sail

Sail into a sustainable future

Roadmap for Sail Transport

The Interreg IVB North Sea Region Programme

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Roadmap for Sail Transport
Interreg IVB SAIL

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Roadmap for Sail Transport

Abstract

Abstract (English): A Roadmap for Sail Freight Transport

Growth in global maritime transport drives increased emissions of CO2 and air pollutants (NO_x, SO_2 and particulate matters. The use of sails for freight transport is a possible answer for this unsustainable situation in the long run, which the SAIL Project INTERREG-NSR has assessed. With a growing cost of fuels and stricter emission thresholds, it becomes economically feasible to build and run wind propulsion ships. Freight lines between small ports or the transport of niche products will be attractive, first, but wind propulsion as an auxiliary power for more classical lines is a possible scenario in the near future. To convince actors, such as bankers, insurers and logisticians, clusters of researchers, users, harbors, designers and manufacturers, one needs to establish collective rules and transparency. This will lift barriers and create opportunities to demonstrate the economic and technical viability of sail transport. However in the near term, public support and incentive measures are needed.

Résumé (Français) : Feuille de route pour le transport maritime de marchandises à la voile

La croissance du transport maritime fait croître sur le long terme les émissions de CO2 et les pollutions de l'air (NO_x, SO_2, particules…). L'utilisation de voiles pour le fret est une réponse possible, ce qu'a étudié le projet SAIL Interreg-Mer du Nord. Pour un prix croissant du pétrole et des limites plus strictes des émissions, il est possible de rentabiliser le transport à la voile, d'abord pour des lignes de fret reliant des ports de petite dimension ou le transport de produits de niches, mais aussi prochainement comme propulsion auxiliaire sur des lignes plus classiques. Pour convaincre les acteurs concernés comme les banquiers, les assureurs, les affréteurs, des consortiums de chercheurs, d'usagers et de constructeurs il faudra établir une transparence et des règles collectives. Cela permettra de lever les barrières et créera des opportunités pour démontrer la viabilité de ces techniques. Cependant, dans un premier temps un soutien public ou des mécanismes d'incitation seront nécessaires.

Abstrakt (Deutsch): Eine Roadmap für den Frachtsegeltransport

Der Wachstum im internationalen Transportsektor führt langfristig zu erhöhten von CO2, NOX, SO2 und Partikeln. Im Interreg SAIL Projekt wurde die Nutzung von Segeln – als Zusatzantrieb – im maritimen Gütertransport als Maßnahme zur Emissionsreduktion analysiert. Mit steigenden Ölpreisen und strikteren Grenzwerten für Emissionen, werden der Bau und der Betrieb von Schiffen mit Windantrieb ökonomisch attraktiv. Anfangs wird es den Transport von Nischenprodukten und über kurze Distanz transportierte Produkte betreffen. aber Segel bieten sich als Zusatzantrieb auch auf langen klassischen Handelsrouten an. Um alle Akteure im Transportsektor – von Schiffsbauern und –designern, Eigentümern und Nutzern von Schiffen und Hafenbehörden über Wissenschaftler bis hin zu Banken und Versicherungen – von Frachtschiffen mit Windantrieb zu überzeugen, sind allgemeingültige Regeln und Transparenz in Bezug auf Segelantriebe von Nöten. Dies wird

Möglichkeiten schaffen, die ökonomische und technische Machbarkeit von wind-unterstütztem Frachttransport zu belegen. Aktuell sind allerdingst öffentliche Unterstützung und Fördermaßnahmen von Nöten um einen ersten Impuls zu geben.

Abstract (Nederlands): Een Roadmap voor Zeilende vrachtvaart

De groei van de mondiale scheepvaart zorgt voor verhoogde uitstoot van CO_2 en luchtverontreinigende stoffen (NOx, SO_2 en fijnstof. De conclusie van SAIL project INTERREG-NSR is dat het gebruik van zeilen voor goederenvervoer een mogelijk antwoord voor deze onhoudbare situatie op de lange termijn. Met stijgende kosten van brandstoffen en strengere emissie-drempels, wordt het economisch haalbaar om deels wind aangedreven schepen te bouwen en in te zetten. Als eerste zullen vracht routes tussen kleine havens of het vervoer van nicheproducten aantrekkelijk zijn, maar de wind voortstuwing als een extra kracht voor meer klassieke vaarroutes is een mogelijk scenario in de nabije toekomst. Om partijen, zoals banken, verzekeraars en logistieke medewerkers, clusters van onderzoekers, gebruikers, havens, ontwerpers en fabrikanten te overtuigen, moet men collectieve regels en transparantie onderling vast stellen. Dit zal barrières opheffen en mogelijkheden creëren om de economische en technische haalbaarheid van zeilend vrachtvervoer aan te tonen. Tot die tijd zijn publieke steun en stimuleringsmaatregelen nodig

Keynote address

By Ralph E. H. Sims

The world's shipping fleet carries around 80% of all internationally traded goods (8.7 billion tons a year) and accounts for nearly 10% of the total annual greenhouse gas emissions arising from the global transport sector. In addition, the emissions of black carbon from the inefficient combustion of marine and diesel fuels are causing growing concerns, both by impacting on local air quality when a ship is in or near port, and even when out on the sea since black carbon also impacts on climate change.

Compared with road and rail, boats can transport freight (and passengers) at relatively low GHG emissions (~10-40 g CO_2/ton-km), and it has been projected that this could be reduced by 20-30% in the next few decades, as outlined in the Transport Chapter of the IPCC 5th Assessment Report – Mitigation (2014).

However, an eventual transition completely away from fossil fuels by all sectors is required if we will have any chance of constraining the global temperature rise to below 2^{o}C, the target level agreed internationally (though even then, we will need to learn to become more resilient to extreme climate events and to adapt, for example, by building higher sea walls). Reducing fossil fuel dependency is particularly challenging for the transport section and especially for aviation and shipping. However, the propulsion of ships and smaller craft through the application of renewable energy sources, such as the wind or solar power, is making steady but significant progress. We know rapid technical advances are possible, (as demonstrated by the high-tech yacht designs of the America's Cup competition), and, in this regard, the research efforts by those working on the "SAILS INTERREG" project are to be commended and should be further encouraged.

Ralph E. H. Sims is Professor of Sustainable Energy and Director of the Centre for Energy Research http://energy.massey.ac.nz/ in Massey University (Palmerston North, New Zealand). He has been Coordinating Lead Author (CLA) of the Transport chapter of the last IPCC report (AR5-WG3), and Member of the Scientific and Technical Advisory Panel (STAP) of the Global Environment Facility (GEF) in Washington D.C.

See *http://energy.massey.ac.nz/ and* **http://www.thegef.org/gef/STAP**

Roadmap for Sail Transport

1. Introduction to the roadmap

Maritime Transport is a key element of globalization. At once, it is a major source of pollution, and the most efficient transcontinental way of transporting goods.

The past decades have seen a tremendous growth in emissions from transport, in particular passenger cars and road freight.

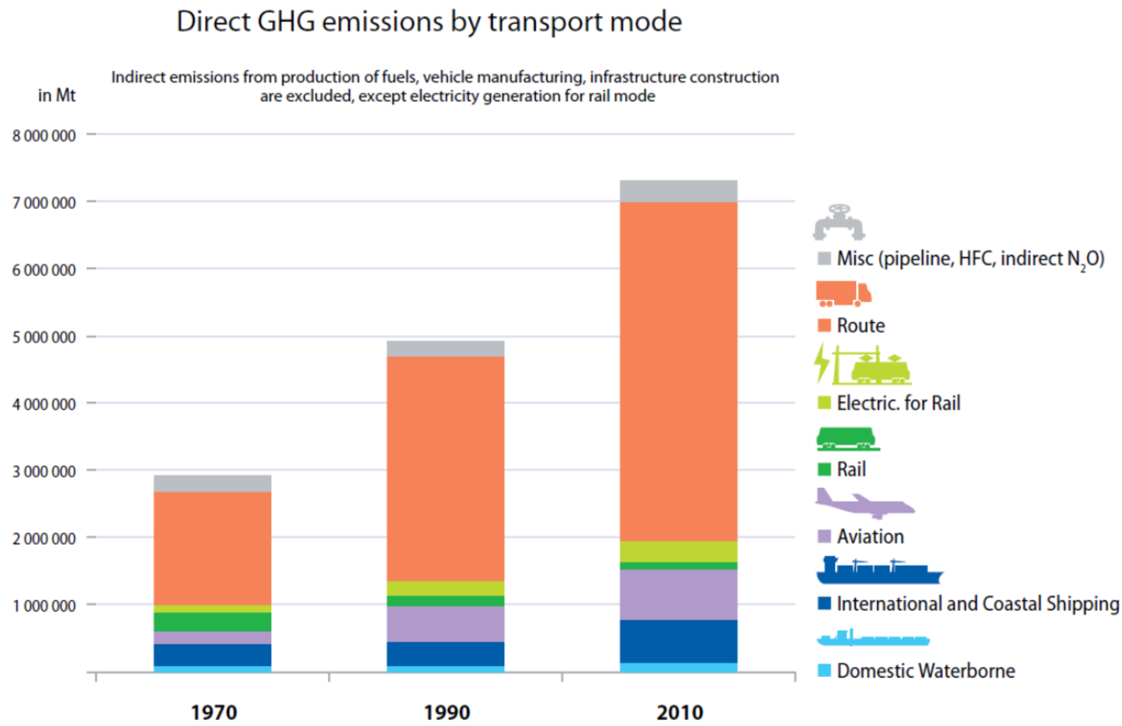

Figure 1. Direct GHG emissions by transport mode (IPCC 2014)

Shipping is not the worst culprit, but it cannot be exempted from a world effort against pollution and greenhouse gas emissions. Without more efforts, this sector may become a dominant emissions source in transport. The International Maritime Organization (IMO) reckons that emissions of the sector are now close to 1 billion tons of greenhouse gas emissions (GHG) a year, a little more than Germany.

“Shipping has a great potential for growth to meet the demand of the world economy but shipping has also, a great potential to significantly reduce GHG emissions, while achieving further growth of maritime transport," said recently Koji Sekimizu, secretary-general of IMO. His organization, led by countries with large fleets[1], is clear that growth will take priority over emissions reductions[2].

The IMO has made some indirect steps to limit emissions, the main one being energy efficiency design standards for new ships. It also requires all operating ships to have energy efficiency management plans, but sets no minimum standard for the content of these. In all, these measures aim at a 40% decrease in emissions per ton transported. But as ships often operate for 30 years or more, fuel consumption of the existing fleet will continue to be a major contributor to emissions. And these gains will also be balance by enormous growth in transcontinental transports.

An analysis of stakeholders in shipping (for example IPCC 2014) shows that many actors would not by themselves correct these trends to a global increase of emissions in a large scale.

In these evolutions, two United Nations institutions will have an impact on shipping. The IMO and the UN Framework Convention on Climate Change (UNFCCC) run on different principles and governance.

The IMO in particular is based on full equality ("no favorable treatment") between member countries. The UNFCCC has been based, in the contrary, on the distinction between rich and developing countries, the "common but differentiated responsibility". In both cases anyway, there is a lack of updated and precise data, on which any serious action could be based.

Beyond IMO and the UNFCCC, countries or groups of countries impact also a lot on shipping, in particular the US and the EU. They notably regulate the pollution of vessels.

A growing interest on renewable energy solutions for shipping

After IMO's third study on greenhouse gas emissions from ships (2014[3]), several reports were released in 2015 that help put the potential contribution of wind assisted propulsion on the agenda.

A major step was achieved with the publication of a technology brief by IRENA[4] recognising that "*the contribution of renewables to the energy mix of the shipping sector, however, is limited in the near and medium terms—even under optimistic scenarios. Nevertheless, developers are increasingly enhancing ship designs and proof-of-concept pilots demonstrating major savings in some applications*". IRENA also points the growing emissions of GhG and local pollutants of this sector and states that, "*the transition from fossil fuels to clean energy for shipping needs to be planned carefully*" (Mofor et al., 2015).The technology brief summarises the current status and applications of renewable energy solutions for shipping, along with the barriers and opportunities for further deployment.

[1] Leading flag states include Panama, Liberia, the Marshall Islands, Hong Kong and Singapore, according to 2013 UN data. Other major members are Norway, Cyprus, Greece, the USA.

[2] http://www.rtcc.org/2014/10/17/global-shipping-emissions-set-to-rise-unchecked/#sthash.SiTGrVoi.dpuf

[3] Third IMO GHG Study 2014, visit: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/ThirdGreenhouse Gas Study/GHG3 Executive Summary and Report.pdf

[4] http://www.irena.org/DocumentDownloads/Publications/IRENA_Tech_Brief_RE_for%20Shipping_2015.pdf

For quick-win solutions, support should focus on small ships (less than 10 000 dead weight tonnes),

which are more prevalent worldwide, transporting less of the total cargo but emitting more of the greenhouse gases per unit of cargo and distance travelled, compared to larger ships.

UK ship classification society Lloyd's Register released a report on barriers to wind assisted propulsion building on a number of trials and study with clients, concluding that operators could still see significant cost savings within relatively short payback periods. "*Wind-assisted propulsion is one of the few technologies potentially offering double-digit fuel savings today*," the report said, adding: "*Lloyd's Register is committed to working closely with technology providers and stakeholders across the supply chain, to overcome these challenges and make wind-assisted propulsion a reality*."

The EU DG ENV+CLIMA also commissioned during the Summer 2015 a study to analyse the market potentials and market barriers for wind propulsion technologies for ships.

For Mr Gavin Allwright, Secretary of IWSA[5]: "The number one barrier that we see is a lack of demonstration vessels on the water proving the technology and challenging the problem of perception that the report outlines. That then ties in with the problem of cost – most senior industry figures would need three points of reference before making a major investment."

In the meantime, a first step of a staged approach to reduce GHG emissions from shipping is the adopted EU Regulation (EU) 2015/757 on monitoring, reporting and verification (MRV) of CO2 emission from shipping was adopted in April 2015[6]. But beyond these short term measures, additional action will be needed to de-carbonise maritime transport

Current agenda in the run up to COP21

On a political level, there is an acceleration to discuss low carbon shipping at the IMO level in the run up to COP21 (Paris) and post 2020 Intended Nationally Determined Contributions (iNDC)[7]. In particular, one could note the speech of Foreign Affairs minister Tony de Brum of the Republic of the Marshall Islands (RMI) at the last Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO). The tiny South Pacific nation is using its position as the world's third largest shipping registry to call on the IMO to set a new global target for reducing greenhouse gas (GHG) emissions from international shipping, a growing sector currently left out of international climate negotiations.

"*We are the first country in the Pacific to set a transport efficiency target for ourselves – a 20 percent cut in the use of fossil fuels for domestic transport by 2020, and we are exploring other ways to green our international registry*," said de Brum.

[5] The International Windship Association (IWSA) was formed in 2014. See http://wind-ship.org/
[6] (http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R0757&from=EN)
[7] The S@IL project has sent a letter to some parties in order to key Parties of UNFCCC promoting inclusion of Hybrid Sail Shipping as a option for sustainable transport.

"*But the actions of one or a small group of registries alone will not be enough. Ships these days can jump easily from flag to flag to avoid tougher standards. Cleaning up this global industry requires a global approach. With a strong wind blowing in the climate action sails en route to Paris, the IMO must move to set a sector-wide international shipping emissions target now*."

Enhancing climate technology action through the existing UNFCCC and IMO processes.

Technology is a key component on the road from Lima COP20 to Paris COP21[8], however, there is little interaction between Technology Mechanism and Finance Mechanism (de Coninck and Sagar 2015)[9]

The Technology Executive Committee is the policy arm of Technology Mechanism. It is notably known for undertaking work on technology needs assessments (TNAs) but also organised a workshop in Oct 2014 to strengthen national systems of innovation. The Climate Technology Centre and Network is the implementation arm of Technology Mechanism and consists of the Climate Technology Centre (hosted by UNEP) and the Climate Technology Network[10] . In addition to the UN process, the growing network of World Bank sponsored Climate Innovation Centres and regional and national policies form part of the global infrastructure to better address the technology challenge. However, an agenda on pathways for a low carbon shipping agenda is non-existent. It is of particular importance for remoted islands where the cost of energy for transport represents an important part of the GDP.

At the IMO level, IMO's Marine Environment Protection Committee (MEPC) started an Ad Hoc Expert Working Group on Facilitation of Transfer of Technology for Ships (AHEWG-TT) within the Promotion of Technical Co-operation and Transfer of Technology relating to the Improvement of Energy Efficiency of Ships.

For now, implementation is limited to the so-called GloMEEP project, which aims at helping "to transform the Global Maritime Transport Industry towards a Low Carbon Future through Improved Energy Efficiency[11]. Funding is secured since July 27th 2015, with International Maritime Organisation (IMO) the Global Environment Facility (GEF) and the United Nations Development Programme (UNDP) allocating US$2.0 million of the total US$13.8 to a two-year global maritime energy efficiency partnership project, which aims to support increased uptake and implementation of energy-efficiency measures for shipping.

The project is part of the IMO's work to help ensure implementation of its mandatory technical and operational energy-efficiency measures (MARPOL) which entered into force on 1 January 2013. This

[8] Parties are not yet clear on how the issue of technology will feature in the new agreement and to what extent the existing Technology Mechanism might be strengthened as part of a negotiated package.
[9] Heleen de Coninck & Ambuj Sagar (2015) Making sense of policy for climate technology development and transfer, Climate Policy, 15:1, 1-11, DOI: 10.1080/14693062.2014.953909
[10] http://www.ctc-n.org/
[11] Ten IMO Member States have signed up to the GloMEEP project as lead pilot countries: Argentina, China, Georgia, India, Jamaica, Malaysia, Morocco, Panama, Philippines and South Africa.

makes certain regulations mandatory — the Energy Efficiency Design Index (EEDI) for certain new ships, and the Ship Energy Efficiency Management Plan (SEEMP) for all ships. The project would help in catalysing an innovative public-private sector partnership within the project framework, through a new Global Industry Alliance (GIA) for maritime energy efficiency.

