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ECEE

2015

Hybrid sailing to reduce the use of fossil fuels in the maritime transportation sector.

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June 2015

4-208-15_Bonduelle

Hybrid sailing to reduce the use of fossil fuels in the maritime transportation sector

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Text Accepted for presentation at European Council for an Efficient Energy Economy (ECEEE) university, June 2015

Abstract

Keywords: shipping, innovative technologies, low carbon targets, co-benefits, wind propulsion

Oil consumption is a challenge for the international shipping industry, both as an economic burden representing often over half of operating costs, and as a source of GHG emissions and pollutants. Many recent projects aim to replace part of this fuel, through the use of gaseous or other alternative fuels or even solar panels. An ancient technology is also regaining more attention: the mechanical use of wind thrust in WASP (Wind Assisted Ship Propulsion), bringing the prospect of adopting Renewable Energy in a sector dominated by oil products

The paper reviews the technical innovations that enable wind propulsion again as an interesting complement to traditional fuels. These consist of automation of sails or other technologies to convert wind force to propulsion, but also routing systems which now allow optimization of the operation of transport lines and generally automation and information systems. Several systems are now operational but their economics have not been demonstrated yet.

Then hypothesis are discussed of possible savings and drawbacks of options to compare hybrid sailing solutions with other alternatives parameters of freight transport. For example, the case of a calculated economic balance of a medium size ship (3 000 tons) transporting bulk freight, could bring fuel savings between 15% and 35% in well-chosen routes.

Then elements of a roadmap are developed, in order to make such developments possible. This comprises both evolutionary developments from existing systems and commercial practice. Some possible innovations allow more routes or freight types to be transported with sails in the future. They may extend the use of sails beyond niche markets such as “zero carbon” commodities, or the service of remote islands and shores not connected with major shipping routes.

The paper relies on work in progress in the course of the SAIL project. SAIL (Sustainable Approaches and Innovative Liaisons) is a European INTERREG program linking research teams, harbours, NGOs and freight professionals across the North Sea Region, in particular from The Netherlands, Germany, Belgium, France, Sweden and Denmark. It will end by mid-2015. It is led by the Fryslan Province (NL). The authors in the E&E Consultant team (Cassel, France) are involved in economic evaluation in the project.

Introduction

The International Maritime Organisation's Third GHG Study 2014 (Smith et al., 2014b) shows that between 2007 and 2012 the world's marine fleet consumed between 250 and 325 million tonnes of fuel, accounting for approximately 2.8% of annual global greenhouse gas emissions (3.1% of annual CO_2 emissions). The sector is also responsible for 92% of global SO_2 emissions and 20% of global NO_X emissions. In addition to acid fumes, the fuel commonly used for the propulsion of commercial ships is particularly harmful as its combustion emits more black carbon aerosols than most other fossil propellants. Because they rely mainly on heavy fuels of the worst kind, maritime emissions will soon be the first source in Europe for sulphur and NO_X, before industries. Thus, emissions from the shipping sector need to be deeply reduced in order to reduce air pollution. The International Convention for the Prevention of Pollution from Ships (MARPOL) has stipulated mandatory technical and operation measures which require ships to be more efficient in energy use and emissions reduction. These regulations came into force in 2013 (CNSS, 2014). The industry itself has targets to reduce carbon dioxide emissions by 20% by 2020 and 50% by 2050.

Currently shipping has a negative impact on climate change due notably to the high sulphur aerosol content of its emissions. Maritime bunkers are not included in existing legislation such as the Kyoto Protocol and neither will they be in the near future. But the issue of climate change cannot be avoided, notably because future propulsion means will have to reduce radically their emissions.

The European Union wants a global approach taken to reducing emissions from international shipping. As a first step towards cutting emissions, the European Commission has proposed that owners of large ships using EU ports should report their verified emissions from 2018.

A paradox of maritime shipping is the use of the most polluting fuels in one of the less carbon-intensive transportation means. Policies that call for a reduction of the ecological footprint of global trade might further increase the volume of maritime shipping: many large corporations are already committed to increasing their relative use of rail and barge services for environmental and economic reasons. Maritime transport can thus be seen with different perspectives:

- It is the main vehicle of globalization, a process which has large consequences on global emissions, both direct and indirect, positive and negative (Peters 2010).

- Shipping is the most efficient transport mode per ton transported, even assuming no new technologies in propulsion, logistics or port systems.

- The cost of energy is a key factor for this industry because oil weights in the variable costs up to 50%, but also because of impacts on demand for transport. Oil price fluctuation in most parts of the world impact volumes transported by shipping (Chen & Hsu 2012), and such rapid variation in traffic induce large swings in the business and by consequence in the rhythm of new constructions.

