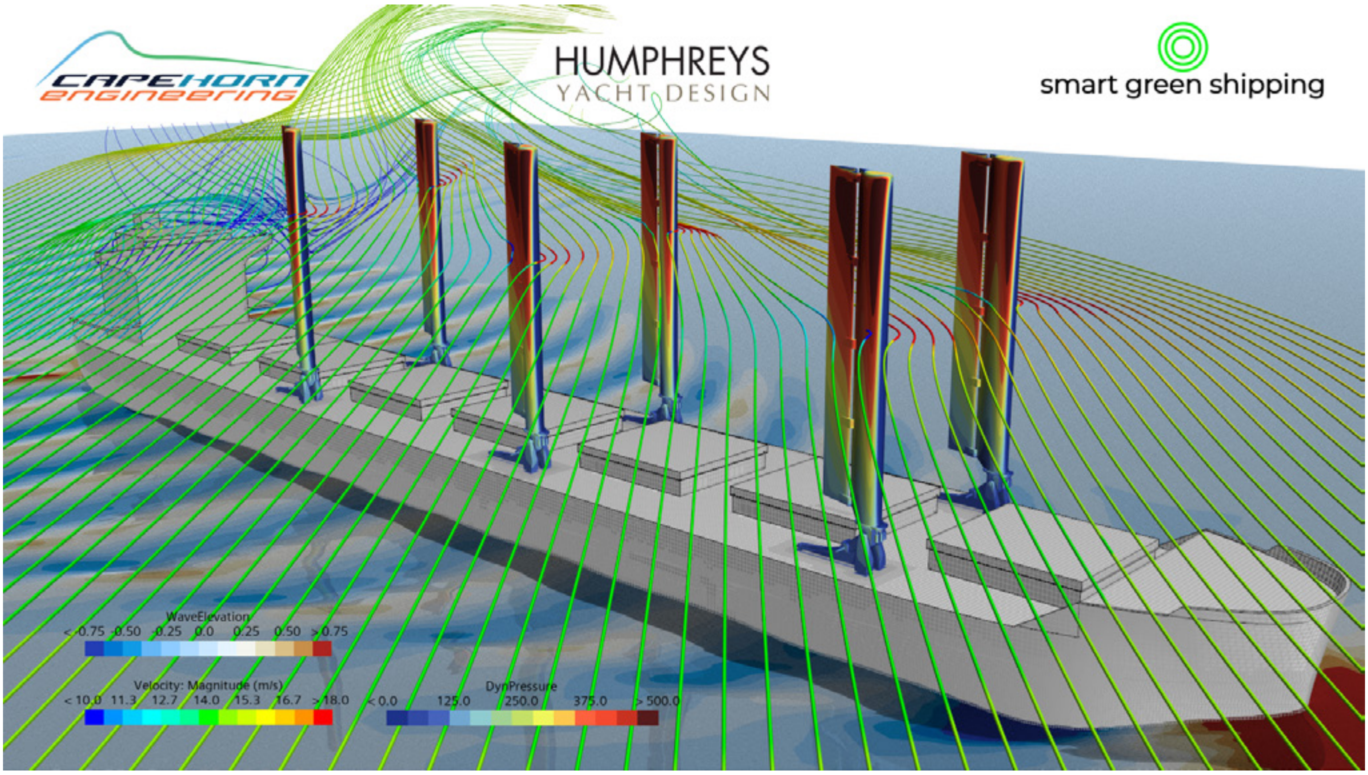
Wilkinson E. and Roberts D., “Through life load monitoring of superyacht carbon fibre rigs experience and new applications” HISWA Symposium on Yacht Design and Yacht Construction, 2016

Wright A.M. "Using CFD in the design environment " Presentation to Southern Joint Branch of RINA, 6th Feb 2013

FastRig Digital Twin

Cape Horn Engineering

December 6, 2022



Background

Cape Horn Engineering was commissioned by Humphreys Yacht Design to help validate and refine the performance of their patented FastRig solid wings, developed for Smart Green Shipping in the UK.