Future IMO measures will focus on the development of Market Based Measures for international shipping. Regarding the slow progress in the establishment of MRV standards, this process is likely to take many years up to a decade. This also accounts for the establishment of a GHG standard, which seems even further on the IMO policy making horizon.

Towards Regional clusters: EU paving the way?

The International Windship Association (IWSA)[12] is currently seeking funding to develop both a virtual and physical wind propulsion cluster for the EU and the potential links with other centres of excellence around the world. This cluster development would significantly help facilitate and incubate technologies and projects. It would enable testing radical and long term solutions.

The case for a radical change in propulsion

International Maritime Bunkers, if unchecked, will represent a large share of greenhouse gas emissions. In the short term, much gain is possible mainly from energy efficiency measures and the switch to gas from diesel in large liners.

But what happens in the long run? Absent some more radical change, and with the growth modelled in the long term, the share of maritime fuels in emissions goes up, even if over 50% of these come from natural gas.

In the next figure the emissions in three of the long term scenarios of IPCC are presented with the total fossil and industrial emissions, in regard to the transport emissions.

[12] The International Windship Association (IWSA) “facilitates and promotes wind propulsion for commercial shipping worldwide and brings together all parties in the development of a wind-ship sector to shape industry and government attitudes and policies.”

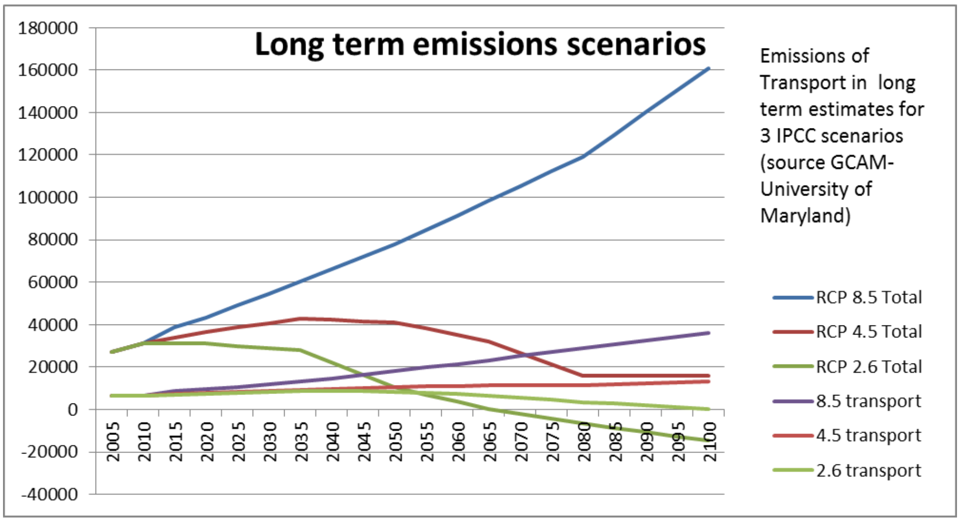

Figure 2. Long term transport emissions in 3 IPCC scenarios (E&E Consultant 2015)

The first scenario is a "no-policy" trend, and it is also implausible both for the extreme strains on the fossil resource and also on the climate consequences. The other two (RCP 4.5 and RCP 2.6) involve very radical measures and extreme technological content. Modelling shows these scenarios will stabilize global temperatures at respectively +3°C and +2°C.

In the projections made for IPCC by the GCAM consortium of laboratories, including the University of Maryland, we can see that by the end of the century, transport has –by far- the largest share of emissions. While industry, electricity and buildings are nearly completely decarbonized by the end of the century in these scenarios, transport represent over 80% of emissions in the "RCP 4.5" and even more in the 2.6, a radical scenario where negative emissions are obtained through the combination of massive biomass use and the capture and storage of emissions (CCS).

Now if we look inside the emissions of transport, international bunkers, both from aviation and from maritime, represent a growing share of emissions. In the case of the reference case RCP 4.5, most efficiency measures and fuel transfers are implemented, for example a massive use of natural gas, efficiency in propulsion systems, hulls and in logistics. By the end of the century, there is even a large share of cold ironing in harbors and use of renewable fuels in auxiliaries and some main propulsion for small ships. But this "full house" of technology is not enough, as shown by the following graphs. They represent global emissions from the transport sector in selected years to 2100, first in the RCP 4.5 scenario and then in the RCP 2.6 scenario as modeled from IPCC AR5 sources.[13]

[13] These projections were standardized to match climate projections of "radiative forcing". RCP4.5 and RCP 2.6 lead roughly to temperature increases of 2°C and 3°C respectively in 2100.

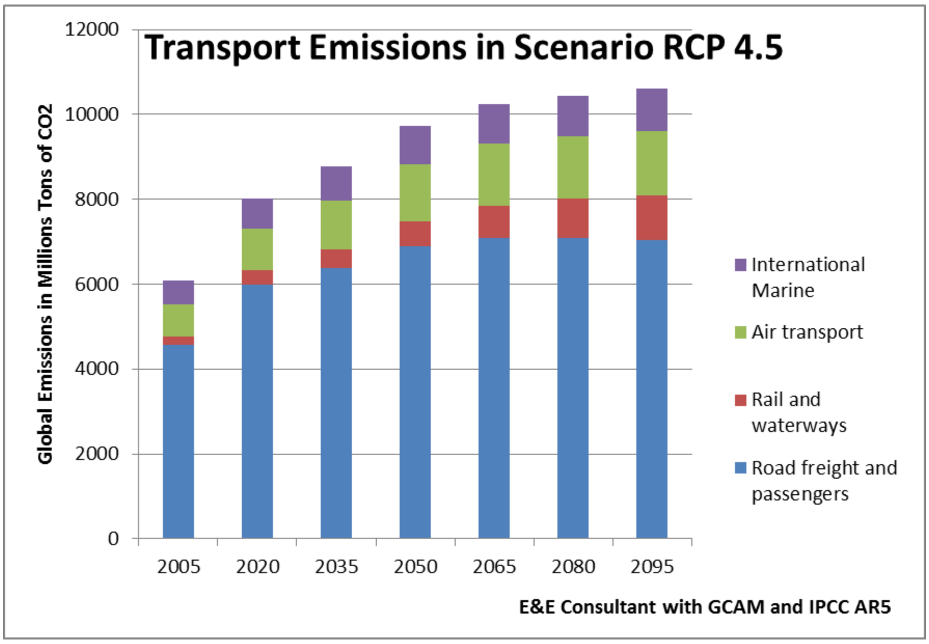

Figure 3.Transport Emissions in Scenario RCP 4.5 / IPCC AR5

In order to limit warming and keep the global carbon budget in the range prescribed by IPCC, on has to strengthen radically the measures in all sectors. This leads to a very different profile for transport, where in particular the electric transport for land freight and passengers become dominant in the second half of the century. But International Maritime transport is not much affected by this trend, as suggested by the next graph.

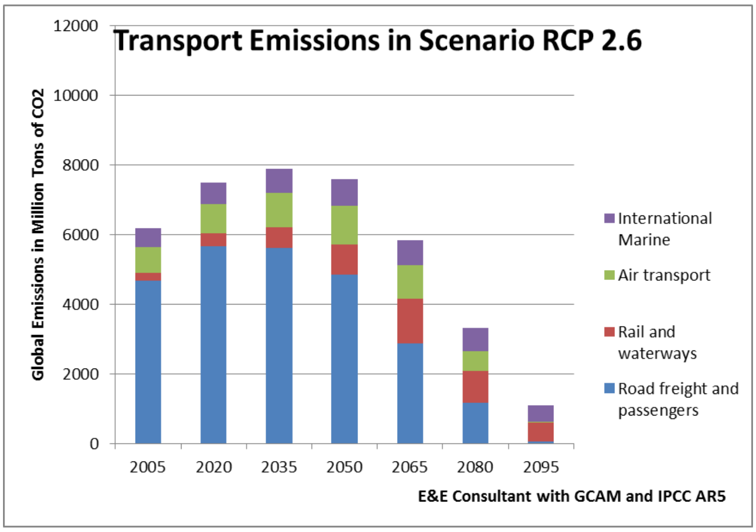

Figure 4. Transport Emissions in RCP 2.6 / IPCC AR5

The share of international maritime transport may even become dominant in the "2.6 scenario" by the end of the century. This is because land transport is then entirely electric or using synthetic fuels from hydrogen, when the maritime transport is still reliant on gas.

Share of International Maritime Bunkers in the "technology rich" scenarios							
	2005	2010	2020	2030	2050	2080	2100
RCP 4.5	9%	8%	9%	9%	9%	9%	9%
RCP 2.6	9%	8%	8%	9%	10%	20%	45%
							E&E Consultant 2015

Figure 5, Proportion of International Marine Bunkers in advanced scenarios of IPCC

Of course, these projections are highly uncertain exercises, notably in terms of global growth. But they integrate most of the progress as envisioned now, often considered as very strong measures. In the case of maritime transport, they show that an even more radical vision is needed to attain the goals of the international community.

Cutting the shipping sector's CO2 emissions in line with global climate change targets will need an approach that goes beyond current regulations, according to the researchers from the Shipping in Changing Climates Consortium at UCL and the Tyndall Centre, University of Manchester shows how avoiding 1.5/2°C, whilst maintaining shipping's present 2-3% share of total anthropogenic CO2, requires at least a halving of its CO2 emissions by 2050[14].

In May 2015 this is the first time that the scale of the challenge has been presented directly at the IMO and articulated in terms of trajectories for individual ship types. This new research illustrates how, with the expected rise in demand, the current efficiency regulation will not be enough for the industry to make a proportionate contribution to avoiding dangerous climate change.

CO2 trajectories for three ship types, container ships, dry bulk (e.g. coal) and wet bulk (e.g. oil) are analyzed under constraints of avoiding both a 2°C temperature rise as well as a 1.5°C rise above pre-industrial levels. The results show that the global fleet will need to be at least twice as efficient by 2030 compared with today under the 2°C target. This is significantly more stringent than currently debated levels.

Of course, this does not mean that one solution such as the use of sail is the unique way to decarbonize maritime transport. There are other options such as the use of synthetic natural gas and liquid fuels, made without emissions from electricity and hydrogen. There is also the possibility of a generalization of the use of biofuels. But these solutions are both costly in efficiency for long distance vessels, and might compete with uses for the same fuels in other sectors, making it more costly.

[14] http://www.tyndall.ac.uk/communication/news-archive/2015/navigating-climate-change-challenge-shipping

2. Can Sail Technologies change the future?

SAIL propulsion is an interesting step towards sustainable shipping. Indeed, technologies for propulsion have evolved a lot since sails, steam and diesel competed a century ago. This story is detailed in [Gael Trouvé 2013] and in [ECEEE 2015]. A lot of material, collected during the SAIL project, develops this topic.

The present stock of technology has two main features: (a) enabling technologies make maintenance and operation of sails quite different from former practices; (b) numerical routing technologies optimize the use of wind, limit risks and help regularity of schedules. Three categories stand out:

- First, new synthetic materials and improvements in all mechanical and wear resistance of all parts of the ship is the first key enabling technology. Carbon masts or Mylar sails are expensive but would last much longer than traditional materials. Such materials also have a better predictability to wear and tear.
- 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. These innovations, sometimes inspired by the sport sailing weather routing systems, combine meteorological advances with the modelling of the wind ship, and reconstructions of historical patterns of winds. 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.

One such example of detailed routing for a specific hybrid propulsion ship (the Ecoliner) in intra-Europe and Trans-Atlantic destinations was performed by the research centre Marin for the SAIL project. In this case, the ship travels from Edinburgh (UK) to Oostende (B), from Gibraltar to Skagen (Denmark), and from Gibraltar to Trinidad.[15] One main result was that rare strong winds from the favourable wind direction led to higher fuel savings than constant weak winds from the favourable wind direction. This result states for wind hybrid propulsion vessels which have a defined time of arrival and activate their engines in order to keep this time. In contrast for sail-only vessels, constant weak winds from the favourable wind directions are positive.

Additionally, a simplified programme for estimations of reduced power consumption by the use of sails was developed within the SAIL project. Example calculations on two intra-European routes performed with this simplified programme are shown in Figure 6.

[15] Marin 2015, "Challenging Wind and Waves, Voyage Simulations and operational performance", final report volumes 1 and 2, Wageningen The Netherlands

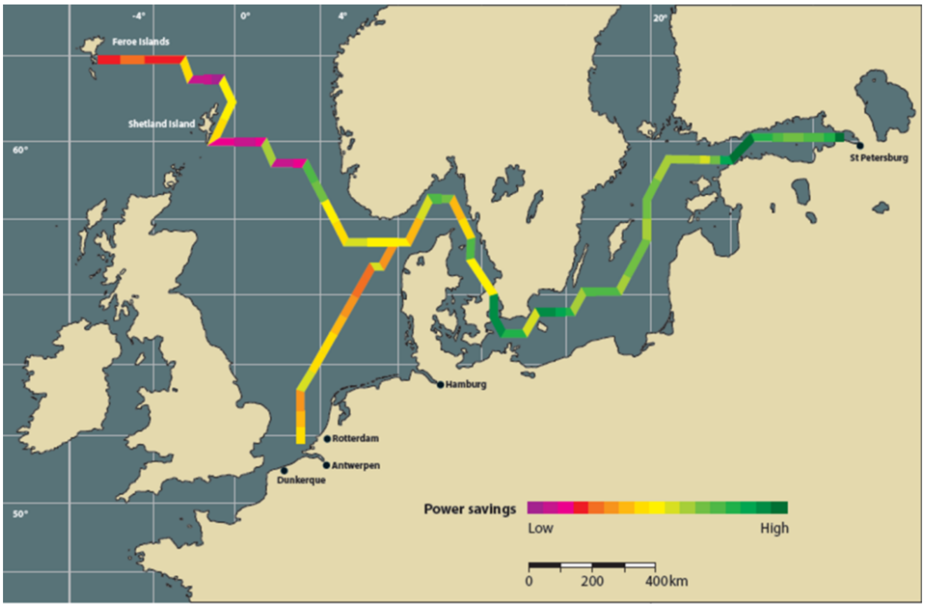

Figure 6. Example of gains calculated through routing techniques for journeys from Oostende to St Petersburg and from Oostende via Denmark and the Shetland Islands to the Faroe Islands.

Wind Propulsion Technologies

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 the hull or the sail structures and principles. These complex engingeering designs have to take into account the hybrid character of most of the proposals, where traditional or electric engines have to be also used efficiently.

Technologies come with widely different credibility and history. At extremes, the traditional square rig has millenary tradition; the Cousteau turbo-sail has not developed further than 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.

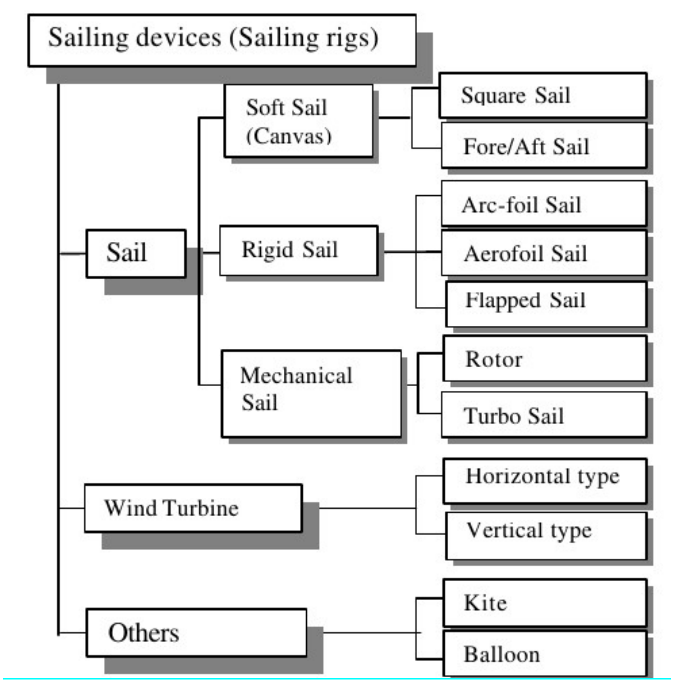

Figure 7: An organogram of the various wind propulsion technologies. Source: Yoshimura, Yasuo, 2002, « A Prospect of Sail-Assisted Fishing Boats », Fisheries Science, 68(Supplement 2): 1815-1818

The main types of wind propulsion systems are presented below: 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 Greenheart 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 five Flettner rotor projects. One such example is the Norsepower Rotor Sail Solution, tried on a Roll-On Roll-Off cargo ship of 9700 DWT with the aim of a 20% share of wind in propulsion.
- Finally, other more exotic propulsion systems include the kite sails which were tested on the MS Beluga and elsewhere. The commercial Skysails propulsion system have had limited market uptakesuccess to date with their first product.

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.

These sail types are applicable in different situations and have different demands on the ship design compared to no sails and among each other. Differences stem from diverging efficiencies of propulsion in low or strong winds, but also notably the deck occupation, the hull resistance to flows, the retrofit option or the combined operation of engine and sails.

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 fins 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[16]. Loading and unloading on Roll-on Roll-off (RoRo) carriers and tankers is not affected by sailing superstructures. However, safety concerns 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 the existing fleets, whose service life of decades make renewal slow.

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

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.

Here, small auxiliary propulsion devices, based notably on electric propulsion make sens, because they 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.