These constraints impose pressure for changes on a profession with limited ability to absorb new technologies. This diagnosis is shared by the mitigation panel of the IPCC in its fifth report (Edenhofer et al. 2014), which insists that, in the present context of transport, implementation of alternatives is difficult, and total mitigation potentials are very uncertain. The Panel suggests that liquid fuels, including some biofuels, and gaseous alternatives will power the bulk of ships in the next decades. IPCC rules out nuclear for reasons of costs, and suggests in the long run the development of fuel cells combined with electric transmissions, supplemented by photovoltaics (PV) or small wind turbines for on-board electricity. PV is already in use in very small crafts for propulsion.

On efficiency potentials, the Panel lists innovations for new built vessels, through changes in engine and transmission technologies, waste heat recovery, auxiliary power systems, propeller and rotor systems, aerodynamics and hydrodynamics of the hull structure, air lubrication systems, electronic control systems of the engines to determine fuel efficient speeds, and weight reduction. Maintenance measure and some retrofit, such as antifouling coatings to cut water resistance, could also provide significant improvements.

Both categories could bring 5-30% gains. In all, for international shipping, combined technical and operational measures is estimated by IPCC to potentially reduce energy use and CO2 emissions by up to 43% per ton ‐ km between 2007 and 2020 and by up to 60% by 2050.

The IPCC also for the first time acknowledges the existence of sail alternatives (Simms et al. 2014). It notes that: “wind propulsion systems such as kites and parafoils can provide lift and propulsion to reduce fuel consumption by up to 30%, though average savings may be much less (Kleiner 2007). This is the issue addressed by the present paper.

Technical Innovations for Sailing Propulsion

Incremental, radical innovations and hybridisation

Wind propulsion is only one among many options to hybridize maritime transportation: fuel substitution (with hydrogen, LNG or bio-gases), and for more localized and small scale use, the energy of a solar or battery-powered engine, are all means to hybridize maritime freight shipping (Royal Academy of Engineering 2013)

But these solutions are not mutually exclusive: an LNG fuelled engine, for example, can be coupled to a wind propulsion device to create a Wind Assisted Sailing Propulsion (WASP) ship (Bows & Smith.2012).

Furthermore, even better but limited energy efficiency could be reached with such a ship through additional minor changes on-board: propeller polishing, water flow optimization, hull coating and cleaning, waste heat reduction, reliance on the auto-pilot and weather routing. Incremental innovation can help to sustain the old regime (‘sailing ship effect’) by defending it against a new development or it can provide opportunities for further change (‘stepping stone dynamic’).

Past technological transitions and the sailing ship effect

The patterns of the competition between high carbon emitting technologies and new green radical or incremental technologies are informed by the socio-technical transitions literature (Geels, 2002, 2005; Grin et al., 2010; Bergek et al.,2013; Smith 2010, 2014a; Schenzle 1985)

There is a small recognition that renewable energy technologies could transform the global shipping fleet again, at all levels and scales (Mofor et al., 2015) but it remains very unclear how and when. The possible transition in the shipping sector is interesting for other sectors. Indeed, there is a debate amongst academics but with wide business implications about the ‘sailing ship’ effect popularised by Geels (2002) or Howells (2002): the ‘last gasp effect of obsolescent technologies’ would occurs where competition from new technologies stimulates improvements in incumbent technologies/firms. Sails were replaced by engines in a century time but change was not smooth but followed a series of energy crises and shipping booms.. This story shows how competing technologies can outlast their perceived economic life (Grübler 1991). Wind propulsion has dominated the history of shipping from approximately 5400 BC to the end of the XVIIIth century. Sail shipping was far from obsolete at the beginning of the XXth century. It only completely disappeared from global trade at the beginning of World War II, in 1940, at a time when steamships were themselves made obsolete by the increasing domination of motor ships. In fact, the various improvements in sailing ships which occurred all along the XIXth century are a good example of the general pattern that established technology improves when it is challenged by a new technology (Grübler 1990).

The first answer of sail ship operators was to shift their focus from transporting passengers and high-value goods to goods where speed was not such an important criterion. Wind powered ships also used the competitive advantage they had as they were relying on well-known technology and adapted infrastructures. During the first decades following their apparition, steam engines were mainly considered as a mean to improve existing sailing ships. The first steam engine equipped boat to cross the Atlantic in 1819, The Rising Star, was mostly a sailing vessel equipped with an auxiliary steam propulsion device. Steam propulsion rapidly became the norm for inland waterways, but it was seen too risky to sail the ocean with a steamship until 1835. So at first, steam propulsion was mainly used to raise the security on-board – by making ships more manageable in case of storm – ensure more precise estimated times of arrival (ETA), raise the ships' average speed and ease movements at ports. But apart from these exotic hybrid ships, sailing ship builders improved ships impressively: in the 1850's in Great Britain, iron started to replace wood as the main construction element allowing the building of larger ships. American ship builders remained faithful to wood but were the first to design the fastest merchant sailing vessels of the XIXth century: the famous clippers, 60 to 70 m long, built for fast speed rather than cargo capacity, associating a large sail surface to a small hull. These ships benefited from the best technology of the time and became a new standard for freight shipping between 1840's and 1870's. And when ocean steam boats were finally technologically ready to conquer international trade, from the 1870's, clippers opposed a strong competition. Their speed, security and reliance were truly holding the comparison against steamships' new standards. And the pressure put on the market by the invasion of steamships triggered further improvements of clippers. The multiplication of masts and sails became common-place as the hulls were elongated to the maximum, thanks to metallic structures, to extend cargo capacity.

