A white paper produced by

Wind Ship association

WIND PROPULSION FOR SHIPS

Technologies ready to decarbonise maritime transport.
An industrial opportunity for France.

This white paper has been produced with the financial support of ADEME, the French Agency for Ecological Transition and

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Translated from French by Amy Cheshire

Contents

Foreword

Developing clean and low-carbon maritime transport is one of the major challenges of this decade in order to fulfil the 2015 Paris Agreement the goal of which is to limit global warming to well below 2°C, and preferably 1.5°C, compared to pre-industrial levels. In 2017, France initiated the Tony de Brum declaration which sets ambitious objectives to ensure the contribution of maritime transport to this global commitment.

One value proposition that is able to create a virtuous cycle is the systematic use of wind energy to propel ships. Sailing is a 7,000-year-old practice. It relies on a fully renewable energy resource that is widely available on the planet. Having previously used all kinds of sails woven in soft materials, the maritime industry of the 21st century is reinventing the merchant sailing ship with new technologies and new materials that combine the laws of aerodynamics with those of hydrodynamics better than ever before. These technologies can be deployed on the majority of existing ships, and easily find their place in the design of new ships.

Yet plans for innovation in the shipping sector are almost exclusively focused on finding the green fuel of tomorrow to power the engines of ships in a business-as-usual model. This "monoculture" use of the internal combustion engine effectively excludes any possible reflection on an alternative energy source such as wind propulsion.

Wind Ship invites you, with this white paper, to discover the fundamentals of wind propulsion for ships – a valid and efficient technological answer that is available today to ensure the sustainability of shipping.

Florent Violain, President
Lise Detrimont, General Representative
Wind Ship Association (France)

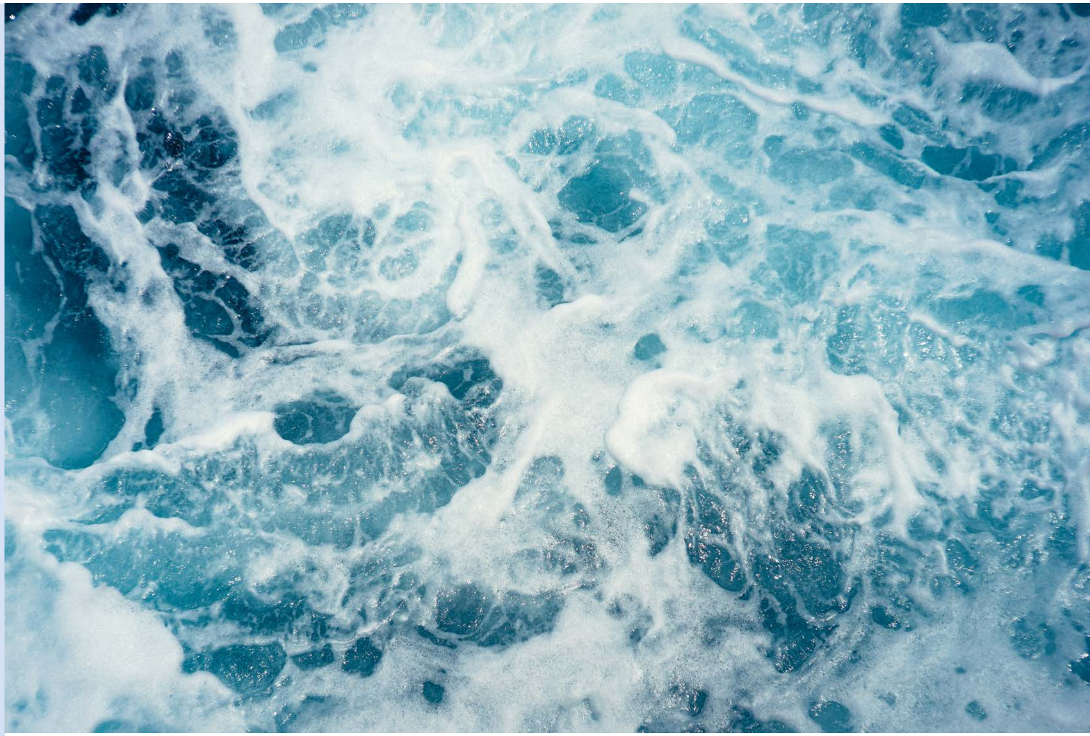
> *All that is just wind... This expression has never seemed so absurd. In a world which has become so complex for us, simplicity is a rare treasure. Yet the evidence is there: wind is everywhere, free, renewable and emission-free. Humanity has explored, prospered and written Maritime History thanks to the wind, except for a short "fossil" digression... The technical challenge may seem difficult, but as in many other areas, it is undoubtedly easier to overcome than the cultural challenge and the change of perspective that is required globally today. Well done to Wind Ship for this white paper that leaves new possibilities for tomorrow in its wake.*
>
> *Roland Jourdain,*
> *Professional yachtsman*

Who is this white paper for?

This white paper presents key factors to understanding wind-powered ship propulsion:

- **For direct users:** shipowners, shipping companies, freight forwarders, port players.
- **For indirect beneficiaries:** shipping users and distribution players.
- **For related service players:** insurance companies, certifying bodies, financiers, investors.
- **For enablers:** elected officials, members of government and administrations, NGOs.
- **For anyone interested** in the opportunity of a new path for clean and low-carbon shipping that has a strong regional dimension and creates new links between society, sailors and the sea.

This white paper is based on the knowledge of Wind Ship and our members and on the experiences and testimonies of many players in the maritime world, local authorities and administrations, institutions and schools, stakeholders in innovation and industry, related services and of course, project promoters.



We would like to thank the partners who enabled us to carry out this work: **ADEME (French Agency for Ecological Transition), Nantes Métropole, the Region of Brittany, CARENE (Agglomeration of St. Nazaire) and CMF (French Maritime Cluster)**. We are also grateful to **Armateurs de France (French shipowners' association), GICAN (French Maritime Industry Group), the Pôle Mer Bretagne Atlantique cluster and Bureau Véritas** for our regular discussions with them. We would also like to thank the many people who responded to our requests for this work or who guided us with their thoughts and connections.

About Wind Ship

Wind Ship is a French association created in 2019 to accelerate the ecological transition of the maritime sector, on its own scale and through its actions promoting the development and deployment of wind propulsion for ships.

Wind Ship works locally, nationally and internationally to position these solutions as a major and already available way to decarbonise commercial shipping and fishing.

Locally, Wind Ship participates in the transformation of the shipping methods and consumption patterns of the area:

- By structuring a local industrial and technological sector for "clean" maritime transport, bringing new opportunities to existing industries;
- By supporting economic models that reduce distances and open up new connections between areas;
- Through value propositions enabling citizens to reduce their environmental footprint and be socially responsible.

On a national level, Wind Ship promotes the visibility of solutions and supports decision-makers and users in their uptake of them, to accelerate their development. Wind Ship reinforces the national representation of wind propulsion to ensure that it is fully considered as a pillar of decarbonisation and that it can rely on a structured and competitive national sector.

At international level, Wind Ship coordinates the Atlantic Europe hub of **The International Windship Association (IWSA)**, a network of 150 members and supporters that work with IMO and the European Union. The IWSA is the body behind the **Decade of Wind Propulsion** campaign.

Wind Ship brings together pioneering companies in wind propulsion and representatives of civil society who wish to support the development of such solutions.

This document was written by members of the Wind Ship association, who are invested in promoting the use of wind in the propulsion of merchant ships. The contributors are therefore project promoters using or planning to use these technologies, developers of these technologies, naval engineering and architecture consultancies, and shipyards.

Through this white paper providing a guide to the fundamentals of wind propulsion for ships, the association wishes to contribute to a better understanding of the possibilities that the use of wind energy on ships can bring.

"ADEME's interest in the development of sail propulsion adapted to the merchant navy goes back more than ten years, having identified the significant place that these sail systems can take in the long-awaited decarbonisation of maritime transport. It would be clichéd to consider the return of sailing ships to the oceans as the preserve of a few sweet dreamers.

The first projects proposed to ADEME were led by well-established companies and naval architects in the field of boating and racing wishing to transpose the technical and scientific achievements obtained from offshore racing and competitive sailing to merchant vessels. The programme of investment in the future provided through ADEME and made by ADEME directly, have thus made it possible to finance ten innovation projects and a thesis, representing aid amounting to 14 million euros, with some already convincing successes.
Sail-powered commercial vessels are already in operation and demonstrators of innovative technologies (e.g. articulated rigid wingsails, kite wings and wingsails, thick sails and profile inversion systems), have shown the tremendous potential for innovation of the French ecosystem. ADEME is proud and happy to have played its part in the initiation of this ecosystem and will continue investing in 2022. The tide is very clearly turning, in shipping's favour. However, clearly, this support for innovation is not enough to accelerate deployment across the entire merchant fleet. Doubts and questions remain, which are justifiable and often out of ignorance.

It therefore seemed natural for ADEME to support the Wind Ship association and its members in this work of writing a white paper. It will be essential for sharing knowledge among stakeholders and identifying the levers to be activated to dispel doubts and answer all questions. Supplements have already been identified on specific subjects (e.g. insurance, inclusion in the logistics chain and the training of sailors) and will be developed soon.

Philippe Cauneau,
Engineer, Transport and Mobility department
ADEME

Summary

Harnessing the wind to propel merchant shipping vessels is a solution that is already available to significantly improve the carbon footprint of the shipping sector. France has a technological lead and a favourable ecosystem that could quickly transform into an outstanding industry with appropriate public and private support. As the race to decarbonise the economy is underway worldwide, many players in Asia and Northern Europe are positioning themselves in wind propulsion for ships. The French offer must therefore stand out quickly and strongly to create jobs and contribute significantly to cleaner maritime transport.

Why is it important to decarbonise maritime transport?

Maritime transport is an essential link in the global trade system.

In 2019, eleven billion tonnes of goods crossed the oceans on some 100,000 ships, and this traffic is constantly increasing, made possible by the increasing size of ships. While this increase in volumes makes shipping one of the modes of transport that emits the least greenhouse gases per unit transported, its overall climate bill is rising due to growth in trade. It is the source of 3% of global CO_2 emissions, i.e. 1 billion tonnes. If nothing is done, "maritime" CO_2 emissions could still increase by 50% by 2050 compared to 2018. Added to this are many other forms of pollution and damage to marine biodiversity.

States have become aware of this situation and have resolved, through the International Maritime Organisation (IMO) which has responsibility for the matter, to reduce the world fleet's greenhouse gas emissions by 50%. However, replacing 300 million annual tonnes of fossil fuel with cleaner energy sources requires huge changes, the cost of which is extremely high and will necessarily affect the cost of transport. The international regulatory framework is being built little by little, but the financial, technological and logistical means for this change are not yet operational.

What role can France have in this field?

It is the International Convention of the United Nations on the Law of the Sea which establishes the rights and duties of States. The latter negotiate international agreements on the prevention of pollution from ships within IMO.

France has little leeway to act directly even in waters under its sovereignty or jurisdiction. However, it does set the penalties in the event of non-compliance with international rules, which means it can make those on atmospheric emissions very dissuasive.

It can also make its pavilion particularly attractive for clean ships. As a coastal State, it could to some extent regulate passage through its territorial waters to protect the environment, but it is the European Commission that has jurisdiction in this respect. This has led to a system of indicators and greenhouse gas emission quotas which will be imposed on shipowners by 2023 in the European maritime area.

France is the world's second largest maritime territory. At its own level, it can participate in accelerating the change in consumption patterns by proposing concrete solutions for reducing emissions, for example low-carbon maritime logistics in the short-distance segment. For this, it can rely on the French companies already offering solutions that use wind propulsion to reduce shipping emissions.

Why are fossil-free fuels only part of the solution?

The world fleet today uses heavy fuel oil, a petroleum residue that is both very inexpensive and exempt from tax, with unequalled energy performance. To replace it, all eyes are now on low-carbon fuels. Biofuels are already used a little, within the narrow limits left to them by regulations and competition from other uses. The most eagerly anticipated low-carbon fuels are synthetic fuels produced from electricity made with renewable energy – often using hydrogen as an energy carrier.

Added to the fact that these fuels are not yet market-ready, they are less efficient than oil and pose high safety risks in some cases. Their production can result in major greenhouse gas emissions, and their use in maritime transport competes with other energy needs.

Finally and very importantly, their use will multiply the cost of energy on board by a factor of two to eight, knowing that energy costs already represent 20% to 35% of the annual expenses of shipowners. It is therefore essential to combine several measures to achieve rapid ecological transition in maritime transport. The first is to reduce the need for fuel. This is precisely what can be achieved with wind propulsion, which contributes significantly to the movement of the ship, complementing engine-power using any type of fuel.

What are wind propulsion technologies?

New technologies are now being developed and used to revive wind-powered shipping, a practice that dates back more than seven millennia. Today's technologies are based on a combination of innovations in different fields, such as shipbuilding and boating, ocean racing, aeronautics and digital technology.

They come in multiple forms of sails or wingsails, rotors or suction wings, and kites. They differ in their position (on-deck or overhead), shape, rigidity and automation, and can be fitted to almost all ships.

One of the major advantages is that they can be installed on existing ships; the decarbonisation of the fleet can therefore begin without waiting for its renewal. Wind propulsion technologies can operate alone or in conjunction with conventional engines (wind-assisted ship propulsion) which means that they can meet the current business model demands of maritime transport, in terms of speed in particular.

What are the advantages of wind for maritime transport?

Wind is a clean and immediately available source of energy that is in abundance almost everywhere on the globe, inexhaustible and inalienable. With wingsails or sails, the wind is used directly by the ship without loss of performance. Its use at sea does not compete with any land use. It has become predictable to a critical enough level to make its use compatible with a commercial activity, especially since the mobile nature of ships allows them to “find their wind” and optimize their route using routing tools. The use of wind to propel a ship does not present any negative external impact for the environment, nor any uncontrolled risk for the crew. On the contrary, wind propulsion reduces underwater noise by reducing the use of engine-powered propulsion.

Why is wind propulsion a serious solution?

Wind energy can propel a medium-sized vessel with enough power to be its main propulsion system on suitable routes, such as transatlantic crossings. Depending on the size and type of vessel, wind propulsion is an additional source of power that, first, allows a stable cost of transport for the part using wind energy, and, second, offers real operational financial gains through fuel savings: 5% to 20% on existing ships, more than 30% on new ships, and up to 80% in cases of medium-sized ships using wind as the main propulsion on a favourable route and carrying low-density cargoes.

These new propulsion systems can be adapted to almost all types of vessels, during construction or retrofitting, with a low footprint. Twenty-two first large cargo vessels, including an oil tanker, bulker, ferry, multi-purpose cargo ship, ro-ro and fishing vessel have already been fitted with wind propulsion technologies and are currently being tested. Their sailing areas vary, from the Northern Seas and the Atlantic to the Pacific and the Indian Ocean. The first new ship to directly integrate a new generation wind propulsion system during its construction was the E-Ship 1. This vessel, powered in part by four Flettner rotors, has been operating commercially since 2010. The next, a 121-metre ro-ro ship intended for transatlantic journeys and equipped with four wingsails each covering 363 sq. metres, will be launched at the end of 2022.

Is wind propulsion recognized by state and professional maritime transport authorities?

Wind propulsion meets the regulations in force, all the more so as IMO is updating its guidelines to take better account of it in the energy efficiency indices used to classify ship types. Decision support tools and services are developing rapidly to facilitate choices for shipowners and the integration of technologies on existing ships or new builds. The major classification societies have published or updated their standards on wind-powered ships. The French maritime administration is now working on a case-by-case basis to change national regulations and has already authorized the commissioning of wind-propelled ships under the French flag. The on-the-ground results of the first experiments are reviewed and verified by a third party, gradually reinforcing the credibility of the solutions. Insurers should soon offer specific policies or even premium incentives for wind propulsion.

What development potential is there for wind propulsion technologies?

Wind propulsion technologies are available today to be deployed on existing ships or incorporated into the design of new vessels. Up to 10,000 ships could be equipped by 2030 and up to 45% of the world fleet by 2050, based on the estimates of two forecasting studies, one carried out for the European Commission and the other for the United Kingdom's Department of Transport. The number of large cargo ships equipped today is expected to double by 2023.

Wind propulsion is particularly effective for medium-sized vessels travelling at moderate speed, which could indeed return to service due to a rise in awareness of the perverse effects of the international division of labour. The COVID-19 pandemic has shown the dependence of many countries, including France, on the places where strategic goods are produced. As a result, there is a desire to relocate some industrial production nearer to home. In addition, the use of renewable energies instead of fossil fuels could reshuffle the cards of the main maritime routes in favour of regional trade. The current organisation of commercial shipping – that is, fast, high-volume shipping, concentrated on a few main routes and in the hands of large operators – could be shaken up by the emergence of secondary lines provided by smaller ships. Lastly, island territories, which are particularly vulnerable to climate change and the uncertainties of the global economy, have a major interest in having a fleet using the free and abundant energy of the wind.

Large corporations are also increasingly showing their desire to decarbonise their supply chain as part of their CSR policy. Some have united under the international Cargo Owners for Zero Emission Vessels or coZEV initiative. In France, the association of cargo transport users supports the approach of fourteen French companies wishing to use shipping mainly powered by the wind from 2025. Fifteen or so French companies have also signed contracts with carriers using wind propulsion.

How developed is the manufacturing of systems today?

There are around thirty technology developers in the world, including around ten in France. French projects are already at a mature stage since two-thirds of equipment manufacturers have installed demonstrators on land or conducted tests at sea. Two manufacturing facilities are already being built. Companies have started to forge links with players working in the fields of offshore platforms and aeronautics which have useful know-how for the integration of wind propulsion systems on ships or for their maintenance. It is now a question of convincing shipowners to equip their ships with these new technologies in order to confirm their performance.

The financing of these projects is a major issue, given that these equipment manufacturers are for the most part start-ups. ADEME supported the initial research and development phases, but the cash requirements for building prototypes are high and, to date, the sector is still low on the radar of “green finance” players. However, the situation may change with the rise and volatility of fuel prices – fossil or not – and the inclusion of maritime transport in the European emissions trading system, which will highlight the validity of wind as an alternative energy.

What are France’s strengths with regard to this potential?

Mainland and overseas France have considerable capabilities to play a significant and international-scale role in the emergence of a low-carbon fleet thanks partly to the wind. French equipment manufacturers have already created more than 180 direct jobs. Young shipping companies are developing zero-emission shipping lines thanks to the wind, using high-sea routes or cabotage along the coast for the transport of goods and passengers, from mainland or overseas ports. Engineering consultancies, architectural firms, industrial subcontracting companies and shipyards have dedicated resources to projects in this sector. A large share of these operators are already united within Wind Ship and the International Windship Association, thus enabling the organisation of exchanges with all those involved in the sector, whether public or private.

These companies base themselves in proactive areas with industrial ecosystems that provide essential know-how from aeronautics, shipbuilding, boating and digital technology. This is the case of the Atlantic seaboard, where the local authorities also provide them with valuable support, such as the centre dedicated to nautical and maritime activities in Nantes, the industrial centre for new propulsion systems in the Saint-Nazaire agglomeration, and the Brittany Region’s activities to promote the industry.

What can be done to support the development of the sector?

The engagement of all stakeholders, whether private (customers, shipowners, shippers, investors and financiers) or public (State and local authorities) will be decisive in accelerating the development of this sector of demonstrated general interest.

Goals must include:

- Promoting wind propulsion and its advantages.
- Demonstrating the effectiveness of wind propulsion and encouraging its recognition by third parties.
- Encouraging users to invest in equipment and facilitating this investment.
- Financing industrial projects and accelerating return on investment.
- Promoting the creation of ecosystems that support wind propulsion at national level (mainland France and overseas) and in pioneering areas.

When passion and innovation combine with the past to pave the way for the future

The "wind propulsion" sector carries with it the deep and ancestral know-how of the entire maritime field combined. From the design of sails, masts and systems as a whole, to the design of ships and intelligent means of operating them, it is the bridge between the academic, scientific and industrial excellence in offshore racing and boating, of ship builders and equipment manufacturers, and in digital technology and materials, without forgetting our classification societies, insurers and financiers who support the deployment of these technologies, as well as schools for training the sailors of tomorrow.

As a long-term solution for the energy transition of the maritime industry and thereby for logistics and mobility chains, wind propulsion now just needs to be encouraged to move from simulations and test campaigns to concept ships that will validate the modelled energy systems with the wind and open up markets.

France is a pioneer in these technologies and must take advantage of its lead to develop an industry that is not new but renewed and strengthened.

Hybridized with new energies and technologies, the wind opens the way to energy mixes that would not be possible without its contribution. Indeed, the lower share of fuel on board, thanks to the contribution of the wind, will certainly make it easier to integrate higher volume energies and technologies that are not adapted to current ships.

Following the first sailboats in operation and the ships soon to be equipped, the next three years will be decisive for embarking various solutions, whether as the main or auxiliary propulsion, on the first segments of fleets and initiating industrialization. Then, the adaptation to other less immediately identifiable fleet segments, taking into account the operational and technical specificities of these types of vessels, will come gradually.

Beyond the need for change, it is a whole community that is prompting a rethink of the ship designs of tomorrow, supported by shipowners and shippers wishing to rethink the way we ship, produce and consume.

The Sector can count on the support of the entire maritime community, just as it has been able to count on the Cluster's T2EM initiative to promote its advantages and make it an industrial priority under the national ambition for zero-emission ships and the international green corridor goals announced at COP26.*
It is my hope that in the next three years French shipowners, from both overseas and mainland France, on the various lines of the globe, will become ambassadors of outstanding technology and a profound conscience, for the sake of the environment, our Planet and Humanity.

Frédéric Moncany de Saint-Aignan
President of the French Maritime Cluster

* T2EM is an acronym for Transition écoénergétique du maritime meaning maritime energy efficiency transition in English.

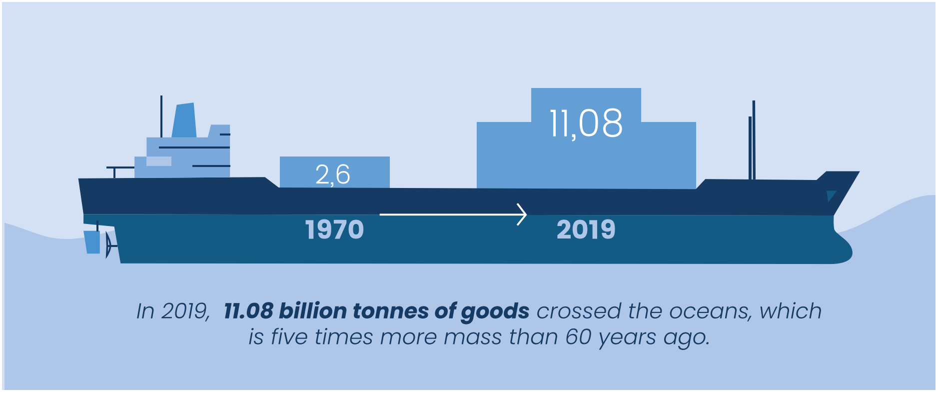
01 Decarbonising Maritime Transport

Importance of maritime transport in the global economy

Today's world lives to the rhythm of trade linked to the production and distribution of goods ... and is entirely dependent on it.

The COVID-19 pandemic has shown the interdependence of countries and their inhabitants on the flows of goods produced and distributed throughout the world. The increased use of outsourcing strategies by large firms, since the 1990s, has resulted in the fragmentation and dispersion of the various activities involved in the creation of value (source: [1]). Global value chains have exploded. It has become much more advantageous to specialize production in certain parts of the world where labour and raw materials are cheap, and to transport components from one side of the world to the other to assembly and transformation lines – steps which account for half of global trade – then transport the finished products for distribution.

Maritime transport is an essential but vulnerable link in the world's economic organisation, ensuring the circulation of intermediate and finished consumer goods, including food, clothing, furniture, cars, medical products, high-tech equipment, etc. Fossil energy, coal, oil and gas, as well as raw agricultural products and ores are also invariably transported by sea.



Explosion of cargo shipments over 50 years

The blockage of the Suez Canal by the grounding of the container ship *Ever Given* from 23 to 29 March 2021 caused a disruption of global maritime transport, the cost of which was estimated at 6 to 10 billion euros a day. This event highlighted the dependence of European trade and industry on Asian manufactured products particularly, as well as the limits of the race for gigantism, which are further proof of the vulnerability of maritime transport.

Climate and environmental impact of maritime transport

A growing climate bill with the intensification of trade

Although maritime transport is the mode of transport emitting the least greenhouse gases per unit transported, its climate bill is nevertheless increasing due to the intensification of trade. The cost of this transport is extremely low thanks to the increase in volumes achieved through the use of large ships propelled so far by a low-cost and tax-exempt petroleum residue – heavy fuel oil.

In 2020, 98,140 ships of over 100 gross tonnage* the oceans (see technical appendices). This represented an annual fuel consumption of nearly 235 million tonnes (source: [2]). Fuel expenses represent 20% to 35% of total annual costs for a shipowner (source: [3]).

Thanks to the size of ships and, consequently, their better energy efficiency, maritime transport is today proportionally one of the means of transporting goods with the least greenhouse gas (GHG) emissions. However, the increased size of ships, and the associated hub logic, engender environmental impacts and costs for society (see technical appendices). These are caused by the expansion of port infrastructure – particularly when dredging is done, which can have very significant implications – and facilities. Longer pre- and post-shipment phases are also a cause.

In addition, the volumes transported continue to grow rapidly. The consumer society model is struggling to give way to a more fuel-efficient and frugal society. And yet, the world population, estimated at 7.8 billion in 2021 (source: [4]), is expected to be 8.9 to 10.5 billion in 2050. Periodically, the volume of goods transported in 2020 will be slightly lower than in 2019, however forecasts predict an annual increase of 4.8% from 2021, and data recently published in the containerized goods sector would appear to confirm this forecast.

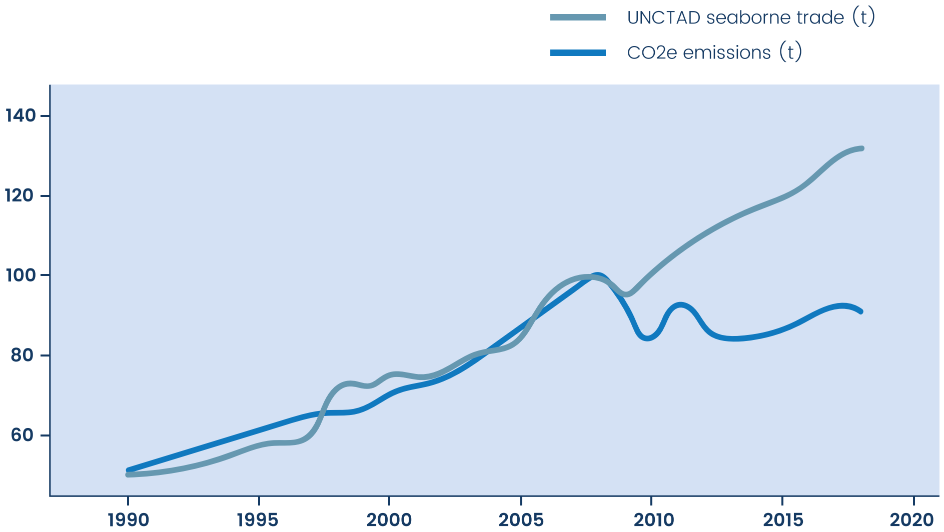
The total impact of maritime transport is therefore increasing globally as a percentage of anthropogenic emissions. International and national maritime transport (source: [5]) was responsible for 919 billion tonnes of CO2 (see note: [6]) in 2018, which is an increase of 8.4 % on 2012. All maritime transport (international, national and fishing) represents 1,076 million tonnes, or 2.89% of global emissions.

European maritime transport emissions in 2018 represented more than 138 million tonnes of CO2 (source: [7]), or more than 3.7 % of total EU emissions, and 15% of total maritime transport emissions. This represents 44 million tonnes of fuel (including 70% heavy fuel oil) or almost 7% of the European Union's total oil demand.

* The gross tonnage of ships is a measure of the volume of their enclosed spaces using a universal calculation formula introducing a logarithmic coefficient. This tonnage is therefore expressed in the Universal Measurement System but has no units.

An important indicator: Carbon intensity

Carbon intensity is an indicator developed to specifically reflect the carbon footprint of each vessel. It gives a volume of CO_2 emitted per tonne of goods and per kilometre (or nautical mile) travelled. This carbon intensity improved considerably between 2008 and 2019 (see note:[8]), to the order of 20% to 30% according to the estimates published by the IMO, thanks to the replacement of the oldest ships, to operational measures (e.g. reduction of speed) or technical ones, but also due to the introduction of even larger ships bringing economies of scale. GHG emissions were thus temporarily uncorrelated from the growth of international trade, which doubled between 1999 and 2018.



Evolution of GHG emissions from maritime transport since 1990

However, half of this improvement took place between 2008 and 2012. Since 2015, improvement has been much slower (around 1% to 2% per year) because the easiest and most immediate measures have been implemented, and this slower rate will not be able to offset the growth in volume of trade. To do so, the United Nations Conference on Trade and Development (UNCTAD) stresses that it is "**necessary to opt for radical changes in engine and fuel technologies**[9]". Without this, projections by the International Maritime Organisation predict that CO_2 emissions from maritime transport could still increase by 50% by 2050 compared to 2018.

Other environmental impacts of shipping

The gases emitted by the combustion of fossil fuels also have an impact on human health and the environment (see appendix). In 2018, emissions from international maritime transport, i.e. 10 million tonnes of sulphur oxides (SOx) or 5% to 10% of global emissions and 18 million tonnes of nitrogen oxides (NOx) or 17% to 31% of global emissions, as well as 3 million tonnes of fine and ultrafine particles were responsible for a deterioration in air quality, particularly along coastlines (see note:[10]).

Ocean noise pollution is beginning to be sufficiently documented and is now believed to have a major impact on marine life by disrupting all interactions in the marine environment. The noise generated by ships and in particular by propeller cavitation increases acoustic pressure on marine ecosystems and endangers biodiversity. This issue has just been included in the work programme of the International Maritime Organisation.

Storing fuel on board can have dramatic consequences for the environment in the event of an accident causing the heavy fuel oil contained in the tanks to spill into the sea. The most recent spill of this kind to have affected the French maritime space (source: [11]) was that of *Grande America* in April 2019. The 214-metre ro-ro caught fire while crossing the Bay of Biscay and sank at a depth of 4,600 metres. The wreck contained 2,200 tonnes of heavy fuel oil in its holds, part of which spilled out as it sank.