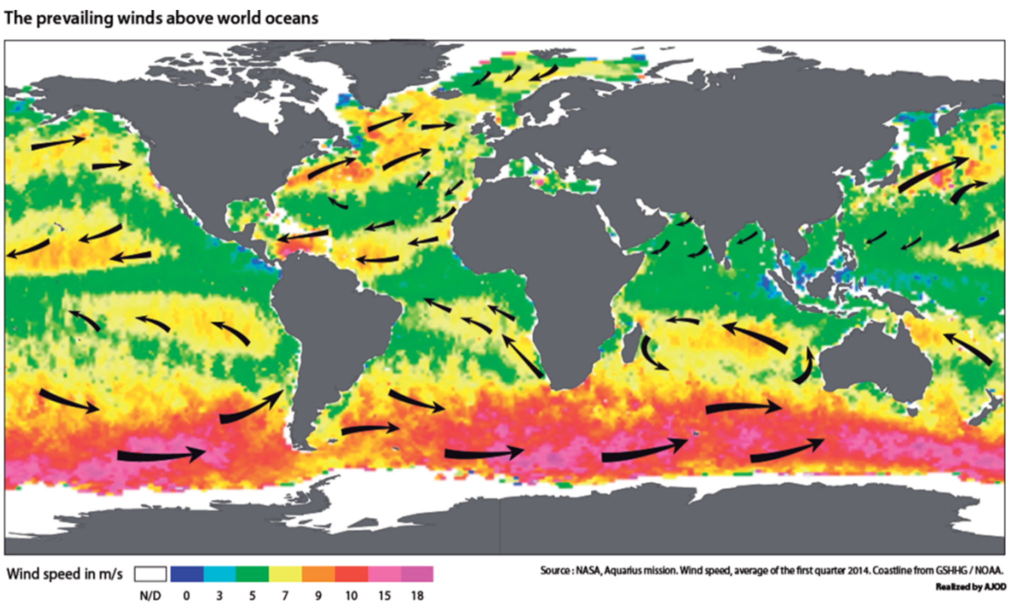

Figure 8 Prevailing winds above world oceans show the main trade winds

3. Do Sails save money?

The calculation of economic gains has to rely on the comparison of similar situations, with or without sails. Not so easy. 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, initial costs, and compare it to other competing technology. Thus simplification is always in order because optimal routing or operational conditions may vary between these configurations.

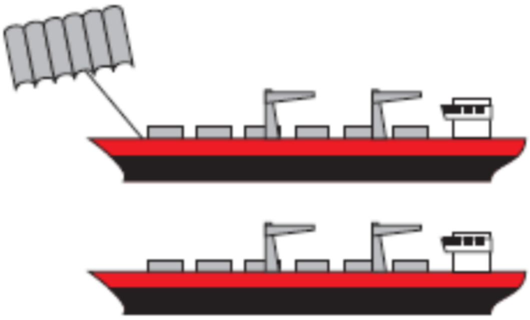

Figure 9 - The base of comparison

How much wind, how much fossil power? (doc CLAC/E&E 2015 for SAIL)

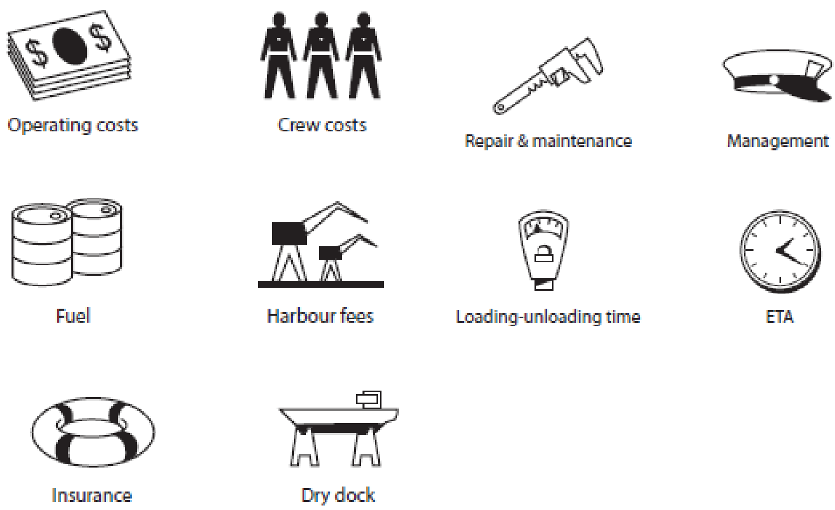

Figure 10: Some of the parameters to integrate in the calculation (pictos from CLAC 2015 for SAIL)

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.

Route determination: As mentioned above, routing is one key field where technology brings significant progress to the development of commercial sail shipping. This has to be factored in the simulations as suggested by the figure below:

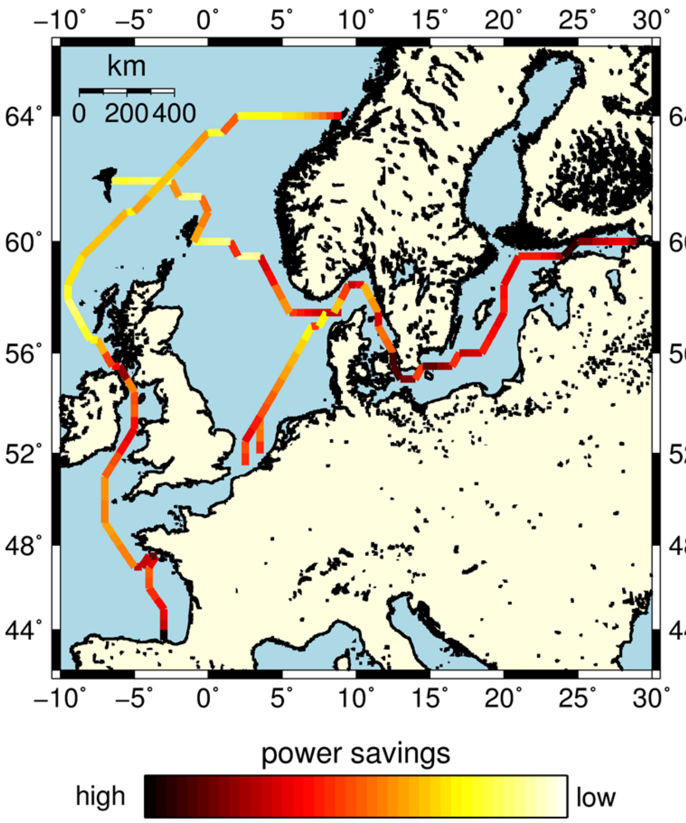

Figure 11 Example of relative gains from sail shipping around Europe and the North Sea. Calculated routes (in the given direction): Oostende – Denmark – Shetland Islands – Faroe Islands; Rotterdam – St Petersburg; Bilbao – Lorient – Trondheim;

The calculations by Lloyd's Register

Lloyd's Register published its report early in 2015. It is based on existing literature but also on eight projects or experiments into which the Register is involved. All use wind propulsion, and most of them are covered by non-disclosure agreements including the names of the organizations.

Based on expert advice, the report tests hypothesis of savings of 10%, 30% and 50% savings with fuels prices of 200, 600 and 1000 $/t and the extra investment for sails of 1, 3 and 5 million $. Results in years of payback time look obviously quite good for expensive fuel and large savings, but surprisingly they are still in the green (under three years of payback time) for spending 1 M$ with 30 to 50 tons of fuel saved per day, and this for fuel from 600$.

This sensitivity analysis was based on seven actual projects being considered or developed by LR customers. This suggests that in the case of cheap LNG developments, only high gains and low costs of sails would make sense, but also that with mandatory low sulfur fuels, a large economic potential do exist for sails.

The report concludes that "wind-assisted propulsion is one of the few technologies potentially offering double digit fuel savings today". Obviously though, a price of oil as low as 40$/bbl modifies substantially this equation[17]In the SAIL project, modelling the economic cases for routes and ship come to similar trends and conclusions. Basically, it calculates "all things equal" the economic consequences of the use of a proportion of sail instead of motor propulsion.

Fuel choice and price rises as the key determining factors[18]

The global maritime regulatory landscape is moving towards stringent emissions control, sooner or later, regionally or globally. To comply with these regulatory changes ship owners need to make a choice among the various emission reduction techniques. Since these emission reduction techniques differentiate themselves mainly on fuel costs, thus future fuel price development is an important input needed for comparison of the "cost-effectiveness" of competing techniques.

Here we first give a brief description of the prominent marine fuels and their observed price relationship with crude oil. Then we explore the different factors affecting crude oil price. Based on this, we finally propose a first scenario of future price development of prominent marine fuels. Our results suggest that marine fuel prices will increase significantly and the relative price differential between the different grades will widen, thereby reducing the economic attractiveness of using distillates for ship operation.

Pollution controls

In recent years, an increased awareness of both local and global environmental issues and the growing realization of the actual impact of emissions from ships have resulted in an accelerated effort

[17] , This huge uncertainty is common to all such calculations. In any case, while the costs have lowered substantially, many shipping company experts are still using a 500-600USD/ton rate for a 3 year average that is informing their investment decision making.

[18] This part stems mainly from the "SAIL briefing note", Navin Jacob, Katell Jaouannet, Christophe Rynikiewicz

by the international community to curb these harmful emissions. In the maritime industry, the International Maritime Organization (IMO) is utilizing regulatory tools to ensure change. In the next decade key environmental regulations for the maritime industry are coming into force to address harmful emissions such as sulphur oxides (SOx), nitrous oxides (NOx), particulate matter (PM) and greenhouse gases (in particular CO2).19 A summary of recent and future emission regulations in the EU can be seen in Table 1. Currently, four ECAs exist: North Sea, Baltic Sea, North America and US Caribbean.

Regulations	2010-2013	2014-2020
Sulphur Oxides (SO_x)	▪ 2010 - Emission Control Area (ECA) fuel oil sulphur limit of 1% ▪ 2012 – Global fuel oil sulphur limit of 3.5%	▪ 2015 – ECA fuel oil sulphur limit of 0.1% ▪ 2020 – Global fuel oil sulphur limit of 0.5% (Subject to IMO review in 2018)
Nitrous Oxides (NO_x)	▪ 2011 – NO_x Tier II emission standards for new ships	▪ 2016 – NOx Tier III emission standards for new ships (Subject to Marine Environment Protection Committee vote in 2014)
Green House Gases (GHGs)	▪ 2013 – Enforcement of Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP)	▪ 2017 – Probable launch of Market Based Mechanisms (MBM's) for GHG reduction in the European Union (EU)

Table 1 - Recent and upcoming maritime emission regulations for sulphur, nitrogen and greenhouse gas emissions in the EU Emission Control Area (ECA) .

Source: (Det Norske Veritas AS., 2012)

A number of solutions are currently available within the maritime industry which can significantly reduce emission from ships. Several incentive mechanisms are currently under examination. IMO has already enacted a mandatory Energy Efficiency Design Index (EEDI) for new-build ships. A brief description of the most prominent emission reduction solutions is given below.

Renewable energy assisted ship propulsion technologies, as developed by the SAIL project, aim at reducing ships emissions by reducing the ship's reliance on fossil fuels and replacing it with energy from renewable sources (wind or solar).
Exhaust gas after-treatment (EGAT) technologies aim at removing harmful emissions from ships exhaust before it is released into the atmosphere. End of pipe techniques add costs.

Alternative clean-fuels are marine fuels that due to their chemical composition and combustion characteristics produce fewer harmful emissions than traditional fuels. Liquid Natural Gas (LNG) burnt in internal combustion engines has been one of the primary alternative solutions which have gained significant attention followed by biofuels, both of them mainly due to the compatibility that they present

[19] (Det Norske Veritas As, 2012)

with the current infrastructure and machinery. Other fuels e.g. Methanol and Hydrogen, and machinery technologies such as fuel cells are envisaged or even tested in the case of a new Stena Ferry in Finland.[20]

For shipping companies, adoption of an emission reduction technique comes at a substantial additional cost. For example, to meet the recently enforced SOx emission regulation within Emission Control Areas (ECA) shipping companies have to choose between:

- One time big investment in exhaust gas cleaning equipment allowing ship operation on regular high sulphur fuels
- Or sustained increase of operating expenses by switching to more costly low sulphur fuels.

This example demonstrates that the cost of compliance to future regulations will be significant for shipping companies and thus “cost-effectiveness” will be a decisive factor in the choice for investment between competing emission reduction technologies.

From a cost perspective, the two important distinguishing factors among the prominent emission reduction techniques are the type of fuel used and the resulting impact of the technique on the ships fuel consumption. Moreover, considering that fuel cost is the largest contributor to a ship’s running costs,[21] it can be inferred that future fuel price development will strongly influence the choice of emission reduction technique widely adopted within the maritime industry. Marine fuel price development has thus become a subject of interest for the shipping and refining industries.

Choosing maritime fuels

There are three major categories of marine fuel: distillate fuel, residual fuel, and a combination of the two to create a fuel type usually called “intermediate” fuel oil (IFO). These categories are listed in Table 2 with their grades and their colloquial industry names.

Fuel type	Fuel grade	Common/industry name
Distillate	DMX, DMA, DMB, DMC	Marine gas oil (MGO) and marine diesel oil (MDO)
Intermediate	RME/F-25, RMG/H-35	Marine diesel fuel or intermediate fuel oil (IFO180 and IFO380)
Residual	RMA,RMH, RMK, RML	Fuel oil or residual fuel oil

Table 2 - Marine fuel types

Source: (U.S. Environmental Protection Agency, 2008)

MDO is typically used in small to medium sized marine vessels and is manufactured by combining kerosene, light, and heavy gas oil fractions (DMC with 10% to 15% residual fuel) in contrast to IFO, one of the most common fuels used in transoceanic ships, which is manufactured by combining visbroken residue[22], Heavy Cycle Oil (HCO) and Light Cycle Oil (LCO).[23] MDO has lower sulphur

[20] (Raucci, Smith, Sabbio, & Argyros, 2013)
[21] (Mazraati, 2011)
[22] This refinery process increases viscosity of the oil through thermal processes.
[23] (U.S. Environmental Protection Agency, 2008)

content (1% sulphur content) in comparison to that of IFO (3.5% sulphur content). Thus, to comply with emission regulations within ECA the use of IFO in ships needs additional exhaust gas cleaning equipment. MDO are sold at a higher price than intermediates, and residual fuels are the least costly. To estimate future prices of marine fuels it is necessary to understand their dependency to crude oil prices.

Setting aside the short term impact of seasonal demand variations and refinery supply outages, the price differential between crude oil and marine fuels depends until now mainly on operational costs of the refining process and the profit margins charged by the refineries. Considering that operational costs and profit margins for processing crude oil remains within a constant range[24,] it can be inferred that the price differential between crude oil and marine fuels shall also remain within a constant range. To verify this inference we compared the yearly average spot prices (in USD/ton) of North Sea crude oil and that of IFO 180 and MDO prices quoted in Rotterdam from 1990 to 2013. This comparison shows that IFO 180 trades at a discount of 20- 40% to crude oil and that MDO trades at a premium of 10-20% to crude oil depending on the year.[25]

It is important to mention here that the price dependencies discussed above remains true only until the refining process remains the same. Any change to the latter will change the price dependencies. For example the global marine fuel oil sulphur content limit transition from current level of 3.5% to 0.5% in 2020 will require refineries to invest in de-sulfurization plants and change in the refining process. Maritime industry experts estimate that these changes will increase global marine fuel oil prices by an additional 10-50 %.[26]

It is equally important to mention here that the sufficient availability of marine fuel with low sulphur in the future is uncertain. This situation can be better understood with an example of the situation in Europe where the refinery capacity to produce 0.1% sulphur marine fuels is small and is matched by low demand.
However after the enforcement of the new 0.1% sulphur limit for marine fuels in 2015, and contrary to pessimistic forecasts, the demand has been met smoothly by suppliers. At the same time, since reconfiguring refineries to produce 0.1% sulphur marine fuel would be very costly, refineries are reluctant to make investments even with better sales prospects or even an expected jump in demand. This raises future supply concerns.[27] This supply situation will be mirrored when the global 0.5% sulphur limit comes into force in 2020. The IMO is set to review the supply situation in 2018 and might postpone the date of enforcement to 2022. In our analysis in this briefing note we have not considered the impact of supply shortage on the prices of marine fuel.

Having recognized the price dependencies between crude oil and marine fuels, price projections for crude oil can help in the estimation of future marine fuel with better degree of certainty.
Factors impacting crude oil prices

World oil prices move together as arbitrage activities of brokerage firms quickly exploit and eliminate any excess price differentials.[28] Therefore fluctuations in crude oil prices globally are quasi-simultaneous. This in part explains why global crude oil prices are highly sensitive to a variety of geopolitical and economic events. This sensitivity is demonstrated by sudden crude oil price surges or

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[24] (U.S. Energy Information Administration, 1996)
[25] Calculated with data from IEA publication (International Energy Agency, 2013)
[26] (Kalli, Karvonen, & Makkonen, 2009) (International Maritime Organisation, 2011) (Blikom, 2013)
[27] (U.K. Department of transport, 2009)
[28] (U.S. Energy Information Administration, 2013)

drops due to events such as the Arab oil embargo (1973-74), the Iranian revolution in the late 1970's and the recent global financial collapse. The probability of occurrence of such events and their impact are nearly impossible to predict.[29] Excluding the impact of such events, the long-term supply, demand and prices of crude oil are influenced by five key factors.[30]

1. Global Demand for petroleum and other liquids.
2. Organization of the Petroleum Exporting Countries (OPEC) investment and production decisions.
3. Economics of Non-OPEC petroleum liquid supply.
4. Economics of Other Liquid Fuel (OLF) production and reserves.
5. Environmental policies.

The interactions between these factors decide the point of market equilibrium between supply, demand and prices. These factors are briefly explained below.