Early steamships (the golden age of steam shipping having last from the 1880's to the 1930's) still needed numerous and skilled crews to be safely operated and could rapidly become dangerous in case of bad weather. A new generation of wind ships, the windjammers, was developed from the 1870's as a complement to clippers. These steel or iron made sailing boats, reaching more than 140 m in length, were the last card of sailing ship builders. They were adequately completing the clippers' speed with high cargo capacity and they occupied a niche in the transport of low-value bulk cargoes of little interest to steamship companies, e.g., lumber, coal, guano or grain from the 1870's until the beginning of the 1920's.

Finally, several drawbacks of sailing ships could not be solved through the optimization process that maintained wind propulsion at a competitive level all along the era of steamships. In particular, low speed, imprecise ETA, need for large crews of skilled sailors, excessive heel angles, limited mechanical power on board and high servicing costs. This last one was central, because big sailing ships needed constant maintenance services and a large inventory of parts, sails and ropes. The emergence of new materials in the last decades changed the resistance to wear, maintenance and the lifetime of equipment which is still one large unknown in the new generation of wind ships.

Enabling technologies for wind

Technologies have evolved since the decline of sails over a century ago.

- First, new synthetic materials and improvements in all mechanical and wear resistance of all parts of the ship is of course one important new enabling technology. Carbon masts or Mylar sails are expensive but would last much longer than traditional materials. Such materials have also a better predictability to wear.

- Second, mechanization determines crew size. Sails mechanization (such as motorized winches, sheets, halyards, furlers...) is now well established. These motorized adjustments are now manageable from a single dashboard to drastically reduce the need for crewmen, even in a traditional sail configuration.

- Third, the information systems allow constantly adapting the ship's itinerary to weather conditions by weather routing. Adapting the sport sailing motivated weather routing systems to needs for commercial shipping may be one option. On-board route optimization solutions can integrate wind patterns given on long periods by climate data with present short term weather forecasts, in order to minimize travel times or fuel use.

In addition to these innovations, the propulsion itself, consisting of the action of wind on a sail and the reaction on the hull, is now widely different, either by the principles involved, or the ability of builders to predict the performance and build in consequence. Such principles are described in the next part.

Wind Propulsion Technologies

Technologies come with widely different credibility and history. At extremes, the traditional square rig has millenary tradition; the Cousteau turbo-sail is just a prototype anchored in the harbour of Caen (F)), while tethered balloons carrying wind turbines above the ship are mere proof of concept. In some cases, the retrofit is possible on existing hulls. The techniques are also more or less versatile and manoeuvrable so as to be adapted to long distance trade routes or to more local use. Finally, only a few of the proposals, in particular the kites, could be adapted to relatively large ships with a benefit for propulsion.

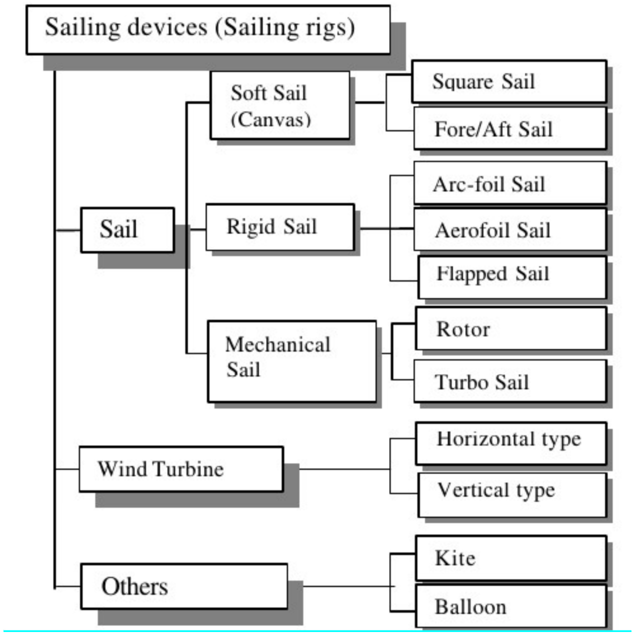

Figure 1: ***An organogram of the various wind propulsion technologies.*** *Source: Yoshimura, Yasuo, 2002, « A Prospect of Sail-Assisted Fishing Boats », Fisheries Science, 68(Supplement 2): 1815-1818*