Institutions and regulation

Under pressure from citizens, their governments and NGOs, rules on ship emissions are tightening, from the international to the local level.

Role of the International Maritime Organisation (IMO)

The International Maritime Organisation (IMO) is the agency entrusted by the United Nations with ensuring the safety and security of maritime transport and preventing pollution of the seas by ships. It is at IMO that member States adopt the rules that they must all respect or enforce. IMO was recognized in 1997 as the competent organisation for managing the reduction of maritime GHG emissions, unlike other industrial sectors which are under the direct responsibility of the States in which they operate. The same special situation applies with international civil aviation, which is under the responsibility of ICAO.

Annex VI of the MARPOL Convention

The requirements on the prevention of air pollution and the reduction of GHG emissions are set out in Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL Convention), which entered into force in 2005 and whose latest update was in 2011.

This Annex requires ships built from 2013 to be more energy-efficient with increasingly restrictive thresholds so that by 2025, ships will be 30% more efficient than those built between 2000 and 2010. The Annex also establishes mandatory monitoring of the energy efficiency of every vessel.

The IMO strategy

In 2018, IMO adopted its initial strategy on the reduction of GHG emissions from ships. It aims to reduce carbon intensity across international shipping by 40% by 2030 and 70% by 2050. It also aims to reduce the GHG emissions of the entire global fleet by 50% by 2050. The reference year is 2008.

The implementation of this immensely challenging strategy relies on the use of two energy efficiency indices – called EEDI* and EEXI** (see appendix) – for existing and future ships of 400 gross tonnage and above. Ships built since 2013 must comply with a threshold, and all existing ships will also have to comply with one from 1 January 2023 – failing which, they will be notified of non-compliance during inspections in ports.

The American Bureau of Shipping classification society estimates that 85% of existing tankers and bulk carriers subject to this new standard will have difficulty complying with the EEXI [12] , which represents more than 18,000 vessels.

* EEDI: energy efficiency design index. ** EEXI : energy efficiency existing ship.

The IMO strategy also relies on a carbon intensity index, called CII*, for ships of over 5,000 gross tonnage (GT). The limits to be respected will be gradually lowered between 2018 and 2030, to achieve a 40% reduction by the end of this period compared to 2008.

Bureau Véritas estimates that, in a business-as-usual scenario, 20% of the current fleet of bulk carriers concerned will not achieve the minimum required score by 2023, and 55% in 2030. More generally, 55% of the fleet could fail to meet the approved standards by 2030.

Using wind propulsion can improve these indicators, or even make it possible to avoid them because hybrid ships are considered as having non-conventional propulsion and are not subject to EEDI (source: 13).

In addition, the idea of considering the entire life cycle of these fuels, including the GHG emissions from their production ("from well to tank"), and not only from their combustion during use ("from tank to wake") is currently being discussed at IMO.

Scope of action of States

The international Convention on the Law of the Sea, which entered into force in 1994, defines zones of waters – internal waters, territorial sea, exclusive economic zone and the high seas – as well as the rights and duties of States in these areas. The latter may act in the capacity of flag State**, coastal State and port State.

* CII : carbon intensity indicator

** The flag State is that in which the ship is registered. It assigns it a home port and exercises its jurisdiction and control in technical, administrative and social fields.

Flag States

The flag State must respect the rules of the International Maritime Organisation as well as EU rules for Member States. It can act within the Organisation to develop this international law but has little leeway to set its own environmental regulations. However, it is the flag State which sets the criminal or administrative penalties that apply in the event of an infringement, which would allow it to be particularly severe in terms of air pollution, for example.

Moreover, the flag State is free to set its registration conditions. The attractiveness of a pavilion is today strongly tied to reduced social costs and tax advantages, and competition between pavilions is strong. Though, a State could use precisely this tax lever if it wanted to attract a low-carbon fleet under its flag.

Coastal States

The coastal State can regulate the passage of ships through its territorial sea in order to protect the environment and to prevent, reduce and control pollution. Some States have used this jurisdiction to impose more stringent standards on ship emissions, such as China, Norway and California for example. China imposed a rate of 0.5% sulphur in fuels for several areas of its coast before the requirement introduced by IMO on 1 January 2020. Norway imposes zero-emission navigation in some of its fjords. France could not adopt these types of rules unilaterally because they fall within the competence of the European Union, but it can actively push the latter to raise its standards.

Furthermore, to prevent maritime accidents, coastal States have signed Memoranda of Understanding allowing the port State – that of a port of call – to control a ship even if it does not fly its flag. This has led to a list of ships that are banned from calling in the ports of signatory states.

Pressure from the European Union

In 2015, the European Union adopted regulation 2015/757, known as MRV, concerning the monitoring, reporting and verification of carbon dioxide emissions from the shipping sector. It applies to all ships of over 5,000 GT sailing to or from a port under the jurisdiction of a Member State. Companies have an obligation to monitor the CO_2 emissions of their ships and report them to the Commission and to the authorities of their flag State. This regulation prepares for the inclusion of maritime transport in the European Union's emissions trading system (ETS), by 2022. This measure comes with obligations aimed at ensuring that shipping companies reduce their carbon intensity by 40% by 2030.

In addition, the FuelEU Maritime regulation, on alternative fuels, proposes to establish a new GHG intensity index for vessels of more than 5,000 GT, including emissions from fuel production. The values to be respected, which are still to be determined, will aim to gradually lower ships' carbon intensity to 75% of the 2020 level by 2050.

Shipowners must quickly find solutions to reduce their emissions because as of 2023 they will be expected to pay based on the tonnes of CO_2 a ship emits.

Corporate environmental responsibility

While maritime transport is regularly singled out for its conservatism and wait-and-see attitude towards key global challenges, individual stakeholders and customers of maritime transport are increasingly being encouraged by social pressure and by the financial pressure on banks to adopt more aggressive environmental strategies.

For this, they can refer to at least three of the seventeen Sustainable Development Goals (SDGs) set in 2015 by the UN – those on responsible consumption and production, climate action and life below water. These SDGs are often taken up as corporate social responsibility (CSR) priorities.

This voluntary approach, although increasingly "legalized", encourages the integration of entrepreneurial ethics and efficiency in business strategies. In concrete terms, this translates to the search for responsible logistics in the production chain. Practices are appearing, from more local supply loops to detailed consumer information, in particular via indicators and certifications.

Indicators and certifications

RightShip estimates GHG emissions from ships and classifies them according to their level (A to G). According to the organisation, its data consultation platform for information on environmental performance and shipping safety has 8,000 users.

The International Association of Ports and Harbours has created the ESI (Environmental Ship Index) to allow shipowners to benefit from reduced port dues when a ship is cleaner than IMO standards on atmospheric pollutant and GHG emissions.

Green Marine is a voluntary environmental certification programme for the maritime industry, initially launched from Canada for North America. Since 2019, Surfrider Foundation Europe has been the coordinator for the Green Marine Europe label. To receive it, candidates must measure their environmental performance annually using the self-assessment guides, submit their results for external verification by an independent verifier accredited by Green Marine Europe and agree to publish their individual results. *Twelve shipowners were certified in 2021*. A criteria relating to GHG emissions which had not yet been developed on the Canadian side was implemented for the first time in France to establish the results for the year 2020.

Business initiatives

The offer of wind-propelled shipping responds to a growing demand.

Internationally, shippers are becoming increasingly active. The "Cargo Owners for Zero Emission Vessels (COZEV)" coalition brings together nine big companies, including Amazon, IKEA, Michelin and Unilever. They have pledged to gradually shift all their sea freight to vessels powered by carbon-free fuels by 2040. This initiative aims to harness the purchasing power of the world's largest cargo owners to accelerate the decarbonisation of the shipping sector and put pressure on maritime operators. The First Movers Coalition launched as part of COP26 is also mobilizing big corporations to decarbonise hard-to-abate sectors such as shipping. In France, the environmental and social commitments of companies using maritime transport, whatever their size, is already translating to orders for wind powered shipping. Airbus, Cemoi, Bénéteau, Clarins, Michelin, Vale, Hennessy, Arcadie, Belco, Manitou, Martell Mumm Perrier-Jouët, ArianeGroup and Longchamp have signed contracts or contract promises in this sense.

Some companies are going further and developing an offer truly based on wind propulsion.

The chocolate and coffee company **Grain de Sail,** based in Morlaix, has been using its own cargo sailboat since 2020 to transport some of its raw materials and plans to charter a second one in 2023 to increase its shipping capacity. The additional cost of wind-powered shipping compared to conventional shipping is estimated at around ten cents of a euro per chocolate bar. In its communications, the company places a strong focus on the shipping mode; its name transforms the last word of the French expression meaning "grain of salt" (grain de sel) into sail, its logo represents a sailboat, and its website reports on the vessel's transatlantic crossings. This low-carbon approach is part of a more all-round sustainable development policy.

The company **TOWT** (TransOceanic Wind Transport) charters sailboats to import and deliver products via several maritime routes, with cross-channel, regional cabotage, European and transatlantic cabotage services. It has created the ANEMOS label for products transported by sail. For these quality, organic and/or fair-trade foodstuffs, the consumer has access to a trip number and to information such as GPS tracking, distance sailed and a logbook with photos and stories.

What can be expected from alternative fuels?

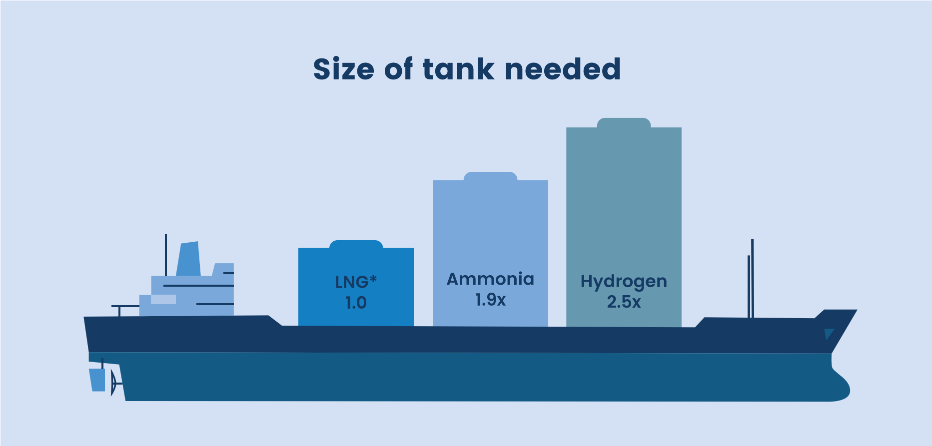
Many avenues are being explored to propel ships in a low-carbon way. There are many possibilities, particularly in terms of synthetic fuels such as hydrogen and ammonia produced from carbon-free electricity or biofuels produced from biomass. No alternative fuel seems able to replace oil before 2030 for long-distance journeys due to the lack of maturity of these solutions and storage, supply chain and logistics issues. However, these solutions are all complementary with wind propulsion.

The greatest difficulty is the cost of these new energy sources, which would multiply fuel-related expenses by a factor of 2 to 8 (source:[14]).

Low energy efficiency and high safety risks

The cold hard fact is that there is no energy source with the same energy density as oil (apart from nuclear power). Biofuels come close, but these pose other problems, which will be discussed later.

For one energy equivalent, much larger volumes of alternative fuels will be needed. Alternative fuels will therefore generally have to be compressed (or liquefied), which poses technical and safety issues. This issue of energy density eliminates, for example, the use of batteries for long-distance navigation and pushes the balance in favour of ammonia over hydrogen and methanol.



Storage of alternative fuel compared to a fossil fuel
*LNG: liquefied natural gas. *Source : **SeaLNG***

Whatever fuel is considered, there are strong impacts and constraints.

In addition to the technical aspects of compression or liquefaction of alternative fuels, their dangerousness is frequently mentioned. The small size of a hydrogen molecule increases the risk of it escaping, and its inflammable and explosive nature will mean important safety measures.

The toxicity of ammonia is also a real challenge, as it is lethal at very low concentrations in the air. In addition, its combustion generates the production of nitrogen oxides (NOx) which will have to be treated to comply with the IMO rules in this regard.

R&D is progressing and will undoubtedly make it possible to reduce certain difficulties through new technologies, but waiting for these to mature does not resolve the urgent climate issue.

Unavailability and competition with other needs

It is not possible today to produce alternative fuels in a low-carbon way and in sufficient quantities for the maritime sector. Support from terrestrial uses is needed to undertake the massive investment required, which also generates competition for the use of end products.

For example, the national strategy for the development of carbon-free hydrogen in France published in 2020 states a target of 6.5 GW of electrolyzers installed by 2030, primarily to decarbonise industry (refining, chemicals in particular), then land vehicles and rail only. Biofuel is another example – the production capacity of the European Union would only be 1.7 million tonnes in 2030, requiring the import of 5.1 million tonnes (source: [15]) to satisfy uses other than maritime transport (for example, it is one of the only fuels that aviation could use).

High cost of production, transport and onshore storage

To reduce GHG emissions by 50% by 2050, 800 to 1200 billion dollars must be invested between 2030 and 2050, i.e. 40 to 60 billion per year for 20 years (source: [16]), according to the study published by the University Maritime Advisory Services (UMAS) in January 2020. If we consider the full decarbonisation of maritime transport, we must add another 400 billion, or a total of 1,200 to 1,600 billion dollars.

This estimate was based on the assumption that the maritime industry would widely adopt ammonia as an alternative fuel – but the choice of another fuel such as hydrogen (see note: [17]) or synthetic methanol would not fundamentally change the scale of investments.

Eighty-seven percent of these amounts are linked to investments on land, in order to produce hydrogen, synthesize ammonia, transport and store synthetic products, then implement bunkering infrastructure. Only 13% of these amounts concern investments on the ships themselves (onboard storage, motorization).

An analysis by Lloyd's List (source: [18]) estimates that the construction of a plant capable of producing enough ammonia in a low-carbon way to supply four post-Panamax ships (capacity > 6400 TEU) would today require an investment of 690 to 791 million dollars.

The cost of producing the current low-sulphur fuel (LSFO) is estimated at 0.039 USD/kWh and the cost of producing ammonia from carbon-free electricity is 0.21 USD/kWh (source: [19]).

Lack of R&D financing

Proposals have already been put forward to finance the R&D necessary for the development of ships, through large taxes on fuel, on CO2 emissions, or measures based on the carbon market. The shipowners grouped within the International Chamber of Shipping have suggested introducing a tax of $2 per tonne of fuel, which could generate a $5 billion R&D fund for the International Maritime Research and Development Board (IMRB) to use, for a period of 10 years, to accelerate the development of zero-emission ships that they believe will be commercially viable in the 2030s.

In September 2020, Trafigura, one of the largest shippers in the world with more than 4,000 maritime shipments per year, proposed the introduction of a tax of $250 to $300 per tonne of CO2 equivalent, which would represent $500 million per year, to finance R&D and to support developing countries impacted by climate change.

In March 2021, two Pacific island countries, the Marshall Islands and the Solomon Islands submitted a proposal to IMO for a levy of $100 per tonne of CO2 equivalent.

Furthermore, the European Union is proposing the inclusion of maritime transport in its carbon market, on which the price of a tonne of CO2 is currently around €50 – part of the revenue generated (3%) could feed an R&D fund, making it possible to develop decarbonisation technologies.

Overview of impacts

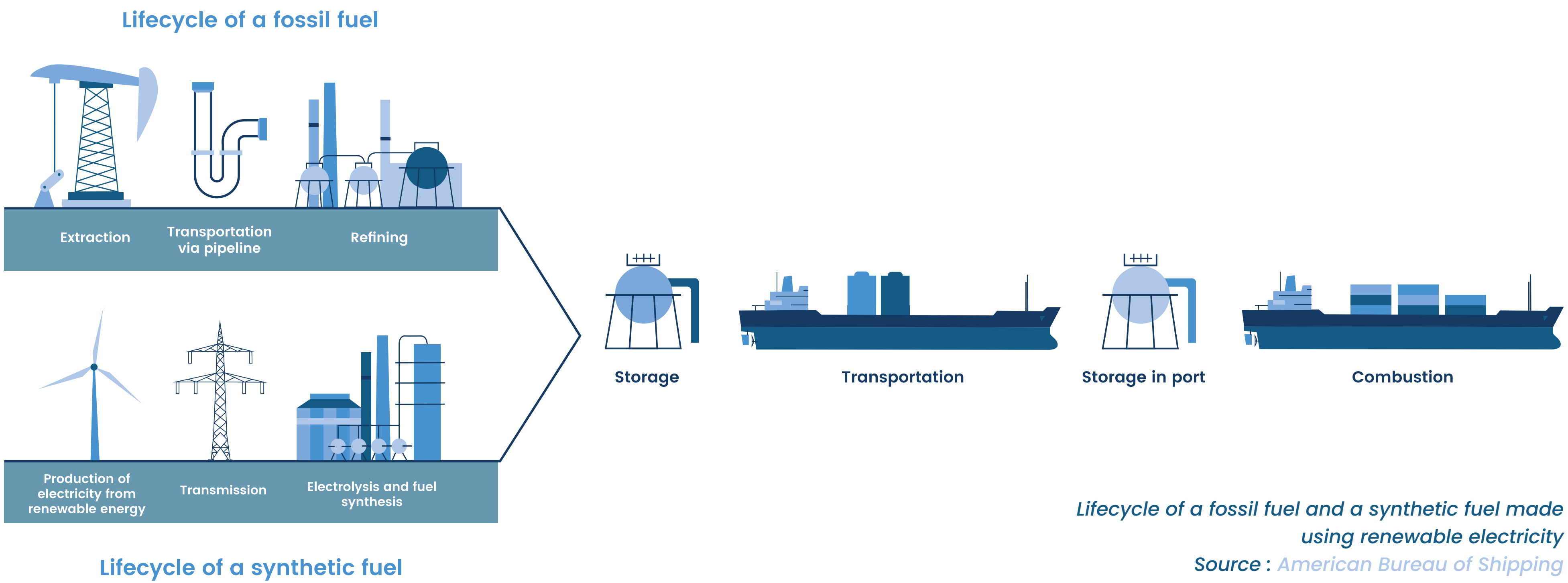
	Safety		Operating constraints					Environment		Social
	Fires/ explosions	Toxicity	Pressure	Corrosion	Cryogenics	Deck space	Hold storage	On-land infrastructure	GHGs/ pollutants	Competition with uses on land
LNG	●		●		●		●	●	●	
Ammonia	●	●					●	●	●	●
Liquid hydrogen	●		●	●			●	●		●
Methanol	●	●					●	●		●
Biofuel								●	●	●
E-fuel	○	○	○				●	●		●
Wind						●				

Impacts of different energy sources for the propulsion of ships

Heavy carbon footprint over the full life cycle

One of the major challenges today for the development of alternative fuels is to avoid marketing an alternative fuel which, of course, makes it possible to reduce pollutants and GHG emissions during shipping, but which has emitted large quantities of GHGs during its production. It is the comparison over the complete life cycle of such fuels that must be taken into account. We thus speak of a well-to-tank emission factor, i.e. the emissions emitted to produce the fuel (extraction, transformation, transport, storage), then tank-to-wake emissions, i.e. the emissions from the fuel use phase during shipping. The addition of these two values will give the overall shipping emission factor, depending on the engine used on the ship.

The diagrams below illustrate these cycles for a current grey fuel (hydrocarbon), and for a green fuel produced from renewable energy. These cycles, which are necessary, result in a significant loss of energy that is ultimately usable, and also illustrate all the preliminary stages requiring energy and infrastructure before the final combustion in the ship's engine.



Lifecycle of a fossil fuel and a synthetic fuel made using renewable electricity
Source : American Bureau of Shipping

Emission comparisons have been published by the American Bureau of Shipping classification society, which examines the emissions of different alternative fuels according to the phases considered: from well to tank, then from tank to wake. This comparison considers the currently available sources of supply and shows the risk of shifting emissions from the shipping phase to the upstream production phase of alternative fuels (see appendix).

The first measure to be implemented for the rapid ecological transition of maritime transport must be to actually reduce the energy needs of ships so that only a residual part of this energy need has to be met using alternative fuels. Wind propulsion allows precisely that, thus providing a significant part of the solution.

02 Forms of Wind Propulsion in the 21st Century

A brief history of sailing

Sailing has been practised since Antiquity and was undoubtedly the most significant driver of the development of France, providing it in the 14th and 15th centuries with a unique commercial and military capacity, and having propelled the emergence of a modern state. The world merchant sailing ship fleet continued to grow until the 1880s, with clippers. These long, fast, narrow ships could be over 100 metres long and travel at speeds of up to 21 knots, thanks to excellent knowledge of the wind patterns and currents on all the seas of the globe.

In parallel, the use of the combustion engine for ship propulsion appeared in the 19th Century. Steam engines were initially coal-fired, before the invention of Diesel's internal combustion engine. Until 1850, only fast and short-distance passenger lines used steam, while trade was still done by sail. Large quantities of coal were required, taking up a large part of the bunker volume, and resulting in non-negligible fire risks.

The appearance of turbines, though, favoured the development of steam, as they reduced coal consumption, freeing up bunker space and improving navigation conditions, particularly in terms of vibrations and noise. Consequently, the tonnage transported by steamships overtook that of sailing ships in 1880. In parallel, the defeat of the French Navy during the bombardment of Sevastopol during the Crimean War demonstrated the inadequacy of wooden sailing ships in the face of floating armoured batteries.

Ultimately, three factors combined led to the disappearance of sailing ships. On the one hand, the opening of the Suez Canal in 1870 lessened the advantage of clippers on long-distance journeys – especially since access to the canal from the Red Sea was unfavourable to sailboats due to lack of wind. On the other hand, the increased capacity of ships required more sailors on board to manage larger sail areas. This resulted in greater costs added to the fact that crews were difficult to recruit. Following significant destruction of the fleet during the First World War, the 1929 crisis finally completed the demise of the tall ships, of which only 70 of such vessels remain in the world today.

The switch to diesel for the fishing fleet took place rather after the Second World War, under the Monnet plans (1947 and 1955). Only the pleasure yacht fleet that appeared in the late 19th Century remains. Today, leisure sailing has developed into a real nautical industry, and is the source of some of the technological innovations that are inspiring wind-powered ship development in the 21st century.

A raft of technological innovations

A wide variety of solutions are now being studied and prototyped to allow the return of wind propulsion for ships, with performance conditions compatible with today's commercial shipping constraints. Some of these innovations date back to the 1920s.

Innovations with varied origins

The Magnus Effect and Anton Flettner's schooner

One of the first modern solutions developed was the rotor, which uses the Magnus effect to rotate a metal cylinder on the ship's deck and generate lift. In 1924, Anton Flettner's German schooner Buckau, which was fitted with two 15-metre-high rotors, used this solution to complete an Atlantic crossing. Another rotor ship operated in the Mediterranean from 1926 to 1929. These first experiments were not continued though because the very low price of oil at the time did not justify investments in renewable energies, but were taken up much more recently, in particular with E-Ship 1, the Flettner ship of the ENERCON company, which has been sailing since 2010.

The turbosail of Captain Cousteau's team

In the 1980s, Commander Cousteau's team, with Professor Malavard and Dr. Charrier, designed a suction wing system called a turbosail and installed it on the boat *Moulin à Vent*. The turbosail optimizes airflow by a suction system down the sides of the wing to create aerodynamic lift. *Moulin à Vent* completed its first crossings between Tangier and New York between 1981 and 1983. The Péchiney company bought the patent to develop the system, but the end of the second oil shock and the drop in oil prices in the mid-1980s put an end to experiments. The *Alcyone* was operated with the turbosail for about ten years and is still sailing. The CRAIN naval architecture and industry research centre in La Rochelle relaunched R&D on suction wing systems in 2015.

Ocean racing and aeronautics

Competitive sailing and ocean racing also nurture innovation. It was the articulated rigid wingsail designed by the VPLP architectural firm that brought *USA 17,* the trimaran of BMW Oracle Racing, victory in the America's Cup in 2010. This concept inspired the development of thick sails by the same naval architecture firm, to be fitted on merchant ships, and, in 2018, led to the setting up of AYRO, a company dedicated to the design and manufacture of these wingsails.

Flying wingsails known as kites are another nautical innovation, however the aeronautics world has played a major role in their adaptation to the merchant navy, thanks to its mastery of flight conditions and safety.

Four of them are on-deck systems, the kite being the exception. Kite systems have the advantage of not cluttering the deck, and of reaching higher for stronger and more stable winds. They work best in downwind conditions.

Rotor and suction wing systems, mentioned above, are very compact, but need external energy to spin, turn or draw in air. Their best performance is obtained over generally smaller apparent wind ranges than other systems.

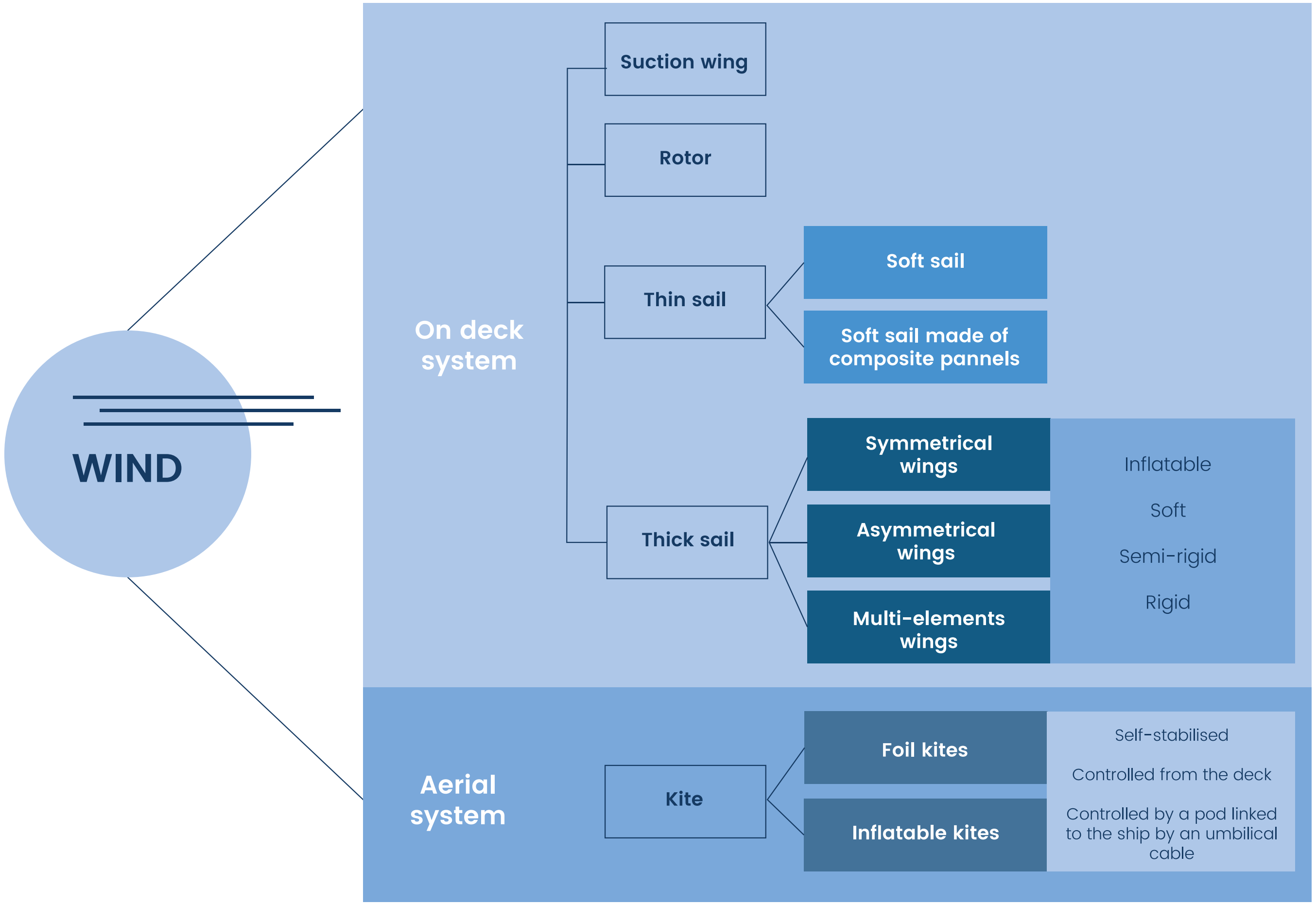
The other on-deck technologies are similar either to sails or wingsails, with a thicker profile (seen in longitudinal section). Their aerodynamic properties vary according to the thickness but also to the camber or the symmetry of the sail or wing. Thick sails have good "aerodynamic fineness", that is to say strong performance when travelling upwind.

Wings and sails also differ in materials and stiffness. A flexible fabric material is easier to lower or reef (reduction of sail area) but wears out more quickly due to exposure to ultraviolet rays and luffing (sails beating in the wind). Some wings made in fabric membrane are rendered more robust through inflation which stiffens them. Rigid systems are built for sturdiness and the ability to orient the wings optimally in relation to the wind.

These categories can be further sub-divided according to features such as the number of elements in articulated wings, the type of articulation (slot, flap) etc.

Categories of wind propulsion technologies

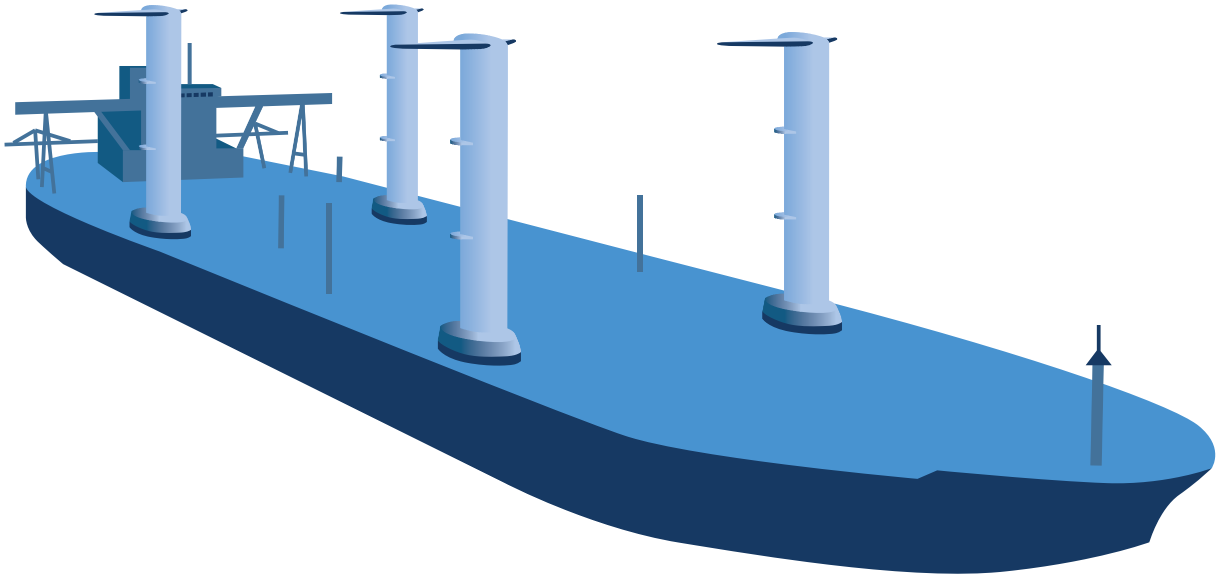
There are five main families of technologies.