Global demand – There is a strong relationship between global demand for oil and economic growth. Economic conditions are directly tied to activities such as manufacturing, power generation, commercial and personal transportation. Transportation and manufacturing operations consume large amounts of oil and in some countries oil remains an important fuel for power generation. When there is a growth in economy, the combined oil consumption of these activities leads to a rise in oil demand accompanied by a rise in oil prices. A decline in the economy will have the opposite effect. Current and expected levels of economic growth are therefore important factors for estimating oil demand and oil prices.[31] The energy intensity of major economies is also expected to change due to technical progress and the move towards low carbon societies.

OPEC production and investment – Countries within the OPEC account still for nearly 40 percent of the world's crude oil production. OPEC sets production targets for its member countries thus exercising considerable influence on the state of crude oil supply in the world. By restricting crude oil production OPEC can proportionally increase prices thereby ensuring sustained revenues for itself in the long term. OPEC also maintains spare capacity which can be brought into use rapidly for short durations allowing world market to respond to potential crises that reduce oil supplies.

Non-OPEC petroleum liquid supply - Non-OPEC production accounts for the balance amount of global oil production. Its centres of production include North America (including shale gas production), regions of the former Soviet Union, and the North Sea. Most of the production activities in non-OPEC countries are carried out by investor-owned oil companies (IOCs) with a primary aim to increase shareholder value and make investment decisions based on economic factors. Non-OPEC producers typically produce at or near full capacity and so have little spare capacity.

Economics of other liquid fuel production - Other Liquid Fuels (OLF) consists of liquid fuels obtained from non-petroleum processes or sources (ex. coal-to-liquids (CTL), gas-to-liquids (GTL), biofuels, and kerogen). OLFs usually have higher production costs and their development depends on country specific policies. Thus OLF production will be economical only in a favourable policy environment and

[29] For the purpose of this briefing note, it is assumed that no unexpected geopolitical or economic event will occur till the year 2040.
[30] (U.S. Energy Information Administration, 2013)
[31] (U.S. Energy Information Administration, 2013)

when their production costs match or are inferior to crude oil prices. World production of OTLs in 2010 represented nearly 2 percent of total world liquids production.[32]

Environmental policies – An acknowledged result of the modelling of the impact of "ambitious" low carbon policies (a target of -80% of GHG emissions in 2050 compared to 1990 usually labelled as "factor 4") is the reduce of the demand for oil therefore notably reducing the international oil price. The price to the consumer would rise due to taxes and carbon penalty. Such results are well detailed in the WETO-T scenarios published by the EU DG Research (2013).[33]

For the needs of the SAIL project, scenarios were developed. In order to project future crude oil prices (and thus marine fuel prices), plausible assumptions have to be made about future development of the above mentioned factors. The U.S. Energy Information Administration (EIA) published a "Reference" scenario which analyses the impact of current political, economic and technological trends on crude oil prices. [34] For this reason the roadmap has taken the assumptions and projections made by EIA in its "Reference" scenario as the basis for calculations. The next section discusses some key assumptions made by EIA for crude oil prices until 2040.

Crude oil price reference scenario

According to EIA projections, the world's real gross domestic product will rise. The fastest rates of growth are projected for the emerging, non-OECD regions whereas in the OECD regions, GDP grows at a much slower rate owing to more mature economies and slow or declining population growth trends. Other factors such as geopolitical tensions or shale oil developments can also influence the trends, as we have seen recently with the actions of Saudi Arabia leading mid-2015 to a price of the barrel as low as 40$/bbl.

Reflecting this economic growth projection, the world energy consumption will grow from 2013 to 2040. Non-OECD countries will account for much of the growth in energy consumption.

To meet this growing energy demand, among the different energy sources, renewable energy and nuclear power will be the world's fastest-growing energy sources. Among the different fossil fuels, natural gas shall be the fastest growing fuel meanwhile coal use (driven by demand in China) will grow faster than liquid fuel use at least until 2030 after which its growth will flatten. This change in the global energy mix will negatively impact liquid fuel demand.

The key assumptions of EIA's "Reference" scenario till 2040 are summarised below:

1. There will be a decline in the global Gross Domestic Product (GDP) growth rate.
2. The liquid fuel consumption per dollar of GDP will decline.
3. The OPEC will maintain a cohesive policy of limiting supply growth.
4. Non-OPEC liquid fuel production will grow rapidly until 2020 (mainly due to tight oil production) after which the growth will be flat.
5. Most OLF production technologies are economical and world production of OTL will double by 2040.

[32] (U.S. Energy Information Administration, 2013)
[33] (European Commission, 2011)
[34] (U.S. Energy Information Administration, 2013)

Table **3** shows EIA's projection of crude oil prices (in real dollars per unit) for its reference scenario. As already mentioned, such trends have still to factor in the recent low in prices (presently the price is as low as 300 $/ton)!

Year	2010	2015	2020	2025	2030	2035	2040
Brent prices $/bbl.	81	96	106	117	130	145	163
Brent prices $/ton	594	703	777	858	953	1063	1195

Table 3 - Brent crude oil prices 2010-2040
Source: (U.S. Energy Information Administration, 2013)

To obtain a yearly price of crude oil for the period 1990-2040, we used two sources: historical crude oil prices published in International energy agency (IEA)'s "Energy prices and taxes, 1st Quarter 2013" and price projections given in
Table **3**.

- For the period 1990-2013, we used data extracted from the IEA's publication.
- To estimate the missing crude oil price for 2014, annual growth rate of -8.06% was calculated using available crude oil prices of 2013 and 2015.
- To estimate the yearly crude oil prices in the projection period 2015-2040, a growth rate of 2.13% was calculated by averaging individual five year period growth rates derived from crude oil prices in
- Table **3**.

Marine fuel prices projections

The crude oil price projections discussed in the above section can serve as basis for the marine fuels (IFO and MDO) price calculations.
By averaging the yearly percent discount of IFO 180 price to North Sea crude oil price from 1990-2013, we calculated a 27% percent discount of IFO compared to crude oil. For MDO the percent premium is similarly calculated but only for the period 1990-2009 due to lack of available data points. It suggests that MDO price is, on average 13% above crude oil prices. An additional 13% price increase for IFO prices is assumed after 2020 to account for the impact of global marine fuel sulphur content reduction from 3.5 to 0.5%.[35]
The resulting IFO and MDO price developments until 2040 are shown in Figure 12.

[35] (Kalli, Karvonen, & Makkonen, 2009) (International Maritime Organisation, 2011) (Blikom, 2013)

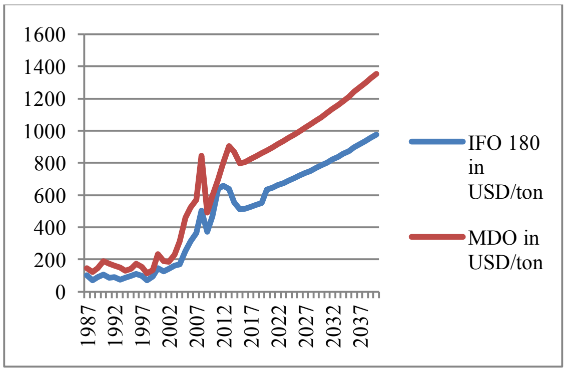

Figure 12 - Price hypothesis of prominent marine fuels till 2040

Base (U.S. Energy Information Administration, 2013) and (International Energy Agency, 2013)

Discussion

The result of the analysis conducted within this briefing note suggests that the global prices of marine fuels will rise significantly. As a reality check for the plausibility of this analysis, Table 4 shows a comparison of the fuel price estimates calculated in this briefing note and the fuel price range estimates for 2020 and 2030 published by the International Maritime Organisation (IMO). Once again, the present price low shows the huge uncertainty on the scenario, but also the plausibility of a remaining price differentiation.

Year	**2020**	**2030**
Our estimates of IFO 180 prices in $/bbl.	98.4	121.5
Our estimates of IFO 180 prices in $/ton	634	784
IMO’s estimated IFO 180 price range in $/bbl.	78 to 140	109 to 171
IMO’s estimated IFO 180 price range in $/ton	500 to 900	700 to 1100

Table 4 - Comparison with IMO estimates of IFO 180 prices for 2020 and 2030
Source: (International Maritime Organisation, 2011)

Once again, the global price of oil can vary widely, but the important trend here is the comparison of oil products. Our first analysis also suggests that the price differential between IFO and MDO will widen further in the future. Since the fuel choice is generally driven by regulations, price and price differential 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. A clearer picture of cost-effectiveness of the various emission reduction techniques can be obtained by utilizing the fuel price projections calculated in this briefing note in a DCF analysis for each technique. Its results will be able to demonstrate in concrete terms how adoption of WASP technology can be beneficial for shipping companies. In addition, our result opens up the following topics for discussion:

Alternative fuels - 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.[36] In this first scenario, which we could describe as a "reference", we also do not envisage the rapid development of alternative fuels and their possible effect on crude oil price. Given the trend for Liquid Natural Gas (LNG) use and public support for the associated infrastructure, this limitation will need to be investigated. As mentioned earlier in the introduction, Natural Gas propulsion is a major move by the marine community, but will not be enough in the long run to fight climate change.

Slow Steaming – The triple benefit of increased fuel savings, lower environmental impact and utilization of overcapacity in the shipping industry makes an interesting case for slow steaming. At marine fuel price development suggested by our analysis, it might even balance out the negative impact of slow steaming such as increased pipeline inventory costs and delays.[37] In this scenario, the difference of sailing speed between standard propulsion options and alternative (WASP, solar or hybrid) propulsion option is reduced reinforcing the economic viability of alternative propulsion options.

*Split incenti*ves – There are basically two forms of contracts between owner-operators and charterers: voyage charter and time charter. These contracts divide the responsibility for capital and running costs (including fuel costs) between a ship-owner-operator and charterer. The result of this divided responsibility for costs is that both parties could have diverging interests to minimize their share of costs at different points in time[38]. In the time charter, the ship owner invests the up-front capital to put in energy-efficient technology, but the savings in fuel cost goes to the charterers: this is what is usually called split-incentives.
In scenarios where marine fuel prices rise significantly, gains made from fuel-savings from energy-efficient ships can be shared by charterers with ship owners in the form of "fuel-savings premium" in addition to the charter rates. These incentives will encourage ship owners to invest in energy efficient ships. The Save As You Sail (SAYS) financial model designed by the Sustainable Shipping Initiative (SSI), is one of them. Such tools could help new technologies scale faster.[39]

Impact on modal share – The price development of marine fuels can also impact current equilibrium between the different modes of transport (road, rail, sea and air transport). Maritime trade experts estimate that the increased fuel price will reduce the competitiveness of sea transport and thus induce a modal shift towards other means of transport. Experts also estimate that the impact in deep sea shipping will be negligible but can be significant for Short Sea Shipping (SSS) within ECA's.
The European Commission looked at several studies assessing the potential impacts on short sea shipping[40]. Given the large range in predictions, there is a clear level of uncertainty to what might happen but studies agree on the fact that the introduction of the 2015 emission requirements will make short sea shipping experience increased costs and competition from road, rail and deep sea shipping. However, none of these reports assume that ships take measures to reduce fuel consumption or switch to new propulsion systems, which are possible ways to improve competitiveness on some markets

[36] (Raucci, Smith, Sabbio, & Argyros, 2013)
[37] (A.P. Moller - Maersk Group, 2014), (Brink & Fröberg, 2013)
[38] (Rehmatullaa, Smith, & Wrobel, 2013)
[39] (Sustainable Shipping Initiative, 2014)
[40] (European Commission, 2007)

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.

The programme compares 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. This example shows preliminary calculations of relative gains on two different routes for one sail type. 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 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).

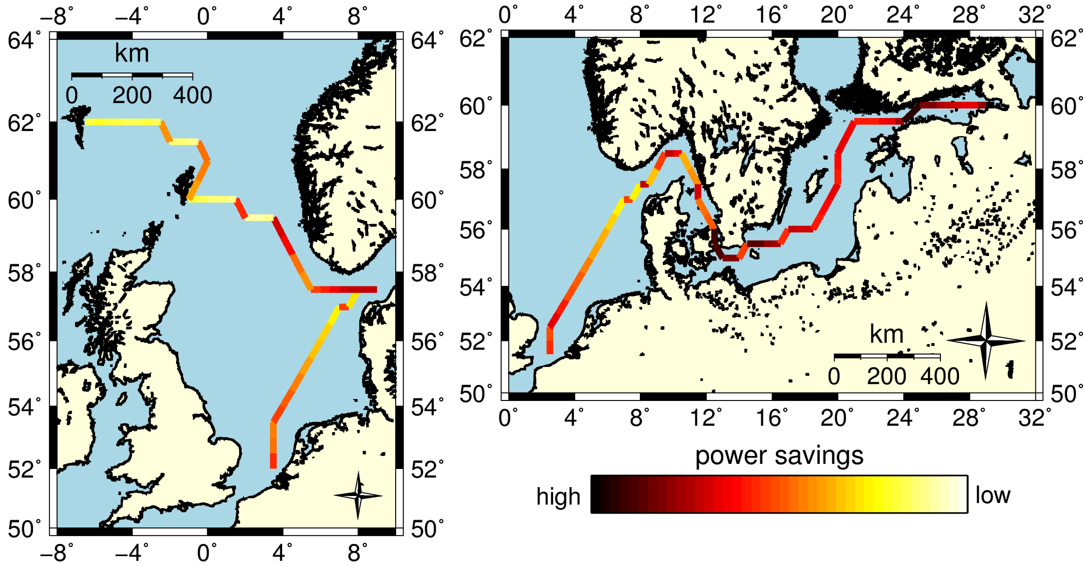

Figure 13 -two sample routes to illustrate relative gains.

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[41]) 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

Species	absolute reduction [tons]		relative reduction	
	minimum	Maximum	minimum	maximum
Fuel	3,143	7,333	0.043	0.100
NOX	233,666	545,220	0.043	0.101
SO2	50,516	117,870	0.041	0.096
CO2	9,955,190	23,228,776	0.043	0.100

Table 5). 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

[41] 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 location, its course, size and further information to surrounding receivers.

exhaust gas cleaning scenarios presented in Matthias et al. (2015). This estimate illustrates the limited short term gains of Sail Shipping if pollution is the sole driver of the development.

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

Table 5: 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 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.

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 little 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 developed a cash-flow model for medium-small bulk ships (3000-10000 tons). 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 methods and discuss the important cost and revenue sources related to ship operation and assumptions made. The 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 in part on approximate or default values.

To take into account actual loaded sailing days, 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% on well-chosen routes. Preliminary model estimates suggest this would in turn bring cost benefits sufficient to balance those of sail equipment and operations.

Modelling SAIL freight transport

The model had been built for the requirements of SAIL project for a small bulk ship and with assumptions related to the dry bulk market. It has been designed to be flexible in order to accommodate a wider range of assumptions which will be further discussed in the next sections. Outputs of the model and their significance are summarized below:

- ***Total Investment and investment breakdown*** allows an assessment of the total investment required for a ship with a given technological solution and also their relative proportions.
- ***Route assessment*** helps understand the breakdown of a chosen route and identify the proportion of the route which contributes to the revenue of the ship.
- ***Cargo assessment*** indicates the proportion of time spent in transporting each type of cargo and the contribution of each shipment to the revenue of the ship.
- ***Cost assessment*** helps understand the breakdown of the cost incurred for the transportation of goods. A comparison of cost breakdown for different technological solutions can illustrate the impact each solution has on the operation of the ship.

- ***Average haulage cost*** signifies the break-even freight (in €/ton of cargo transported) required by the ship to earn back its investment during its lifetime. This figure can be calculated for various technological solutions and their comparison can show which solution moves cargo for the lowest cost.
- ***Average freight earned*** (in €/ton of cargo transported) by the ship for the transport of a given combination of cargo on a given route. A comparison of this value with the break-even freight can help conclude if a given combination of chosen route and cargo type will be profitable for the chosen technological solution.
- ***Scenario net present value (NPV)*** represents the present value of the combined future earning of the ship for a chosen scenario. A positive NPV indicates that a project will be profitable for the ship owner. Comparison of NPV calculated for the different technological solutions can help establish a profitability ranking.
- ***Internal rate of return (IRR)*** is the discount rate at which the present value of all future cash flow is equal to the initial investment or in other words the rate at which an investment breaks even. This result will be helpful to in determining the investment priority between two technological solutions which have the similar NPV's.
- ***Payback period*** allows an estimation of time required to recover the investment in for each scenario. The model also has the option to calculate the required increase in freight rate that will be needed for a desired payback period.

In order to calculate these values 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, the model uses default value for calculations. A description of the default values and the assumptions behind their calculation are discussed in the next section.

Ship characteristics and measurement assumptions

The deadweight (DWT) of the ship, (i.e. the safe cargo limit without the weight of the ship) forms the basis on which all the default values in the model are calculated. In the absence of cargo carrying capacity information the model takes the default DWT of 3000 tons. The DWT is used to estimate the various ship characteristics and measurements which will be necessary inputs for the cost estimation of the ship. In the paragraphs below we discuss these calculations further in detail.

Gross registered tonnage (GRT) is a measure of the total permanently enclosed capacity of the ship. GRT calculation requires measurement of every open space in the ship and is considered a laborious process. GRT was part of the old measurement system which has been replaced by a more simplified Gross tonnage (GT) which is calculated from the total volume of all enclosed spaces, measured in cubic metres, using a standard formula. [42]

For some ship types with complex hull forms the GT and the GRT may be significantly different. However, in the cash-flow model it is assumed that there is no difference between GT and GRT as

[42] (Stopford, 1997)

bulk ships have simple construction. In this model, GT serves as the reference from which manning costs and port charges of the ship are calculated. The relationship between these costs and the GT is further discussed in the next section.