The main types of wind propulsion systems are presented below (Trouvé 2013): traditional sails, wing-sails, Dynarig, Flettner rotors and Cousteau turbo-sail, Towing kites. Four main practical options are presently:

- Existing traditional sails used in present cargo sailing vessels. Fairtransport BV trading and shipping (NL) uses a three mast ship of 32 m to trade chocolate and rum from the Antilles to Amsterdam. The Greenhart project aims at servicing places with no harbour and small needs, such as islands in the Southern Seas or shores in Africa. The “Undine of Hamburg” transports goods from the ports of Flensburg to Sylt Island.
- More recent developments are wing-sails (rigid or soft sails with the shape of a plane wing) or the Dynarigs. These are fully automated square rigs where sails are folded parallel to the mast (Dykstra, 2013). The Maltese Falcon, a luxury yacht, uses fully automated Dynarigs.
- The Flettner rotor creates a force by the rotation of a vertical cylinder and the friction on air (Traut et al. 2013), while the Cousteau Turbo-Sail removes turbulence of a wide vertical wing with the injection of air in holes on the side of a fixed vertical wing. Enercon’s 12,800 tons ‘E-Ship 1’ is the most famous example of the use of Flettner rotors. However, the economics are difficult to apprehend due to the lack of public data. According to Lloyd's Register (2015), experts of Lloyd’s Register currently participate in 5 Flettner rotor projects.
- Finally, other more exotic propulsion systems include the kite sails which were tested on the MS Beluga. The commercial Skysails propulsion system had limited success to date.

Mofor et al. (2015) published a section on performance and costs of WASP technologies and order of magnitude of fuel savings. The report also proposes a summary of renewable energy applications and their potential for shipping. The main conclusion of the technology brief is that “For quick-win solutions, support should focus on small ships (less than 10 000 dead weight tonnes), which remain more prevalent around the world, transporting less of the total cargo but emitting more greenhouse gasses per unit of cargo and distance travelled, compared to larger ships”. The economic analysis suggests that even smaller ships could be interesting economically.

Specificities

These sail types are applicable in different situations and have different demands on the ship design compared to no sails and among each other. They concern of course the efficiency of propulsion in low or strong winds, but also notably the deck, the hull, the retrofit option or the engine combination.

- Hull : The types differ in the maximum ship speed which can be reached with them and the efficiency with respect to the apparent wind angle (angle between ship movement direction and wind). Also the structural integrity of the ship’s hull and the stability of the ship need to be considered. For the optimal yield of the sails, the vessels hull needs to be optimized for the sail type. Strong side forces act on ships equipped with Bermuda sails or square rigs. In order to reduce leeway drift a deep keel or submersible swords on both sides are needed when these sail types are installed. In contrast, Flettner rotors are favourable on ships with a flat wide hull. For this criterion, kites are less interesting because they cannot go against the wind.
- Deck space: Masts are obstacles during the loading and unloading process. While kites can be removed completely, masts commonly remain in their place. The presence of a sailing rig on the deck of the ship complicates or restricts crane movements. The problem is less pronounced for bulk cargo, such as coal or ores[1]. Loading and unloading on Roll-on Roll-off (RoRo) carriers and tankers is not affected by sailing superstructures. However, security reason may speak against sails on these two ship types. RoRo carries should have a low healing angle while Bermuda sails or square rigs may cause high healing angles. Flettner rotors are more appropriate for them.
- Retrofit: One important advantage of the kite is that it could in theory be retrofitted to most types of ships. This gives the kite an edge for implementation on a fleet that is rather slow to renew.
- Auxiliary Power: Ship’s main engine is optimized for one loading range – such as between 70% and 80% of loading – in which fuel consumption per produced Joule of propulsion energy is minimized. Sailing vessels have a variable need of propulsion energy which causes a traditional diesel direction engine to often run outside of is optimal range causing increased fuel consumption. Hull shape and engine layout can be optimised for sails of a certain type when a new ship is designed and built. Therefore, retrofitted ships may not utilise wind power as efficient as new builds.

This would go well along small auxiliary propulsion devices, based notably on electric propulsion, which are more adapted for variable regimes. These propulsion systems can minimize the unpredictability of ETA and help in case of emergency. Such decentralized power systems, now in wide use, make it possible to avoid altogether the installation of a large power system.

All these characteristics impact on performance, investment, operations and maintenance. In addition, when designs are established, standards and insurance practice will depend on the risk history and thus the initial design choices.

Estimating the gains of sails

Within the SAIL project, some European and one transatlantic shipping routes were analysed with respect to possible fuel savings and emission reductions through wind propulsion techniques. For this purpose, an open source programme was created which calculates power savings based on wind data (Publication in Preparation).