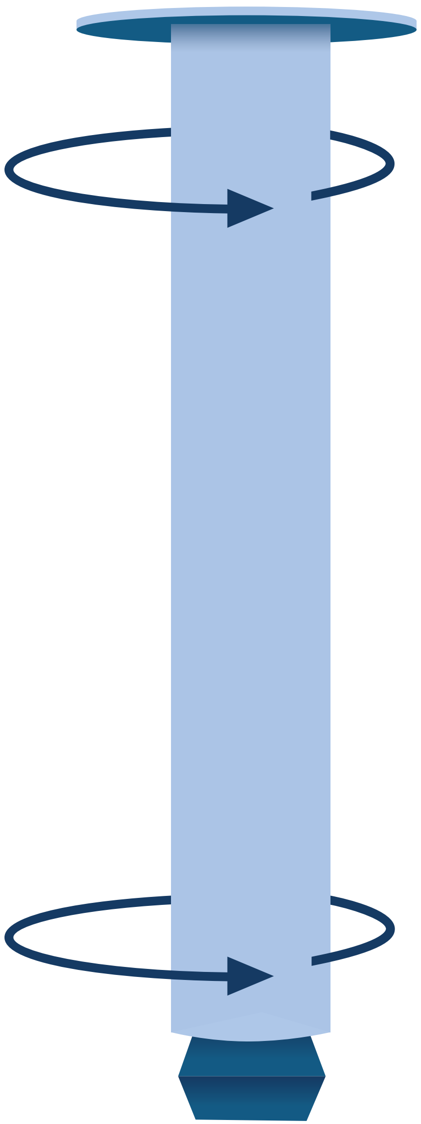
Other categories : turbines to produce electricity, hull form, ...

Suction wing

Suction wings consist of a vertical cylindrical metal or composite wing, equipped with a suction grid and a flap that optimises the lift of the system.



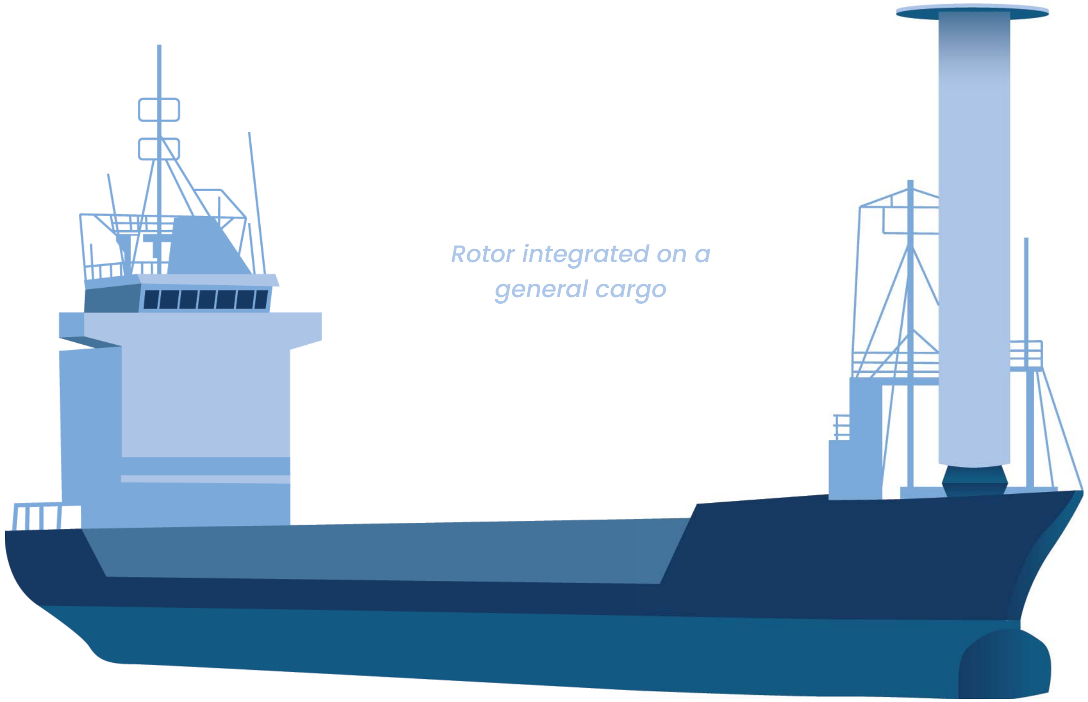
Suction wing integrated on a tanker

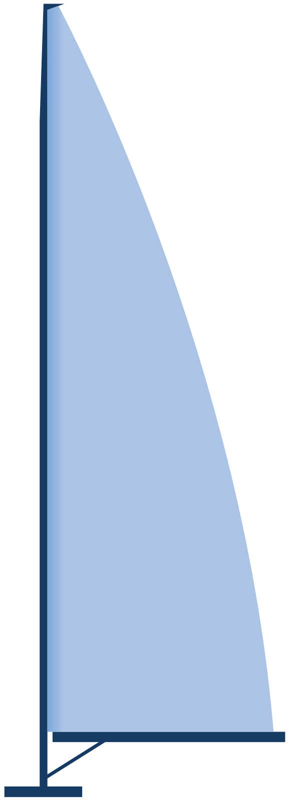


Rotor

The rotor is a metal or composite cylinder rotated by a motor. This rotation allows the cylinder to generate thrust using the Magnus effect.

Rotors can be equipped with a tilting system to reduce their air draft.

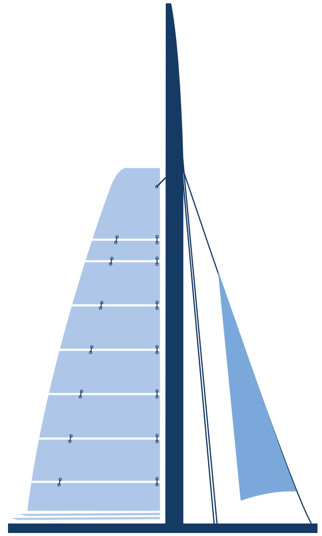


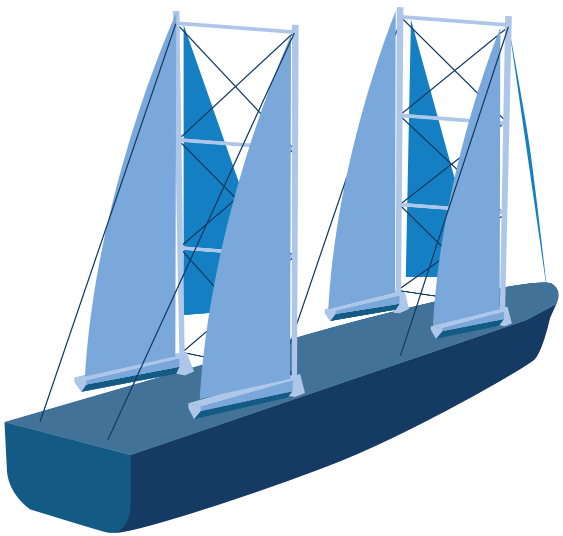


Thin sails

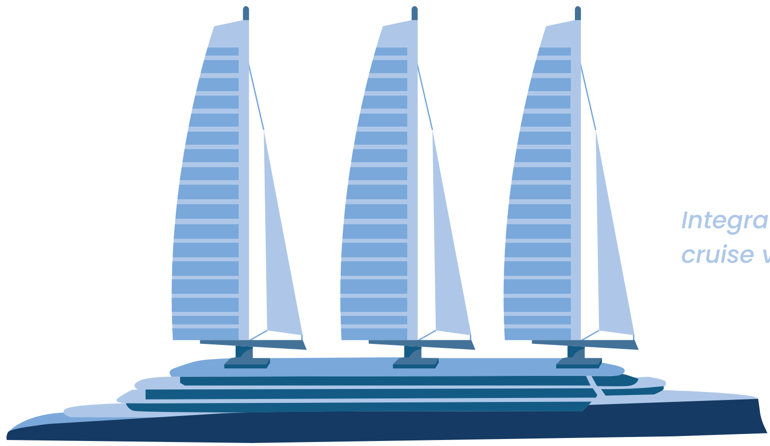
Flexible textile sails can be rigged in different ways. They are reefable and furlable. In some cases, the masts can be tilted to pass beneath bridges.

The sail membrane can be made of fiberglass with textile bonds between movable panels. It deforms under aerodynamic pressure without luffing. It can be mounted on a balestron rig able to rotate independently through 360° permitting the vessel to remain on course without manoeuvering and to control the forces according to the wind.





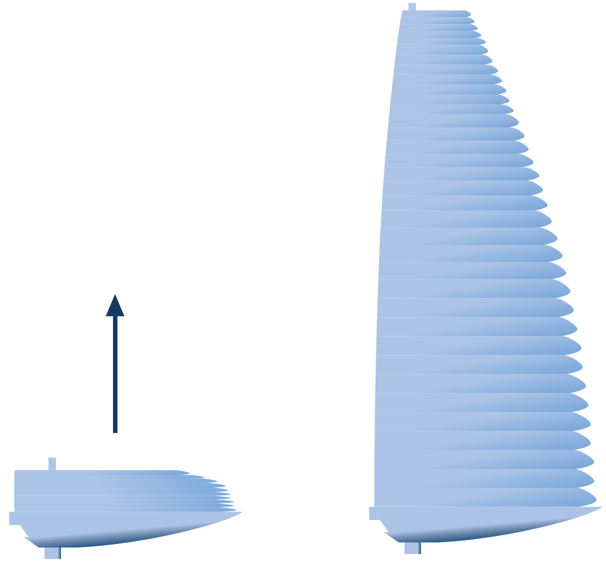
Integration on a ro-ro ship

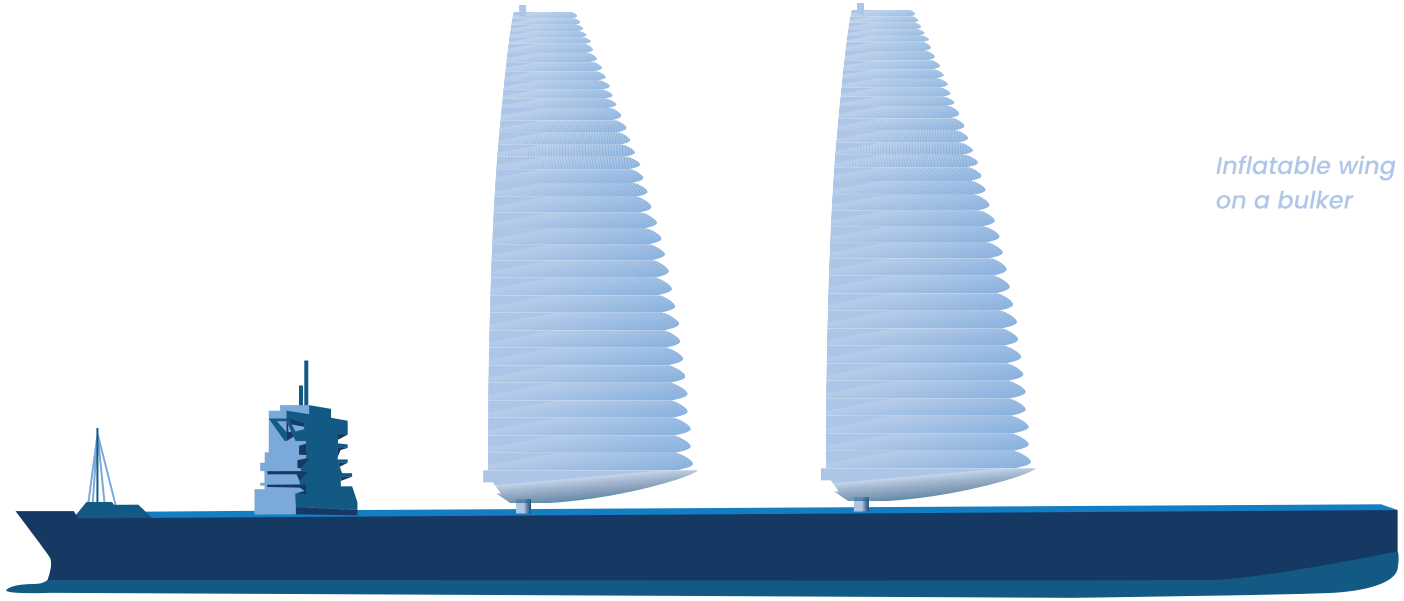


Integration on a cruise vessel

Thick sails

Symmetrical inflatable wings are made of textile, inflated and equipped with a telescopic mast that can be retracted.

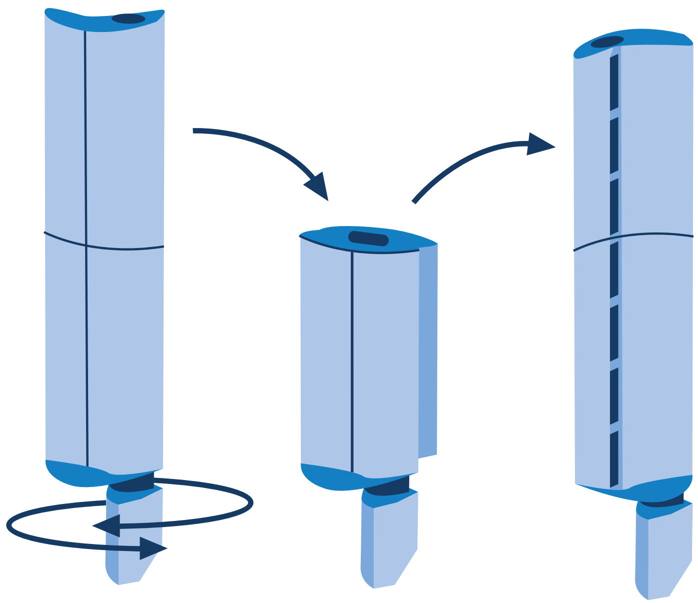


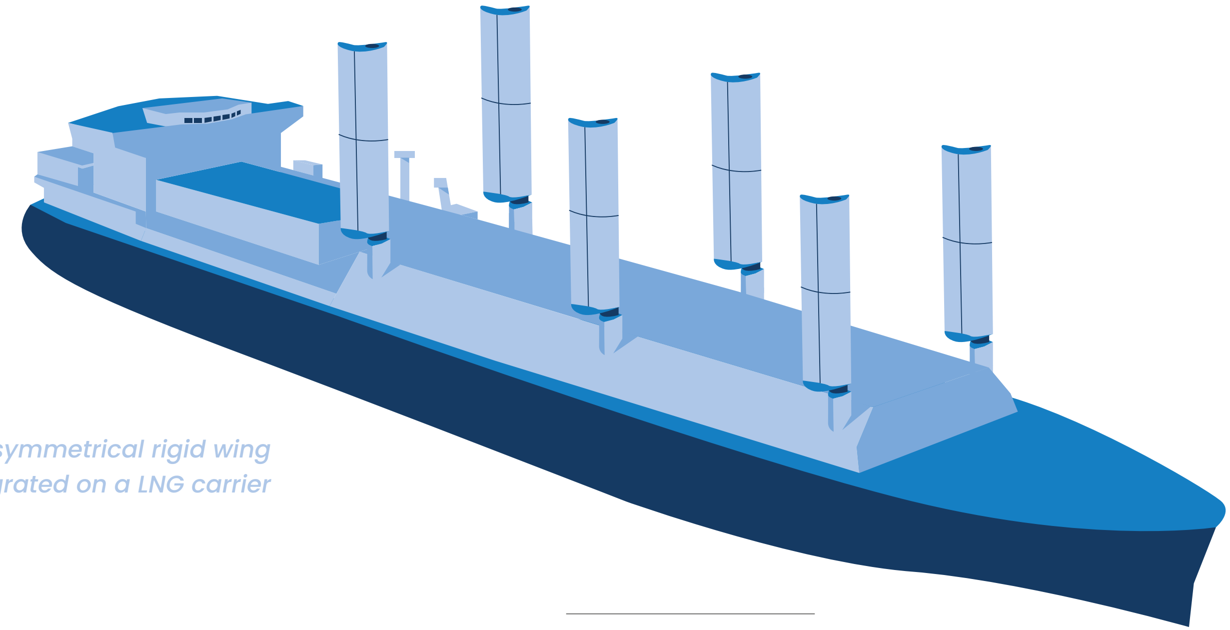


Inflatable wing integrated on a bulker

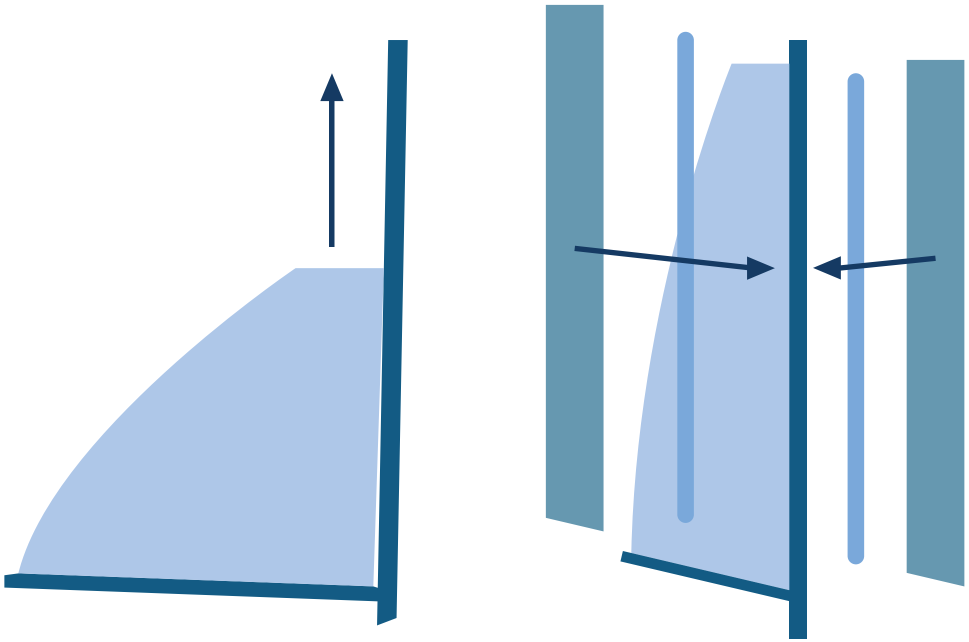
Thick sails

Asymmetrical rigid wings are made of composite material like wind turbine blades. They can be unfolded in either direction to invert and orient themselves in an optimal way.





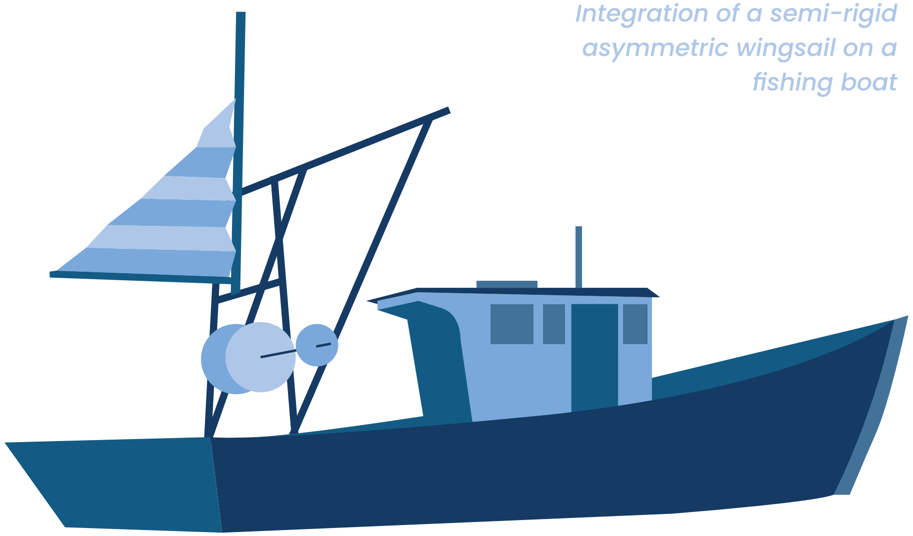
Asymmetrical rigid wing integrated on a LNG carrier



Thick sails

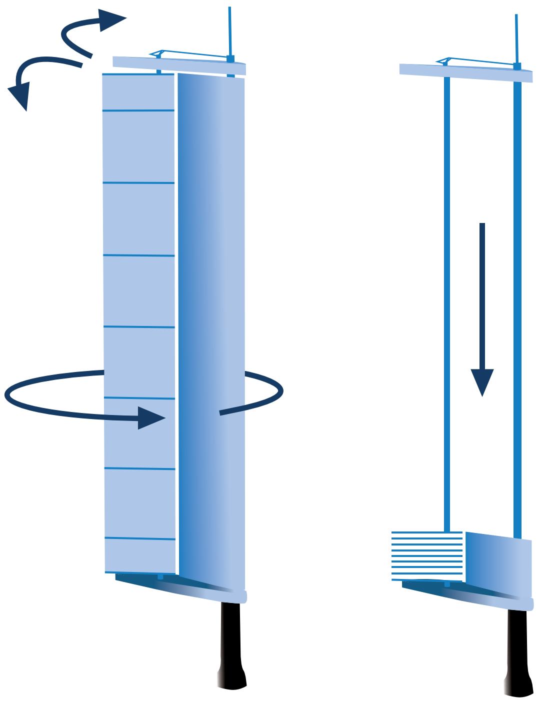
Semi-rigid asymmetric wings are composed of a classic sail equipped with flexible plates and an inflation system to avoid flapping.

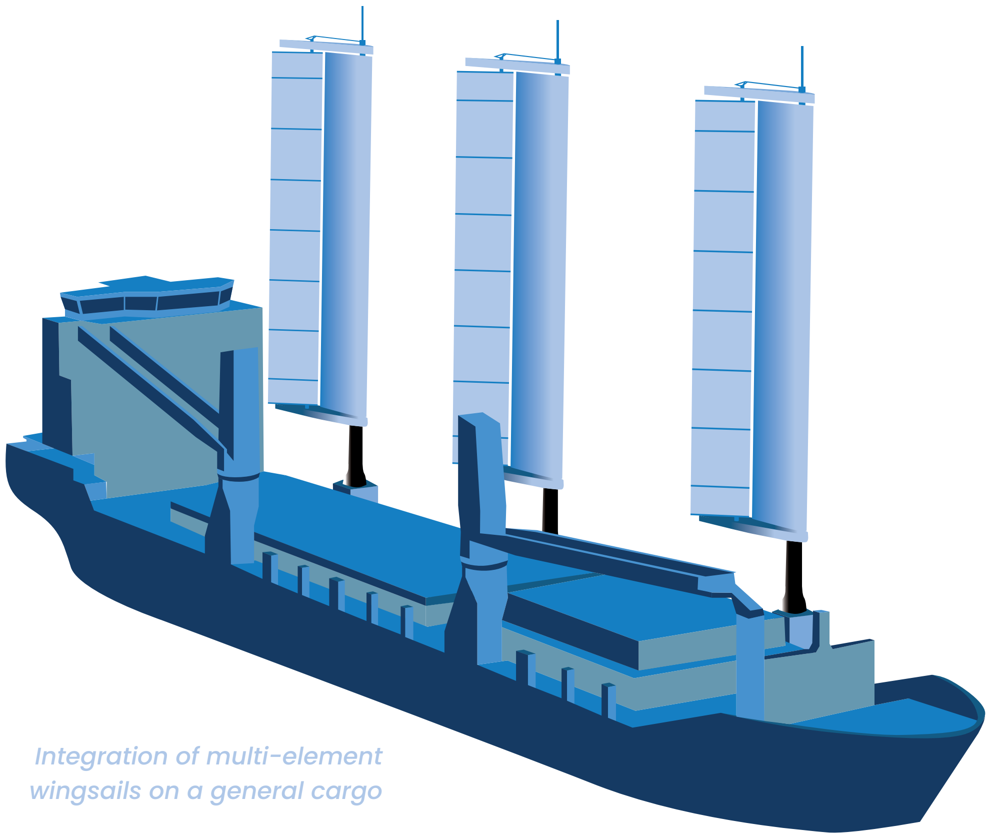
Integration of a semi-rigid asymmetric wingsail on a fishing boat



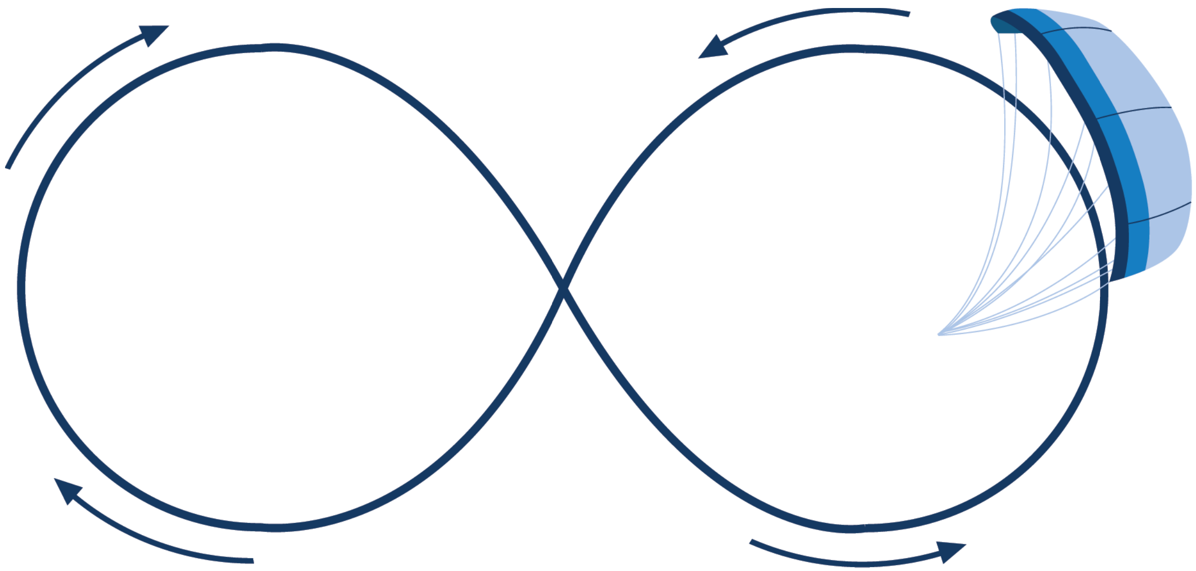
Thick sails

Multi-element wingsails have a semi-rigid composite structure and a textile cover. These sails are reefable and furlable.