Compensated gross tonnage (CGT) was developed for purpose of measuring the level of shipbuilding output. The CGT of a ship can be determined by the following equation:

$$CGT = A*GT^{B}$$

Where:

CGT – Compensated gross tonnage of the ship
A – Constant representing the influence of ship type
B – Constant representing the influence of ship size
GT – the gross tonnage of the vessel

Equation 1 - Relationship between GT and CGT

Source: (OECD Directorate for Science, Technology and Industry (STI), 2007)

The CGT value will be necessary to estimate the capital cost of building a ship and the relationship between the two is discussed in the section 0.

Light-displacement (LDT) is defined as the weight of the vessel as built, including boiler water, lubricating oil and the cooling system water and excluding cargo, fuel, water, ballast, stores, passengers and crew. The relationship between LDT and DWT can be seen below. LDT measurement is often used to define the price at which a ship is sold for scrapping to a scrap yard. The price of ship scrapping will be further discussed in the section 0

Ship power and speed values are required in the model to estimate the investments required for emission reduction equipment and for estimating the fuel consumption of a ship. The power required for the ship depends upon the size of the ship, desired service speed and design of the hull. Design speed requirements for a ship depend not only on the size of the ship but also on the type of cargo traded by the ship. Figure 14 shows the design speed requirement contrast for comparable bulk and tanker ships.

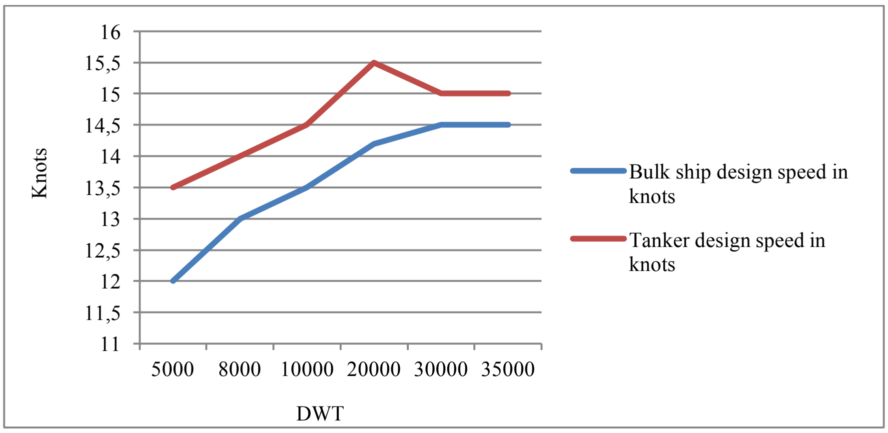

Figure 14 - Service speed comparison of bulk ship and oil tankers

Source: (MAN Diesel and Turbo SE, 2014), (MAN Diesel and Turbo SE, 2013)

These differences in speed and structural design impact the power requirement of a ship as illustrated below.

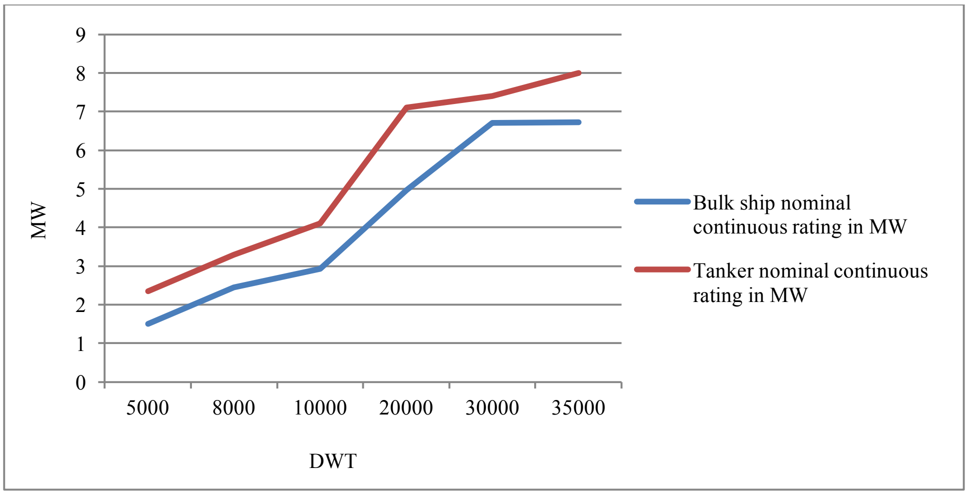

Figure 15 - Nominal continuous rating comparison of bulk ships and oil tankers
Source: (MAN Diesel and Turbo SE, 2014), (MAN Diesel and Turbo SE, 2013)

In the cash-flow model, data from MAN Diesel and Turbo study of bulk carriers and oil tankers is taken to estimate the engine power and design speed for a given ship DWT. The complete power-DWT curve and speed-DWT curve for both types of ship (bulk and tanker) used in the business model is illustrated in fig. 14.

For roll on roll off (RORO) ships the model also calculates the power and design speed using the following equation.

$$P = 164{,}578 * GT^{0{,}435}$$

$$V = 2{,}34 * P^{0{,}23}$$

Where:

P = Installed power in MW
GT = Gross tonnage
V = Design speed

Equation 2 - Power speed and size relationship for RORO ships

Source: (Trozzi, 2010), (Italian ministry of infrastructure and transport, 2011)

Traditionally, bulk ships contain several engines for different purposes. Main engines (M/E) are used to turn the ship's propeller and move the ship through water whereas Auxiliary engines (A/E) provide power for the ship's electrical systems. Since the contribution of A/E operation to ship’s fuel consumption is significant the model also calculates the total installed A/E power on a ship. **Fout! Verwijzingsbron niet gevonden.** depicts the observed relationship between the main engine size and auxiliary engine size for different types of ship. The M/E power calculated using the assumptions discussed above can thus be used in calculating an approximate value of A/E power. This ratio can also be helpful to estimate possible gains of auxiliary generators using renewable energy such as PV Solar.

Type of ship	Power rating ratio A/E to M/E
Liquid bulk ships	0,3
Dry bulk carriers	0,3
Container	0,25
General Cargo	0,23
Ro Ro Cargo	0,24
Passenger	0,16
Fishing	0,39
Other	0,35
Tugs	0,1

Table 6 - Estimated average power ratio of A/E to M/E by ship type

Source: (Trozzi, 2010)

Ship fuel consumption characteristics are important input needed to estimate the fuel cost associated with the operation of the ship. Fuel used for ship propulsion constitutes a major part of the fuel consumed by a ship; auxiliary machineries such as boilers and power generators account for the remaining fuel consumption of a ship. Table 7 depicts the capacity utilization and specific fuel oil consumptions (SFOC) of main and auxiliary engines while at sea and at port. An estimation of fuel consumption of a ship at sea or at port can be made using the A/E and M/E installed power information discussed above along with the fuel consumption information given in Table 7.

Variable	At sea	At port
% load of M/E capacity	80%	-
M/E IFO SFOC in g/kWh	195/213*	-
M/E MDO SFOC in g/kWh	185/203*	-
% load of A/E capacity	30%	40%
A/E IFO SFOC in g/kWh	227	227
A/E MDO SFOC in g/kWh	217	217

*For M/E power more than 3,2 MW, lower SFOC values are considered in the model due to higher efficiencies of large two stroke engines compared to small four stroke engines

Table 7 - Estimated load and fuel consumption for M/E and A/E

Source: (Trozzi, 2010), (Man Diesel and Turbo SE, 2014)

An important point to remember here is that fuel consumption is related to the service speed of the ship. Most ship fuel consumption is quoted in design speed but this value varies significantly depending on the actual service speed of the ship. The design speed of bulk ships is within the range of 12 to 15 knots depending on their size.[43] The relationship is defined by the "cube rule" illustrated by the formula below.

$$F = F_D * (S/S_D)^3$$

Where:

F = Actual fuel consumption in tons/day
F_D = Design fuel consumption in tons/day
S = Actual service speed in knots
S_D = Design speed in knots

Equation 3 - Relationship between fuel consumption and ship speed

Source: (Stopford, 1997)

Fuel consumption of a ship also varies with the amount of cargo it is carrying. Some studies suggest that the difference in fuel consumption per unit of distance covered in ballast voyage may be 6% to 13% lesser than fully loaded voyage.[44] The calculation in the model takes the relationship between ship size, ship speed, engine power and engine consumption discussed above to calculate fuel consumption of a fully loaded ship and this fuel consumption is adjusted linearly to the loading of the ship assuming a maximum of 13% reduction of fuel consumption for ballast voyages.

Emission abatement technology assumption

The maritime industry is moving towards stringent emission control driven by an increased international awareness of the impact of these emissions on the environment.
Penalties for non-compliance to regulations can have adverse economic impact on shipping companies and thus act as effective dissuasive measures. Compliance to the evolving regulatory landscape of the maritime industry requires ships to be installed with emission abatement technologies which are a source of additional cost (significantly lower than penalties) to shipping companies. Emission regulations set emission limits per unit of energy produced on a ship. Since hybrid (renewable energy and fuel) propulsion systems depend on a conventional engine they still need to invest in emission abatement technologies. In the paragraphs below we will briefly discuss the emission abatement technologies being considered in this model.

Sulphur Oxides (SOx) emission from ships can be reduced by switching ship operation to low sulphur fuels (Marine Diesel Oil, Marine Gas Oil, Liquefied Natural Gas etc.). Shipping companies that wish to use cheaper Intermediate Fuel oil (IFO) with higher sulphur content needs to be equipped with a SOx scrubber.

Available SOx scrubbers systems can be classified into two categories: wet scrubbers that use water to wash out SOx from the flue gas and dry scrubbers that use calcium hydroxide to bind sulphur

[43] (MAN Diesel and Turbo SE, 2014)
[44] (Georgakakia, Coffey, & Sorenson, 2004)

oxides in the form of calcium sulphate (gypsum).The wet scrubber system can be further divided into two types based on their configuration namely open loop and closed loop systems. Open loop system uses sea water for cleaning the flue gas and the effluent is ejected out of the ship after being treated to comply with pollution standards. Closed loop system consists of a closed cooling and scrubbing circuit to which caustic soda solution is added to rinse out the sulphur oxides. According to naval architects a comparison of cost effectiveness of the various systems based on capital expenditure, operating expenses, loss of cargo carrying capacity due to scrubber equipment dimensions and additional energy requirements suggest that open loop sea water scrubbers out-perform other systems. This comparison however does not take into account a possible implementation of 'zero discharge' areas in the future in which scrubber effluent will be stored in an additional large tank and the associated costs of such storage.[45] . Default investment and operational cost for the scrubber are calculated using Table 8and M/E power estimated in section 0. The default lifespan of the scrubber in the model is taken as 15 years.

Total engine power	New-build capex €/MW	Retrofit capex €/MW	Opex €/MWh	Add. Fuel as % of ship fuel consumption
Less than 3 MW	118000	168000	0,8	0,9%
Between 3 to 6 MW	118000	168000	0,8	0,15%
Between 6 to 15 MW	118000	168000	0,5	0,15%
More than 15 MW	118000	168000	0,3	0,15%

Table 8 - Costs associated with open loop sea water SOx Scrubber

Source: (Walter & Wagner, 2012), (Entec UK limited, 2005)

Apart from the above mentioned costs, the additional weight of the scrubber results in an equivalent cargo carrying capacity loss for the ship. The approximate weight of the scrubber system can be calculated by the following formula.

$$S_W = 0{,}9382 * P + 6{,}1809$$

Where:
S_w – Weight of scrubber system in tons
P – Engine power in MW

Equation 4 - Total weight of open loop sea water SOx scrubber

Source: Adapted from (Walter & Wagner, 2012)
In the model this lost cargo capacity due to the weight of the scrubber is deducted from the total cargo carrying capacity of the ship during revenue calculation. If the entire capacity of the ship is not utilised then only the surplus lost cargo capacity is considered. This can be better understood by the following

[45] (Walter & Wagner, 2012)

example, for a 5000 dwt bulk ship using 99% of its capacity, its free capacity is 50 tons then a scrubber weighing 7,6 tons will have no impact on the earnings of the ship as the systems weight is lower than the free capacity.

Nitrogen Oxides (NOx) emission can be lowered by either reducing the elevated temperatures of the combustion cycle, reducing oxygen available for NOx formation or by using exhaust gas after-treatment. The prominent solutions are: reduction of combustion temperatures through engine modification, introduction of water to reduce combustion temperatures (injecting water in fuel or humidifying the inlet air), re-circulating exhaust gas to reduce oxygen content of inlet air or treatment of the exhaust gas with urea to remove NOx emissions (Selective Catalytic Reduction).

So far only Selective Catalytic Reduction (SCR) has demonstrated its capability to achieve the target NOx reduction in a reliable and repeatable way as a standalone technology. Other technologies may have the theoretical potential to realize IMO Tier III reduction levels. However, it is highly probable that in practice, combinations of two or more of these technologies are necessary in order to achieve compliance at optimum general performance and for minimum total lifecycle cost.[46] For this reason for the purpose of calculations in the model only SCR is being considered as the method to comply with NOx regulation. In the model M/E power estimated in section 0 along with estimates of Table 9 are used to calculate the default investment and operational costs for SCR. The default lifespan of the SCR in the model is taken as 15 years.

Total engine power	New-build Capex €/MW	Retrofit Capex €/MW	Opex IFO operation €/MWh	Opex MDO operation €/MWh
Less than 6 MW	64000	96000	6	4,2
Between 6 to 15 MW	46000	69000	4,8	3,5
More than 15 MW	42000	63000	4,5	3,4

Table 9 - Costs associated with SCR systems

Source: (Entec UK Limited , 2005)

Wind assisted hybrid propulsion indirectly reduces emissions by reducing the amount of fuel burnt by the ship. There are numerous technologies being researched currently such as Flettner rotors, delta wing sails, Dynarig etc. The cash-flow model has been built to compare three hybrid technologies on 6 different routes. For the purpose of this report, only publically available data for delta wing sail is considered. For the delta wing sail it is assumed that the cost of installing delta wing sail is 17% of the ship building cost and the yearly operating expense of delta wing sail is 2% of the installation cost. It is also assumed that at ship speeds of 20 knots the delta wing sail can reduce fuel consumption by 9% and for 12 knots speed the fuel reduction is nearly 19%.[47] For intermediate speeds the fuel consumption reduction is calculated in the model from afore mentioned figures by assuming linear relationship between speed and reduction in fuel consumption.

[46] (Wartsila Corporation, 2011)
[47] (Seagate, 2014)

Ship cost assumptions

The cash-flow model requires investment and operational cost information for calculations. The assumptions behind the various default cost values used in the model are discussed below.

Investment costs

Investment costs represent the total upfront capital required to acquire a ship. The calculation of investment cost is done in two steps. In the first step acquisition cost of a basic ship without any emission reduction technology is estimated. In the second step additional investment cost for inclusion of emission reduction technology (discussed in the above section) is calculated. The addition of the costs calculated in the two steps gives the total investment cost of the ship.

Shipping companies have the choice of either building a new ship or buying an existing ship from the second hand market. The decision to buy or build depends on the freight market conditions and on the relative difference between new-building prices relative to second hand purchase prices. The assumptions used for calculating costs for each option are discussed below.

New-building prices depend on global steel prices, demand for new ships and global yard capacity utilization. Demand of new ships depends on future earnings potential (Freight rates, time charter rates and bunker costs) of ships. Figure 16 shows the past price evolution of new-building prices. The average global new-building price for the last decade was approximately 2218 USD per CGT and has been used in the model to calculate ship acquisition cost for new ships.

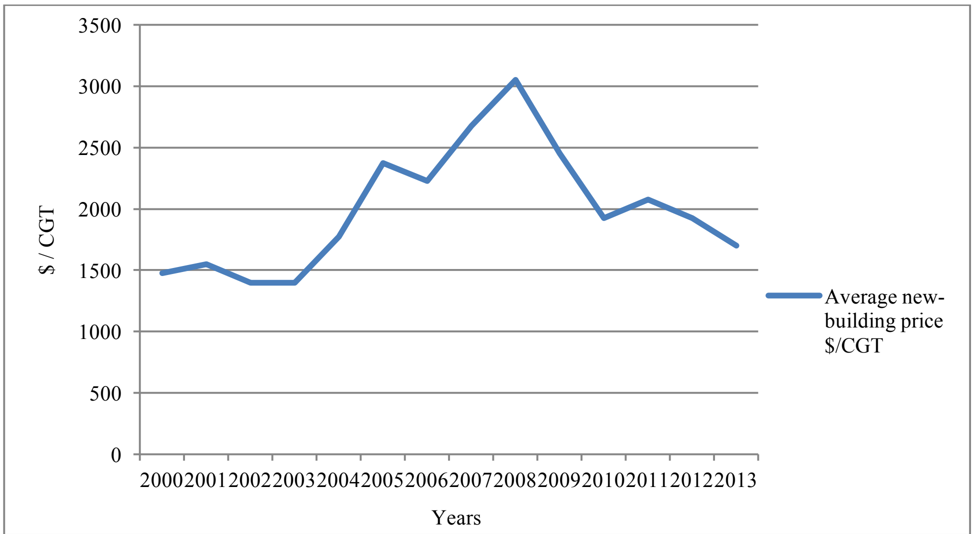

Figure 16 - Average global new-building price development
Source: (Danish Ship Finance, 2013)

Second hand sale and purchase market determine the asset value of a ship. The prices in the second hand market are volatile and depend a lot on the shipping market factors such as future earnings potential, scrapping prices and new-building prices. It is a known fact that though the benefit of buying a second hand ship is the reduced initial investment, this benefit is counterbalanced by increased operational and dry-docking costs as shown in Table 10.