The programme currently undergoes a validation process against detailed voyage simulations based on ocean currents, wave and wind data (Grin et al. 2005). First results indicate power savings between 15% and 35% at 11 knots speed, as illustrated in Figure 2. This example shows preliminary calculations of relative gains on two different routes for one sail type, still to be validated. Routes with constant wind angle and constant presence of wind are favourable for sail-only vessels, even if the wind speed is low. These preliminary results within the SAIL project show that hybrid freight sailing vessels with fixed minimum target speed need a minimum wind speed for effectively using wind propulsion. Thus, one day

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[1] Bulk carriers are also favourable for sails with respect to ship speed because they travels with lower speeds (10 to 14 knots) in contrast to container vessels (20 knots).

of strong wind and two low wind days may be more favourable than three days of low wind conditions. However, results and inferred recommendations depend on sail type and target speed of the vessel. In the same way, fuel and emission reduction cannot be scaled linearly with power savings, mainly because the propulsion is hybrid. If ship engines do not run on optimal loading range the fuel consumption per Watt on the shaft increases. Engines of new built wind ships may be may be adapted to fluctuating propulsion power needs while engines of retrofitted ships probably are not adapted (e.g. fig 15 in CNSS (2014)). Additionally, not the whole energy generated is used for propulsion but for other processes, such as lighting, cooling or heating. Therefore, exact conversions from power to fuel savings can only be performed on individual ship and route level. Some emissions linearly depend on fuel consumption, such as SO2 emissions. Other emissions, such as NO_X emissions, depend on the availability of air during the combustion process and on the combustion temperature. Again, individual ships need to be considered here for detailed conversions. To get a rough idea, one may assume a linear dependency and come to 15% to 35% of fuel savings and emissions reductions. This range overlaps with detailed voyage simulations performed for the Ecoliner by Dykstra Naval Architects (Dykstra, 2013).

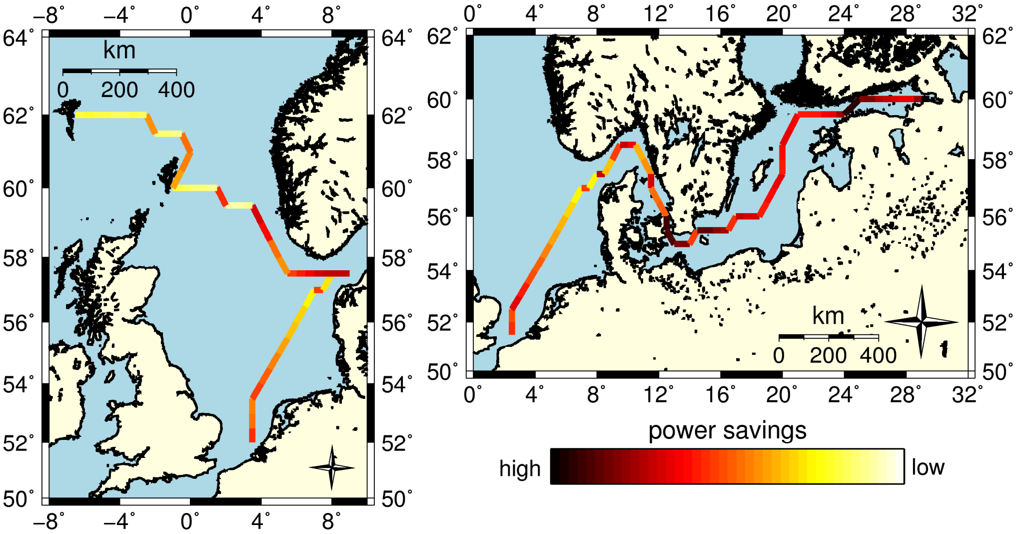

Figure 2: Two sample routes show relative power savings within segments of each journey. Calculations were performed for one sail type. Absolute gains depend also on hulls, aerodynamics, and present weather situation. Fuel savings would additionally depend on the main engine setup.

Within the sail project, bulk carriers of a gross tonnage between 3,000 and 10,000 were considered to be the first ships to be equipped with sails.. Travel speed of these bulkers is around 12 knots which seems to be a sensible target speed for sailing vessels. Ships travelling with 20 knots and more cannot be propelled effectively by current sail systems. Based on AIS (Automated Identification System[2]) data and a calculation approach presented in Aulinger et al. (2015) the emission reductions by equipping all of these small bulkers with sails were estimated. Even in the best case of 35% power reduction by sails, the overall reduction (compared to all ships of all size classes) of NO_X, SO_2 and CO_2 emissions in the North Sea region is below 0.1% (see Table 1). This figure is mainly due to the limited market for this early niche of WASP. In particular, it is still of limited value when compared for example to emission reductions through different fuel use and exhaust gas cleaning scenarios presented in Matthias et al. (2015).