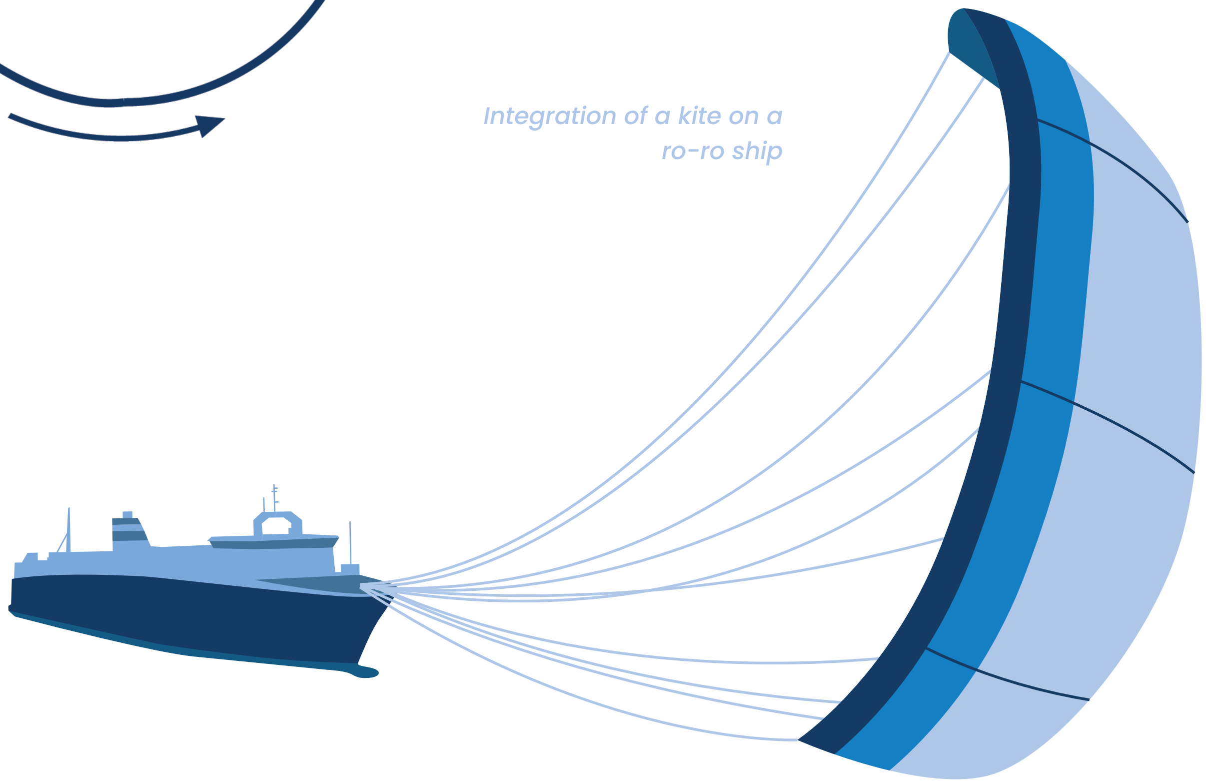




Integration of multi-element wingsails on a general cargo



Integration of a kite on a ro-ro ship



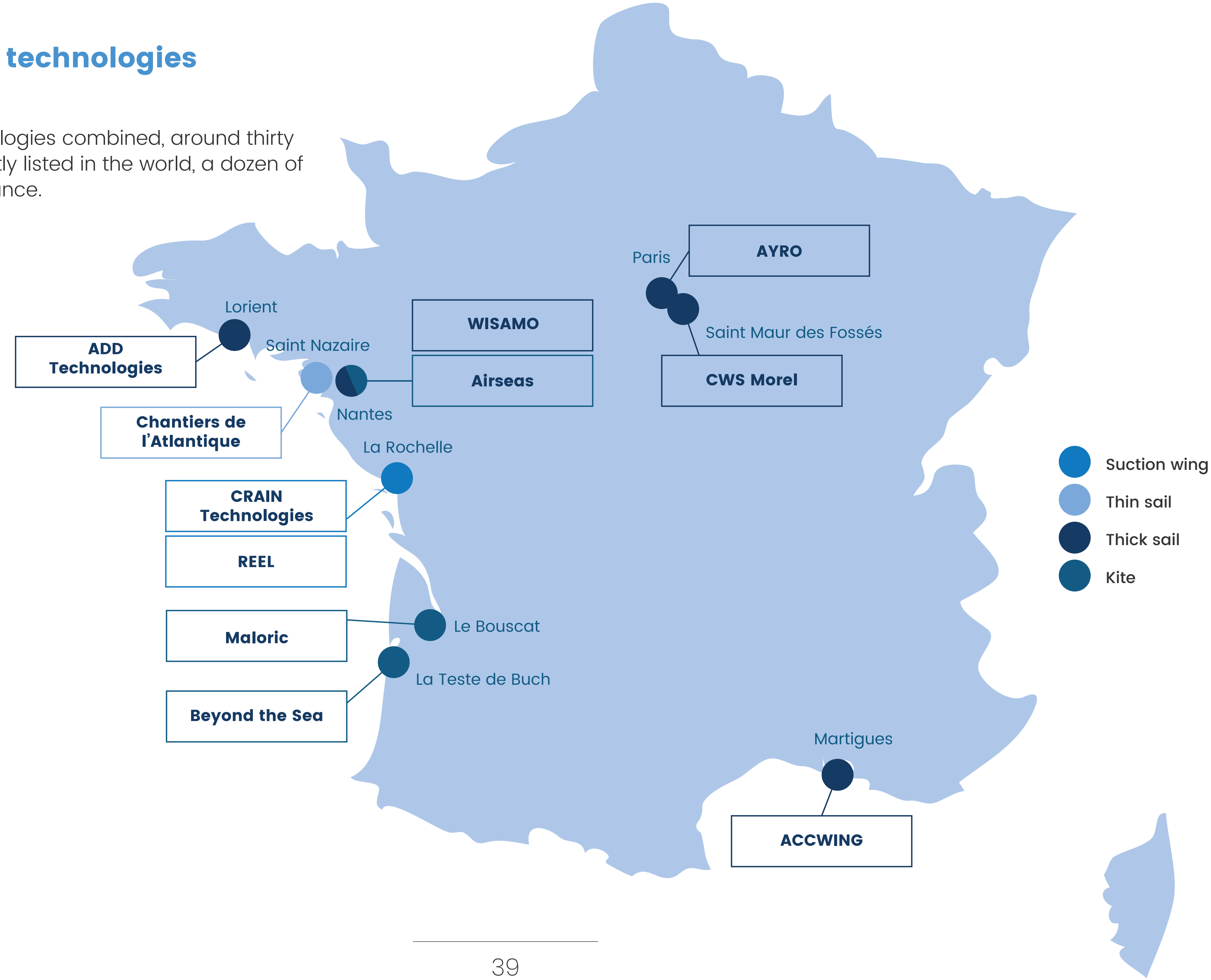
Kite

The kite provides lift and traction for the vessel via one or more lines.

The kite operates upwind in static flight (at the same speed as the vessel) and downwind in dynamic flight where it draws figure eights which increase its apparent wind and therefore its output per unit area.

Mature French technologies

Considering all technologies combined, around thirty developers are currently listed in the world, a dozen of which are based in France.



The level of maturity of the various technologies developed in France is mostly high, around 6 to 8, i.e. ranging from the prototype demonstration stage in a representative or operational environment to ready for wide-scale production.

Several onshore demonstrators are being tested. This is the case of the CRAIN suction wing and the Airseas kite in La Rochelle, as well as the panel sails of the Chantiers de l'Atlantique in Saint Nazaire. The tests are not all for full-scale models, but Airseas installed its 500 sq. metre prototype on the Ville de Bordeaux ro-ro vessel in December 2021, while Chantiers de l'Atlantique doubled the size of the rig to more than 80 metres high with 1200 sq. metres of sails (full-scale) at the start of 2022.

Other systems are being tested at sea, such as AYRO's Oceanwings® onboard *Energy Observer;* the new *Canopée* ship currently under construction is to be equipped with the wings. A demonstrator of ADD Technologies' wingsail has been fitted to a fishing vessel and the system was also used to successfully complete an Atlantic crossing in the 2021 Mini-Transat race. WISAMO's inflatable wingsail is sailing on Michel Desjoyaux's* boat, while Chantiers de l'Atlantique tested their panel sail on Jean Le Cam's* 60 footer and then for a year on the *Le Ponant* cruise ship of the company of the same name.

AYRO and Airseas have also started building their production facilities in Caen and in the Nantes area.

* Leading French offshore racing sailors

Applicable to most shipping segments

The various current wind propulsion technologies are adapted to the needs of most segments of maritime transport. Some provide propulsion with closed wind angles, compatible with the relatively high speed sought by container ships, while others will operate with the strong and stable winds of the seas of Northern Europe, and others will be selected for their versatility.

These technologies are already fitted to ships of various sizes and types.

Eleven large ships (> 5000 GT) have been fitted with rotors, including a bulk carrier, tanker, cargo ship, ro-ro, and a ferry, mainly in the North and Baltic Sea, but also on trans-Pacific routes, in the Caribbean and on the Europe-Asia route. Four wing sails systems and a kite are now installed, and six existing ships have been fitted with suction wings, including cargos, passenger ships and a fishing vessel, sailing in the North Sea, the Baltic Sea and the English Channel, and in the Atlantic, the Balearic Islands and the Pacific.

New installations are planned which will further broaden the range of applications, to include vehicle transportation, cruise ships, and also small ships for secondary services along the coasts of mainland or overseas France. Concepts have also been drawn up for container transport. Existing container ships have a particularly occupied deck, leaving little scope for on-deck wind propulsion, but kites could be accommodated. However, new container ship concepts integrating on-deck systems have received approval in principle from one classification society (see note: [20]).

Wind, an extraordinary source of energy for maritime transport

Wind is a safe and available source of energy; routing optimizes its use and makes transport more reliable.

Free energy

Wind energy is used directly on the spot without competing with other energy needs such as those onshore.

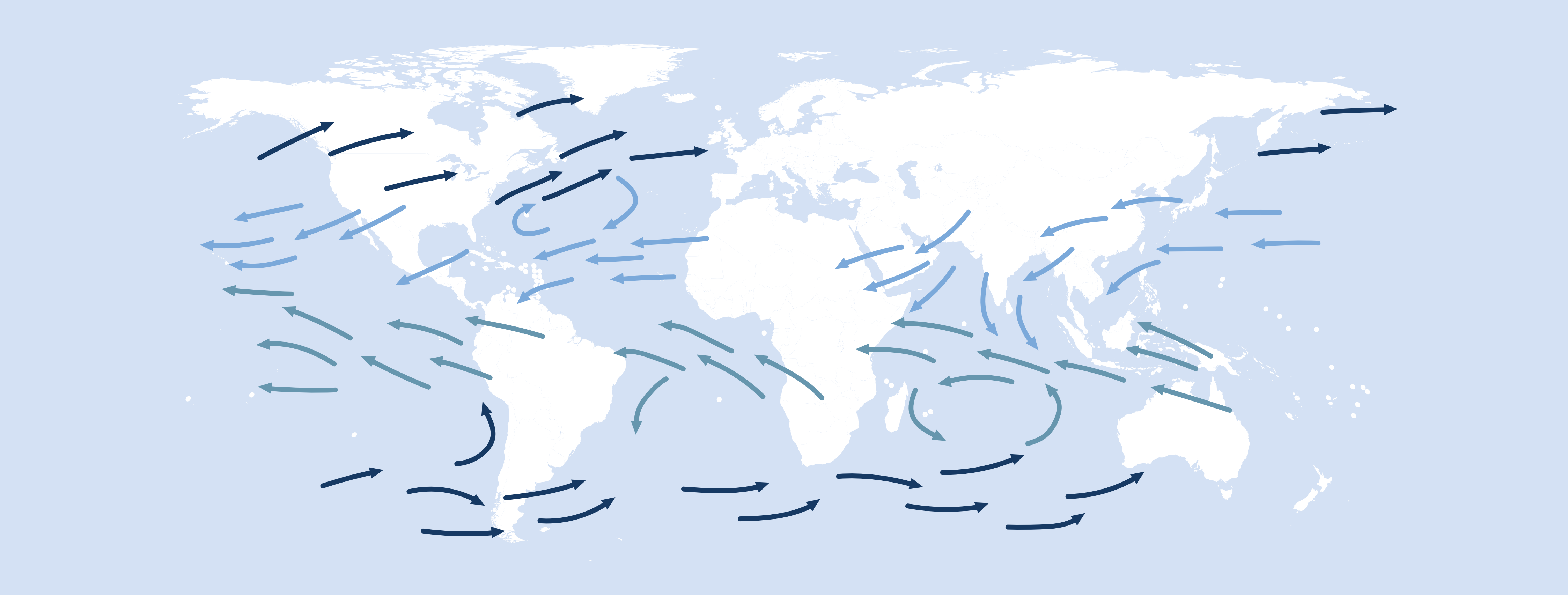
Wind energy is free, whereas the levels of financial investment linked to the production of new fuels are extremely high. It is found at sea and requires no transformation, transport, or storage on land. It requires no bunkering and can even produce energy for other uses on board, in addition to propulsion, thanks to hydro-generators for example.

Abundant availability

Wind energy is available across the globe and major shipping routes, including in countries and islands with less access to current (and future) fuels. It is even one of the main parameters of atmospheric activity on the globe [21] .

The main flows are called the trade winds (or easterlies), which are the permanent east-to-west prevailing winds in the tropics. They blow mainly from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere. The winds located further north or south of the trade winds are the westerlies, which blow mainly from the southwest in the northern hemisphere and from the northwest in the southern hemisphere. They are stronger and more variable, especially in the northern hemisphere, than the trade winds.

Winds are generally weaker at latitudes close to the equator (intertropical convergence zone or doldrums), which limits the power generated by wind propulsion systems in these places where the weather is unstable.



Westerlies

Trade winds (Northern Hemisphere)

Trade winds (Southern Hemisphere)

Prevailing winds on earth
Source : Wikipedia

Coastal navigation is more dependent on local conditions, as journeys are shorter and the coastline can make the possibilities of route adjustments limited. However, the use of wind propulsion remains valid most of the time – the thermal breezes that occur in the summer period, for example, are largely capable of propelling ships when the operating speed is suitable.

The wind in the Mediterranean, which is a closed sea, is more irregular. Conversely, in the Caribbean or Polynesia, the winds are relatively constant.

Predictability

The major weather systems across the globe are well known and make it possible to anticipate maritime routes with advantageous wind conditions. In addition, the predictability of wind conditions is increasingly understood across the board. It is therefore possible today to have access to reliable weather forecasts with a 7- to 10-day range as well as to historical weather data for the last 20 years.

Forecasting capabilities are constantly increasing thanks to rises in computing power. Météo France, for example, changes its engine every four years to improve the quality and reliability of forecasts in terms of finesse and depth, which adds a day to the forecasting range every 10 years.

More specifically, there are different scales and different types of meteorological models: deterministic for 5-day forecasts and less, and probabilistic for those of up to 15 days (see note: [22]). Long-term forecasts (>15 days) integrate ocean-atmosphere interactions, couple models by decade and compare anomalies with a norm.

Thanks to the European Copernicus Marine Environment Services programme, which provides the general public with particularly fine and representative historical meteorological data (these are forecasts which have been readjusted with observations), it is possible to check wind data for anywhere on the globe. Ship-level wind forces are also understood. Indeed, wind propulsion systems are located on the deck of ships, which can already be 20 or 30 metres above sea level, or even at 100 to 300 metres altitude for kite systems, and we know that wind speed increases with height above ground level, between zero and 500 metres.

This is why the basic data used for the wind is measured at an altitude of 10 metres. From readings taken on a global network of measurement points, digital methods model the wind from the surface of the Earth to the last layers of the atmosphere, at 15 kilometres altitude. These models are validated by balloon releases twice a day around the world (see note:[23]), and cross-checked by satellite measurements, also taken twice daily. Moreover, the mean profile for wind speed increase from zero to 100 metres has been widely measured by the offshore and wind farm industries, and from 100 to 500 metres, numerical modelling results have been validated by Lidar measurements.

Climate change will not induce any major disruption of major atmospheric circulation systems for the next 50 years. Although global warming is causing local meteorological changes (El Niño becomes La Niña), the major known atmospheric circulation systems in place today are unaffected by it. This means that there will be no major wind drop or disturbance in these systems in the coming 50 years. The established seasonal patterns also remain applicable. What we are seeing today is an increase in strength rather than in frequency of cyclonic-type phenomena. The warming of the oceans slightly changes the trajectories of these cyclones and keeps cyclonic dynamics in place for longer. Thus, the cyclones that are born off the coast of Africa, cross the Atlantic thanks to the trade winds, gain strength in the Caribbean and travel further and further north along the American coast, exceeding the hitherto established limit of southern New Jersey.

Here again, it is possible, thanks to the historical meteorological data available, to see the changes of the last few years and trends.

Optimization by routing

Global wind distribution is of interest when it comes to transoceanic expeditions or journeys with some sailing on the high seas. For such navigation, weather routing can significantly compensate for an absence or lack of wind, and help to avoid storms.

The quality of current routing tools makes shipping more reliable

Weather routing is an optimization exercise that makes it possible to find the best route for a specific vessel and for a particular voyage, taking into account meteorological and oceanographic forecasts, currents and operational constraints.

Routing was already widely used by commercial sailors, who used nautical publications to aid sailing, but it is through offshore racing that techniques and technology really developed. Although these solutions were transferred from offshore racing to shipping, the low dependence of merchant ships on wind conditions, and the need for professional mariners to be focused more on safety than on performance mean that they did not take off. Traditionally, these systems optimized a single aspect at a time – either journey time or the ship's consumption. However, in order to minimize consumption, it is essential to optimize both the ship's route and its engine power along the voyage, which complicates the calculation and renders some of the old approaches obsolete.

The work carried out in recent years on weather routing technology now allows users to carry out this type of route optimization. The goal is always to ensure that operators' commercial commitments are met while reducing fuel consumption as much as possible by making the most of installed wind propulsion systems.

Used at the design stage on historical weather data, routing algorithms make it possible to estimate the fuel reduction achievable through the installation of wind propulsion systems on a given route and thus establish the business model and return on investment.

Used in operational mode during navigation, weather routing makes it possible to anticipate bad seas or adverse winds for non-retractable systems, but above all to anticipate favourable weather conditions for the use of wind propulsion systems.

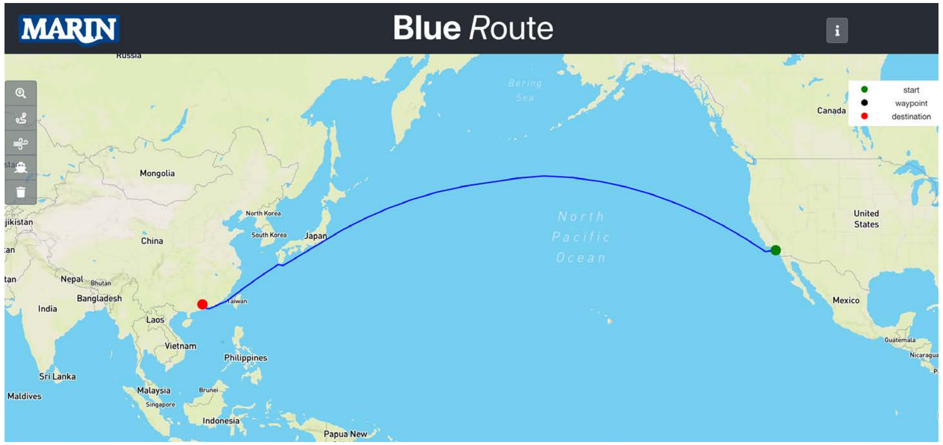
Several tools are now available to shipowners and operators

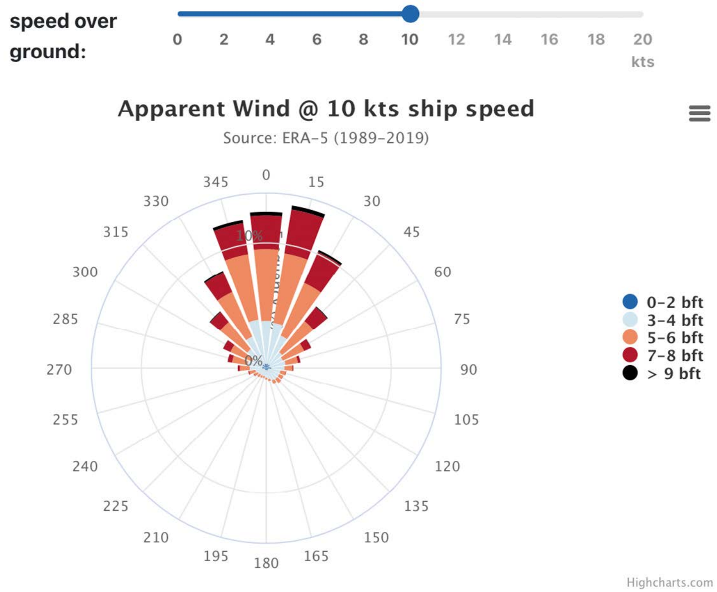
These tools allow either to check wind data for a given route, or to simulate the potential gain of installing a wind propulsion system on the ship.

For example, the Blueroute system (source:[24]) from the MARIN institute makes it possible to test a route with a type of ship and to understand the winds that will be experienced according to its speed, on the great circle route (shortest course).

The system then estimates the CO_2 emissions that will be emitted with the ship loaded or on ballast, and with or without the use of wind propulsion.

In the example below (excerpt from the Blue Route system developed by Marin), a test is performed on a great circle route between Los Angeles and Guangzhou. The vessel in question is a New Castle Max type bulk carrier (named after the Australian coal-exporting port), which is 50 metres wide and 300 metres long. It is tested as being equipped with four rotor sails.





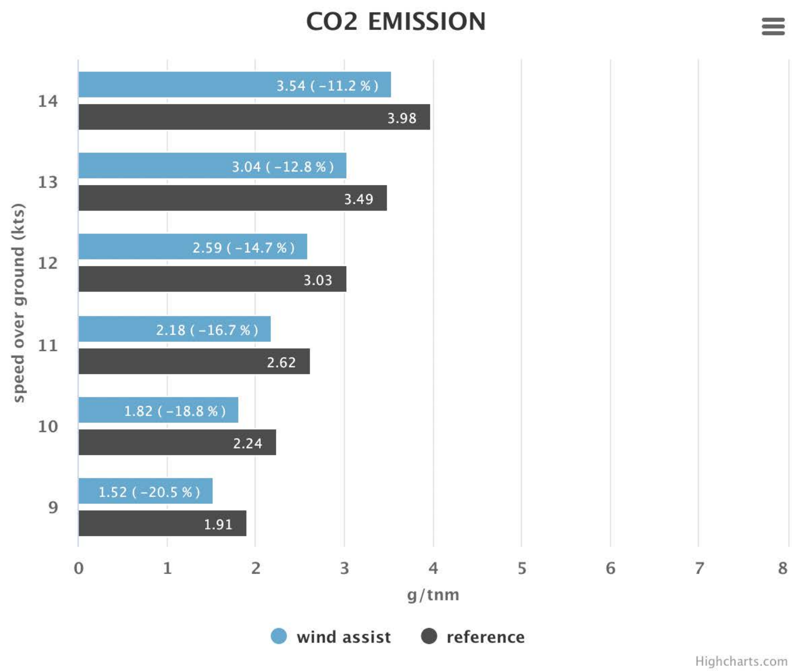
Average wind conditions
Source : BlueRoute

On this route, the ship will mainly experience apparent winds of force 5 to 6 (Beaufort scale), within angles of 45°, for a navigation speed of 10 knots.

Thanks to the wind, it should save 11.7% to 22% in CO_2 emissions depending on its sailing speed when loaded.

New Castle Max Bulk Carrier - Ballast

Configuration 4 Flettners



CO2 savings generated
Source : BlueRoute

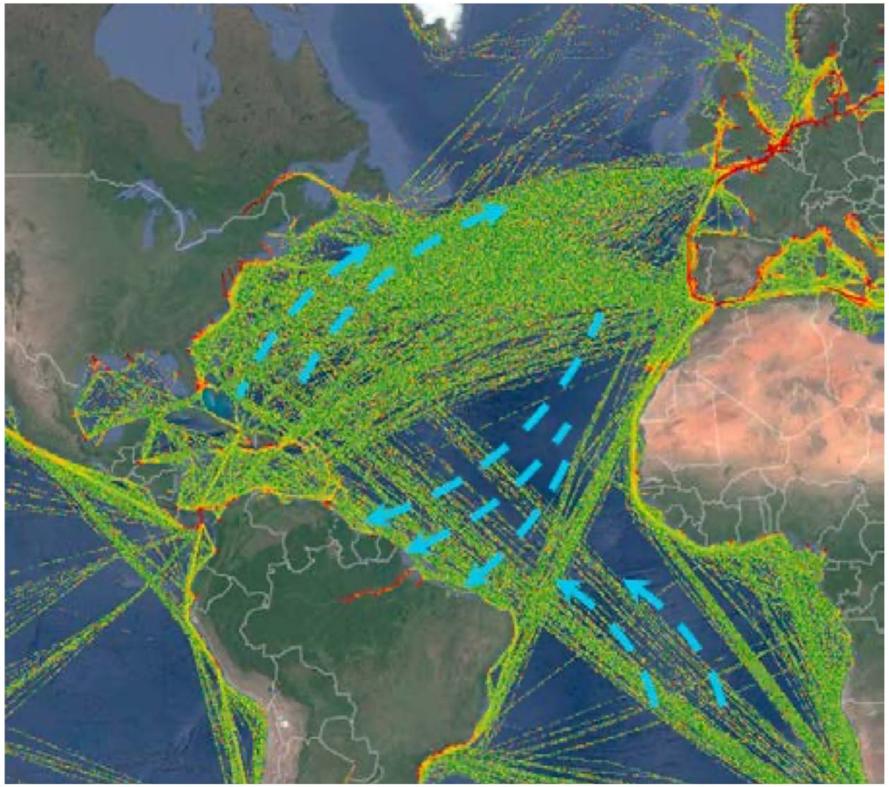
The Satori system (source:[25]) from D-ICE Engineering allows you to select different types of ships, then integrates the effect of waves, currents and wind, over multiple trips, in order to estimate the proportion of propulsive power generated by the wind, and thus estimate the fuel economies associated with the combined use of routing and sail propulsion. Several design firms such as CRAIN Technologies are also offering numerical and experimental methods.

Some routes will be of more interest than others for wind propulsion

As pointed out by the classification society DNV in a 2019 study (source: [26]), the availability of wind as an energy source is unlimited, but it will be all the more interesting if the best wind conditions can be combined (i.e. wind of constant force and direction), with a maritime route that allows some freedom of course.

For example, transatlantic or transpacific routes are highly interesting because ships can decide to optimize their route by passing further north or south. On a Europe-Asia route, a ship goes around Europe, through the Mediterranean and the Suez Canal, around India, and into the Strait of Malacca. These are relatively short stretches and leave little leeway for deviation, unless you decide to go via South Africa.

The illustration below shows the intensity of transatlantic journeys coupled with the trade winds. The opportunities for wind propulsion are significant.



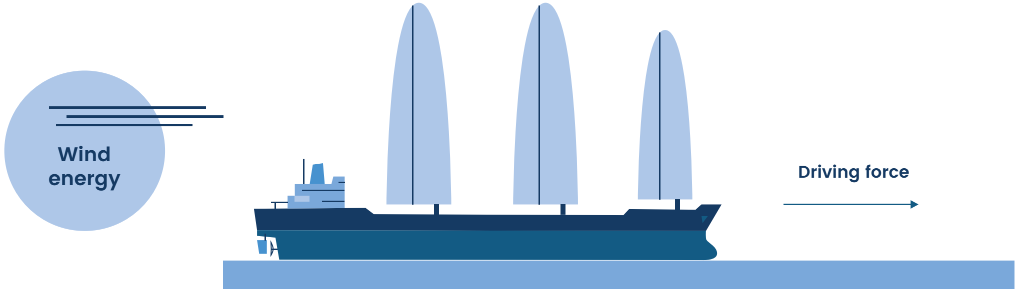
Transatlantic sea routes and trade winds
Source : DNV GL

A solid answer to the urgent need for decarbonisation

Easy-to-use systems that lower vessel energy requirements

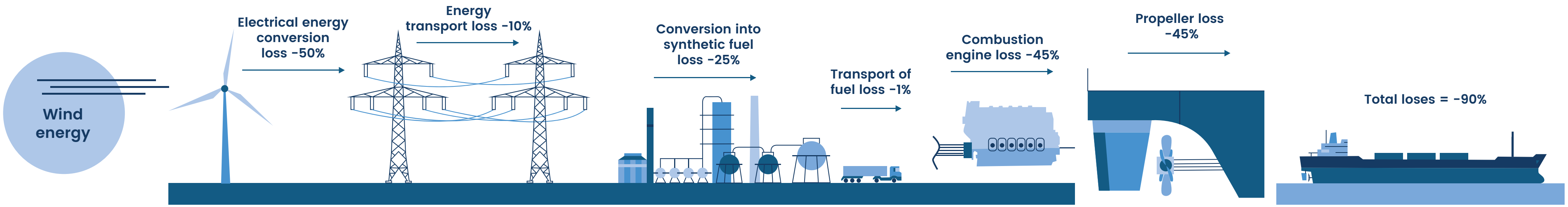
The technologies developed convert wind energy, fully on the spot, into propulsive energy without loss of intermediate efficiency. This clean energy makes it possible to avoid all polluting emissions from this part of propulsion, and therefore limit overall polluting emissions linked to the propulsion of the ship.

Wind energy does not need to be stored on board. The propulsion system, however, takes up space on deck, which will vary depending on the type of technology chosen.



Use of wind as the primary energy to propel the ship

Using wind as a primary or secondary energy
Source : Herbert Blüemel, 2019



Theoretical diagram of the production of a synthetic fuel from wind energy to power a ship

The use of wind energy is silent, releases no pollutants and does not add any particular major risk, such as risk of explosion or fire.

While the wind is widely available and predictable, it is also variable, as we will see later. This is why, depending on the targeted navigation speed and the route envisaged, it can be used as the main source of propulsion or as a supplement – with the hybridization of propulsion systems.

One of the great assets of most of these systems is the possibility to install and uninstall them without major structural changes to the ship's hull, and without a long period of immobilization, or even without dry docking. This means that a large share of existing ships can be quickly retrofitted with them.

Substantial efficiency gains

Wind-assisted propulsion is one of the few technologies potentially offering double-digit fuel savings today.

The levels of decarbonisation envisaged by the technologies currently being developed range from 5% to 20% for retrofitted ships. This represents a substantial improvement that it is crucially needed today on the existing fleet to achieve decarbonisation requirements.

The level of decarbonisation envisaged in the case of new ship constructions is 50% and can even exceed 80% where wind is the main source of propulsion on a favourable line for medium-sized ships carrying low-density cargoes.

Carbon footprint of technologies

Even technologies that use wind energy have a carbon footprint, which needs to be assessed. However, a first study published as part of the Wallenius project (see note:[27]), shows that 99% of ship emissions are linked to their running. Even if the installation of a wind propulsion system means a currently higher initial investment due to the additional cost of prototypes, as well as greater emissions during the construction and dismantling phases (because an additional system is installed on the ship), the reduction in fuel consumption allows financial and environmental gains that position wind propulsion as an excellent solution.

Propulsive power and ship handling

Significant power

The propulsive power provided by the wind propulsion system depends on:

- true wind speed
- the speed of the ship
- the angle the wind makes with the ship
- the surface area of the propulsion system exposed to the wind
- the technology used.

The propulsive power reaches its maximum at certain ranges of apparent wind angles, which are determined by the technology concerned. Generally, this maximum is encountered for apparent winds (wind experienced by the ship in motion) between 50° and 100° in relation to the axis of the ship.

It should be emphasized that propulsion power also depends on the surface area of the propulsion system exposed to the wind, which means that to have strong propelling force, you must be able to install a system of significant size.

Therefore, for each ship, there is a compromise to be found, which must take into account:

- the intended navigation area and the type of navigation (oceanic, coastal, etc.),
- the size of the vessel and the intended commercial speed,
- the space available for the installation of a wind propulsion system,
- the optimization of the vessel in terms of shape of hull and keel.

This search for a compromise often requires several iterations, and makes it possible to establish the elements needed to decide on one wind propulsion system over another, and to determine the proportion of wind power in the energy mix of the ship.

To illustrate the power of a system with conventional soft sails: a medium-sized cargo ship (11,000 tonnes displacement) of between 130 metres and 140 metres in length requires approximately 1,100 kW of effective hull power to be propelled at a speed of 11 knots. If it is equipped with a rig of 4,000 sq. metres of sails, the rig will deliver an annual average effective propulsive power of:

- 850 kW on a transatlantic route, or approximately 77% of the propulsion requirement
- 550 kW on a major European cabotage route, or about 50% of the propulsion requirement.

The power developed through wind propulsion can thus be sufficient to propel cargo ships the majority of the time.

Simple handling, optimized with crew training

Any mariner working on board a merchant ship must have the required qualifications and certificates. Licences and certificates are subject to an international standard (see note: [28]). The associated code establishes a detailed set of skills required to perform each of the functions on board (captain, bridge watch supervisor, qualified deck sailor, etc.). There is no obligation in terms of training seafarers for the handling of vessels equipped with wind-assisted propulsion systems, and such vessels are already in operation with no reports of accidents, due to the sufficient expertise of crews.

Today's technologies offer automated adjustment systems, with associated procedures, which have been assessed for risk. However, we are in experimental phase for new technologies, and handling will be improved if fleet managers and sailors, in particular bridge crew, take full ownership of the operation of the rig, in order to effectively manage the balance between speed and course, depending on the routing options offered to them. Finally, the issue of making the ship safe in the event of an emergency is essential and insurance companies require proof of sailors' training in this area.