Age	10 years	20 years
Reduction of acquisition cost	-14%	-67%
Increase in operational cost	21%	63%
Increase in dry-docking cost	44%	177%

Table 10 - Ship cost relationship to acquisition age Source: (Stopford, 1997)

This difference in costs can be explained by the technological advancement of equipment and optimised hull design of new ships compared to existing ships. Thus the decision to buy or build boils down to whether the price differential between new-building price and second hand ship price will be able to compensate the increased operational and dry-docking costs. In the model to estimate the existing ship acquisition cost, linear relationship is assumed between the cost variation (illustrated in the table above) and the age of the ship. The default age of existing ship is taken as 3 years.

Capital financing assumptions

Capital required to finance the ship can be obtained through bank loans (debt), shareholder equity or a mixture of both[48]. The advantage of debt financing is tax deductibility and lower interest rates (compared to return expected on equity) but the downside is the periodic large loan repayment obligations and the risk of bankruptcy. It is thus often observed that ships are financed with a combination of debt and equity.

As ships constitute the biggest share of shipping company's asset value, it can be assumed that the ratio of debt financing to equity financing of a ship is equal to the overall debt to equity ratio of the company. The European small bulk market consists of mostly small private companies (Arklow shipping, Arkon shipping, Fast-lines etc.) and some small public companies (Wilson, Rederi AB TransAtlantic). A summary of information found in financial statements and press releases of Wilson and Rederi AB TransAtlantic is shown in Table 11.

	Wilson ASA	TransAtlantic	Average
Debt to equity ratio	2,20	1,25	1,72
Interest rate on debt	7%	5%	6%
Return on equity goal	15%	12%	14%
Corporate tax rate	27%	22%	25%
Discount rate	8%	8 %	8%

Table 11 - Company profile summary Source: (Wilson ASA, 2012), (Rederi AB TransAtlantic, 2013)

[48] Green bonds etc.

Internal sources within SAIL project estimate that to build a bulk carrier for a loan of € 6 Million for a period of 15 years, the bank charges an interest rate of 4,5% to 5% per annum. In the cash-flow model it is assumed:

- the ship is financed with a debt to equity ratio of 1,72
- Return on equity requirement is 14%
- The corporate tax rate is 25%
- The bank charges an interest rate of 5% on the loan amount with annual repayment for a period of 15 years.

The discount rate used to determine the present value of future cash-flows in the model is calculated using the following equation.

$$I_d = (E/A)*R_E + (D/A)*R_D*(1-T_C)$$

Where:

I_D = Discount rate
R_E = Return on equity requirement
R_D = Debt interest rete
E = Market value of the firm's equity
D = Market value of the firm's debt
A = Total asset value (E + D)
T_C = Corporate tax rate

Equation 5 - Discount rate for discounted cash-flow analysis

Ship operating cost assumptions

The various costs associated with ship operation can be classified as follows.[49]

1. Operating costs
2. Dry-docking and special surveys
3. Voyage costs
4. Cargo handling cost
5. Carbon tax

Some companies utilise the term running cost to signify the combined operating and dry-docking cost of a ship. Figure 17 shows the distribution of running costs for a typical small bulk ship (SBS).

[49] (Stopford, 1997)

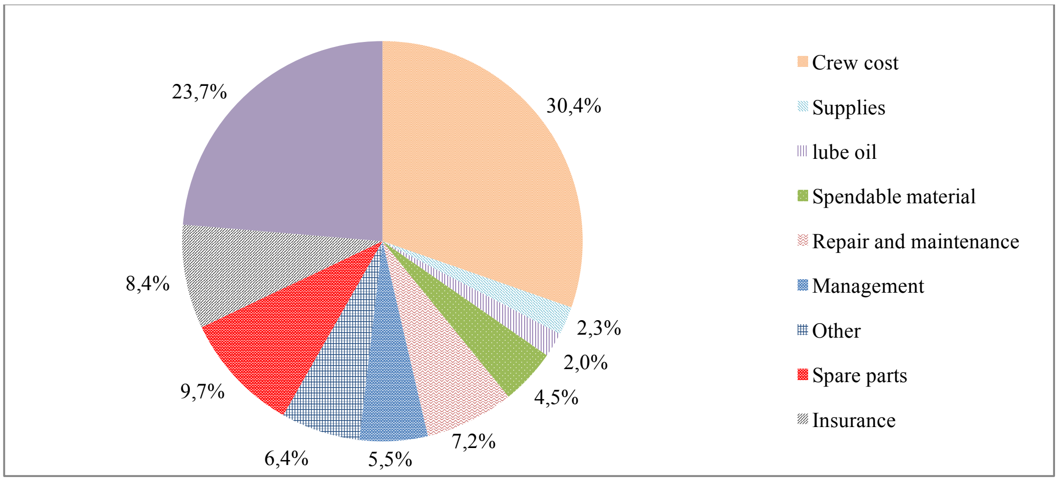

Figure 17 – Typical distribution of running costs for a small bulk ship

Source: (Wilson ASA., 2014)

Operating costs consist of the expenses involved in the day-to-day running of the ship such as crew, stores, maintenance, administration and insurance costs.

Crew costs are the largest contributor to operating costs for a small bulk ships (SBS). The flag of registration lays down regulations which decide the minimum number of crew on a merchant ship. A reduction of crewing is allowed for ships with high degree of automation of mechanical operations in the engine room (unattended engine rooms) as opposed to low automation engine rooms (attended engine rooms). The International Transport Workers' Federation (ITF) lays down minimum basic monthly wages for all ranks, as well as rates and leave as part of its world-wide wage scale. A sample of the minimum manning requirement for Marshall Island registered ship and the corresponding minimum monthly wages is included. The model uses the GT of the ship to determine the manning requirement and minimum monthly wages and thus it can calculate crew costs for all sizes of ships. For example the monthly crew wages for a 3000 DWT bulk ship is approximately $17000 per month and for an 8000 DWT ship is approximately $ 23000 per month.

Dry-docking and special surveys costs consists of the expenses incurred during ship dry-docked or during special survey. The off-hire duration of a small bulk ships for dry-dock is on average 24 days and the interval between dry-docks is 2,5 years.[50] Internal sources within SAIL project estimate that the dry-docking period for a 5000 DWT ship can be as low as 10 days which is also the default value of the model.

Voyage costs consist of variable expenses stemming from port charges, canal dues and fuel consumption during a particular voyage. More than half of the voyage costs are due to fuel expenses.[51].

[50] (Stopford, 1997), (Wilson ASA., 2013)
[51] (Stopford, 1997)

In the cash-flow model the fuel prices depicted in the reference scenario described above have been used as the default value for calculation of fuel cost of the ship.

The second largest contributor to voyage costs is port related costs. This consists of fairway charges, port dues, mooring/unmooring charges, pilot fees, towage charges and cargo handling charges. These charges can vary from port to port. In the model, when exact port charges are not known, default values are extrapolated from the trend line equation seen in in Figure 18 assuming linearity between the various costs and the GT of the ship. If otherwise not specified cargo loading and discharging charges for bulk goods in the model is assumed to be equal to that charged by the port of Rotterdam in 2013 (0,63 €/ton of cargo).[52]

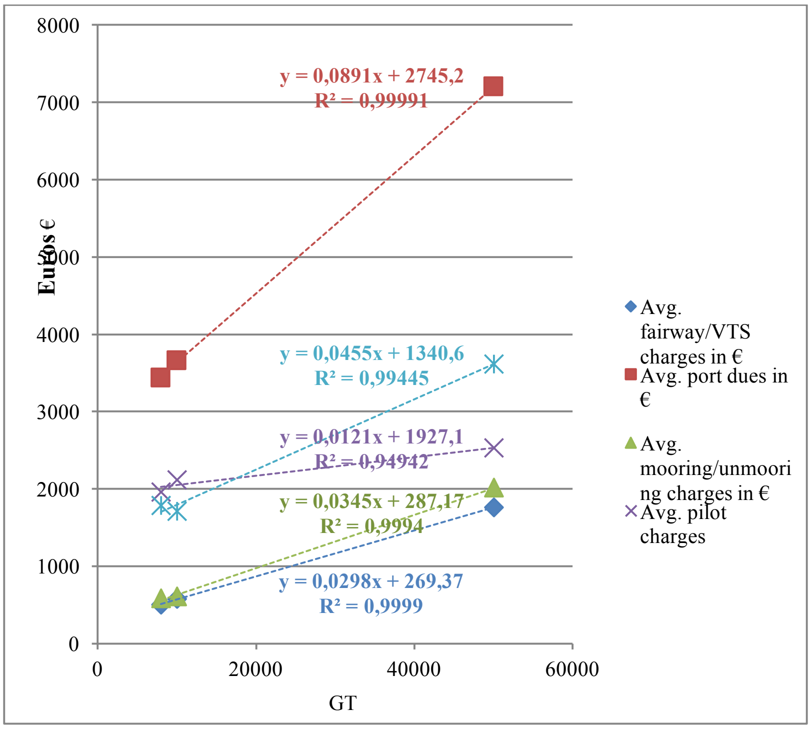

Figure 18 - Average port related cost for Rotterdam, Le Havre, Hamburg and Koper

Source : (The Maritime Transport Coordination Platform, 2007)

Another important variable which must be considered is time spent by a ship in the port. In the model the port time is calculated from the trend line equation in Figure 19 assuming linearity between size of the ship (GT) and hours spent in the port. These figures are probably conservative because at present ships tend to stay shorter in port.

[52] (Havenbedrijf Rotterdam N.V, 2013)

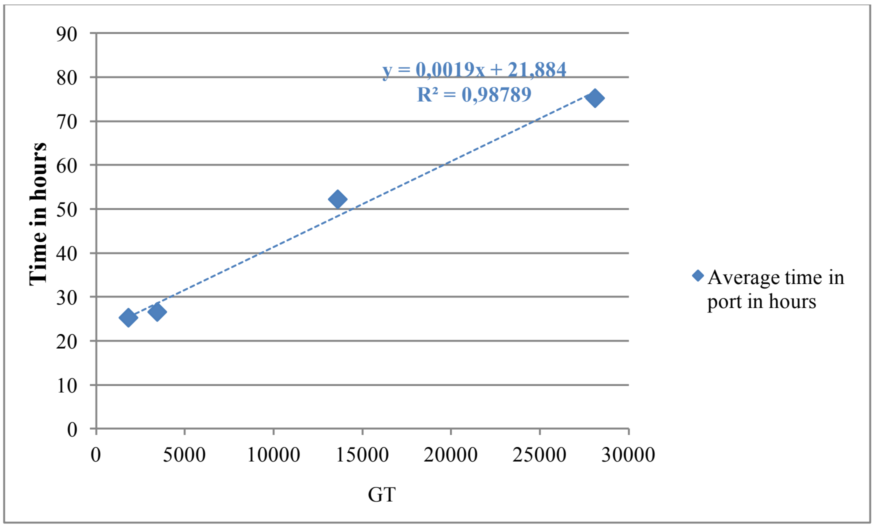

Figure 19 - Relationship between ship size and time spent in port

Source: (Kahveci, 1999)

Time spent in port is also impacted by congestion at port resulting in delays. In the cash flow model it is assumed that port congestion represents an additional 21% of the time spent in the port.[53]

Carbon costs are expected to become a major cost element associated with ship operations. European Union Emissions Trading Scheme, a major pillar of EU climate policy, is the biggest emissions trading scheme in the world aimed at combat climate change.[54] The EU targets 20% reduction in greenhouse gas emissions by 2020 and 40% reduction by 2040.[55] These trends suggest that the CO_2 emissions will soon become a significant cost for ships that depend on conventional fuels for operation. In the calculations of this report we assume that this cost will be € 10 per ton of CO_2 emitted[56]. The roadmap for transition to wind assisted propulsion until 2050 will include a sensitivity analysis to better understand the impact of rising carbon prices.

Ship revenue assumptions

Freight revenue is the biggest and the most important source of revenue for a ship. Freight rates levels depend on the balance between the demand for ship tonnage and its availability in the market.

Marine analysts describe freight rate fluctuation in terms of shipping cycles which can be better understood with the following example. In a market with high freight rates, investors place order for new ships to be built. Eventually excess orders create an oversupply of ship tonnage in the market and start to undermine freight rates. Lower freight rates stall new orders from investors and encourage demolition. At the low point in the cycle, reduced ordering and increased demolition shrink the supply

[53] (CLECAT and FIATA, 2006)
[54] (Siikamäki, Munnings, & Ferris, 2012)
[55] (Global CCS institute, 2013)
[56] This is considered the normative floor price of the European Trading System (ETS), even if prices do set lower.

and set the stage for a rise in freight rates and the circle starts all over again.[57] The duration and frequency of this boom and bust cycle is impossible to predict. However it can be safely inferred that the current tough market condition represents a low point in the cycle and marine analyst estimate a gradual improvement in the near future.

Table 12 and

Figure 20 give a snapshot of EU sea bulk trade and corresponding freight rates per ton-mile in 2011.

Type of cargo	Freight rate in €/ton-mile
Coal	0,0299
Animal Feed	0,0151
Non-Metallic Products, nec.	0,0143
Other 18 dry bulk commodities	0,0143
Fertilizers and Pesticides	0,0123
Grain	0,0115
Iron and Steel	0,0114
Stone, Clay and Other Crude Minerals	0,0105
Ores and Scrap	0,0085
Oil Seeds	0,0072

Table 12 – Cargo freight rates

Source: (Metal Expert LLC, 2012), (BMTI Technick & Informations Gmbh, 2012), (Ports.com, 2014)

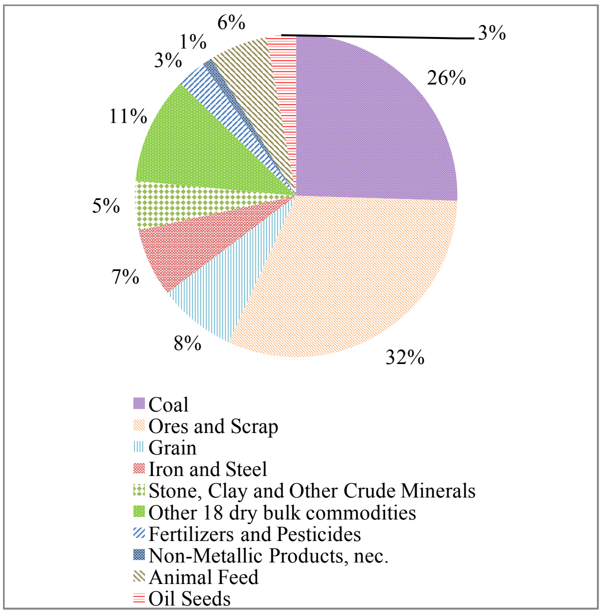

Figure 20 - Distribution of EU bulk trade by cargo type

Source: (European Commission, 2011)

Of the 10 categories of bulk cargo considered in
Table 12, the top 5 categories (Coal, Ore, grain steel and minerals) constitute nearly 80% of bulk cargo transported by sea. Based on the above values a weighted average freight rate of 0,0161 €/ton-mile can be calculated for bulk ships operating within EU. This figure will be used in the cash-flow model for scenarios where ship route or cargo information is not available. In the cash-flow it is also assumed that the average deadweight utilization of the ship is 90% and the ship is on off-hire for 7 days per year.
Scrapping marks the end of a ships life. At this stage the operational cost of the ship becomes prohibitively high due to aging in-efficient equipment and an equally elevated maintenance cost.

[57] (Stopford, 1997)

However, a large proportion of the ship is made of metal which can be recovered and recycled. Given the high global demand for scrap metal, ship scrapping becomes an important source of revenue for the capital intensive shipping industry. Ship scrapping activity is geographically concentrated in certain countries such as India, Bangladesh, China and Pakistan with the two former countries representing nearly 50% of the total tonnage scrapped in the world.[58] Scrap prices are quoted in dollars per ton of light-displacement (LDT) of the ship. The average scrap price for bulk ship scrap transaction from 2010 to 2013 is approximately $410/LDT. [59]. The average demolition age of bulk carriers for the period from 1998 to 2010 is approximately 28 years. These scrapping price and scrapping age values discussed above will form the basis of calculations.

Scenario comparison

Scenarios are a way of developing alternative futures based on different combinations of assumptions, facts and trends. The cost assumptions discussed in the above section can aid in calculating the cash flow of different scenarios and help in identifying the best paths for a better future.

In this report we will define four scenarios to compare the impact of choice of fuel (IFO or MDO) and use of wind assisted hybrid propulsion (delta wing sail) has on the economic performance of a bulk ship. For the purpose of calculation it is assumed that, at 11 knots speed with delta sails, fuel consumption for a bulk ship while sailing can be reduced on an average by 18%.[60]

Marine Diesel Oil scenario (MDO) – In this scenario all calculations are made assuming that the ship operates on MDO.

Marine Diesel Oil and wind scenario (MDO wind) – In this scenario all calculations are made assuming that the ship operates on MDO but it is also equipped with a delta wing sail

Intermediate fuel oil scenario (IFO) – In this scenario all calculations are made assuming that the ship operates on IFO and is equipped with an open loop sea water scrubber.

Intermediate fuel oil and wind scenario (IFO wind) - In this scenario all calculations are made assuming that the ship operates on IFO and is equipped with an open loop sea water scrubber. The ship is also assumed to be equipped with a delta wing sail.

The cash flow model constructed from the assumptions discussed in the above section can be used for any route and any cargo. For the purpose of this report publicly available data for a real bulk ship "Wilson Caen" and its route and cargo information will be used (published by Wilson ASA in their 2011 annual report).

Table 13 lists the data assumption of the ship which will remain fixed for all four scenarios. Figure 21 and Table 14 detail the route followed by the ship, type of cargo carried and freight earned per ton of cargo for each trip.