Table 1: Provisional estimates of fuel savings and emission reductions assuming 15% (=minimum) to 35% (=maximum) of propulsion power savings by sails and a linear relationship between power production, fuel consumption and emissions. Bulk carries of a gross tonnage between 3,000 and 10,000

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[2] The AIS (Automated Identification System) is a vessel tracking system. Each vessel with a gross tonnage over 300 on international voyage is obliged to be equiped with an AIS transreceiver. Regionally, such as in EU waters, also smaller vessels of certain types have to be equipped with AIS transreceivers. The AIS broadcasts a vessel's localtion, its course, size and further information to surrounding receivers.

are considered to be equipped with wind propulsion devices. Ships of other sizes or types are assumed to be unmodified. 'Relative reduction' refers to all shipping emissions in the North Sea region.

Species	absolute reduction [tons]		relative reduction [%]	
	minimum	Maximum	minimum	maximum
Fuel	3,143	7,333	0.043	0.100
NO_X	233,666	545,220	0.043	0.101
SO_2	50,516	117,870	0.041	0.096
CO_2	9,955,190	23,228,776	0.043	0.100

In a developing country context, conforming with (S)ECA (Sulphur Emissions Control Areas) thresholds is less relevant. Instead, the lacking availability of fuel and fuel costs are reasons for employing sails. In this context, financing sailings vessels does not rely on private investors but rely on international mechanisms, such as public aid (ODA) from the Green Climate Fund or new (market) mechanism building on carbon finance such as the Technology Mechanism and evolutions from the Kyoto Protocol's CDM - Clean Development Mechanism.

The economics of existing projects such as the Ecoliner or the existing cross-Atlantic ships operated by FairTransport rely in part on the transport of passengers or trainees. These niche markets use notably the "no carbon" labelling for luxury cargoes: chocolate, rum, exotic products.

Ships operational perspective

Future fuel price development is an important input needed for comparison of the "cost-effectiveness" of competing techniques. Jacob, Jaouannet & Rynikiewicz (2013) described the prominent marine fuels and their price relationship with crude oil. Their analysis on possible future trend of global prices of marine fuels for 2030 – 2040 suggests that a price differential between IFO ("intermediate" fuel oil IFO) and MDO (Marine Diesel Oil) will widen further in the future.

Since the fuel choice is generally driven by regulations, price and differential with other blends, it can be inferred that an increase of price gap will reduce the economic attractiveness of the emission reduction by switching ship operation to distillates. This price development of marine fuels also makes the development of alternative fuels an option worth exploring. It expands the scope of interesting alternative fuels from "Infrastructure and machinery compatible" LNG or biofuels, to less explored ideas such as Methanol and Hydrogen. All these developments may limit the relative gains of sails.

An economic assessment of a wind-assisted ship must take account not only of fuel costs but also other factors: operational requirements, such as cargo handling, routing, crewing, types of cargo, maintenance policies, first costs, and compare it to other competing technology. (Hoffmann et al 2012; Eide et al. 2009). Wind assisted hybrid ship propulsion is one of the numerous solutions investigated by the international community to reduce harmful emissions stemming from maritime transport. Although each competing solution (cleaner fuels, exhaust gas treatment, renewable energy based ship propulsion etc.) has its merits, focus is now on comparing the cost effectiveness of each solution from a ships operational perspective.

The IRENA Technology Brief (Mofor et al, 2015) lists many different types of applications and designs in various stages of development, tests and design. But insufficient data is published in most cases on final costs and benefits. Very few comparative data on other costs of ship/industry operation externalities have been published that would be needed to produce real meaningful data to support a comprehensive analysis.

In the SAIL project, Jacob & Jaouannet (2014) have proposed cash-flow model for small bulk ships. It aims to compare the various solutions, especially the contrast between scenarios with wind assisted propulsion to those without it. Jacob et al (2014) present the cash-flow model and discuss the important cost and revenue sources related to ship operation and assumptions made. The cash-flow model requires data relating to size of the ship, cargo carrying capacity, speed, fuel consumption characteristics, cost streams, revenue streams and capital financing information. In the absence of actual figures or for confidentiality reasons, the model still relies on approximate or default values.

One of many parameters to assess is the split between revenue earning period (loaded sailing days) and non-revenue earning period (port days, ballast sailing days and off-hire days). Therefore the profitability of a given route depends on a large extent on the time spent carrying cargo. Thus the aim should be to choose routes which maximize the time spent by the ship to carry cargo and minimize the non-revenue period notably the time spent in port (to reduce additional port related costs). Moreover, it is estimated that the difference in freight rates for different cargo types would widen. Thus special attention is needed when defining the cargo suitable for transport by wind assisted ships. One recommendation is to conduct a stakeholder analysis to identify types of cargo and key stakeholders whose support will be necessary for the success of wind assisted hybrid ship propulsion. One specific market to be investigated is the biomass supply market, especially in the context of the objectives in the European Union in this respect.

For example, the case of a calculated economic balance of a medium size ship (3 000 tons) transporting bulk freight, could bring fuel savings between 15% and 35% in well-chosen routes. Preliminary model estimates suggest this would in turn bring cost benefits sufficient to balance those of sail equipment and operations.