This is why the Wind Ship association, the École Nationale Supérieure Maritime and the company D-ICE Engineering, are working on the development of a set of training requirements for the optimized handling of ships with wind propulsion systems (see note: [29]).

From 2023, a theoretical and practical continuous training module will be offered to operators and their sailors.

Topics will include weather, a revision of the physical principles of hydro and aerodynamics, and safety, for better and safer navigation.

This training in the handling of wind-powered ships is also an extraordinary opportunity for the mariners' world, which is struggling to attract young people. The feedback from sailors on ships already equipped with such technologies is extremely positive. The manager of Boomsma Shipping noted the interest of his crew when equipping his vessel *Frisian Sea* with suction wings from Econowind, as well as the crew's rapid familiarization with them.

Experiences with wind propulsion

Twenty-four large cargo vessels using wind by the end of 2022

Oil tankers, ro-ro vessels, bulk carriers, ferries and cargo ships have been equipped through retrofit operations since 2018; Enercon' s E-Ship 1 is an exception since it has been equipped for wind propulsion since 2010. The technologies implemented are rotors, suction wings and thick sails (rigid wingsails). These large ships have a length of 80 to 340 metres. Half of them have a gross tonnage ranging from 4,000 to 10,000, and the other half from 64,000 to 325,000 (the Vale mining company has equipped an ore carrier), which represents a total of just over 1 billion tonnes deadweight. This capacity is expected to double by 2025.

Half of these ships cruise in the waters of the North Sea, the Baltic and the English Channel, but some also operate in the Caribbean, the Pacific, the Indian Ocean, and the South Atlantic, as far as Indonesia and the Sea of China (see next page).

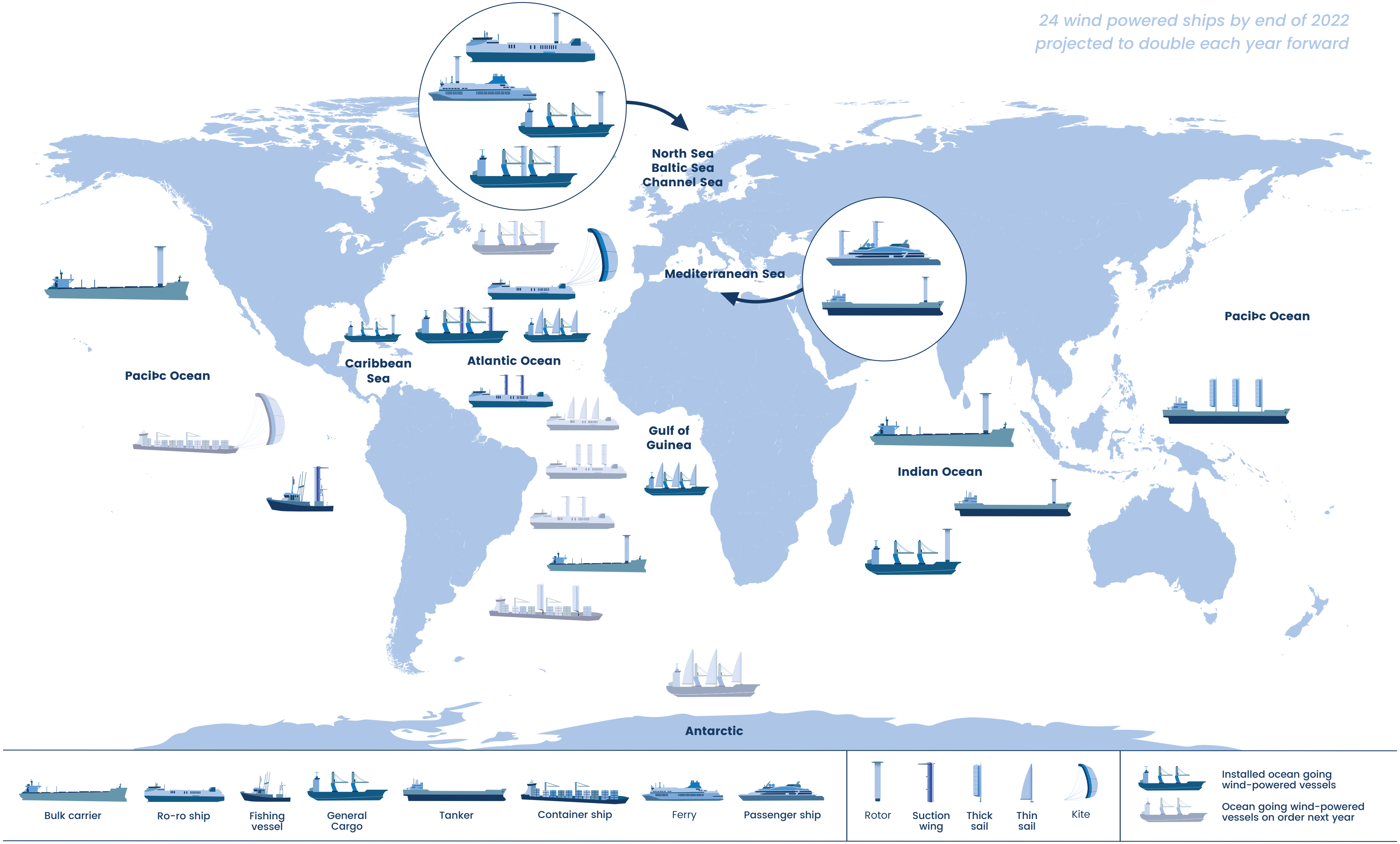
About twenty other smaller vessels are also equipped with wind propulsion systems, and the fishing sector is also beginning to take an interest in them.

Fishing vessels are being equipped with new systems, such as in Quiberon (France), where a test is underway on Oceania, a ten-metre gillnetter – a thick sail is used to stabilize the vessel and improve its seakeeping both while in motion and fishing, thus generating fuel savings – or the installation, in June 2021, of a thick, rigid wingsail system of 12 metres high (approved by Bureau Veritas) on Balueiro Segundo, a 41-metre and 593-tonne fishing vessel. Kite equipment is also being developed specifically for fishing uses.

First validations of new technologies

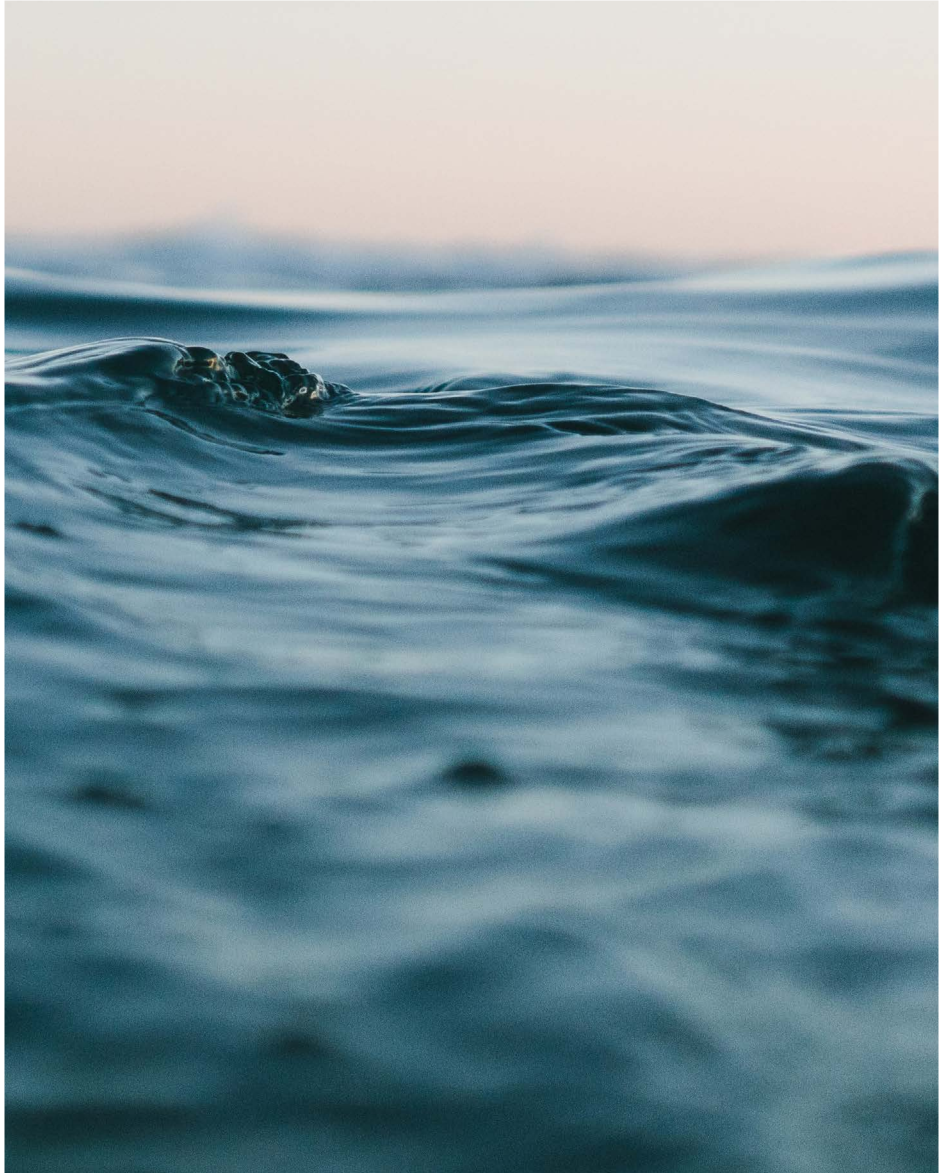
Late 2022/early 2023 will see the launch of newly built ships designed specifically for wind propulsion and therefore optimized for this purpose. But it is already interesting to look at testimonies from the first navigations using a rotor. E-Ship 1 has travelled more than 1.1 million nautical miles since entering service, equipped with auxiliary wind propulsion. It transports components all over the world. Wind propulsion allows it to save 20% of fuel a year on average, or 920 tonnes of fuel a year (for an average speed of 13 knots). The *Maersk Pelican*, which was fitted with wind propulsion in 2018, acted as a performance test platform for a year and showed a saving of 8.2% in fuel consumption for the year, equivalent to 1400 t of CO_2. These performances have been validated by the independent company Lloyd's Register.

24 wind powered ships by end of 2022
projected to double each year forward



These first results on prototypes are encouraging for future projects developed in France, which target different savings depending on the case (retrofit, new ship, main or auxiliary propulsion) and higher performances than these first trials, thanks to different technologies.

New concepts of wind propelled ships are very regularly being proposed in all shipping segments, such as the bulk carrier of the CHEK project supported by the European Union, the container ship *Meltem* and the tanker equipped with the Wind Challenger; approvals in principle are regularly granted for them by classification societies, such as for the 2500 TEU container ship *Trade Wings* 2500 equipped with thick sails.



03 The Revival of Wind Propulsion in Maritime Transport

Operational aspects

WAVE

The use of wind makes it possible to envisage an ambitious level of decarbonisation, but the operational strategy must be all-encompassing – this is what the WAVE approach seeks to achieve.
WAVE is the acronym that stands for all the measures that can be combined to minimize the carbon footprint of a sea voyage, while seeking the best adaptation strategy for the operational profile of the vessel* concerned.

- **Wind :** use of wind propulsion on the ship to avoid polluting emissions and reduce the energy needs of the ship
- **Activity :** optimization of operating conditions, through the use of routing, speed reduction, fleet and voyage management, crew training, etc.
- **Vessel :** improvement of the ship itself through an optimized design, good onboard energy management, reduction of engine power, use of windshields, air lubrication, etc.
- **Eco-carburants and eco-design :** use of alternative fuels from renewable energies and design of ships with a low carbon footprint.

Most of these measures work best when combined. Hence, reducing the speed of navigation makes it possible to increase the share of wind propulsion and also limits underwater noise and the risk of collisions with sea animals. For example, installing two wind propulsion systems and a windshield may be more efficient than four wind propulsion systems. It is always about searching for the best balance in terms of optimization. Reducing speed increases the time spent at sea. For some cargoes, this is not a problem, whereas for refrigerated cargoes, this will increase the energy bill. It is therefore necessary to compare the results of such actions with the emissions savings achieved by slowing down the ship.

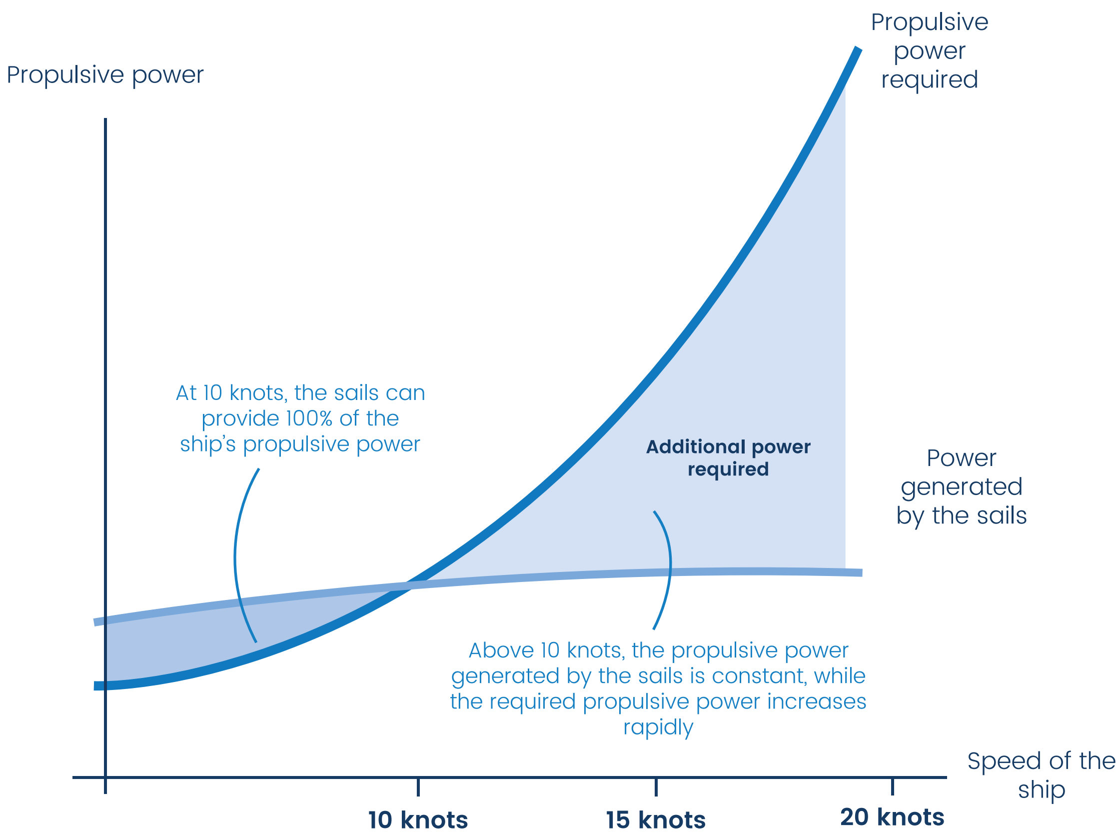
* A ship's operational profile reflects the different stages of a sea voyage (loaded voyage, voyage on ballast, time at sea, time in port), as well as navigational speed and main and auxiliary engine usage.

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.

Speed and propulsive power generated by the wind



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.

Thus, for certain technologies and certain routes, wind can provide the main propulsion at a moderate speed. By way of illustration, the Neoline project, which will have a 4000 sq. metre rig of soft sails, plans for a commercial speed of 11 knots, allowing the force of the wind to be used for nearly 80% of the propulsive energy needs (on average annually).

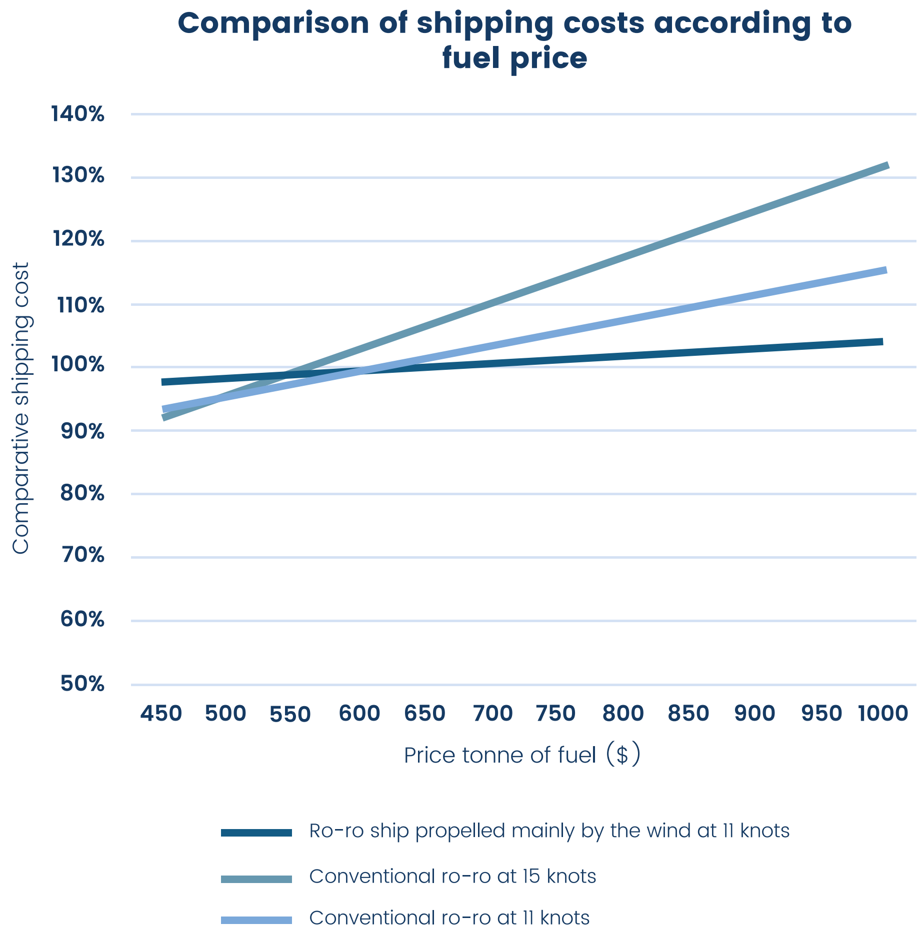
For other technologies and projects, maintaining a certain speed through additional engine power switches the system to auxiliary propulsion, but makes it possible to sail very close to the wind, and to make the most of the installed technology. An example of this is the Canopée project. This ship being built to transport the components of the ArianeGroup's Ariane 6 launcher will be equipped with four Oceanwings developed by the company AYRO.

Whatever the project, multiple simulations are carried out based on the routes that will be taken, in order to determine the optimal speed to fuel economy ratio. This serves as the basis for the ship's operation. If the wind decreases during a journey, the engine can be used to compensate if necessary in order to keep to the contractual transit time.

Much lower running costs and more stable shipping costs

A fleet propelled by the wind will be the source of substantial savings. Indeed, using wind energy enhances the autonomy and energy independence of the ship in terms of fuels, which will become high and volatile in cost and less available.

The graph hereafter shows a simulation carried out for a ro-ro ship in different configurations – the share of wind propulsion makes it possible to keep shipping costs stable.



It also reduces the bill for specific equipment (tanks, etc.) that will be needed to store new energies on board, as well as the associated insurance, particularly in the case of alternative fuels presenting specific risks.

Cargo safety

Goods transported using wind propulsion are subject to no higher a level of risk than when transported on a conventional ship. Vessel stability is checked and certified upstream by the classification society. Towing or propulsion using the wind even stabilizes the vessel and reduces rolling movements, limiting lateral accelerations and making navigation smoother for the crew and the load.

Integrating systems on board vessels

> *« The integration phase is the one that will transform the simple addition of a wind propulsion system into a true decarbonisation solution »*
>
> *C. Hypousteguy, Sofesid Engineering company*

A critical stage

Installing a new system on a ship amounts to integrating a new block of compliance with regard to classification societies' regulations, in order to obtain their approval, whether for a new ship or a retrofit. This integration involves various areas, such as structures, safety, power management, control command systems, motorization, etc.

It is this integration phase that determines the ultimate scope of wind propulsion installation on the ship. Thanks to this, the entire ship is reviewed and adapted so that the investment made in wind propulsion is not reduced by other unsuitable parameters. In particular, it is essential that the entire energy chain of the ship be reviewed and adapted in order to achieve the best possible energy efficiency in all operational situations.

Harnessing existing skills and organizing integration

There are companies on the market with the capabilities to carry out these integration phases. Some rely on the know-how they have developed in the integration of complex systems on ships for the oil sector, whose crane and lifting gear systems are similar to the masts used in wind propulsion.

This engineering phase can be carried out by the shipowner, the equipment manufacturer or the shipbuilder, or even by a charterer wishing to support his shipowners in selecting the best combination of solutions. It is the contractual organisation of responsibilities which defines this framework and which must be anticipated as much as possible.

Planning ahead to reduce costs

Initial experiences indicate that this integration phase is sometimes undertaken too late. To be truly effective, and to reduce the cost of the integration itself during construction, engineering must be deployed as early as possible. Considerable amounts can be saved during the construction phase thanks to the identification and resolution of critical points early on, keeping return-on-investment (ROI) within an acceptable level.

The shipowner can obtain a prior approval in principle from the classification societies. The investment committed for this work ensures that the project will meet the requirements of these companies. It also sets the bases for the concept, for example, the level of repetition required for the systems, the availability, the level of automation, etc.

The integration phase enables works to be planned and downtimes to be reduced. Experts now believe that the installation of retrofit wind propulsion systems can take place during scheduled stoppages every five years, without generating additional downtime. To achieve these goals, knowledge of the yard, its lifting apparatus, the number of parts to be installed, their weight, and so on, is essential. Although most equipment manufacturers are today still in the prototype phase, the definition and prefabrication of elements in advance, made possible by industrial-scale production, will allow fast integration.

Adopting an integrated approach

Integrating a wind propulsion system involves various areas of expertise, but does not require any new skills. The experience that the companies working on wind propulsion projects are gathering will lead to optimal organisations that will reduce the risk of the integration phase.

On new builds, the standardization of operations is feasible – this will not be the case with retrofits, which are too specific to each ship and vary according to the operational profile.

However, this integration requires a coordinated approach, and cannot be dealt with topic by topic without an all-round vision. All constraints must be examined together, and in an iterative manner, in order to find the best compromise between the possible evolutions of the vessel concerned. The addition of wind propulsion, which is a reliable and proven technology, requires thinking of the ship as a whole to make the most of the propulsion chain.

Choosing a technology

In order for a shipowner or a shipping operator to be able to choose the technology that seems most suitable to him for his operations, he must have tools that can predict the performance of the envisaged systems.

Existing performance prediction tools

Several companies are already capable of providing performance predictions by comparing different technologies. For example, the first versions of the performance prediction programme developed by D-ICE Engineering has made it possible to carry out comprehensive studies comparing the gains obtained by different systems on the same ship on several routes. A company like Syroco carries out comparison work on wind propulsion systems on part of CMA-CGM's shipping fleet.

However, there is still no completely successful model for predicting performance for all types of ships, all sea and wind conditions and all technologies. Every technology developer or ship designer thus develops his own performance prediction model based on numerical models known as Computational Fluid Dynamics, or CFD, and tests in a wind tunnel or in real conditions on instrumented prototypes to establish the Velocity Prediction Program (VPP) of the ship equipped with its wind propulsion system.

Standardization work is needed in order to identify good practices for estimating ship performance (taking into account the effects of lateral forces, yaw moments, interactions with the engine or between thrusters and the ship's superstructure, etc.) and harmonize them between players. Collaborative projects are already being developed to produce tools validated by the scientific community. A thesis is in progress at the

École Centrale de Nantes and a joint industrial project, called the WISP project, has been launched between several European partners.

Stronger monitoring of energy management on board

Operational performance, though, is not just a matter of technology choice. It is common to see that on a similar trip, the same ship equipped with a combustion engine can incur expenses or, on the contrary, save fuel to the tune of 10% due to wind conditions and the state of the sea and navigational decisions made by the captain and crew.

This variability could be reduced with the installation of tools for monitoring and managing energy on board, allowing the crew to better control energy consumption – as long as they have been trained and encouraged to play a role in this issue.

Current limits of comparison

Difficulties comparing technologies with one another

There is not yet a performance comparison database in which technologies can be compared under similar operating conditions. The results that are aggregated must therefore be used with great caution because the method used to estimate fuel savings can vary considerably.

It is therefore not possible to draw an immediate conclusion on the "best" wind propulsion technology, but the question to be answered is rather which technology is the most suitable for which type of vessel, for what type of route and what is its potential.

The results from 12 studies carried out between 2006 and 2019 on auxiliary wind propulsion systems were compiled as part of the European Interreg North Sea project, WASP (appendix 6). The tables included (source: [30]) list the savings made with different systems. Without a robust and shared methodology making it possible to formalize the most important parameters to be considered to estimate ship performance, and without repeating experiments under similar conditions, it is not possible to interpret these results for the purpose of comparing technologies.

Necessity to take into account the routes envisaged and the type of ship

In addition to the technical aspects, ship performance also depends on the geographical area concerned, the route taken, the direction in which the route is sailed and the season. The first reference studies are being prepared and some examples from these are reported below. These reference materials (listed in the bibliography) will grow as new wind propelled ships are launched, and will provide a decision-making aid for future shipowners.

Long-distance journeys show less variability in fuel economy than short-distance journeys and fuel savings are greater because wind speeds tend to be higher on open seas.

In the case of rotors, fuel savings are greatest on the west coast of Europe, the South China Sea, the Indian Ocean and the Arabian Sea, while they are lowest in the Mediterranean and off the west coast of Africa. Other studies also suggest that fuel savings vary significantly depending on the geographic areas considered.

Seasonal differences in fuel savings have been observed on the Argentina-UK shipping line where rotors work better in winter while a thick sail works better in summer. The wind speed is higher in winter in the northern hemisphere, allowing the rotors to provide greater fuel savings.

The direction of travel is also to be taken into account. For example, the prevailing westerly wind direction in the Atlantic Ocean resulted in significantly greater fuel savings on Baltimore to Wilhelmshaven trips (36%) than Wilhelmshaven to Baltimore trips (14%). In the case of the Neoline project, routing studies have also shown that during a westbound voyage, the vessel will sail at tight apparent wind angles (30° to 50°) whereas for an eastbound voyage, the range of apparent wind angles is wider, with two stronger occurrences between 30° and 60° and between 130° and 180°. The fuel savings generated will therefore be different.

Maintenance of wind propulsion systems

Robust and standardized parts

With some of the technologies, such as thick rigid sails or suction wings, the robustness of the equipment is one of the main focuses. A good third of the solutions currently developed use proven industrial material, the lifespan of which is equivalent to that of the ship (20 to 25 years). These products are already used in marine renewable energy infrastructure and are proven for use in aggressive and corrosive marine environments. The rigs fitted to ships are not equipped with any specific weather instrumentation. They have relatively few sensors and electronics, which reduces causes of failure.

Some wearing parts will need to be replaced (bearings, for example), which is no difficulty in particular due to the existence of these parts as standard in the industry, and can be done without immobilizing the vessel.

Textile elements with varying renewal needs depending on use

Other technologies, such as thick semi-rigid sails, use fabric envelopes or associated textile elements. It can be estimated that these envelopes or elements may need renewing after three to six years of use depending on the material used. Much effort is now focused on resistance to UV rays, which is one of the main factors of fatigue in textiles.

Finally, some of the technologies such as kites use a textile material whose need for renewal will be highly dependent on how much it is used. For intensive use, renewal is likely to be annual. Ships can be kept in operation while this equipment is changed.

Inspections

Equipment maintenance includes a regular periodic visual inspection (every six months) of the system's components, and the usual maintenance of the mechanical elements and possibly the paintwork. This maintenance can be carried out by the crew and is equivalent to that suggested for conventional industrial products (checking of bearings, lubrication of components, etc.).

Depending on the certification levels obtained by the ship, an annual inspection integrated with those usually carried out on any ship, is generally required by the guides published by classification societies on wind-propelled ships (ABS, BV, DNV, Class NK). This should assess the condition of the propulsion system structures to detect any deformation, excessive wear, corrosion, etc.

Periodic servicing

An in-depth service should be performed every five years, which is the frequency of regulatory ship overhauls, to check mechanical elements and change wearing parts according to the standards of the classification societies.

A general verification of automated systems may also be offered by the supplier to the shipowner via the provision of a dedicated mobile team. With the expansion of the market in major international maritime centres, local offerings for the maintenance of this equipment will develop and be incorporated into supplier agreements.

Preventive maintenance

Tools for the monitoring, assessment and analysis of equipment condition are being developed to allow preventive maintenance. This involves detecting faults in order to correct them before their criticality is high, triggering downgraded operating modes to preserve equipment and evaluating its remaining lifespan. These are important factors for reducing operational costs, maximizing performance and enhancing asset value.

Developments to be envisaged

Performance certification

One of the challenges for accelerating the adoption of wind propulsion technologies is the third-party certification of expected ship performance, to allow shipowners to make an informed choice and clarify the level of investment risk for financiers. Classification societies and maritime engineering firms are currently developing services to this end.

Several engineering firms are working on simulation-based performance evaluation using digital twins of ships, or multiphysics simulations.

Classification societies are then asked to validate the results of the system performance studies, whether carried out by technology developers or by specialist firms. The classification society will judge the value of these results by examining the quality of the method implemented.

There is no guide yet on the evaluation method for the performance of wind propulsion systems. Collaborative work to forge a shared doctrine would allow developers to make their studies more robust, and evaluators to make their process more reliable.

Consideration of wind propulsion in international regulations

The contributions of wind propulsion are today taken into account in calculating the indices for ship energy efficiency (EEDI, EEXI) and carbon intensity indicator (CII), and are also considered in the EU's future GHG intensity index. Wind propulsion is therefore promoted as a means of improving ship performance.

The MEPC.1/Circ.815 guidelines presented to IMO in 2013 specify how to take into account the effects of innovative technologies such as wind propulsion systems in EEDI. This is based on a wind probability matrix (appendix 7) as well as a technical guide defining the performance tests to obtain the wind propulsion system propulsive forces matrix.