[58] (Knapp, Kumar, & Remijn, 2008)
[59] (RS Platou, 2013)
[60] (Seagate, 2014)

Description	Unit	Value
Deadweight	tons	4450
Engine room type	-	Unmanned
Deadweight utilization	%	98%
Speed*	knots	11
Ship lifespan	Years	28
NOx abatement	-	SCR
NOx abatement lifespan	Years	15

* Assuming no change in speed, port days, ballast days and loaded days.

Table 13 - Fixed data assumptions Source: (Wilson ASA, 2012)

Figure 21 - Scenario route map used in the example

Source: (Wilson ASA, 2012)

From	To	Cargo or Ballast	Freight €/ton
Frederiksværk	Grenaa	Scrap	0,50
Grenaa	Kambo	Ballast	0
Kambo	Stavanger	Oat	5
Stavanger	Eikefet	Ballast	0
Eikefet	Stettin	Aggregates	8
Stettin	Klaipeda	Ballast	0
Klaipeda	Bayonne	Fertiliser	26
Bayonne	Tonnay-Charente	Ballast	0
Tonnay-Charente	Leixoes	Wheat	9
Leixoes	Sines	Ballast	0
Sines	Holla	Coal	42
Holla	Raudsand	Ballast	0
Raudsand	Slite	Iron oxide	12

Table 14 – Voyage profile small bulk ship

Source: (Wilson ASA, 2012), (BMTI Technick & Informations Gmbh, 2012), (Metal Expert LLC, 2012)

Result and discussions

A closer look at the route and cargo information from Table 14 can help draw preliminary conclusions. In Figure 22 the above route (same route for all scenarios) is categorized into revenue earning period (loaded sailing days) and non-revenue earning period (port days, ballast sailing days and off-hire days).

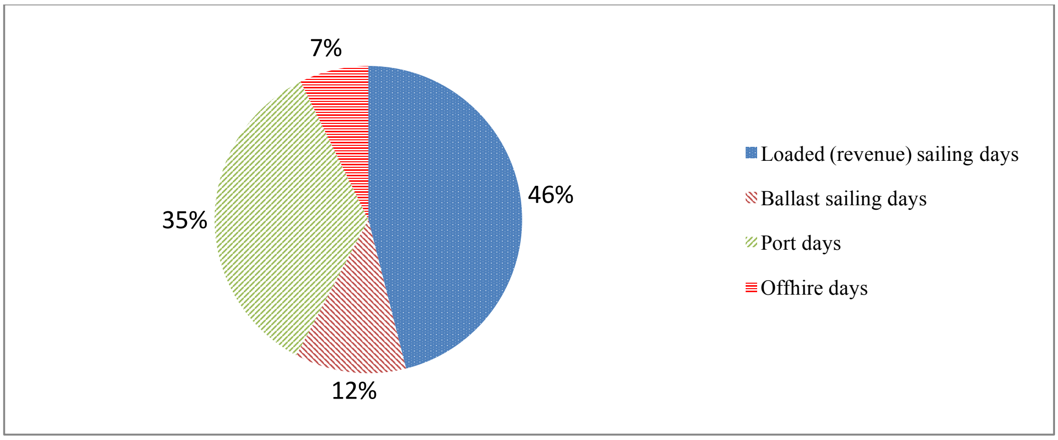

Figure 22 - Route distribution

Based on this distribution we can conclude that 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). Similarly, a closer look at the time spent for transporting each type of cargo (
Figure 23) and the revenue earned by each type of cargo (
Figure 24) helps conclude that the preference should be given to carry high freight earning cargo for the longest loaded stretch the ship travels on a particular route as this has the highest impact on the average freight earned by a ship. Thus special attention is needed when defining which the cargo is suitable for which leg of the shipping route.

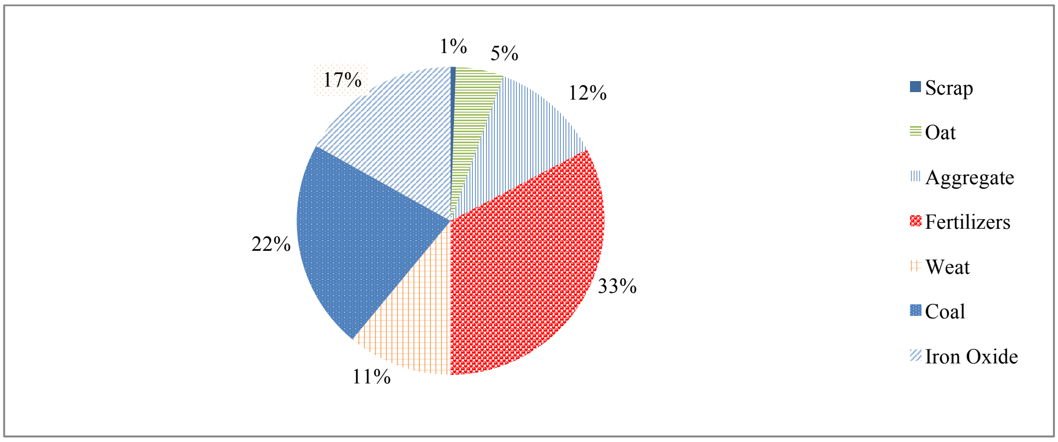

Figure 23 - Distribution of time spent in transporting for different cargo type

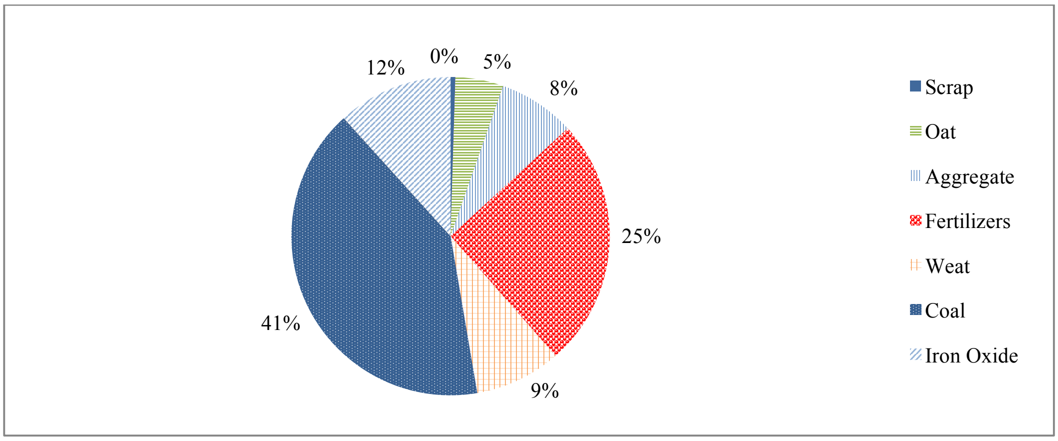

Figure 24 - Distribution of revenue contribution of each cargo type

The result of the calculation for the four scenarios is summarised in the table below.
🏆 Best result for each category

	Unit	MDO	MDO wind	IFO	IFO wind
Total investment	Million €	5,79🏆	6,76	5,95	6,92
Present value of future earnings	Million €	0,64	1,35	3,54	3,76🏆
Payback period	Years	16,71	15,32	9,46🏆	10,49
Internal Rate of return	%	9%	10%	14%🏆	13%
Average haulage cost	€/ton of cargo	101	98	90	89🏆
Average freight earned	€/ton of cargo	103	103	103	103

By comparing scenario MDO with scenario IFO wind, we see that by choosing a ship that runs on fuel oil and has wind assisted hybrid ship propulsion technology:

- The haulage cost can be reduced by as much as €12 per ton of cargo carried for the given route (nearly 12% reduction).
- The payback period for the investment in IFO wind scenario is reduced by 6 years.
- The net present value of future earnings of IFO wind scenario is nearly €3 million more than the MDO scenario.

Different stakeholders of the shipping industry will interpret the above result differently. For example ship owners would prefer the IFO wind results as in this scenario the freight to haulage cost difference is highest which means increased cash-flow (necessary especially in an economic crisis). Banks will also prefer this scenario with higher cash-flow as for them it means that the ship owner will be able to fulfil his debt repayment obligations. In contrast to these stakeholders, the company investors/shareholders will prefer the IFO scenario as in this scenario the balance between investment, returns and risk is better than other scenarios.

However, the results strongly suggest that using only distillates for ship operation is the most unfavourable scenario for all of the three stakeholders mentioned above. The result of the analysis also suggests that this concept has real potential for development and can result in economic benefits for ship owner, end consumers and the environment.

Discussion

The calculations in this report are based on publically available information hence it is important to highlight that better choices in-terms of routes (higher wind potential) and better technological options (higher fuel savings) may improve or alter results. Calculations are based on assumptions which reflect current economic conditions. Thus future impact of high carbon prices is not discernible in the calculations done in the preliminary scenario comparison, nor the large uncertainties on fuel prices. Moreover, the model assumes that the impact of inflation will be passed on to the end consumers.

4. Building up a technological Innovation System?: role of stakeholders and policy suggestions

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 Oceania Centre for Sustainable Transport (OCST) develops such a network of countries and projects aiming to reduce dependency of PICs[61].

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).

[61] http://pace.usp.ac.fj/ocst/HomePage.aspx

Stakeholders and their interest in Wind Propulsion

The discussion of the economics of wind propulsion relies on macro-economic factors such as the price of oil or the taxation of carbon or pollution emissions. In part, the adoption of sails for freight will rely on the maritime industry taken as a whole, with for example possible regulations or standards that will apply globally or in large regions.

Maritime transport is on the verge of radical change driven by international regulations, aimed at reducing the environmental impact of ships, but also for adaptation to ever more difficult conditions of competition. This change has implications for all stakeholders of shipping industry (ship owners, port facilities, shippers, governments, consumers etc.). Although this change is inevitable, there is a growing debate about the most cost-effective method to implement the environmental change. For instance to reduce sulphur oxide emissions (SOx), the industry opinion is divided between effectiveness of cleaner fuels (with low or no sulphur content), exhaust gas after-treatment (wet and dry scrubbers) and –in a more limited fashion- renewable energy driven propulsion (wind, solar, etc.), with proponents of each camp arguing on the merits of their respective solution. It is thus interesting to explore the factors influencing these stakeholders.

In the end, investment choice will come mainly from micro-economic factors, i.e. the decisions and interference made by actors at a smaller scale: the firms which decide to invest or to lend, who pays who, what reluctance some actors may have. This discussion and a list of the main actors are presented in the table next page.

Type of stakeholders	*Description*	*Requirements of the trade*	*Influence*	*Possible position on Wind Assisted Ship Propulsion*
Charterers and shippers	This group of stakeholders consist of individuals or companies that transports or receives goods by sea, land, or air.	Requirements – Shippers and charterers want ships that lift the cargo they need and can perform a voyage in the time required for the lowest possible cost. Ship-owners, increasingly, have to demonstrate the performance of their ships – and be held to those claims. The penalties potentially imposed by charterers for not meeting performance criteria can wipe out any potential profit.	Influence – In the current economic climate, the commercial balance of power is with this group of stakeholders as the supply of ship tonnage in the market is a lot higher than the demand.	Position on WASP – For bulk trade, where drop in service speeds is relatively low and there is a potential for significant reduction of haulage cost, shippers will tend to support such ships. However, for Roll-on Roll-off (RORO), where drop in service speed is large, even with significant haulage cost reduction the total benefits of using WASP will not be able to balance the additional inventory and warehousing cost for shippers. Thus for such trades, shippers will be opposed to WASP. Charterers have also a very short term horizon for their reasoning, an important factor against new developments.
Ship owners	This group of stakeholders consist of companies that own ships.	Requirements – Ship owners require ships which require the least amount of investment and is that have the highest possible operational efficiency while complying with international regulations. While deciding routes, ship owners consider whether there is sufficient demand and whether the freight earned by the ship will be sufficient to make the operation of ship profitable.	Influence – In the current market, ship owners have low influence due to the unfavourable imbalance between demand and supply.	Position on WASP – Ship owners will support WASP if it shows the potential of a return on investment, shorter payback period and better cash-flow. In some cases Wind may also be a showcase and a way to differentiate their service, especially if it is reliable. But owners fall into the "split incentive" issue with a limited direct interest in lowering operation costs compared to investment.
Investors	This group represents shareholders and other private equity investors. They invest money and sometimes business skills in companies/projects to help them become profitable.	Requirements – Investors require prefer investing in projects which have low risk and high returns. For riskier projects, Investors require higher returns.	Influence – Investors possess large funds and the ability to mobilize these funds. As a result, their influence on projects is considerable especially in tough economic conditions.	Position on WASP – From preliminary scenario calculations, it appears that the balance between risk return are marginally in favour of IFO run ships without WASP as opposed to ship run with WASP. Thus it is possible that investors might pose mild opposition to the introduction to WASP on ships. This position will however inverse if CO2 prices increase.[62]
Banks	This group of stakeholders consist of 'syndicate' of banks or other lending institutions that provide loans to a project in exchange of interest and repayment	Requirements - These loans are most commonly non-recourse loans, which are secured by the project assets and paid entirely from project cash flow. Thus for long-term	Influence – In the maritime industry, banks exercise considerable influence as they are a major source of funds required to finance a ship.	Position on WASP – Banks support energy efficient ships as this ensures greater cash-flows and reduces the risk of a default by the ship owner. Thus promising WASP technology should be backed by banks. But these institutions are also very averse to risk, and this feature might be dominant.

[62] Most investment funds have a commitment –sometimes judiciary- to maximize profits for investors, one more factor for limited support for new technology. But some investment funds are searching for credible renewable or low carbon investment, which gives a possibility for alternative transport solution. Nevertheless, such "green" investment is associated with warranties both technical and financial, that cannot be present for a first in a series.

Type of stakeholders	Description	Requirements of the trade	Influence	Possible position on Wind Assisted Ship Propulsion
	agreements.	financing of projects banks require that the projected cash flows of the project is sufficient for repayment of the loan.		
International Policy makers	These consist of international organisations (IMO, EMSA, etc.) which are global standard-setting authority for the safety, security and environmental performance of international shipping. Their main role is to create a regulatory framework for the shipping industry that is fair and effective, universally adopted and universally implemented.	Requirement – These organisation require that ships to meet the standards and rely on national authorities to ensure that ships comply with the international standards. Alliances – International policy makers work in tandem with flag states for the implementation of regulations. They also consult other maritime stakeholders before taking policy/regulation decisions	Influence – These stakeholders have considerable influence on the maritime industry but decision making and implementation of new measures is slow. Experience from the past is that IMO measures, once established and whether mandatory or voluntary Guidelines, have a strong positive influence on R&D and innovation in the sector. It is also the main source for education of seafarers, in terms of good seamanship and marine environmental awareness (Marine Environmental IMO Model Course / STCW)	Position on WASP – The IMO considers wind as promising source of energy for the shipping industry. These stakeholders may be strong supporters of WASP ships once technical feasibility is proven. Regarding the slow process in the field of GHG market measures and emission standards, the IMO should consider the WASP development as a new promising market opportunity. Both in the fields of safety and environment, the two pillars of the organization, IMO profiles itself as the main policy making body of world wide shipping and thus will be hostile to outside input from other regulating bodies.
National and European Authorities	The EU and National Governments have developed Climate and Environment policies		Influence – their research arm is often the key decision-makers for R&D funding.	Agencies are now frustrated by the slow pace of progress in IMO and may support innovations outside multilateral frameworks. Developments are possible here.
Flag State (Regional/National regulators)	The flag state of a commercial vessel is the state under whose laws the vessel is registered or licensed. The flag state has the authority and responsibility to enforce regulations over vessels registered under its flag, including those relating to inspection, certification, and issuance of safety and pollution prevention documents.	Requirements - Flag states require ships to abide by regional/national regulations on safety and pollution prevention.	Influence – Flag state have direct regulatory authority on ships that enter their territory. Thus their influence on hips is high.	Position on WASP – Flag states will support measures which reduce pollution caused by ships, or at least not oppose them[63].
Classification societies	Classification societies set technical rules, confirm that designs and calculations meet these rules, survey ships and structures during the process of construction	Requirements – Ships must conform to technical and design standards set by the classification society in-order to be certified.	Influence – The advent of open registers, or flags of convenience, has led to competition between classification societies and to a relaxation of their standards. This made it attractive for ship	Position on WASP – Classification societies should be neutral to WASP ships as they are not liable for the safety, fitness for purpose, or seaworthiness of the ship. One important step could have been the Lloyd's Register report to awake the Classification Societies to the new developments.

[63] Even flags of convenience are moving slightly. For example, the Liberian registry has set a new "Green Registry" which reduces fees for more efficient ships.