Elements for a roadmap

This section focuses on a few elements of a roadmap including technology, finance, regulations and operation methods, in order to make such developments possible. Evolutionary developments from existing systems and commercial practice are needed, but also some possible innovations allowing more routes or freight types to be transported with sails in the future. The challenge is to change scale and identify the drivers to go beyond niche markets and maybe even propose “zero carbon” commodities.

WASP potential in existing roadmaps

Wind Assisted propulsion is currently not seen as plausible important contributor to reduce significantly the local pollutants and GhG emissions at the world fleet level. Indeed, most economic analysis and proposed marginal abatement curves (MAC) such as those produced by the reports such as “Pathways to low carbon shipping. Abatement potential towards 2030” (Det Norske Veritas, 2009) , indicates a slow take up of WASP. Other scenarios such as Wärtsila Shipping 2030 scenarios or the SSI (Sustainable Shipping Initiative) vision 2040 do include hybrid sailing.

At the geographical level, maritime fuel use is currently excluded from most debate over reducing Pacific Island Countries (PIC) dependency on imported fossil fuels (Nuttall et al, 2014a, 2014b) or Development Banks are not financing low carbon shipping solutions. In this area, GHG emissions reductions and access to small scale energy systems are of key importance in countries so remote that all imports travel thousands of miles in small quantities. The Greenheart project is one project aiming to reduce dependency of PICs.

Closer to Europe, Wind Assisted Sailing Propulsion is mentioned in the CORICAN roadmap in France (2014) or the recent Sustainable Baltic Sea Shipping Green Technology and Alternative Fuels Draft Roadmap for future actions 2014–2016 and 2017 – 2025. It is therefore necessary to estimate the conditions and the associated timing of a momentum towards Wind Assisted Sailing Propulsion technologies and support the emergence of niches and the demonstration of pilot activities.

On the way to the build-up of a Technical Innovation System around wind ship sailing

Various activities and conditions are needed to achieve development, diffusion and use of a Technical Innovation System in the shipping sector (Jaouannet & Rynikiewicz, 2014). They are usually structured into seven functions: Entrepreneurial activities; knowledge development; knowledge diffusion; guidance of the search; market formation; resource mobilization, and support from advocacy coalitions. These functions clearly work together in a virtuous circle, one inducing another.

Opportunities as seen by stakeholders need to be explored in more detail as to characterise the market value and identify relevant sources of capability for delivery (and potential gaps that will need to be filled).

Removing barriers suppose at fist an understanding of business opportunities in particular niches, crossed with innovative technical projects.

Limiting the financial risk through policy incentives

One barrier often expressed is the risk adversity of investors in the sector, especially following the collapse of freight markets ten years ago, after a steep shipping boom. Another key issue is the lack of access to capital. One compounding factor is the recent collapse of fuel prices.

However, one has to keep in mind that shipping market is not homogenous, notably in terms of asset markets and key drivers. Numbers of sub segments, that are uncorrelated to one another and subject to different drivers, are performing well (such as LPG, Container boxes, Offshore).

Necessary issues to be dealt with to increase technology uptake are:

1. Capping of vessel emissions (through mandatory limits and/ or emissions trading), which force the vessels to adopt new technologies like auxiliary wind propulsion.
2. Governmental subsidies for investments in auxiliary wind propulsion or similar environmental investments, which create better payback periods for the technology.
3. Extension of ECA (Emissions Control Areas) to other regions than EU or US waters (Mediterranean, …)
4. Tackling Split Incentives - focused on the split incentives faced by ship owners.
5. Establishment of carbon trading standards and methodologies for wind propulsion (new & existing vessels) to gain access to such funding
6. Stranded Assets & Risk Management – working on the creation of scenario trajectories/long-term and aspects of asset management from a strategic point of view - Risk management & Insurance focus.

The main barrier to increased penetration of renewable energy solutions in the energy options for shipping remain the lack of commercial viability of such systems and also the existence of split incentives between ship owners and operators, resulting in limited motivation for deployment of clean energy solutions in the sector. Furthermore, the shipping sector is seldom visible to the general public, resulting in less societal pressure on the industry to transition to cleaner energy solutions.

Barriers to technology uptake

Several publications (Rojon & Dieperinck, 2014; Acciaro et al., 2013; European Commission, 2013 or Rehmatulla et al., 2013) deal with barriers to the adoption of RE in shipping. According to (Mofor et al. 2015), with regards to organisational, structural and behavioural barriers, limited financing of research and development, particularly for initial ‘proof of concept’ technologies is a major limitation, together with the concern of ship owners over the risk of hidden and additional costs. Shipowners do not see yet the opportunity costs of any renewable energy solutions. This is particularly so as historically there has been lack of reliable information on costs and potential savings of specific operational measures or renewable energy solutions for the sector. This is the main present dilemma: although technical advances have been made, any market has to rely on experience to be gathered by early adopters. But up to now such needed pioneers are either shy in data sharing, either are still waiting prudently.