New recommendations have been adopted at IMO in order to provide the most robust calculation methods possible for the best consideration of the contributions of wind propulsion in the indices. In particular, this involves wind tunnel tests when relevant, while avoiding extremely costly recommendations such as the performance of systematic tests on hulls equipped with thrusters. More precise definitions of the calculation methods to be used by the classification societies are also proposed in order to categorize systems. These recommendations will be approved by IMO during the next environmental protection committees. They will in principle also be applicable to the EEXI.

"*In a context of increasingly strict regulations on greenhouse gas emissions and expectations with regard to the urgency of the climate crisis, wind propulsion is a solution with great potential that can contribute to the long-term decarbonisation of the maritime industry. We know that wind energy, although not always available, can make a significant contribution to the propulsion and design of clean ships. Wind propulsion systems can play an important auxiliary role by providing substantial propulsion energy and in some cases wind could be used for primary propulsion. Many options are possible, some are in their infancy, but the wait-and-see approach is untenable. The industry's most important asset will be information and collaboration, which will support both innovation and decision-making, and this is where classification societies like Bureau Veritas can play a key role. Our expertise and knowledge in developing comprehensive technical guidelines and rules for ships, combined with our close collaboration with manufacturers, has enabled us to publish specific rules for sail propulsion systems and offer WPS1 and WP2 class notations for vessels fitted with sail propulsion systems. These rules enable safe innovation, guiding shipowners, shipyards and technology providers. Moreover, our neutral position allows us to provide ideas and information that support the key decisions faced by shipowners and operators, without advocating a particular solution, because the optimal solution for each shipowner may be different according to its business, its ships and their trade routes.*

Aude Leblanc,
Technology Leader, Sustainable Shipping
Bureau Veritas

Issuance of navigation certificates

International regulations (SOLAS and COLREG in particular) governing working navigation allow the use of wind propulsion but do not deal with it specifically. The flag State supplements the regulatory requirements in this area. Sections of regulation known as Technical Divisions specify the provisions applicable under the French flag. Division 221, which incorporates SOLAS, states that ships under the French flag must be able to remain manoeuvrable and advance at a speed of seven knots in conditions of good weather and calm seas, which as a consequence requires ships to have an engine and sufficiently large tanks for any crossing they wish to perform.

Issues related to visibility or manoeuvrability are studied on a case-by-case basis and resolved by installing radars, as is already the case for container ships, for example, and by securing the sail propulsion system to avoid any strain. Risk assessments including the effects of wind propulsion on stability and the impact of a ship's list on cargo or passengers, are reviewed by classification societies, which validate the proposed system dimensions.

The most delicate subject today is linked to the stability of the ship, because current criteria require the simulation of extreme conditions which will not be encountered in reality because wind propulsion will have already been stopped and made safe. Managing these issues on a case-by-case basis with the administration of the flag makes it possible to apply these criteria in a realistic way.

Notation by classification societies

The main classification societies (BV, ABS, Class NK, DNV, LR) have updated their standards. Specific class notations have been developed for Wind Assisted Propulsion Systems (WAPS), and many concepts have already been approved.

Fleet insurance

Insurance plays a major everyday role in the maritime world that is sometimes little known. Once the choice of a wind powered ship has been made, it is necessary to be able to insure it under good conditions. The world of insurance is evolving, like that of finance, and it seeks to make responsible initiatives an increasing part of its business. While attention is often on hydrogen and synthetic fuels, wind propulsion is not at all off the table, and is welcomed by major insurers.

Marine insurance will typically cover all risks related to the construction and operation of ships, with various guarantees, such as body and machinery, for damage suffered in the event of collision, striking, fire, financial losses relating to these damages and liability insurance (protection & indemnity or P&I) for damage caused to third parties.

The major market leaders have shown interest in the first projects and are working to offer tailor-made offers. To refine their quotes and be able to establish the level of risk and therefore the associated underwriting, their appraisers must have technical information on the operation of these new technologies and in particular automation, maintenance and lifespan of systems, the operational risks connected with loading and unloading phases, the means and costs of repairing systems and sailor training.

Work is therefore undertaken throughout projects with specialized brokers and hull and P&I insurers, so that the insurance provided offers precise coverage of the risks. Some risks will be less than for conventional ships – such as the risk of pollution linked to the volume of fuel in the hold, or engine damage as the engine will be used less. Other risks need to be assessed precisely, such as the ability to obtain spare parts or to repair the ship without immobilizing it in the event of damage to the rig.

As experience is gained on projects, insurers will be able to offer policies with specific terms for wind propulsion, or even introduce a proactive pricing policy for ships using wind energy.

04 Industrial Development Prospects

Tremendous potential for development

Size of the global market

The obligation to develop cleaner propulsion solutions concerns the entire global fleet. Although wind propulsion is not ideal in all circumstances, it can be integrated in a great deal of situations.

Two studies have estimated the global market size for wind propulsion.

The first, conducted in 2016-17 on behalf of the European Commission and its Climate directorate (source:[31]), estimates that while the first wind propulsion systems are being installed in 2020, 3,700 to 10,000 ships will be equipped by 2030, avoiding the emission of 3.5 to 7.5 million tonnes of CO2 and generating 15,000 to 18,000 jobs. This study was carried out before IMO built its strategy for reducing greenhouse gas emissions, therefore in the absence of emission reduction targets. Moreover, it studied only four technologies, and thus does not cover the full extent of the possibilities now available.

The second study (source:[32]), carried out for the UK government, estimates that 40% to 45% of the world fleet could be equipped with wind propulsion by 2050, i.e. 37,000 to 40,000 ships, due to the lower cost of this propulsion and its wide availability.

Factors favourable to rapid growth in demand

The cost of oil, restrictive regulations and pressure from banks on shipowners are the primary drivers of change. The opening of secondary lines with smaller vessels, demand from shipping customers who want an offer matching their high level of social and environmental responsibility and the adaptation of port environments to wind propulsion are also factors encouraging the use of the latter.

Rise of secondary lines and cabotage

The concentration and massification of flows of goods have reduced the cost of shipping. Container use has facilitated these changes for manufactured products. Ship sizes have increased, making more but shorter calls in ports. Lower costs for the shipping carrier, though, does not necessarily mean lower costs for port and inland transport operators, who need increased capacity in terms of trucks, port space, intermodal connections, investments for dredging and larger cranes, or for the shipper whose freight rate is not necessarily reduced.

The pandemic experienced in 2020 is reshuffling the cards and a paradigm shift could emerge in order to better manage risks and strengthen resilience (source:[33]). The established "just-in-time" model could then be reassessed to include these new considerations.

Diversifying sources of supply, routing and distribution channels should take on greater importance. This is also leading a number of shipping companies and port operators to take an interest in potential supply chain business opportunities using inland logistics.

The large hub-and-spoke organisational structures that link nodes to a transshipment centre will likely persist for larger vessels. But it seems possible to see the emergence of secondary lines, serving secondary ports, bringing goods transported by sea closer to trading zones, thanks to services using smaller ships. The end of the use of fossil fuels and the use of renewable energies could also redistribute maritime routes. Regional shipping requirements could increase sharply, creating new trade routes with smaller packages and a period of strong growth in demand for ro-ro ships, small container ships and dry bulkers (source:[34]).

This is what some of the new wind-propelled ship projects are offering – the capacity of ships corresponds to this new demand, with ships calling at ports which cannot be used by the largest vessels. The de-concentration of the flow of goods – which is an important factor of cost – is then partially offset by bringing the goods to be transported closer to their place of production or delivery. It would be interesting to estimate the economic and social added value brought to these secondary ports by the arrival of merchant vessels, in terms of jobs and the revitalization of maritime life along French coasts.

Demand from intermediaries as part of their CSR policies

To succeed in optimizing flows that are spread across the planet, most companies use intermediaries for the shipping phase. These intermediaries – brokers, carriers and consignees – are responsible for carrying out loading, unloading, groupage, routing, surveillance, customs operations, etc. The environmental aspects of corporate social responsibility are starting to be reflected in customer demands. To date, it is especially in sectors of high value-added products that the subject is the most mature. Their intermediaries must therefore have the capacity to offer alternatives such as shipping lines covered by wind propulsion. The demand is there and will increase once the first shippers have tested this mode of transport and confirmed their confidence in the maturity of the technologies to deliver the goods entrusted to the carrier to their destination and on time.

Adaptation of job skills and port environments to wind propulsion

The possible presence of masts – this is not the case when a vessel is equipped with kites – which can often be retracted or folded down, will not necessarily require investments in new special handling equipment. Nevertheless, support for these projects from port stakeholders is necessary.

The mooring operators who perform mooring and unberthing operations should not experience any particular problem for the docking of these vessels, which will all be equipped with engines for manoeuvres. When pilots board the ships, wind propulsion will have been stopped allowing the engine to take over in approach manoeuvres. The professionals in this field are inherently skilled at adapting to any type of ship. Developments ongoing in the trade are constantly monitored, and training can easily be put in place if the need arises. Handlers responsible for the loading and unloading phases will have to be attentive to the rigging installed on the deck of the ships, but this is no particular challenge for teams accustomed to operating in various cluttered environments.

How not to be enthusiastic about the idea of transporting goods by sail, contributing to the decarbonisation of the shipping sector, and more particularly for the Overseas Territories, whose exceptional marine biodiversity deserves to be preserved?

It is not a question of taking pleasure in replaying history but rather of drawing inspiration from old maritime routes and knowledge of the winds that we can combine with the new technologies available today or coming ones in the research & development phase.

Sailing in the archipelagos and under the trade winds has long been a tradition – how not to think of the Polynesians – and is becoming a reality with great overseas projects, such as the transport of Ariane rocket modules between mainland France and French Guiana on board the ship Canopée, the Canada-France route which will pass through Saint Pierre et Miquelon, or even the companies TOWT and Grain de Sails which sail round-trips between the Caribbean and the French ports on the eastern Atlantic seaboard to transport manufactured or gourmet products.

Let us hope that the momentum set in motion can continue to develop, for more sustainable shipping!

Alexandre Łuczkiewicz
Head of Overseas Relations and Actions, French Maritime Cluster

An opportunity for France

France has 20,000 km of coastline and 10.2 million sq. km of seas under its jurisdiction or sovereignty, and shipping is one of its key economic sectors (Appendix 8). French shipbuilding and nautical skills have persisted and the development of other sectors such as aeronautics and digital technology allow France to position itself among the leaders of the transition to greener shipping.

It can rely on these strengths to become a world reference in wind propulsion, both for fitting out ships and the use of a fleet using these technologies.

Mobilizing issues

Decarbonising domestic shipping

Although maritime transport is very largely international, national trade should not be neglected. CITEPA, the technical reference centre for air pollution and climate change, estimates the emissions of national maritime transport, in 2020, at 1.1 million tonnes of CO_2, i.e. for journeys between two French ports in mainland France and certain overseas territories: Guadeloupe, Martinique, Reunion, French Guiana, Mayotte and Saint-Martin. These emissions represent 1% of total emissions from French transport (source:[35]).

The objective of carbon neutrality implies a complete decarbonisation of maritime and river transport, by facilitating conversion to low-carbon technologies such as sailing (as well as batteries, biofuel and hydrogen). It is also planned to encourage the transfer of freight transport towards alternative modes to the road.

The challenges of energy transition and the decarbonisation of industry and transport are encouraging marine industrialists to innovate by offering green solutions to maritime players, in particular shipowners. Emission reduction targets for pollutants from our ships are both a challenge and an opportunity for our industry. A challenge, because we must simultaneously work on improving technologies, enhancing their reliability and the industrialization thereof and on the economic model allowing the mass adoption of these solutions. An opportunity, in that they contribute to regional development in the fields of industry, technology and jobs. Several demonstrator projects integrating wind propulsion have emerged in France and represent key benchmarks for both small and large ships. The challenge is to set a strong industry in motion to conquer a buoyant market, in which French shipbuilding can now position itself as a world leader. Support for research and development related to these technologies but above all the industrialization and production of wind propulsion (sails, rotors, kites, wind turbines, etc.) will ensure that most of the added value of these ships can be produced domestically. Several French maritime players are now preparing the know-how and technologies necessary for the development of these projects in line with the priorities of the recovery plan (i.e. Ecology, Competitiveness and Territorial Cohesion).

Philippe MISSOFFE
General Delegate, GIGAN
(French Marine Industry Association)

Moreover, overseas territories are the most vulnerable to the reduced availability and high cost of alternative fuels, even though maritime transport is essential for them. The fleet of French Polynesia, for example, has an average age of 35 years and its renewal with wind propulsion ships is therefore relevant.

Mobilizing aeronautics know-how and people

Some industrial sectors are strongly linked to fossil fuels and must reinvent themselves. This is the case of the French aeronautics industry, which has already become involved in the development of wind propulsion technologies for ships. Its skills in the design (modelling, digital simulation, command control algorithms), manufacturing and maintenance of complex systems provide a clear competitive advantage.

Although aeronautics is going through a major crisis, it could be the key to the wide adoption of French technologies by the world fleet, contributing its capacity to industrialize critical systems while guaranteeing controlled production costs and proven reliability.

Developing innovations from boating

The French nautical sector is also rich in companies capable of creating crossovers with the equipment of merchant ships for wind propulsion, by adapting technology from ocean racing, for example. The VPLP firm proposed a wingsail concept incorporating an innovation developed for the America's Cup.

The Mer Forte naval architecture consultancy, at the crossroads of boating and shipbuilding, is able to quickly assess the development potential of immature innovations and develop them using calculation and design tools to bring them to the market. The MerConcept company is today a purpose-driven enterprise that is also committed to making its know-how in the design of complex and innovative ships benefit the maritime world by supporting technical transfers between offshore racing and the shipping industry.

Specialized deep tech companies, such as D-ICE Engineering, MaxSea or Syroco are extremely valuable to the development of projects thanks to their work on the dynamic simulation of ship behaviour, onboard software and routing. D-ICE Engineering has equipped the *Canopée* ship with its Oceanics software and MaxSea is a partner of the Airseas project.

Structuring a sector with high development potential

All these opportunities make it possible to consider wind propulsion as a powerful and job-creating sector for the French economy in the future. Projections from the Wind Propulsion Study carried out in 2016 by the CE Delft consultancy on behalf of the European Commission estimate that 15,000 to 18,000 jobs could be created by 2030. In France, Wind Ship estimates that at least 350 jobs are already devoted to this area. By 2030, this figure could be multiplied tenfold.

Increasing the attractiveness of the maritime world

Operating these ships, maintaining them and organizing the maritime lines of tomorrow, within a more agile but also more complex management environment, requires a transfer of skills from aeronautics and digital technology to the maritime world, but also a reappropriation of navigation methods by fleet managers and sailors.

This is more of an advantage, though, than a repellent – these new methods represent both a serious avenue for safeguarding jobs and an opportunity to attract and retain talent, as evidenced by the numerous job applications received by wind propulsion players.

“ ***Wind-assisted ship propulsion is for Pôle Mer Bretagne Atlantique a tremendous source of innovation, both technologically speaking and in terms of uses. It deploys technologies as diverse as composite materials, fluid mechanics, satellite communications, oceanographic measurements, onboard electronics, system automation, and more.***

Beyond these innovations, wind propulsion is also driving changes in port services, the creation of new maritime routes and the transport of different goods. Transfers of technology and skills between offshore racing or aeronautics and the entire maritime sector are a real opportunity for the development of cleaner and low-carbon shipping using energy from the wind, which will be a creator of jobs and value.

The Pôle Mer Bretagne Atlantique, by fostering a dynamic and innovative ecosystem, is supporting ecological transition to which wind propulsion contributes.

Patrick Poupon
Director, Pôle Mer Bretagne Atlantique

France's strengths

Pioneers in the business

France already has pioneers who have been working on these projects for several years, and an ecosystem of historical skills that are being reinvented for a new purpose. Companies, most of which start-ups or SMEs but also major players, are working side by side to develop technologies, representing more than 180 direct jobs. ADD Technologies, ACCWING, Airseas, AYRO, Beyond The Sea, Chantiers de l'Atlantique, CRAIN, CWS, Maloric and WISAMO are key examples.

Already, shipping companies are investing in wind-powered ships that will sail on the high seas, e.g. Alizés (Zéphyr & Borée and Jifmar), Grain de Sail, Neoline, Ponant and TOWT, as well as newcomers with design projects, such as Eco Trans Ocean, and EcoBreeze.

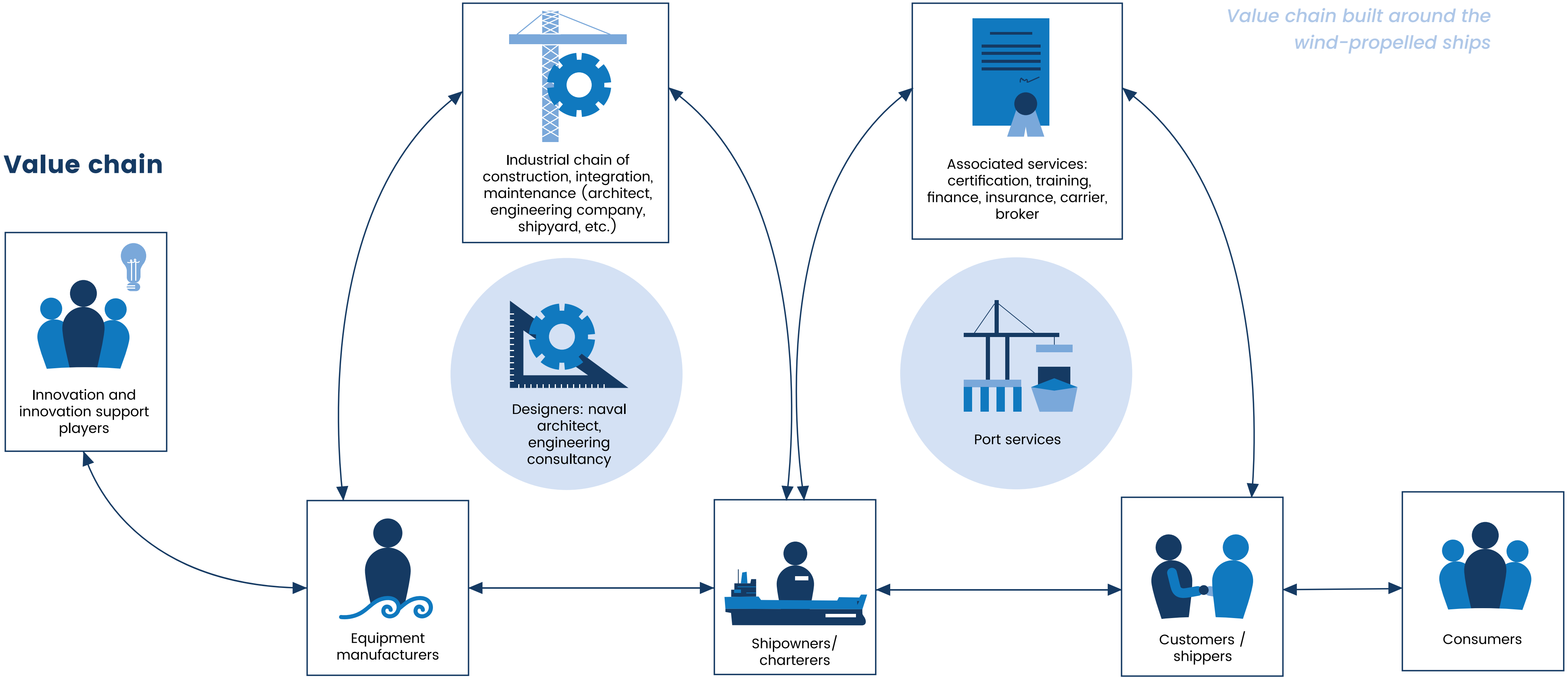
At the same time, others are equipping or aiming to equip ships for coastal journeys or professional navigation, in mainland France and overseas, e.g. Avel Marine, Iliens, Seafret Caraïbes, Skravik, Eol'Lien, Bourlingue & Pacotille, Blue Schooner Company, Amarres d'Amour, and the Glaz Project.

Many of these players are already united within the Wind Ship association and its international network, International Windship Association.

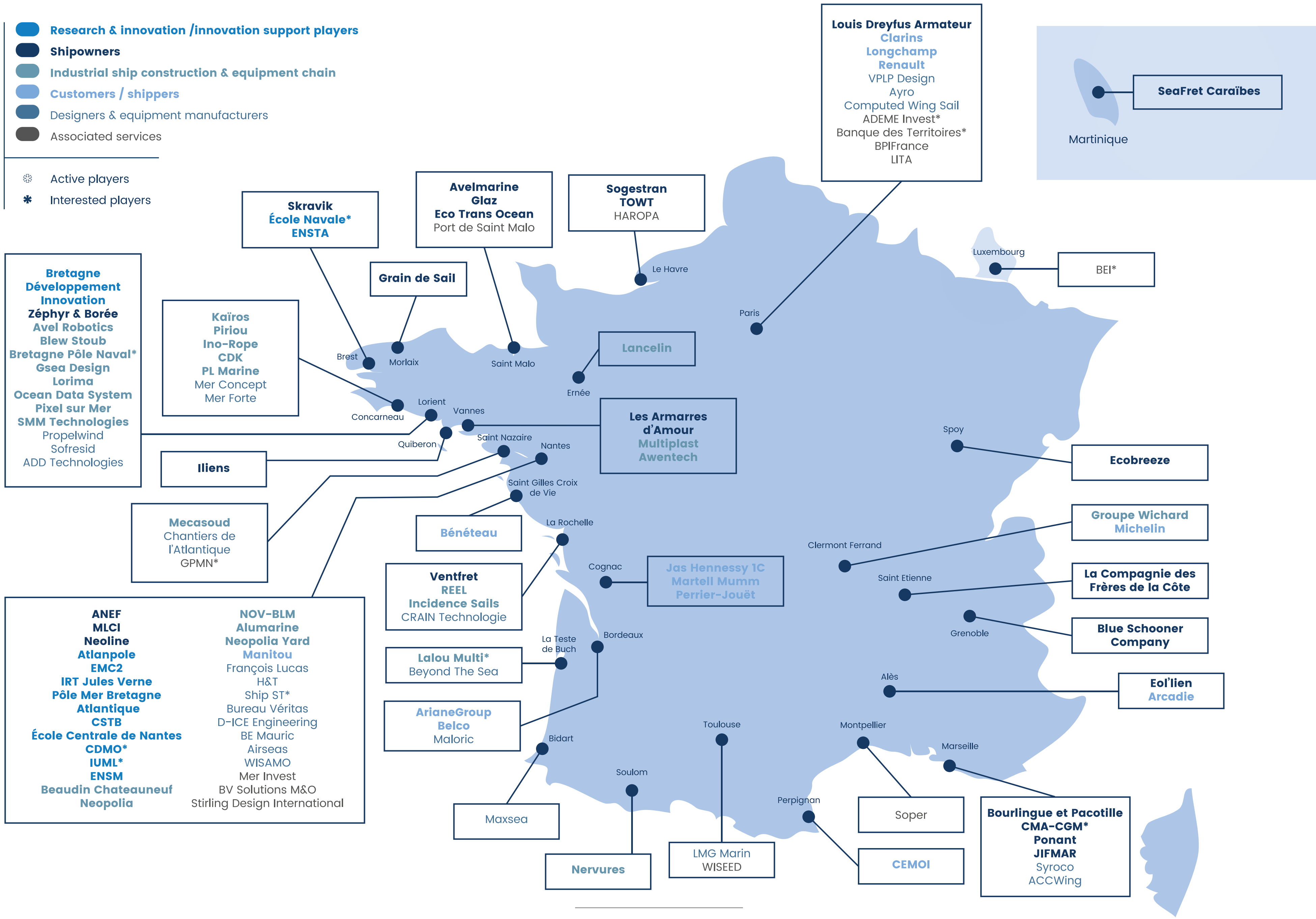
An increasingly complete value chain

An increasingly complete value chain is being built across France, to produce and export equipment but also to open new lines.

Value chain



Value chain built around the wind-propelled ships
Industrial chain of construction, integration, maintenance (architect, engineering company, shipyard, etc.)
Associated services: certification, training, finance, insurance, carrier, broker
Innovation and innovation support players
Designers: naval architect, engineering consultancy
Port services
Equipment manufacturers
Shipowners/ charterers
Customers / shippers
Consumers


Research & innovation /innovation support players
Shipowners
Industrial ship construction & equipment chain
Customers / shippers
Designers & equipment manufacturers
Associated services
Active players
Interested players
Louis Dreyfus Armateur
Clarins
Longchamp
Renault
VPLP Design
Ayro
Computed Wing Sail
ADEME Invest*
Banque des Territoires*
BPIFrance
LITA
SeaFret Caraïbes
Martinique
Skravik
École Navale*
ENSTA
Avelmarine
Glaz
Eco Trans Ocean
Port de Saint Malo
Sogestran
TOWT
HAROPA
Le Havre
Luxembourg
BEI*
Grain de Sail
Bretagne Développement Innovation
Zéphyr & Borée
Avel Robotics
Blew Stoub
Bretagne Pôle Naval*
Gsea Design
Lorima
Ocean Data System
Pixel sur Mer
SMM Technologies
Propelwind
Sofresid
ADD Technologies
Kaïros
Piriou
Ino-Rope
CDK
PL Marine
Mer Concept
Mer Forte
Brest
Morlaix
Saint Malo
Paris
Lancelin
Ernée
Concarneau
Lorient
Vannes
Quiberon
Saint Nazaire
Nantes
Les Armarres d'Amour
Multiplast
Awentech
Spoy
Ecobreeze
Iliens
Saint Gilles Croix de Vie
Mecasoud
Chantiers de l'Atlantique
GPMN*
Bénéteau
La Rochelle
Groupe Wichard
Michelin
Clermont Ferrand
Cognac
Jas Hennessy 1C
Martell Mumm
Perrier-Jouët
Saint Etienne
La Compagnie des Frères de la Côte
Ventfret
REEL
Incidence Sails
CRAIN Technologie
Grenoble
Blue Schooner Company
ANEF
MLCI
Neoline
Atlanpole
EMC2
IRT Jules Verne
Pôle Mer Bretagne Atlantique
CSTB
École Centrale de Nantes
CDMO*
IUML*
ENSM
Beaudin Chateauneuf
Neopolia
NOV-BLM
Alumarine
Neopolia Yard
Manitou
François Lucas
H&T
Ship ST*
Bureau Véritas
D-ICE Engineering
BE Mauric
Airseas
WISAMO
Mer Invest
BV Solutions M&O
Stirling Design International
La Teste de Buch
Bordeaux
Lalou Multi*
Beyond The Sea
Alès
Eol'lien
Arcadie
ArianeGroup
Belco
Maloric
Toulouse
Montpellier
Bidart
Marseille
Soulom
Perpignan
Maxsea
Soper
Bourlingue et Pacotille
CMA-CGM*
Ponant
JIFMAR
Syroco
ACCWing
Nervures
LMG Marin
WISEED
CEMOI

The decarbonisation of logistics flows is a central issue for many shippers (industrial and commercial companies, importers or exporters) and is the focus of many of their actions. Their professional association, the Association of Freight Transport Users (AUTF), which is already very committed to the reduction of CO_2 emissions from land and short sea transport, through the FRET21 initiative that it is leading with ADEME, supports the emergence in France of a sector allowing transoceanic container shipping by vessels equipped with propulsion systems using mostly sails, to reduce the carbon footprint of the goods transported in this way. In particular, the AUTF is co-piloting a project aimed at pooling the needs of various companies to create sufficient shipping demand on transatlantic routes between Europe and the United States to encourage the creation of a regular cargo service sailing on these lines. Other initiatives may follow. We hope that 2022 will see this project materialize and others begin.

Denis Choumert
President, AUTF
(Association of Freight Transport Users)

Design firms, naval architects, industrial subcontracting companies and shipyards are showing strong involvement in the sector. For example, the AGORA project led by Neopolia, a network of industrial companies, in the maritime sector especially, aims to create a unique French industrial centre offering capabilities dedicated to the construction of sailing ships. Ocea, Mecasoud, Piriou and Chantiers de l'Atlantique are among those positioning themselves in this market. But it is also a whole chain of industrial subcontracting, ship financing, and shippers that are mobilizing today in France. The recent initiative of a coalition of major shippers supported by France Supply Chain and the Association of Freight Users (AUTF), which wishes to order a dozen wind-propelled ships from 2025, is proof.

Proactive regions

The pioneers of wind propulsion tend to be concentrated in proactive regions that want to explore these new practices with them, driven by strong societal and environmental values. These companies are also born and set up in the heart of industrial ecosystems that bring essential know-how to the sector, such as aeronautics, shipbuilding, boating and digital technology. A significant concentration of players can be found on the Atlantic/Channel coast, from New Aquitaine to Normandy, particularly in Brittany and Pays de la Loire. The PACA region and the French Mediterranean coastline is also home to a growing ecosystem. Finally, Ile-de-France is where many major clients and research centres are based.

Regions as well as cities play a key role in supporting and leading these ecosystems. Nantes Métropole is creating a centre dedicated to nautical and maritime activities to become a place of maritime importance once again.

The Nantes ecosystem has the ability to bring out and de-risk wind propulsion projects from a technology, market or financing point of view, from the idea stage to the testing of models, thanks to the presence of innovation support and innovation players, physical test facilities and relevant companies.

Saint-Nazaire Agglomeration (CARENE) wishes to develop an industrial centre linked to new propulsion systems. The ecosystem of the port of Saint Nazaire and the Chantiers de l'Atlantique shipyard has the infrastructures and companies needed to carry out full-scale physical tests, on land and at sea, and to integrate new propulsion systems on ships, from design to execution.

The Brittany region has just assessed the ability of its industrial base to position itself in the wind propulsion sector for ships. The results showed that 156 companies from the shipbuilding, boating and competitive sailing sectors are interested in this market, and 55% of them consider it a priority for their development. The sector is already estimated in Brittany to represent 28 million euros and 155 jobs. In addition to its industrial chain and research resources, Brittany has the potential to become a real-size test bed for technologies, uses and business models. Brittany has several medium-sized ports, numerous exporting companies, and a strong and growing need for passenger transport to its islands. Low-carbon solutions are required for all of these local logistical needs. The Pays-de-la-Loire region is investing in a planned new carbon-free shipping line by financially supporting the Neoline project, and facilitating the set-up of the Airseas plant. The port of Le Havre is preparing to welcome the construction of the new TOWT ship and the Chamber of Commerce and Industry of Caen Normandy, which operates the Port of Caen-Ouistreham, is facilitating the set-up of the AYRO factory in this commercial port.

This type of support, these ecosystems and the experiments being carried out, just a few of which are mentioned above, are extremely important for the development of a French wind propulsion sector.