In this initial investigation, Cape Horn Engineering applied their 6-degrees-of-freedom simulation workflow to validate existing efficiency predictions obtained with a Velocity Prediction Program, which is based on individual force models. In contrast to the VPP predictions, the high-fidelity RANS-based CFD all-in-one simulations can capture all of the physics, including interactions between each wing and between the wings and the hull, all at once. This workflow has been recently developed by Cape Horn Engineering to directly compare the efficiency of wind assisted propulsion (WASP) devices and to validate lower fidelity modelling tools. For the case study presented here, power savings larger than 50% are demonstrated in moderate wind conditions of 20 knots from the side.

The Digital Twin

The high fidelity simulations take into account the most important effects of adding wings or any other type of wind powered device to a vessel. Both the water flow experienced by the hull at a given vessel speed and the air flow experienced by the 6 FastRigs are modelled simultaneously in a single simulation. The wings are mounted on deck, and aerodynamic details include the hull top sides, deck, hatches and superstructure. The wind speed and direction was varied to simulate different real world conditions, and the simulations were repeated with the vessel without the wings to have an exact baseline for comparison.

The wind conditions above the water surface are modelled with an accurate wind profile taking into account the atmospheric boundary layer wind gradient. This results in a variable apparent wind speed and direction at different heights, due to the combination of a moving ship and a wind strength that varies with height, something that sailors are very much aware of so that they need to twist the sails towards the top of the mast.

In the simulations, the vessel is sailing at a constant speed of 11.5 knots, and an actuator disk models the effect of the propeller using the open water propeller curves. Depending on the vessel resistance and the amount of thrust generated by the FastRigs, the thrust produced by the propeller balances the degree-of-freedom in the direction of travel and is used as an input to the actuator or virtual disc model. This determines the propeller RPM and propeller torque and therefore the delivered power.

The simulation further considers the deformation of the free surface or waves generated by the vessel, the dynamic sinkage and trim, the drift or leeway angle, the heel angle and the rudder angle to keep a constant course. The wind forces on the hull, superstructure and FastRigs induce the drift and heel angles, with the rudder angle changing during the simulation via a PID controller, balancing the yaw moment of the whole system. Thus, in total the 6 degrees-of-freedom are considered.

The simulation are stopped once they have converged to a quasi-steady solution. Then, comparing the case of the vessel with and without the FastRigs for the same wind conditions, the reduction in delivered power to the propeller can be compared, and with that the engine fuel and emissions reduction.

The table below shows the conditions investigated. At 11.5 knots, two True Wind Speeds of 12 and 20 knots each at 3 True Wind Angles of 70, 100 and 135 degrees were simulated. For each of the 6 combinations, the wings were adjusted with a different sheeting angle or rotation with respect to the vessel centre line. These values were taken as best estimates from existing VPP predictions, however, the sheeting angles of the 6 wings, independently of the position on deck, were the same within each simulation. The flap angle with respect to the chord line of each main wing element was also the same for all wings and all wind conditions. Greater performance could be achieved in the future from aerodynamic simulations to trim the 6 wing angles and 6 flap angles independently for a given wind condition.

Table 1: Wind Conditions and Wing Trim Angles

	Vessel Speed [Knots]	TWS [Knots]	TWA [deg]	Wing Sheeting Angle [deg]	Flap Angle [deg]
Case 01	11.5	12	70	24.4	20
Case 02	11.5	12	100	38.2	20
Case 03	11.5	12	130	55.4	20
Case 04	11.5	20	70	32.6	20
Case 05	11.5	20	100	53.2	20
Case 06	11.5	20	130	83.5	20

Results

Figure 1 gives the delivered power results from the simulations, shown in watts on the left graph, and as power saving percentage on the right. For the 6 conditions investigated, the minimum savings are 8% and the maximum 54%, with an average saving of 29%. The maximum saving occurs for the stronger wind of 20 knots from the side, and the minimum for the lighter wind from the aft quarter, since the apparent wind speed is most reduced in this case. A 54% power reduction is a considerable amount, and this value could improve even further if a more adequate propeller is used for motor sailing conditions. Ideally, the vessel would be fitted with a controllable pitch propeller to always be operating at the optimum efficiency, thus have the greatest benefit from wind assisted propulsion. At higher wind speed the vessel could even be sailing with the engine just idling.