Ultimately, market forces working within a tightening regulatory regime will govern the speed of uptake of renewable energy technology for shipping, though this will also be tempered by infrastructure lock-in and other non-market factors. Therefore, a set of organisational/structural, behavioural, market and non-market barriers needs to be removed before renewables can make meaningful contributions to the energy needs of the shipping sector.

As stated by the interest of IRENA towards RE in shipping, “the transition from fossil fuels to clean energy for shipping needs to be planned carefully” (Mofor et al., 2015).

Table 5. Principal barriers to renewable energy uptake in the shipping sector

Barriers	**Examples**	**Key Actors**	**Approaches/Solutions**
Organisational/ Structural	• North/South power dynamic • Political and legislative structures • Conservative culture • Fragmented and incremental approach • Focus on large versus small vessel sectors	• International Maritime Organisation, International Chamber of Shipping • Classification societies • Banks and Financial Institutions • National/International governments	• Lobbying for sustainable shipping incentives • Establish a clear, stable legal and regulatory framework • Develop multi-stakeholder technology research and development programmes • Sustainable shipping projects in developing markets
Behavioural	• Perceptions of complexity and cost of solutions • Inertia to invest and innovate • Lack of reliable information of true cost of solutions • Lack of awareness of viable solutions and their scope • Limited research and development transparency	• Technology providers • Shipbuilders • Academics • Seafarers • Policy makers	• Demonstration/pilot commercial programmes • Independent research think tanks • Training, education programmes
Market Failures	• Principal-agent problem as a result of information asymmetry • Split incentives • Lack of policy and regulatory framework and market incentives • Long investment horizons and vested interests	• Policy makers • Ship owners • Ship operators/ charterers • Technology provider • Investors	• Charter changes/adjustments • Eco-labelling initiatives (industry and consumer) • Increased transparency and investment analysis • Market based mechanisms and initiatives • Accurate long-term energy needs assessment • Cradle to cradle analysis
Non-Market Failures	• Technical uncertainty and complexity of solutions • Lack of research and development investment • Safety and reliability issues • Hidden costs • Access to capital • Lack of risk management	• All shipping actors • Ports and logistics owners • Local/national governments • Investors, banks and other financial institutions	• Increasing PPP collaboration • Demonstration projects/ships • Development of innovative financial systems • Sharing risk through multi-stakeholder developments • Promotion of technology transfer

***Table 2**: Compiled from (Rojon & Dieperink, 2014); (Acciaro et al., 2013); (European Commission, 2013) and (Rehmatulla et al., 2013)*

The need and first exploration of the perceptions of the barriers have been identified, produced or underway (Rojon & Dieperinck, 2014, Rehmatulla, 2014). More work is needed and underway on the perceptions of government bodies and banks on the need and risk to invest in WASP technologies[3]. Recent funding for cleaner ships, LNG corridor development and recent commercial trials by the finnish company Norsepower (Flettner Rotor technology) or kites are opening new windows of opportunities.

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[3] This section might be updated for the final version of this paper following undergoing work and newly published work on the perceptions of different stakeholders.

Conclusion

Important technical progress has been made to facilitate the adoption of wind technologies in maritime transport. On paper, smooth operation of freight lines and logistics, limited manpower and risks could bring economic benefits sufficient to justify sails on some specific routes and products. But these preliminary results would apply on only a small share of the maritime fleet, and would be justified more on local pollution abatement than on actual reduction in GHG emissions. It is still a long journey to any large scale adoption of RE through sails, or even its routine inclusion in the business plans of freight operators.

It remains that alternative propulsion systems for freight is a key issue in a sector that has grown explosively in recent decades and show no sign of slowing its pace. The INTERREG SAIL project tries to contribute to this widening of the reach of Renewable Energies in one of the most oil dependent segment of the world economic activity.

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Acknowledgements

Authors would like to thank Katell Jaouannet, Navin Jacob, Gael Trouvé (E&E consultant F), Peter Nuttall (University of South Pacific), Gavin Allwrigh of the International Windship Association (IWSA) as well as Alice Bows (Manchester University UK) and Tristan Smith (UCL London) for fruitful discussions and openness to share data and information (Bows and Smith 2012). Thanks also to participants of the INTERREG SAIL project, in particular Bernhard Schwartz-Röhr (Jade Hohrshule Elsfleth DE), Rogier Eggers (Marin NL), Pierre-Yves Glorennec (Avel-Vor Technology F) for the work and open discussions on windpower prediction programme and technologies. Thanks also to Armin Aulinger (Helmholtz-Zentrum Geestacht DE) for providing ship emission data shown within this paper, and the organizers of the project in the Province of Fryslan (NL).

“Usual disclaimer applies”: errors or misinterpretation remains our responsibility