The complexity of ship financing

The issue of financing of ships is not specific to wind propulsion, but it is more complex for first-in-series vessels.

A radically changing world

The world of shipping financing is undergoing profound changes. The 2008 crisis caused a collapse in freight rates and overcapacity in the merchant fleet on a global scale. Since then, shipping banks have been torn between the rules of prudence imposed by the Basel agreements – i.e. a capped contribution and a level of 40% equity required for the shipowner – decarbonisation principles such as the Poseidon principles (see note: **36**), and competition from Asian banks.

The construction of merchant marine vessels mobilizes capital whose volume obviously varies according to the scale of the vessels considered. For example, a sailboat like *Grain de Sail* (25 m, 50 t payload) cost 2 million euros. The company's next vessel (50 m and 350 t) will remain below the 10 million euro mark. The *Canopée* or *Neoline* vessels (>120 m, 5,000 t), on the other hand, represent investments in the region of 40 to 50 million euros. While the valuation of ship hulls does not pose a problem for financiers, having them recognize the value represented by wind propulsion rigs is difficult, because it is something completely new.

Opportunities

Fuel cost volatility

However, such rigs represent substantial value because they make it possible, during the operation of the ship, to partly escape the volatility in fuel costs – since these are lowered by reducing fuel consumption – which ultimately stabilizes the economic model of operating a shipping line.

In any case, validating the performance and solidity of wind propulsion systems, through the feedback of experiences, is an obligatory step which should give funders the necessary assurances to assess the value of rigs and validate the robustness of economic models for operating vessels.

Rising carbon prices in European waters

The entry into force between 2023 and 2026 of a revision of European regulations will oblige ships of over 5000 gross tonnage to cover 100% of their CO_2 emissions in European waters. Thus, any emissions avoided will be financially valued under the emissions quota trading system. In 2021, the price of a tonne of CO_2 was €65. In the example of a ten-year-old bulk carrier (see note: [37]), of 37,000 dwt, which emits 6,000 tonnes of CO_2 during intra-European voyages and at berth, the ship will have to pay € 300,000 a year to cover its emissions (minus any free allocations and modulo the change in the cost of a tonne of CO_2). For a more recent 22,500 dwt ro-ro, the 2,000 t of CO_2 emitted per year will equate to an annual bill of €100,000.

> *A century ago, ships went from sailing to steam. Today, to reduce the climate impact linked to the operation of ships, the wind is once again inviting itself into ship propulsion systems. Available everywhere in the world, free and without GHG emissions, the wind is an energy there for the taking! The technologies are already available and many ships can benefit from them depending on their sectors. Some of our members have already chosen this solution (Neoline, Jifmar, Zéphyr & Borée and TOWT) and the others are following the development of the various technologies very closely. France can be proud of its pool of businesses in this area, but must maintain this momentum throughout the sector as a whole. Armateurs de France, alongside the Wind Ship association, supports the deployment of wind propulsion. To this end, it is imperative that concrete incentive tools be implemented by the State.*
>
> *Jean-Emmanuel Sauvé,*
> *President of the French shipowners' association*
> *Armateurs de France*

Extra cost of prototyping

Vessels equipped with innovative wind propulsion technologies, whether through retrofitting or new builds, must integrate an additional cost linked to the fact that wind propulsion systems are still prototypes. For this reason, it is not yet possible to publish returns on investment (ROI) or stabilized costs from these first operations.

Developers of wind propulsion technologies are in what is commonly called the "valley of death" (source: 38), i.e. the moment when the first stages of development are conclusive but high amounts of cash are needed to start installing the technologies on full-scale demonstrators before launching industrial production.

This means, on the one hand, that pioneering shipowners will have to assume an additional cost and take the risk of being the first testers, and, on the other, that the product installed will likely have a lower re-sale value because industrial production will have started by then, with more successful products on sale at a lower cost.

State support

This type of obstacle is reminiscent of the obstacles encountered with the development of renewable energies. These benefited from State support either upstream in the R&D field, or in the industrialization phase, through support for demand and commercial deployment (for example through feed-in tariffs and additional remuneration, calls for tenders or tax measures). This support reduced the levelized cost of the energy produced – a trend which has continued even after the end of public support thanks to lower capital and operating costs.

We can highlight here the very active role of ADEME in supporting the R&D component of wind propulsion technologies, which represents almost 7% of funding, or € 12.5 million, for future investment programmes, (source: 39). But banks, investors and green funds are still very far behind when it comes to financing the fitting out of ships. Their project audit phase is still relatively difficult due to a lack of feedback of experiences.

New developments are emerging in this field however:

- Incentive tax schemes are being improved under the "Fontenoy du Maritime" initiative. The accelerated depreciation of wind propulsion systems is one of them. This must be improved to be really applicable and effective, and reworked for systems that come in the "auxiliary propulsion" category, which, due to the formula currently used, penalizes the majority of wind propulsion projects.
- Leasing models are being studied so that the costs of equipping ships with wind propulsion comes under operating expenditure (OPEX) rather than capital expenditure (CAPEX). Indeed, if a ship is to be decommissioned, the elements of the wind propulsion system can be dismantled and reinstalled on another vessel.

Paths for structuring and accelerating the development of wind propulsion

For shipping to quickly make its transition to cleaner practices and for France to really play a prominent role in this area, both objectives must be pursued with new intensity, and several actions must be taken. These require the mobilization of business, including the companies who use shipping, those already operating in the shipping sector and those entering it. They also require the strong involvement of the French State and local authorities.

1 Acknowledge the immediate availability of technologies

Wind propulsion must benefit from special support because it is not subject to the same constraints as alternative solutions which will only be available after 2030.

2 Convince users of the relevance of solutions

- Validate vessel performance by adopting a harmonized assessment framework and allocating resources to monitoring the first projects.
- Give visibility to the wind propulsion offer by communicating with shipowners and shippers.

3 Accelerate the return on investment of projects at the prototype stage

Propose suitable financial support for the operators, owners or financiers of vessels for this transition period, such as:

- a subsidy scheme like the one proposed by Germany, which covers up to 55% of the cost of investment and installation of a wind propulsion system (see note: 40),
- an improved version of the accelerated green depreciation scheme to make it applicable and efficient, and to include auxiliary wind propulsion in a way that really encourages it.

Give a financial value to avoided GHG emissions.

- Use energy saving certificate programmes to finance studies, awareness and communication, and facilitate the implementation of specific activities related to wind propulsion projects.
- Assert a clear French position on the need to introduce carbon pricing in European and international discussions.

4 Support the sector through orders or regulations

- Make wind-assisted propulsion compulsory or allow variants of wind propulsion or hybridization in calls for tenders for public contracts for the State fleet, public service delegations, etc.
- Facilitate the set-up of industrial facilities by equipment manufacturers.
- Propose incentive flag conditions for any wind-propelled vessel.
- Multiply proposals for low-carbon wind-propelled lines from ports in mainland and overseas France so that the first commercial lines have a knock-on effect.
- Encourage the creation of new local services and the networking of proactive ports.

5 Federate and structure the emerging industry

Support initiatives that bring together and federate players at regional, national and international levels.

Appendices

Presentation of Wind Ship members

The association regularly welcomes new members.
The updated list is available on the website
www.wind-ship.fr

ADD Technologies a pioneer in the design of inflatable wingsails, is a Lorient-based design firm which works in close collaboration with shipyards and shipowners. The goal is to provide a propulsion wingsail system for working vessels and the existing shipping fleet. The components of its system are based on proven technologies and are manufactured by a network of partners, then assembled in its workshops.

https://add-modules.com/en/

ACCWing (automated camber control wing) is a patented thick, soft wingsail concept. The start-up, based in Châteauneuf-les-Martigues, aims to market this innovative sail solution to equip pleasure boats, yachts and shipping vessels. The camber control of the ACCWING wing is semi-automated, and a demonstrator boat has been sailing since 2020. Full automation is now under study with Sirehna, a subsidiary of Naval Group. ACCWing is currently working on a project involving a 75-metre-long clipper equipped with four wings, for freight and passenger transport. Other smaller projects are also under consideration.

https://www.accwingsail.com/

Airseas is a company created in 2016 by engineers from the Airbus group who wanted to transfer aeronautical expertise to the maritime sector in order to contribute to its decarbonisation. Harnessing a combination of aeronautical and maritime expertise, Airseas commercializes the Seawing, a 1,000 sq. metre kite wing capable of towing the largest ships that generate the most emissions in the world. The Seawing is a simple, automatic and safe integrated system. It saves 20% of fuel and associated emissions on average.

http://www.airseas.com/

AYRO is a French company that designs and manufactures Oceanwings®, a patented wingsail concept that is furlable and automated. This wind propulsion system can be installed on merchant ships and yachts, and can thus reduce greenhouse gas emissions from maritime transport. Following an industrial demonstrator aboard *Energy Observer* and two years of sailing, the first four Oceanwings® 363 are being manufactured and will be delivered for the *Canopée* ship at the end of 2022. *Canopée* is a 121-metre-long ro-ro ship designed by the naval architecture firm VPLP Shipping and under construction at the Neptune Marine shipyard. It will be operated by Alizée, a joint venture between Jifmar and Zephyr & Borée, and will transport Ariane 6 launcher components for ArianeGroup between Europe and French Guiana.

https://ayro.fr/

Beyond the Sea®, created in 2014 by Yves PARLIER, is a resolutely innovative company with a very environmentally friendly approach. The principle is simple. Beyond the Sea® offers kites of all sizes, capable of handling some or all of the energy required to tow a ship, depending on your sailing area, the performance and characteristics of your boat and the sailors' objectives. The kite, connected to a fixed point on the ship, will be either moving or fixed according to the desired pulling force, all in perfect safety. The kite can be controlled automatically or manually.

https://beyond-the-sea.com/yves-parlier/

Bright Future Marine Solutions is a French engineering and T&I support company created in Lorient in 2017, and now established internationally.
It specializes in maritime and offshore renewable energy, with particular expertise in:
- the hybridization and electrification of cargo ships and pleasure boats
- the implementation of innovative engineering solutions preventing ship pollution.

BFMS also participates in projects requiring expertise in innovative composite materials like linen and bio-sourced resin, and in alternative propulsion systems such as turbosails and rigid sails.

http://www.brightfuturemarine.com/

CHANTIERS DE L'ATLANTIQUE is a shipyard specializing in cruise and military ships.

As part of improving the carbon footprint of cruise ships, Chantiers de l'Atlantique has developed the Solid Sail – a sail for large sail-powered ships – and Aeol Drive – a balestron rig which can tilt to reduce air draft and pass under bridges when necessary. With these Aeol Drive and Solid Sail products, Chantiers de l'Atlantique seeks to take a significant share in sail propulsion solutions in the years to come, in the cruise, cargo ship and super yacht segments.

https://chantiers-atlantique.com/

Le CRAIN which stands for Centre of Research for Nautical Architecture and Industry, is a design consultancy based in La Rochelle. Involved in boating and competitive sailing since the end of the 1980s with numerous participations in the America' s Cup, CRAIN has turned its focus to energy transition, putting its skills in naval architecture and aerodynamics to good use. CRAIN has developed performance models for different wind propulsion solutions, tools for predicting the performance of vessels using hybrid propulsion and routing software. More recently, CRAIN developed an optimized thruster solution based on the suction wing concept with wind tunnel testing and a 7.50-metre prototype tested on land in a representative environment.

http://site.craintechnologies.com/

D-ICE Engineering is a deep tech company created in Nantes in 2015. It aims to reduce the carbon footprint of shipping, improve performance at sea and produce clean energy by supporting and offering its solutions to players in the following sectors:

- Advanced scientific software for naval engineering
- Modelling, performance evaluation of naval platforms
- Onboard navigation and piloting systems.

Its expertise includes modelling, simulation, hydrodynamics, applied mathematics, robotics and control, and software and system engineering.

https://dice-engineering.com/

CWS offers an innovative sail propulsion system for the maritime sector. The CWS wingsail is a rigid, asymmetrical wingsail that is invertible and lowerable. It reduces a vessel's fuel consumption by assisting the main engine and can be deployed on both existing ships and new builds. Its performance, in particular its finesse, ensures steady propulsion even on fast ships and limited drift effects; operation is automatic and maintenance is minimal. CWS also provides integration, fuel savings and EEDI/EEXI impact analysis according to best practices.

https://computedwingsail.com/

Eco Trans Océan is a Saint Malo-based shipowner established in 2021. It aims to provide shipping between different regions of France with an innovative sail-powered cargo ship. The cargo sailboat is an effective solution for the shipping industry of tomorrow which makes it possible to reduce and control the pressure on the natural environment. Eco Trans Océan is developing sustainable commercial lines, through a people-centred and regional approach. By 2025, Eco Trans Océan will concretize its goals with its first ship.

http://www.ecotransocean.com/

François LUCAS is the naval architect behind the sailing cargo ship *SEAFRET 35*, intended for inter-island freight in the Caribbean, on behalf of the shipowner Seafret Caraïbes. This 35-metre vessel with a cargo capacity of 100 tonnes will benefit from the trade winds. These regular easterly winds which blow constantly throughout the year guarantee that it always sails crosswind on the outward and return journeys. Fuel consumption should be reduced by more than 50% compared to a conventional combustion-powered coaster vessel. This concept of sailing coaster with reduced draft could be adapted to meet the demands of shipowners around the world or along European coasts for local trade.

https://www.fr-lucas.com/

The **Grain de Sail** adventure began in 2010, on the waterside in Morlaix, with the idea of travelling to source coffee and chocolate on the other side of the world while keeping carbon footprint to a minimum thanks to a unique means of transport – the cargo sailboat. Olivier and Jacques Barreau, twin brothers from St. Brieuc and experts in renewable energies, are the founders and managers of the company. In 2020, *Grain de Sail*, the first modern cargo ship with international merchant marine standards, made its first transatlantic round-trip (St. Malo ->New York -> Dominican Republic -> St. Nazaire). This schooner-type ship of 24 metres and 50 tonnes of cargo capacity, makes two transatlantic round-trips a year of three months each, but this is only the beginning since Grain de Sail will be operating a second cargo ship (50 m and 350 t cargo capacity) from 2023.

https://graindesail.com/

MAXSEA is a maritime navigation software publisher and a major player in on-board solutions for professional fishing and yachting. Founded in 1984, Maxsea developed the first maritime navigation software for on-board PCs, and today offers a wide range of products. After 30 years of development and innovation, Maxsea International markets its solutions under the TimeZero brand. This range of products meeting all electronic navigation needs is sold in 25 countries, on five continents, and is available in 13 languages. Maxsea offers a new eco-routing solution to optimize the performance of wind-powered navigation. It is already installed for sea trials on board a merchant ship.

https://mytimezero.com

MerConcept created 15 years ago by the French sailor François Gabart, emerged from the desire to develop an offshore racing team at the forefront of innovation and performance. Today MerConcept is a purpose-driven company committed to innovative, efficient and sustainable offshore racing. It works on ambitious, meaningful projects, whose significant innovations allow technology transfers for more sustainable maritime mobility.

https://merconcept.com/

CT Mer Forte is a design, engineering and naval architecture firm created in 2009 by Michel Desjoyeaux and Denis Juhel.
Stemming from ocean racing and naturally focused on innovation, the CT Mer Forte team, backed since 2020 by the international group CT INGENIERIE, has, since its creation, applied its expertise to sail propulsion projects for ships.

https://www.merforte.com/

WISAMO – standing for Wing Sail Mobility – is an incubation initiative of the Michelin Group. Its ambition is to help decarbonise maritime shipping by improving the environmental footprint of merchant ships, reducing their fuel consumption and therefore their GHG emissions. The WISAMO solution is a large inflatable, retractable and automated wingsail which harnesses the wind, a free, universal and inexhaustible source of propulsion, suitable for all types of boats.

http://www.linkedin.com/showcase/wisamo/

Neoline is developing a low-carbon shipping line connecting Saint-Nazaire and the American east coast, calling at Saint-Pierre-et-Miquelon. This line will be operated from 2024 with one then two ro-ro ships (136 metres long for 5300 tonnes of capacity) with sails as the main propulsion, saving more than 80% of fuel. Its purpose is to demonstrate the possibility of achieving a low-carbon, efficient and industrial logistics service using the wind.
Major French companies, such as Groupe Renault, Groupe Beneteau, Manitou Group, Michelin, JAS Hennessy & Co, Clarins and Longchamp already plan to use the service.

https://www.neoline.eu/

PROPELWIND offers a low-carbon maritime transport solution (in the form of a license) using wind as the main propulsion. The initial focus is on monohull vessels, suitable for various low-density and fast cargoes. The first small vessels (2,000 dwt) are to be delivered in 2025. The objective is to gradually scale-up to 25,000 dwt in 2040. A totally zero-emission and more efficient trimaran configuration is being developed in parallel for niche markets.

https://propelwind.com/

REEL is an independent company created in 1946 and has nearly 2,500 employees. REEL develops, builds, installs and maintains complex handling systems and ensures their integration into each client's process. The company operates in the fields of aeronautics, defence, energy, metals, offshore and industry, with customers all over the world. Since the opening of its offices in the Atlantic port of La Rochelle, REEL has been involved for several years in developments with other members of the emerging wind propulsion sector.
Today, in partnership with CRAIN and the Nouvelle Aquitaine region, REEL is committed to the design, production and marketing of a suction wing system for maritime transport.

http://www.reelinternational.com

After having chartered old sailing boats for ten years and transported more than 1,000 tonnes of goods under sail (tea, coffee, cocoa, rum, etc.), **TOWT** is launching the construction of a fleet of four modern cargo ships which will transport goods in a low-carbon way (90% less carbon footprint on average) on behalf of major brands like Cémoi, Belco, Martell Mumm Perrier-Jouët etc. These 80-metre-long cargo ships have a capacity of 1100 tonnes and will serve North and South America, Africa and Asia, saving up to 2400 tonnes of CO2 and transporting 10,000 tonnes of goods per ship per year.

https://www.towt.eu/

Syroco is a scientific and technical laboratory that generates innovation to support energy transition, through pioneering achievements. Based in Marseille, the start-up notably markets Syroco EfficientShip, a software platform based on a digital twin of a ship and its propulsion systems. Using scientific foundations developed around research into wind speed and harnessing the power of wind, Syroco EfficientShip enables energy-efficiency decision making, both during design and operation of a ship or a fleet.

https://syro.co/fr/

VPLP Design is a naval architecture agency founded in 1983, with offices in Vannes, Nantes and Paris. Its team of architects, engineers and designers work on projects around the world. VPLP is a benchmark for sailing vessel designs, whether in racing, cruising or super yachting. The agency is also at the forefront of innovation in low-carbon shipping, with unique know-how in the design of hybrid vessels with sail assistance. VPLP notably carries out engineering studies in the fields of hydrodynamic modelling and simulation, performance prediction, and composite design and engineering.

https://www.vplp.fr/

Zéphyr & Borée is a sail shipping company. In partnership with Jifmar, it is currently having the *Canopée* ship built, which it will commission in 2023. With a length of 121 metres, *Canopée* is the first modern sailing freighter. Zéphyr & Borée aims to decarbonise maritime transport and diversify into the development of container ships and ro-ro ships to move towards zero-emission shipping.

https://zephyretboree.com/

Technical appendices

The Merchant Fleet in 2020

In 2020, the global merchant fleet comprised 52,961 ships of over 1000 gross tonnage, accounting for almost all of the world's capacity (2,047 billion deadweight tonnes).

The world fleet comprises 98,140 ships of over 100 gross tonnage, representing a capacity of 2.061 billion deadweight tonnes, of which just over 45,000 are small and represent less than 1% of world capacity.

The capacity of this fleet increases every year (+4.1% in 2019).

It can be divided into different segments*:

- The most important are container ships, bulk carriers, oil tankers and multi-purpose cargo ships.
- Some vessels are more specialized, e.g. chemical tanker, gas tanker, ro-ro, vehicle transport, refrigerated bulk, etc.
- Others transport passengers: ferries, cruise ships.
- These vessels are also divided into size categories.

Oil tanker	Handysize	Panamax	Very large Crude Carrier (VLCC)
Capacity	*Up to 35 000 dwt*	*35 000 to 80 000 dwt*	*>80 000 dwt*

Bulk carrier	Handysize	Panamax	Capesize
Capacity	*Up to 35 000 dwt*	*35 000 to 80 000 dwt*	*>80 000 dwt*

Container ship	Feeder	Panamax	Ultra Large Container Ship (ULCS)
Capacity	*Up to 2 000 EVP*	*2 000 to 5 000 EVP*	*>15 000 EVP*

* This fleet belongs for more than 50% in number and 70% in tonnage to owners in Greece, Japan, China, Singapore, Hong Kong, Germany, the Republic of Korea, Norway, Bermuda and the United States. The fleet under French ownership represents just over 400 ships, or 0.65% of the world fleet. Some 35,000 vessels representing 71% of world capacity are registered under the flags of Panama, Liberia, the Marshall Islands, Hong Kong, Singapore, Malta, China, Bahamas, Greece and Japan.

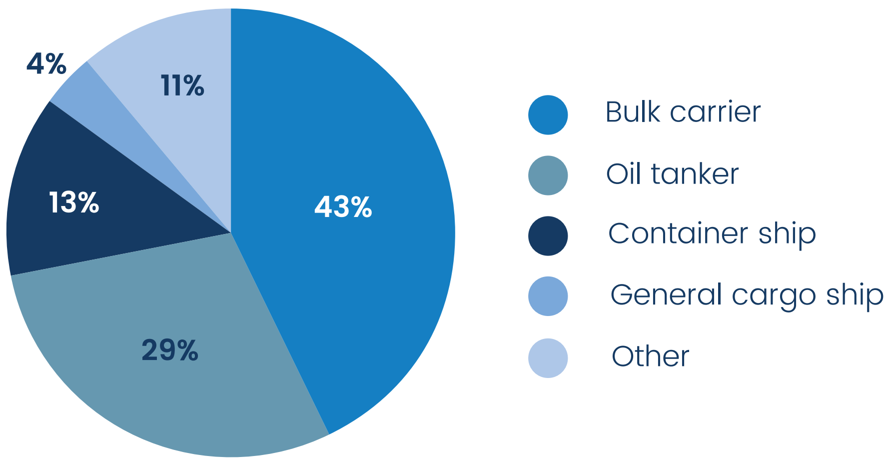
Note

The gross tonnage (GT) of ships is a measure of the volume of their enclosed spaces using a universal calculation formula introducing a logarithmic coefficient. This tonnage is therefore expressed in the Universal Measurement System but has no units.

The deadweight tonnage (deadweight tonnes or dwt) is the maximum weight that a ship can carry, and reflects the loading capacity of the ship.

The capacity of container ships is referred to by the number of 20ft equivalent containers (TEUs) they can carry.

World fleet by vessel type
(as % of total capacity in dwt, 2019-2020)



In addition, there are:

- Offshore industry vessels
- Service vessels, partly mobilized by port operations, e.g. pilot boats,
- dredgers, tugs, barges, buoy layers, cable layers, support boats for maritime works
- Training ships and oceanographic research ships.

Container ships, bulk carriers and oil tankers represent, in total, more than 80% of global emissions of CO2 and atmospheric pollutants* due to the size of their fleet, which represents 85% of global capacity. Looking at emissions by ship type, LNG carriers and cruise ships emit the most CO2, followed by container ships, vehicle carriers, ferries and ro-ros.

The average age of the world fleet is 21 years if we reason in terms of number of ships, but 10 years if we reason in terms of shipping capacity.

The ships built in the last four years are much larger than 20 years ago**. We now have a large fleet of smaller and older ships on the one hand and a younger fleet of larger ships on the other.

Looking at capacity, bulk carriers are the youngest fleet, followed by container ships and tankers.

* According to the UNCTAD report of 2020, p.93-94.
** An oil tanker is on average nine times larger than 20 years ago, a container ship is four times larger, a cargo is three times larger and a bulk carrier two times larger (source UNCTAD, RMT 2020).

These ships are on average between nine and ten years old. The cargo ship fleet is twice as old. The average age of ships when dismantled is about 30 years, but it is higher for small ships than for larger ones. At the current rate, we would have to wait until 2033 for the renewal of half of the tankers and container ships, 2037 for the renewal of half of the cargo ships and 2040 for the renewal of half of the bulk carriers, chemical tankers, gas carriers and ferries*.

Thus, small ships are generally older, and are currently being rapidly renewed. They generally have a long operating life – new units built in 2020 will remain in navigation until 2050. They must therefore be immediately equipped with technologies to reduce their impact. At the same time, the existing fleet of larger vessels is younger and will not be renewed straight away. It should therefore be retrofitted without delay to minimize its impact.

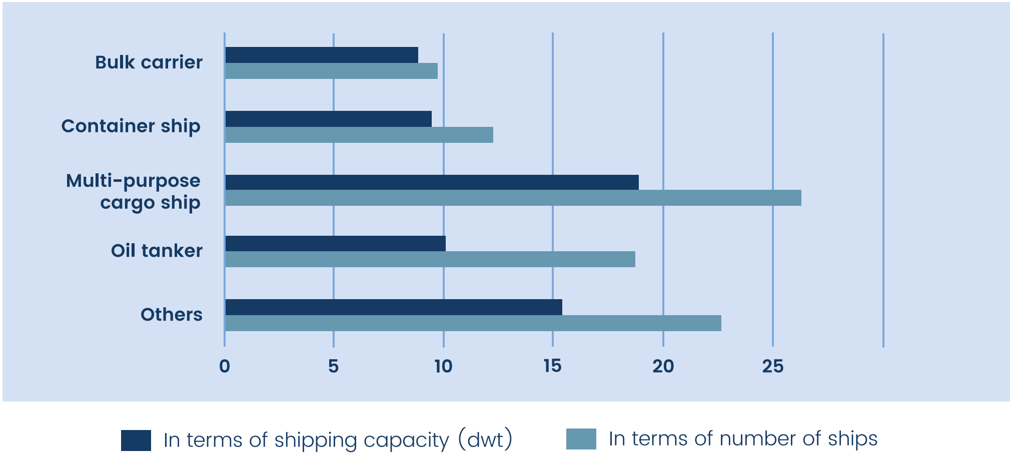
In addition, there are 4.56 million fishing vessels (2018 figures) on the oceans and seas, including more than one million decked vessels. These vessels, which are much smaller in size for the vast majority, but nevertheless motorized for 63% of them, are not the subject of this document, but their ability to integrate wind propulsion will be discussed in another publication.

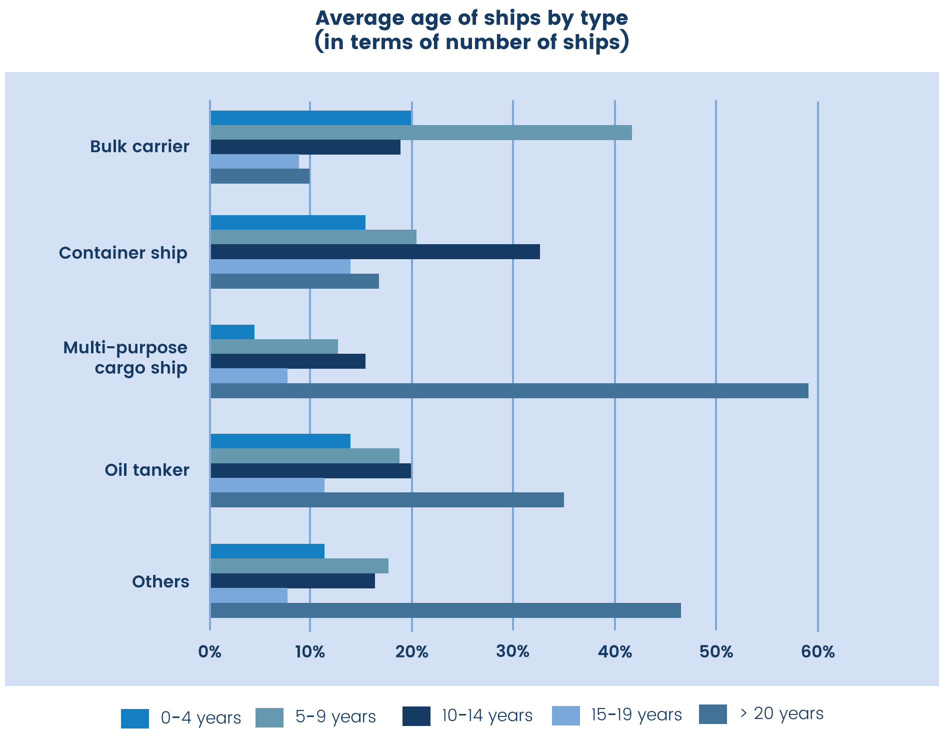
* According to the article published by Jan Hoffmann on 25 February 2020, Decarbonising Maritime Transport: Estimating Fleet Renewal Trends based on Ship Scrapping Patterns, Article No. 45 [UNCTAD Transport and Trade Facilitation Newsletter No. 85 - First Quarter 2020] consulted online on 4 November 2021

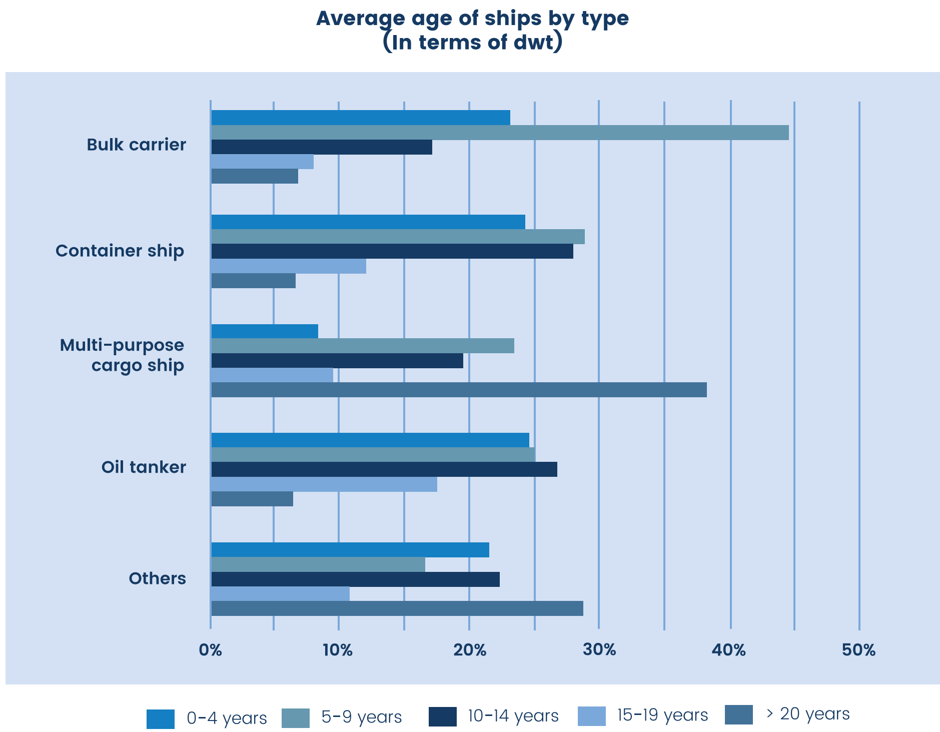
Summary tables and charts showing the average age of the world fleet

		Average age of fleet					
		0-4 years	5-9 years	10-14 years	15-19 years	> 20 years	Average age in 2020
Bulk carrier	Expressed in terms of number of ships	20%	42%	19%	9%	10%	9,69
	Expressed in terms of capacity (dwt)	23%	45%	17%	8%	7%	8,87
Container ship	Expressed in terms of number of ships	16%	20%	33%	15%	17%	12,29
	Expressed in terms of capacity (dwt)	24%	29%	28%	12%	7%	9,43
Multi-purpose cargo ship	Expressed in terms of number of ships	5%	12%	16%	8%	59%	26,3
	Expressed in terms of capacity (dwt)	9%	23%	20%	10%	39%	18,89
Oil tanker	Expressed in terms of number of ships	14%	19%	20%	11%	35%	18,77
	Expressed in terms of capacity (dwt)	25%	25%	27%	18%	6%	10,11
Others	Expressed in terms of number of ships	11%	18%	16%	8%	47%	22,7
	Expressed in terms of capacity (dwt)	22%	17%	22%	11%	29%	15,42

Average age of fleet




Average age of ships by type
(in terms of number of ships)
Bulk carrier
Container ship
Multi-purpose cargo ship
Oil tanker
Others
0%
10%
20%
30%
40%
50%
60%
0-4 years
5-9 years
10-14 years
15-19 years
> 20 years


Average age of ships by type
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Oil tanker
Others
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10%
20%
30%
40%
50%
0-4 years
5-9 years
10-14 years
15-19 years
> 20 years

The Impacts of Shipping on GHGs, Infrastructure and Air Pollutants

GHGs and air pollutants

CO_2 is the most frequently mentioned gas in terms of global warming. There are other gases than CO_2 emitted during the combustion of fossil fuels, which also have an impact on the greenhouse effect. This is the case with methane (CH_4) whose global warming power is 80 times greater than that of CO_2 on a 20-year scale, nitrous oxides (N20) and black carbon which, when taken into account, increases the total GHG emissions attributable to international maritime transport. The Fourth GHG study carried out by IMO in 2020 estimates that methane emissions increased by 87% between 2012 and 2018, due to the increase in LNG consumption in non-optimized engines (mixed fuel engines generating high specific emissions).