Another interesting aspect of the results is that the heel and leeway angles are very modest, see Figure 2. The rudder angles needed to maintain a constant course get larger for the stronger winds from the side. However, by trimming the wings differently forward to back, the yaw moment could be reduced and an optimum in efficiency found. This remains the objective of a follow up investigation.

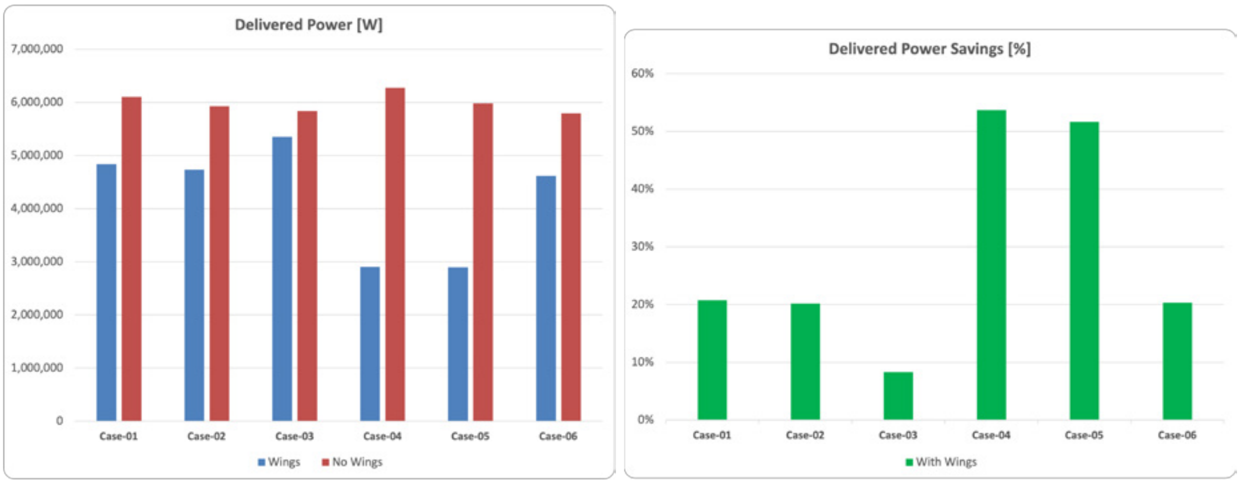


Figure 1: Delivered Power and Power Savings

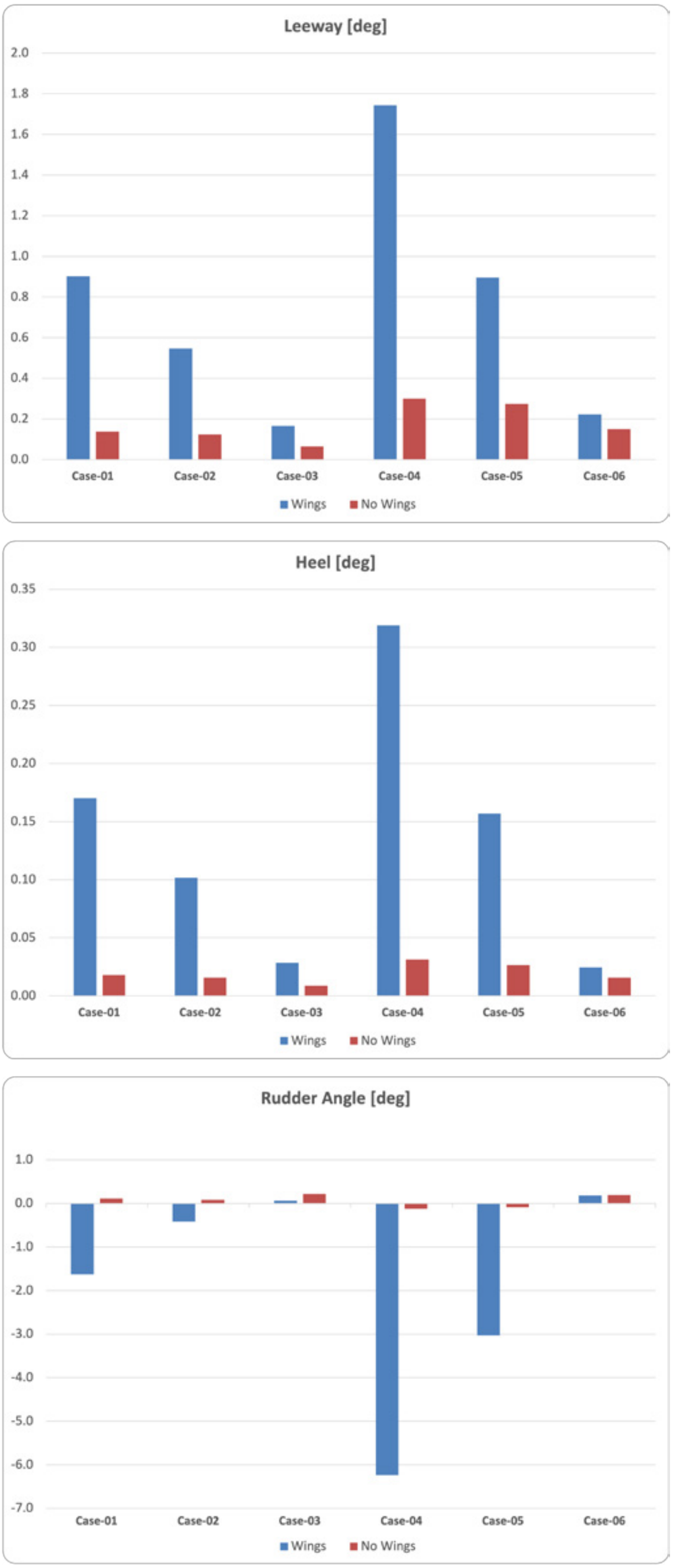


Figure 2: Leeway, Heel and Rudder Angles

ANNEX II – M

Fishing Vessels in Focus

Name: Balueiro Segundo (Bound4Blue)
Size: 593 GT, 41m LOA
Location: Spain (Peru)

System: eSAIL® -fixed suction wing system
Description: This 12m rig is installed in the stern, a stubby, non-rotating wing sail with vents and an internal fan generating suction which pulls in the boundary layer around the wing generating an enhanced effect.

Work Underway: Continued monitoring of commercial fishing activities and further development of the system.

Name: Grand Largue (Avel Vor Technologies)
Size: 16m trawler
Location: Brittany, France

System: Automated soft sail
Description: Two bipods masts, allowing for retrofit. Three self-steering jibs, with operations of winding/unwinding by an hydraulic roller + automation system for controlling sails.
Sea trials: decrease in fuel consumption (wind conditions/route) + decreased rolling consistently.

Work Underway: two generations are using soft sail configurations + rigid wing sails being considered.

Name: SailLine Fishing
Size: Various small test vessel sizes
Location: Scotland

System: Retractable Balpha Mast Soft Sail
Description: A complete foldable mast system for mast lengths up to 8.5m. The stainless steel mast housing would fit directly onto a mast step and the mast is carbon fibre 100 x 70mm. Length up to 8.5m made to suit vessel requirements.

Work Underway: Continued monitoring of commercial fishing activities and further development for scaled versions.

Further information on Fisheries and Wind-Assist Technologies (pages 19-21) - European Commission, Directorate-General for Maritime Affairs and Fisheries [DG MARE] - Possibilities and examples for energy transition of fishing and aquaculture sectors, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2771/828897