Concentration & massification

According to the 2020 UNCTAD report, the economies of scale obtained by bringing larger ships into service do not necessarily benefit ports and inland transport service providers, as total transport costs often increase throughout the supply chain. Often, an increase in the average port call volume or average size of ships leads to a peak in demand for trucks, storage areas and intermodal connections and makes it necessary to invest more in dredging and the purchase of larger cranes. As goods are moved by larger ships to fewer ports, often only a small number of companies operate in the sector. Cost savings achieved by shipping players are not always passed onto customers in the form of lower freight rates. This is most evident in small island developing States, which have only a few operating service providers. Additional costs must be borne by shippers, ports and inland transport service providers. In other words, the economies of scale obtained by bringing larger ships into service mainly benefit shipping carriers.

NB : The CEREMA reports illustrate the effects of dredging:
Document 1 and Document 2

Air pollutants and health

The impacts of polluted air on humans are, in the short term, reflected in an increase in mortality and morbidity in sensitive subjects, as well as the development, in the long run, of pathologies in healthy people, resulting in mortality and a decrease in life expectancy that can exceed two years. The impacts of polluted air on the environment are manifold. Under the effect of sulphur and nitrogen oxides, rain becomes acidic and alters the soil and waterways, plant and animal life are affected (decline in pollinator populations, necrosis of leaves), and the increase in greenhouse gas (GHG) concentrations in the atmosphere causes climate change which leads to global warming. This pollution has a high health cost.

According to an epidemiological study by Corbett et al.* , 2007, 60,000 premature deaths in the coastal areas of Europe and South and Southeast Asia are thought to be caused by atmospheric emissions from ships. In 2015 and 2016, the NGOs France Nature Environnement and NABU carried out a campaign to measure air quality in Marseille and demonstrated that the number of ultrafine particles near the port where a large cruise ship calls is multiplied by 20 compared to other parts of the city, and by 70 on board a cruise ship. The main pollutants with implications for health are sulphur and nitrogen oxides and fine and ultrafine particles, and for the greenhouse effect, carbon dioxide.

* CORBETT J. J. et al, « Mortality from ship emissions: global assessment », Environmental Science and Technology, 2007, December, vol. 41, No. 24, pp. 85512-8518

EEDI

The EEDI concerns all vessels over 400 gross tonnage. It has been mandatory since 1 January 2013 under Regulation 20 of the MARPOL Annex VI. It consists of a theoretical calculation outlined in resolution MEPC.212(63) which compares the ship's emissions (in grams of CO_2 emitted) to its capacity and speed, i.e. a ratio [engine power / (speed x capacity)], including correction factors related to the nature of the fuels used. This EEDI must be less than the required EEDI whose value is calculated and validated at the MEPC and which has been reduced every five years from 2013 in order to achieve a 30% improvement in 2025.

The EEDI, which sets a threshold not to be exceeded, has undoubtedly led to improvements in the design of ships, but only in part. As of 2014, many ships already complied with the EEDI required for 2020, and 34% of container ships and 43% of cargo ships met the required standards for 2030* .

As a result, the entry into force of phase 3 of the EEDI was brought forward from 2025 to 2022. Container ships with a tonnage above 80,000 dwt must even achieve an improvement of 35% and those above 200,000 dwt, 50%. A phase 4 is under discussion. This requirement only applies to vessels for which the construction contract was signed after 1 January 2013 and therefore renewal of the fleet is required for the measures to be fully effective.

Based on this:

- 7,974 out of 10,903 tankers over 4,000 dwt, are exempt from the EEDI,
- 1,220 out of 1,847 gas tankers over 2,000 dwt, are exempt from the EEDI,
- 3,777 out of 4,713 container ships over 10,000 dwt are exempt from the EEDI
- 8,523 out of 11,421 bulk carriers over 10,000 dwt are exempt from the EEDI.

All these vessels exempt from the EEDI will be subject to the EEXI.

NB : The EEDI is checked by the flag State or by an organisation duly authorized by it (a classification society) which issues the energy efficiency certificate (IEE), which the ship must present to the port State during calls in port.

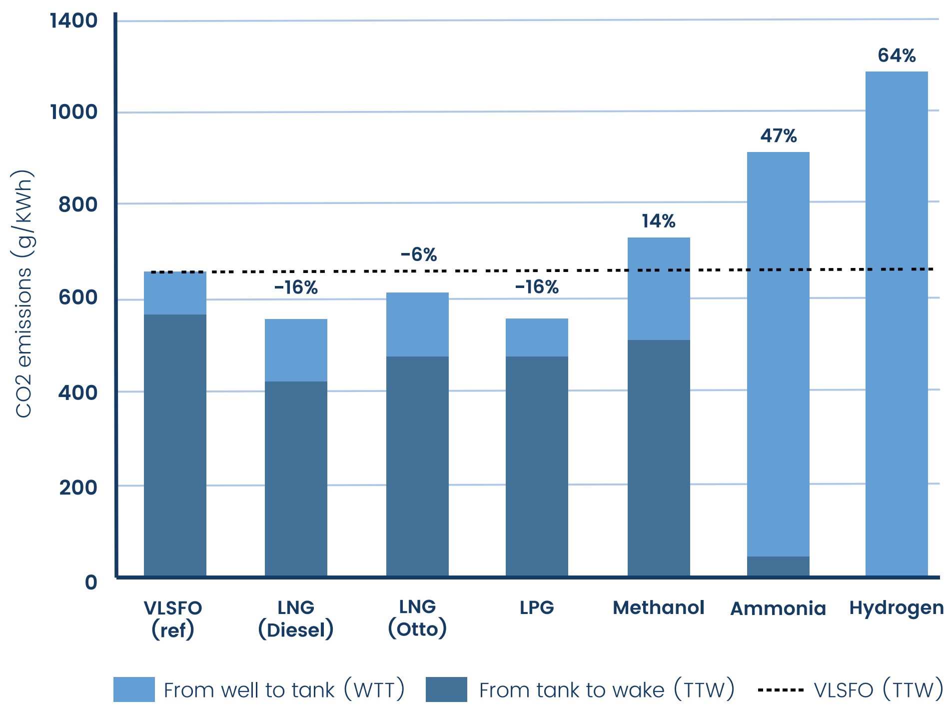
* Faber J. et al, CE Delft, Estimated Index Values of New Ships, Analysis of EIVs of Ships that Have Entered The Fleet Since 2009, March 2015

CO2 Emissions from the Production and Combustion of Different Fuels

This figure* illustrates the CO2 emissions connected with different fuels during both their combustion (from tank to wake) and their production (from well to tank). In this comparison, hydrogen was produced using natural gas and ammonia by adding nitrogen. Hydrogen intended for use as fuel is liquefied for storage. As can be seen here, the production of alternative fuel does not result in an overall reduction of CO2 emissions from shipping. It is therefore necessary to reduce a ship's energy requirement as much as possible, so that only the residual requirement must be covered by fuels.

- **VLSFO :** Very-low sulphur fuel oil
- **LNG (Diesel) :** Liquefied natural gas (at -162°C) used by a high pressure 2- or 4-stroke engine (compression ignition)
- **LNG (Otto):** Liquefied natural gas (at -162°C) used in an Otto cycle engine (spark ignition)
- **LPG :** Liquefied petroleum gas (petroleum by-product consisting of a mixture of propane and compressed butane).

CO2 emissions during the production and combustion of fuels (compared to VLSFO)



* Plevrakis G. et al., Setting the Course to Low Carbon Shipping, View of the Value Chain, American Bureau of Shipping, 2021, 76 p.

Physical Principles of Wind Propulsion

A sail-propelled vessel – sail being understood in the broad sense to include kites, wingsails, etc. – is in contact with air and water, which subjects it to aerodynamic and hydrodynamic forces that are exerted on the hull, sail and appendages (keel, rudder, etc.).

The wind picked up by the sails, wingsails or kites of a ship is directly translated by the system into lift and drag which, by a game of balance with the anti-drift plane that forms the hull – where designed to this effect – and its possible appendages, translates partly into propulsive energy. A ship is downwind when the wind is coming from astern, and upwind when it is sailing close to the direction from which the wind is blowing.

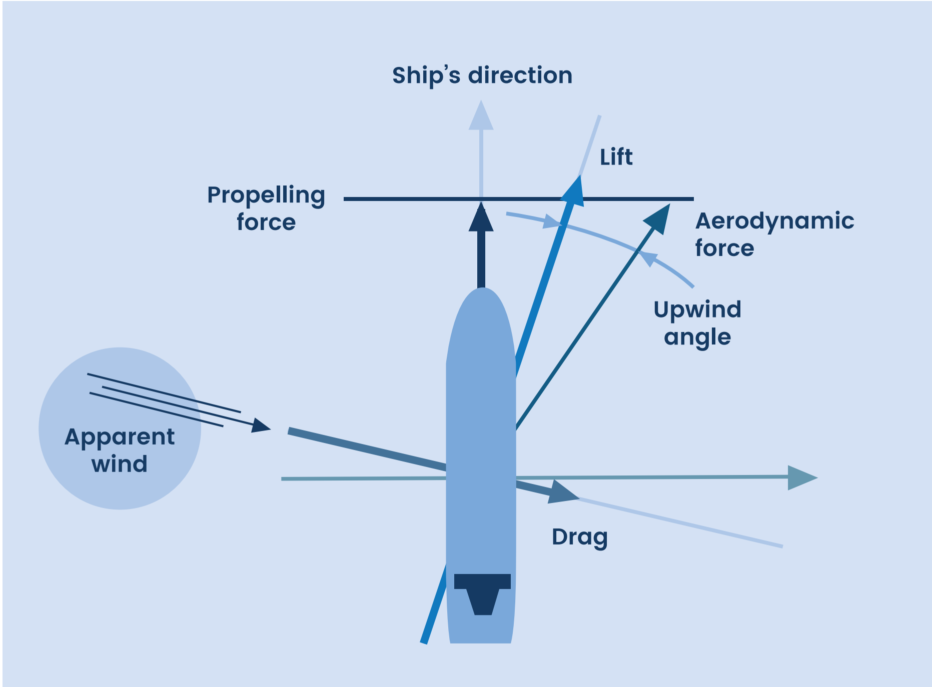
Aerodynamic principle

The wind moves air along the surface of the form provided by the sail, wingsail, kite etc. This form deflects the air particles from their initial rectilinear trajectory. The so-called "sail" force exerted on the ship breaks down into lift and drag in a system of points of sail relating to the direction of the wind.

They are described by coefficients (CD, aerodynamic drag coefficient and CL, lift coefficient).

Lift and drag are calculated by multiplying the square of the velocity, sail area, air density and the respective coefficients.

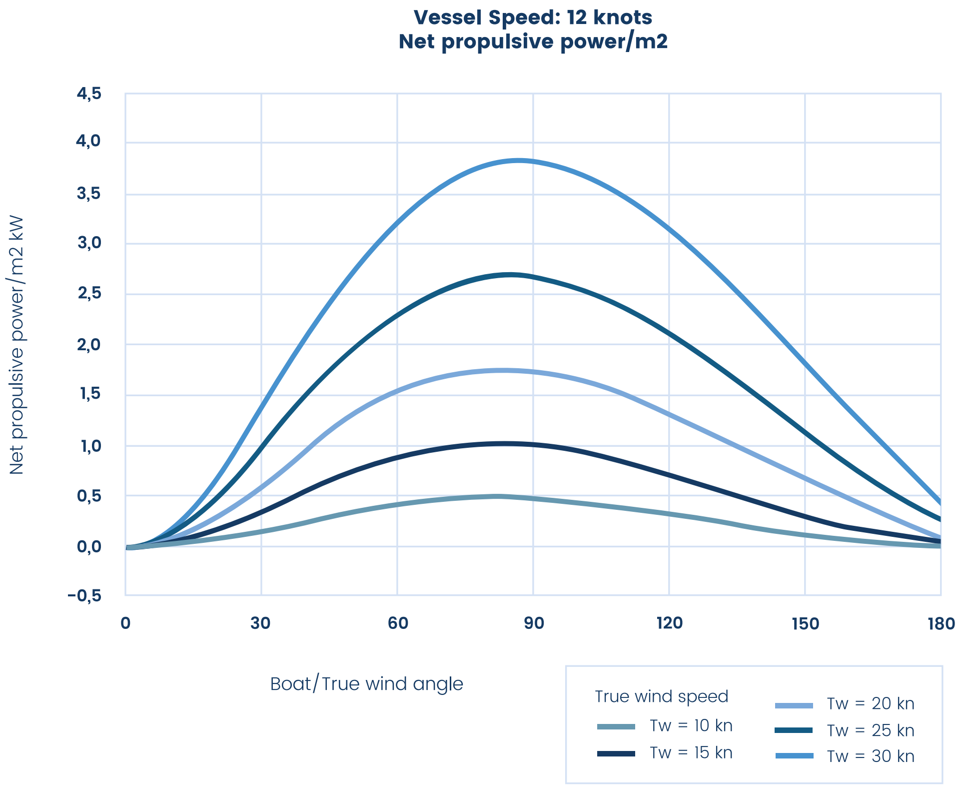
For example, a ship equipped with a wingsail of 340 m2 with a height of 32m, a lift coefficient of 1.9 and drag of 0.4 sailing at 12 knots at 70° to a wind of 23 knots (45° apparent wind of 32 knots) generates a total aerodynamic force of approximately 105 kN comprising a propulsive force of 55 kN and a lateral drift force of 90 kN.



Forces exerted on a ship

Fineness, which is the lift to drag ratio, represents the ability of the system to travel upwind. The fineness of systems varies from 2 to 8 according to their technology. Systems developing a very high force per sq. metre tend to be the least optimized for travelling upwind. High fineness is particularly suitable for ships propelled mainly by sail, or faster ships because the angle formed by the wind and the direction of the boat becomes smaller with the increase in vessel speed.

Using these coefficients, one can construct the propulsive power polars of the system, which are the curve of the propulsive power based on the angle of the boat to the wind for different wind speeds.



Example of a power polar where power is expressed per unit area

Hydrodynamic principle

As for the hydrodynamic force, it results from the friction of the water on the hull and the appendages. It is broken down into two forces, the anti-drift force and the hydrodynamic drag force.

[Propulsion, propeller and resistance]

Ships must overcome a certain running resistance or drag to be propelled.

The drag force is composed of two elements:

- Frictional resistance (which depends directly on the wet area of the ship's hull)
- Wave resistance, because the ship's motion generates a wave pattern which dissipates energy. This latter resistance is more complex to calculate, and depends mainly on the speed of the ship and the hull form (for high speeds, long and tapered hulls are better).

A ship's drag increases faster than the square of its speed. This means that to increase its speed by 20% a ship will have to increase its propulsive power by more than 50%.

For engine-powered vessels, only part of the power of the engine driving the propeller shaft is transformed into propulsive power, because part of the energy dissipates through mechanical friction, the propellers and the propeller-hull interaction. Generally, the overall efficiency between the mechanical output power of an engine and the power actually transmitted to the hull is between 0.55 and 0.65. As for wind, the propulsive power is directly transmitted to the hull, avoiding any loss of efficiency.

Of course, all of these elements are affected during navigation by sea conditions, wind and currents, which can greatly increase drag, and therefore reduce the vessel's speed. Wind propulsion can be of benefit in this regard, on the one hand, because the use of routing tools make it possible to avoid the trickiest zones, and on the other hand because sail propulsion systems can dampen the movements of a ship with the support of the wind.

Compiled Study Results on the Performance of Ships with Wind Propulsion

Scientific literature is being regularly enriched with comparative tests. However, most of this comes from tests on rotor and soft sail technologies, and occasionally kites.

The results presented below reflect only part of the technologies, tested in specific conditions.

For example, Flettner rotors have been compared to soft sail systems like Dynarigs through simulations on identical ships. These technologies lead to savings on routes and vessels where the rotor is particularly advantageous according to studies by Lu & Ringsberg (2019), Nelissen et al. (2016), and Tristan Smith et al. 2013).

Traut et al. (2014), who compared the contribution of a Flettner rotor and a kite on five routes, found that the power of the kite is greater but more variable than that of the Flettner rotor, the latter generating propulsion power over a wider range of wind directions. However, the test was for only one rotor whereas it is possible to install several, undoubtedly improving the total power of the system. The performance of Flettner rotors seems less sensitive to weather conditions, although in this study the routing had not been optimized to find the most favourable winds. A similar result is found in Nelissen et al. (2016).

Kites have a number of advantages over Flettner rotors as they can reach stronger winds at a higher altitude, thus providing more propulsion and saving more fuel. They are safer for the vessel due to a lesser impact on the heeling moment when a ship rolls, and they take up little deck space (Naaijen et al., 2006). However, this impact on the heeling moment during rolling should be studied further on real installations and in real navigation conditions.

The dimensions of rotors and wingsails can increase with the size of the ship, and therefore be more powerful. Kites only take up a small amount of deck space, which makes them particularly attractive for container ships (Nelissen et al., 2016).

Kites produce the greatest propulsive power under downwind conditions, while Flettner rotors offer more effective propulsion with side winds (De Marco et al., 2016; Leloup et al., 2016; Lu & Ringsberg, 2019; Nelissen et al ., 2016; Ran et al., 2013; Traut et al., 2014).

Although absolute fuel savings increase for rotors and wingsails as vessel speed increases, relative fuel savings decrease. Indeed, at higher speeds, the engine power demanded by the ship has a greater effect on the fuel consumption than the contribution of the rotors or the wingsails (Lu & Ringsberg, 2019; Nelissen et al., 2016; Tristan Smith et al., 2013). Kites generate more absolute savings at lower speed than rotors (Nelissen et al., 2016; Ran et al., 2013).

Wind Modelling in International Regulations

Wind modelling for the purpose of international regulations continues to focus on calculations rather than a “realistic” vision of the wind.

During the 62nd Environmental Protection Committee in May 2011, the MEPC.62/INF34 document was shared to clarify wind probabilities for the main shipping routes.

This document was written with the aim of estimating the propulsion power of wind propulsion systems, to calculate the EEDI value required for ships under Regulation 20 of Annex VI of the MARPOL Convention.

For this, the main world maritime routes were charted. These are not routes connected with wind-propelled navigation, but orthodromic or great-circle routes, (i.e. the shortest route on the surface of the earth between two points), followed by merchant shipping for a century.

On this map of major shipping routes, wind condition charts were constructed, based on 868,500 individual wind data from WetterWelt, 2011. For each point, a probability of wind speed and direction relative to the course of the vessel was estimated and placed in a matrix which now serves as the basis for the calculation of this EEDI index.

This document concludes that on these maritime routes, the winds mainly have a headwind or downwind orientation, with a higher probability (>10%) of a speed between 4 m/s and 8 m/s (force 3 to 4 Beaufort). These results are extremely general as they are statistics applied to routes which have not been optimized for wind propulsion. They make it possible to estimate an energy efficiency index of the ship’s design but cannot be used to reflect the operational reality of the wind conditions encountered at sea.

Territorial Waters, Ports & the French Fleet

As of 1 January 2020, France occupied the 28th place among world fleets – it represents 0.4% of world tonnage, and ranks 12th among European fleets (ranking by flag).

It includes 190 shipping vessels (oil, gas, cargo and passenger vessels) and 233 vessels linked to maritime services (i.e. specialised, offshore and port vessels) with a tonnage greater than 100 (expressed in UMS). Half of the shipping vessels are registered in the French international register (French Flag RIF) while half of the service vessels are registered in the mainland France register, with the overseas France registers listing 20% of shipping vessels and 6% of service vessels.

The French shipping fleet is relatively young with an average ship age of around ten years – the European and world average is 15 years – but shows disparities between relatively young oil, gas and container ships, and older passenger ships.

The ports along the French coasts saw the transit of 307.7 million tonnes of goods in 2020, which was 13% less than in 2019 (354 million tonnes) due to the combined effects of social unrest in late 2019/early 2020, then the two waves of the coronavirus pandemic, BREXIT before the agreement signed in December 2020 – and finally a low cereal harvest in 2020.

For comparison, the port of Rotterdam saw the transit of 436 million tonnes, that of Antwerp 230 million and that of Hamburg, 126 million in 2020. The ports of Ningbo, Shanghai and Qingdao in China welcomed 1,414 million, 651 million and 605 million tonnes of goods respectively, closely followed by Singapore in Malaysia (590 million tonnes) and Busan in Korea (411 million tonnes).

Container traffic is relatively low in France compared to ports in Northern Europe. It remains mainly concentrated in the Seine valley with 2.4 million TEU for Haropa (Port of Le Havre) where 22% of the traffic is with China, and Marseille (1.3 million TEU, mainly from traffic with the United States and Algeria).

Overseas French ports are strategically placed to supply the local market with manufactured products and basic necessities, and have the potential to become regional hubs that shipping lines can use for transhipment.

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6. These results are based on a ship-based distribution of emissions. Another assessment estimates the distribution of emissions by travel and excludes emissions from domestic shipping, which gives the figure of 740 million tonnes of CO2 in 2018 against 701 in 2012, i.e. an increase of 5.6%.

7. Figures taken from the European Commission's annual report on MRV, 2019 Annual Report on CO2 Emissions from Maritime Transport, C(2020) 3184, European Commission, 19 May 2020, 5 p. see p.3

8. Carbon intensity improved by around 23.6% when considering the annual efficiency index (AER, i.e. GHG emissions compared to the theoretical quantity of goods that the ship can transport), or 33.3% when considering the operational efficiency index (EEOI i.e. the GHG emissions related to the actual quantity of goods that the ship has transported).

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13. MARPOL, Chapter 4, Reg. 19, Paragraph 3.

14. Maersk Mc-Kinney Moller Center for Zero Carbon Shipping, Industry transition strategy, October 2021, consulted online on 5 November 2021

15. Draft FuelEuMaritime proposal, quantifying the risk of a climate and environmental disaster in the making, Transport & Environnement, June 2021, consulted online on 5 November 2021, see p.5

16. Krantz R., Søgaard K., Smith T., The scale of investment needed to decarbonise international shipping, Insight brief, January 2020, consulted online on 5 November 2021

17. The difficulty with fuels produced using green energy lies in particular in the low yield of the production chain; ADEME has identified overall yield as 25% or even 30% on the hydrogen chain from the source to hydrogen use in fuel cells.

18. Adamopoulos A. et al., Decarbonisation, a special report, Lloyd's List, 2021, 30 p., consulted online on 5 November 2021, see p.18

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20. Bureau Véritas has validated the proposed design for Trade Wings, a container ship of 196 metres long with six thick sails, intended for cabotage of 2500 TEU, while Meltem (1830 TEU) will be 185 metres long with eight thick sails, see the article consulted online on 5 November 2021

21. It can be visualized through interfaces like the one proposed here which allows visualization of global weather conditions predicted by supercomputers and updated every three hours.

22. At global level, fixed-grid or variable-grid global models are used. They are more accurate in certain geographical areas (for example the Arpège model has better sensitivity in France than in Australia), hence the interest in comparing models according to the area considered. Temperature and precipitation are easier to predict than wind, but today's models are of very good quality.

Short-term forecasts are based on either deterministic or probabilistic models from atmospheric observations. In the first method, the idea is to determine a value per geographical point. In the second, which has been for about the last ten years, the idea is to display a level of uncertainty around a value (this is referred to as the value's risk threshold); for example the probability of having a higher wind at 20 knots in this area is greater than 80%.

23. A number of ships take part in these surveys at sea by releasing balloons on behalf of Météo France.

24. Marin Blue Route application : https://blueroute.application.marin.nl

25. Satori : https://satori.d-ice.net

26. DNV GL – Maritime, Assessment of selected alternative fuels and technologies, June 2019, ID 1765300, consulted online on 5 November 2021

27. This was estimated as part of a study conducted by Chalmers University of Technology (Olsson & Carlsson, Sweden, 2020) on a wind-propelled vessel intended for the shipping of vehicles. Methods related to life cycle analysis (in accordance with ISO 14040/2006) and cost are applied by comparing the performance of the wind propelled ship with the performance of the same hull propelled only by LNG, biogas or biomethanol. In this study, the installation of wind propulsion systems entails a higher initial investment, as well as higher GHG emissions during the construction and dismantling phase than for a vessel without wind propulsion. However, it is the ship's operation phase that accounts for 99% of GHG emissions. The reduction in fuel consumption during operation (80% in this case) therefore leads to financial and environmental gains that place wind propulsion in a much better position than ship configurations using LNG, biogas and biomethanol. In terms of reducing emissions, the study shows that biomethanol could compete with wind propulsion, but the associated cost is extremely high (3 to 10 times higher).

The propulsion system life cycle analysis here considers steel-built wings. Upstream emissions come from the production of this steel, which gives a high emission factor, but which is decreased due to its high recyclability (estimated here at 81%). The ship service life is considered as 30 years, sailing at 8 or 11.4 knots.

In this study analysing the life cycle of a ship equipped with a wind propulsion system, wind constantly comes out as a first-choice solution.

28. The 1978 International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, or STCW.

29. The DIGI4MER project in which this training reference system is being developed is financed under France's third "Investments for the Future" Programme (PIA).

30. Chou T. et al, D 5.B New Wind Propulsion Technology, A Literature Review of Recent Adoptions, Interreg North Sea Region WASP, 24.09.2020, 32 p., consulted online on 5 November 2021, see p. 18 to 20

31. Nelissen D. et al., Study on the analysis of the market potentials and market barriers for wind propulsion technologies, CE Delft, November 2016, 127p., consulted online on 5 November 2021, see p.7

32. Bell M. et al., Reducing the maritime sector's contribution to climate change and air pollution, Economic opportunities from low and zero emission shipping. A report for the Department for Transport, Frontier Economics, July 2019, 51 p., consulted online on 5 November 2021. See p.44.

33. Sirimanne S.N. et al., Résumé de l'étude sur les transports maritimes de 2020, CNUCED, 2020, 17 p., consulted online on 5 November 2021, see p.13 Review of Maritime Transport 2020, UNCTAD https://unctad.org/system/files/official-document/rmt2020summary_en.pdf

34. Shipping Market Review, Danish Ship Finance, November 2021, consulted online on 6 November 2021, 63 p., see p.10

35. It would, however, be interesting to have this data for the other French overseas territories, which make heavy use of maritime transport.

36. The reference framework known as the "Poseidon principles" was established at the initiative of banking institutions in June 2019 to integrate the climate dimension into their decision-making criteria for the financing of maritime transport. These principles should enable financial institutions to align their ship finance portfolios with responsible environmental behaviour and encourage the decarbonisation of international shipping. They were signed in particular by BNP Paribas, Bpifrance, Société Générale, Crédit Agricole, CIC and Crédit Mutuel Alliance Fédérale.

37. Example from the 2019 MRV monitoring implemented by the European Commission since Regulation 2015/757.

38. Smith & al., Wind Technologies: Opportunities and Barriers to a Low Carbon Shipping Industry, UCL& Carbon War Room 2017 (Marine Policy 75 (2017) 217-226

39. Bilan thématique Navire, Edition 2020, Thematic review of the Investments for the Future Programme (PIA), Reference 010931, consulted online on 5 November 2021

40. NaMKü scheme for the modernization of coastal vessels presented by the Federal Ministry for Transport and Digital Infrastructure. Guideline on promoting the sustainable modernization of coastal vessels.

Harnessing the wind to propel merchant shipping vessels is a solution that is already available to significantly improve the carbon footprint of shipping, which is responsible for 3% of global greenhouse gas emissions today.

France has a technological lead and a favourable ecosystem that could quickly transform into an outstanding industry with appropriate public and private support.

As the race to decarbonise the economy is underway worldwide, the French offer must therefore stand out quickly and strongly to create jobs and contribute significantly to cleaner maritime transport.

Wind Ship invites you, with its white paper, to discover the fundamentals of wind propulsion for ships – a valid and efficient technological answer that is available today to ensure the sustainability of shipping.

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