Type of stakeholders	Description	Requirements of the trade	Influence	Possible position on Wind Assisted Ship Propulsion
	and commissioning, and periodically survey vessels to ensure that they continue to meet the rules. To avoid liability, they explicitly take no responsibility for the safety, fitness for purpose, or seaworthiness of the ship.		owners to change flag. A ship owner that is dissatisfied with class can change to a different class relatively easily. This has led to more competition between classes reduced their influence on the maritime industry.	
Insurers	This group of stakeholders that provide financial coverage to ship owners against physical loss or damage of the ship/cargo, against third party liabilities such as damaging a jetty or oil pollution and in some cases against war risks, strike risk and loss of earnings risk.	Requirements – Insurers require that ships conform to flag state regulations and have valid certification from classification societies. The premium charged by insurers reflects the risk associated with a ship.	Influence – Insurers in maritime industry have a position of strength with respect to ship owners especially for third party liability coverage. Insurers work often with banks for projects and tend to reinforce each other's position on a project. Moreover, Investors can in some cases demand insurance backing for projects as a pre-condition for investments.	Position on WASP – Insurers might demand higher premium for first few WASP ships to compensate unknown technology risks and eventually reduce the premium only after large scale commercialization of WASP technology. They can be an important force to impose data sharing because this is the key input for their trade. In other fields such as industry efficiency, insurers and their controllers tend to be conservative towards innovation. This can be matched by the improved collective attitude of insurers towards climate and energy evolutions.
Ports	This group of stakeholders consist of Harbour based organisations equipped with cargo, ship supplies and passenger handling equipment, and which provides ship berthing facilities.	Requirements - Ports require ships to operate quickly and efficiently. They also want ships to be less polluting and even set incentives for efficiency or low emission measures. Ports invest in long term horizons, so understanding the future vessels that will use their facilities is important.	Influence – Some ports incentivise cleaner/more energy efficient ships. Their influence is moderate compared to other stakeholders as there is intense competition among ports thus their clients can easily choose to switch ports if the measures enforced are economically constrictive.[64]	Position on WASP – Ports should be supportive of WASP ships as it helps reduce pollution, with the provision that logistic operations work smoothly. This point may not be filled at once with Sail ships, especially when experimental. Resistance could happen regarding special requirements for handling WASP vessels. New types of ships may also bring new industrial developments, and this could be a favourable argument especially in shipbuilding or maintenance industries.[65]
Employees and trade unions	This group consist of ship crew and their unions that are concerned with the rights of seafarers and safe working conditions on board ships.	Requirements – Trade unions require that the ship offer a safe work environment to its crew and that the wages paid to the crew conform to international rules	Influence – Trade unions have large resources and the ability to mobilize thus their influence on maritime issues is considerable	Position on WASP – A two way argument Safety concerns for this type of ships is not yet clear. For example a sailing ship might have a sustained trim for an entire voyage which raises concerns for crew safety and comfort. If these concerns are not met, then Unions will oppose WASP ships. Additionally, as with any new technology, seafarers have to learn new skills and undergo training to operate the ships. Such ships will also result in seafarers to shoulder

[64] However, some incentive schemes to stimulate and rank ships environmentally have proven to be successful, such as the Green Award system and more recently the Environmental Ship Index. Many of those systems focus at middle size and large ports. Since smaller size ships are a focus irt WASP, a more dedicated incentive schemes could be developed for smaller size ports, which such ships will visit. Many ports have (eco) innovation as a main focus in their strategy. WASP is an inspiring and relatively new working area. Ports that have a strong innovation profile, should consider taking on board in their industry development more prominently.

[65] In attempting to establish trade routes and outlets for WASP, ports could consider a role as stimulators and facilitators. This might increase commercial possibilities and growing markets on the one hand, and on the other hand solidify the ports CSR profile to the surrounding community and society.

Type of stakeholders	*Description*	*Requirements of the trade*	*Influence*	*Possible position on Wind Assisted Ship Propulsion*
				additional responsibilities and liabilities. Thus it is conceivable that Seafarers demand higher wages[66]. But innovation in sails may also bring interesting advantages for staff and owners alike[67].
Refineries	Refineries process petroleum to produce marine fuels.	Influence – The refinery industry is capital intensive and is thus occupied by a few consolidated players. This control of supply gives them considerable influence in the maritime industry.		Position on WASP – Refineries will be opposed to WASP ships as it directly reduces the demand of fuel oil. Refineries would be more interested in promoting distillate fuels as these fuels earn them higher margins.
Bunker fuel suppliers	This group consists of fuel suppliers to ships. They possess the infrastructure and network required to transport marine fuel from refineries to ships.		Influence – Bunker supply for maritime transport is fragmented and there is intense competition among suppliers. Thus their influence is limited.	Position on WASP – Bunker suppliers will be against WASP as the adoption of such technologies will reduce the demand of fuel and thus reduce the revenues earned by the suppliers.[68]
Ship designing, building and repair yards	This group of stake holders are involved in the conception, design, building and dry-docking of the ship.		Influence – Ship building is a demand driven industry. Today, there is an excess supply of shipbuilding capacity in the market and in-sufficient demand. Thus, the influence of this group of stakeholders on the maritime industry is low.	Positions on WASP – WASP ships do not offer any economic benefits to ship building industry. However, it does represent for shipyards an opportunity to differentiate themselves from their competitors and also capture a niche market. Moreover, building ecological ships will aid in improving their corporate image. For these reasons it is conceivable that ship builders support WASP ships. This focus on high tech and R&D requirements may play well, especially in high cost zones such as Northern Europe.
Equipment manufacturers OEM's	This group of stakeholders consist of ship propulsion machinery manufacturers (OEM) and fuel treatment/conditioning equipment manufacturers. They supply equipment ant repair services to ship owners.		Influence – The influence exerted by this group of stakeholders is low with respect to ship owners as competition is high and demand is low.	Position on WASP –WASP technologies such as flettner rotors, where OEM manufacturers can participate in supplying a combined package (Flettner rotor + diesel electric setup + control system), will find support by this group of stakeholders. However, technologies such as Delta sails, ecoliners etc. will result in smaller engines on ship and lower revenues for OEM's thus they will oppose such technologies. Thus this argument has to be refined depending of technology and the region concerned.
Scrap yards	Scrapyards buy ships that are at the end of their operational life and dismantle them. They generate revenues by selling the scrap metal recovered from the ship. They have			

[66] A transfer of some of the operational gains from fuel to labour should be welcomed.
[67] WASP advantages that benefit both staff and owner : reduction in maintenance on engines, reduction in noise and vibration for crew and passengers, better on-board air quality. Low carbon vessels can be the pride of concerned sailors or cadre. This latter argument is of key importance to attract new talent in technical and officer positions.
[68] Bunker fuel suppliers share common interest with refineries and OEM manufacturers and regularly collaborate with these stakeholders for defining fuel standards, quality check and quality control. Bunker fuel suppliers also form partnerships with Port facilities in-order to build the infrastructure required to deliver fuel to ships.

<table>
<tr><th>Type of stakeholders</th><th>Description</th><th>Requirements of the trade</th><th>Influence</th><th>Possible position on Wind Assisted Ship Propulsion</th></tr>
<tr><td></td><td colspan="3">little influence on technology uptake in the maritime industry. They do not benefit economically from WASP ships and it is unlikely that they will support WASP ships just for corporate image improvement.</td><td></td></tr>
<tr><td>Brokers and service providers</td><td colspan="3">Brokers and service providers act as intermediaries for maritime transactions. They provide a wide variety of services for activities such as ship sale/purchase, cargo freight fixing, charter agreements etc. Their influence within the maritime industry is low.</td><td>Brokers do not benefit economically from WASP ships and it is unlikely that they will support WASP ships just for corporate image improvement.</td></tr>
<tr><td>Media and press</td><td colspan="3">Media and press are important stakeholders needed to spread information and interest in WASP ships. Their role in increasing public awareness is essential for the success of WASP ships</td><td>For the media to become allies it needs sustained development and communication by WASP industry groups including follow-up. Absent this, sails are only a “nice story”.</td></tr>
<tr><td>NGO and Academia</td><td colspan="3">NGO and Academia can push for policy change on a national/international level through focussed research and lobbying.</td><td>WASP is one of many innovative solutions to the global crisis. A sustained interest by the research networks is a requisite for success of sails</td></tr>
<tr><td>General Public</td><td colspan="3">Awareness about WASP technologies along with their benefits within the general public can help in generating demand necessary for the success of WASP concepts</td><td>In general the public is not much interested in international trade. Sails brings alive the issue</td></tr>
<tr><td>Retailers or manufacturers</td><td colspan="3">Both specialized and general food or goods suppliers for the general public or niche markets such as hotels or restaurants have developed various green strategies</td><td>Large companies such as Unilever are already key players for the development or “green solutions”, in particular on the end of logistic chains.</td></tr>
<tr><td colspan="5">E&E Consultant / SAIL project 2015</td></tr>
</table>

Box: the example of windpower

One can look back at the wind power development in the last decades: A traditional technology has become the first in global sales, before established technologies such as coal, nuclear and even gas recently.

Olaf Hohmeyer (Hohmeyer 1988)[69], a professor at the University of Oldenburg at the time, had shown already in 1988 that the learning curves of wind, and to a lesser extent of solar, would cross the main electricity sources at a date comprise between 2007 and 2017, when taking or not into account a "social cost" of electricity estimated at the time.

Events unfolded close to his estimates, not so much through completely new designs (most had been already described or built) but through incremental changes. They also used the recent progress in meteorological science, material and mechanical techniques, light materials. In particular:

- Turbines were better and better sited
- Gear to multiply movements had improved resistance comparable
- Heights were higher, with longer blades allowed by progress in composite materials
- Electronic controls of pitch and brakes made possible the use of small breeze up to near-gales
- Construction on site was industrialized and normalized
- Parts and ensembles were built in the hundreds, then the thousands in more and more optimized factories

At the same time, clusters of industry, research, policymakers made sure the market conditions were right. Insurers and bankers were less worried because the machines were certified, measured, with transparent institutions to ensure that reliability was nominal.

One of the early secrets of wind, in particular in its infancy in Denmark, was that players had to show their data in order to get public support. No "integrated" firm could escape the scrutiny on its failure or success, every machine had to publish their statistics in registers such as the "Windstat" review. Mistakes and failures were numerus but they have all been reviewed and discussed for the common later good.

Denmark also imposed that increments in power were small (50kw at a time) so that failure was not catastrophic. This was in a huge contrast with the huge prototype tested at the time in the US, Germany and France with large scale subsidies… and no serious results. Large firms, often linked to armament, with integrated use, made sure the money was spent without much responsibility in the end.

The next step was the large scale funding through German Power Networks, mandated by climate and nuclear policies. This brought in line the mighty industrial networks of this country, large scale

[69] Hohmeyer O. 1988, "Social Costs of Energy Consumption", Springer Editions

research centers, and users such cities and citizens. This time the whole goal was the common success and gradual improvements.

One more step was taken with the Kyoto "Clean Development Fund" and local public systems, particularly in China, where growth of wind was even more spectacular, taking over all other forms of new generation in less than ten years.

The case for small ships

While freight transport is studied for bulkers of medium size, or mixed cargo and passengers, in Europe there is a case for smaller specialized ships. For many years, due to the globalization, the concentration of maritime transport and the search for scale economies, cargos have become bigger and ports have become bitter competitors. On the fringe of this continuous upsizing, alternatives have to emerge, based on smaller ships.
In the North Sea Region (NSR), because they rely on people appeal and willingness to pay more for products with zero carbon emissions, all the projects described below are based on models using traditional, square-rigged old ships reshaped for commercial purposes.
Several examples have emerged in specific niches, made possible by situations combining entrepreneurs, existing ships, and geographic peculiarities such as islands. Several such transport firms or projects illustrate "weak signals" that room for sail propulsion is possible. Here are three best known examples:

Figure 25 - Undine shuttles between Hamburg and Sylt

The Undine (D): Entrepreneur Torben Haas has developed with selected partners a model based on a shuttle line between Sylt and Hamburg, (around 15-19 hours). Both goods and paying passengers[70] are transported. A specific label has also been developed to guarantee the quality of transportation: « Guaranteed hand-sailed ».

[70] a maximum of 9 are allowed on board, paying 85€ each for the trip but not participating to the ship management

Leenan (F): The Leenan Head from Brest to Auray to Nantes in France. This model is similar to the Undine's as both no perishable products and people are transported on this shuttle (for 40€ per day). People interested order on line, making supply and demand match.

Fairtransport's fleet: The Tres Hombres[71] on various European coastal lines from Spain to Denmark

- From Roscoff to Copenhagen : organic wine
  This line creation has been motivated by the search for global coherence and by a dominance of maritime issues in Denmark. The model is based on an optimized supply chain starting from the wineries. Demand is currently growing for these bottles labeled « Shipped by sail power – the carbon-neutral option » that allow the customer tracking the product: the label contains codes which link to a series of information such as dates of departure and arrival, logbook, name and picture of the skipper, estimated carbon emissions saved and more information.
- From Brixham to Ouessant to Spain: organic ale, rum, café, chocolate, salt, wine, soap and more…
  There is no shuttle here but stops in various ports to charge and discharge the products that are distributed by small firms that based their model on quality. They are labelled Fair Transport or TransOceanic Wind Transport.

Entrepreneurial activities including brokerage are acting as virtuous circle in developing system functions such as market formation, resource mobilization, support from advocacy coalitions and knowledge diffusion[72]. Such firms bring the dimension of "real economics" to a sector acting still largely as a symbol.

Other "low carbon/short haul" circuits do not rely on sails but are experimenting innovative combinations of technologies. One example is the transport of locally produced goods trade "Salish Sea Cooperative" in Puget Sound (Seattle, US). The Cooperative works in conjunction with Organic Producers, Coffee Lounge and several Northwest co-ops to bring fresh produce to the city of Seattle from the north end of the Peninsula without using fossil fuels: a farm to table delivery. Set up as a Community Supported Agriculture (CSA) program, customers must reserve their box of fresh products three days in advance by sending an email message to the co-op.
At a larger scale, upscale supermarkets in Paris such as the Monoprix chain are supplying their shops with a combination of barge transport with electric bicycles, or dispatching small electric trucks from a platform outside the city. These hybrid systems all rely on a niche: customers in large metropolis are the most sensitive to what they buy, and at the same time access to the city centre is difficult or even forbidden for traditional delivery systems.

Success factors and particular contexts

Coastal projects have been able to develop due to particular contexts such as access difficulties (for the islands), already existing ships, entrepreneurs willing to prove the usefulness of the wind assisted propulsion technology for coastal freight, positive signals from certain governments aiming at reducing maritime pollution, mobilization of a few partners or capital investors and client demand and willingness to pay for these products. But even if all of these very small markets are not yet big enough, they have started to create a virtuous circle, starting with the model of shuttle connections with islands.

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[71] the boat is also used for transatlantic trips
[72] See for example : www.towt.eu

In other regions, other conditions have made projects develop. For example, the Greenheart Project is attempting to build a vessel in the 75-100 DWT range, to operate in the South Pacific Ocean. There, low volume routes with long distances between ports, with limited infrastructure and high fuel prices make such project desirable through the development argument.

In such a developing country context, conforming with (S)ECA (Sulphur Emissions Control Areas) thresholds is less relevant. Instead, the limited availability of fuel, high fuel costs and even the lack of port infrastructure are reasons for employing sails or small scale ships. In this context, financing sailings vessels does not rely on private investors could 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 such projects differs a lot from the niche market of Norther Europe described above: Sail transport in a Southern Island context may transport tourists, but is above all a way to link insular communities for their supplies or to enable economic development through the trade of local production.

Although implementation has been postponed and cancelled within IMO, future developments for a NECA (Nox emission Control Area) in the North Sea and Baltic region could further enhance the case of WASP in the North Sea region. NOx emissions remain to be one of the main problems in our regions, and WASP offers an opportunity to also decrease emissions for this pollutant. This has a strong relation to ambient air quality.

Barriers to technology uptake

Several publications[73] 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. Ship Owners 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, or 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 shown 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).

[73] i.a. Rojon & Dieperinck, 2014; Acciaro et al., 2013; European Commission, 2013 or Rehmatulla et al., 2013

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

Barriers	Examples	Key Actors	Approaches/Solutions
Organisation al/ 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** : 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).. 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. The latter was awarded the Fathom Energy Efficiency Solution award of 2015[74].

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).

Several of the issues to be dealt with to increase technology uptake are:

1. Limit the “first mover” impediment supposes to give advantage to actors that accept to be the first ones to take the risk, before this risk can fully be assessed.
2. Establish solid institutions to share collective knowledge such as failures or track records, while at the same time encouraging innovative firms.
3. Capping of vessel emissions (through mandatory limits and/ or emissions trading), which force the vessels to adopt new technologies like auxiliary wind propulsion. A simple tax does not promote radical change.
4. Governmental subsidies for investments in auxiliary wind propulsion or similar environmental investments, which create better payback periods for the technology.
5. Extension of ECA (Emissions Control Areas) to other regions than EU or US waters (Mediterranean, …)
6. Tackling Split Incentives - focused on the split incentives faced by ship owners, where gains in operations do not affect owners directly.
7. Establishment of carbon trading standards and methodologies for wind propulsion (new & existing vessels) to gain access to such funding, either with still existing Kyoto Mechanisms, or new instruments to be developed.
8. 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.

[74] The price was selected by Lars Robert Pedersen (BIMCO); Craig Eason, (Lloyd's List); Oskar Levander, (Rolls Royce); Tristan Smith, (UCL) and Roger Strevens, (Wallenius Wilhelmsen), with Katharine Palmer (Lloyd's Register) as chair.

Policy Suggestions

Several policy suggestions can be proposed as a conclusion:

Help the first movers

In order to circumvent the risks for first movers, subsidies are in order, either through the R&D existing tools, or in mutual guarantees. Public institutions (such as the KfW in Germany) can help through mutual financial and technical guarantees for the first few ships. Such policy tool, supplement to the R&D budgets, is key to open third party financing. Such funding is based on the future incremental gains of the investment (here sails or rotors) but investors have to be insured that the device is sound. Such measure goes with a “collective due diligence” made by independent engineers. In the case of the EU, this group of measures should be taken in the framework of an industrial cluster.

Record and publish

Beyond setting the conditions for the first movers, the establishment of a track record is also a sure way to convince other companies that the risk is limited. The issue here is more to establish a track record going from validated calculation codes to experience at sea and at port. This knowledge is key to include funding firms, but also insurance companies, and other actors described above.

Transparency of tests and trials for projects supported by public money, and start of one or several registers for availabilities and performance. This is a way to ensure that the “industry learning curve” is optimized. Therefore, failures and successes have to be documented. The key motto here is MRV for “Measurable, Reportable, Verifiable”, a concept promoted notably by OECD.

This can take example to the beginnings of wind power, in particular in Denmark. One further step is the standardized assessment of wind technologies and proposed savings, best vessel application etc. This will enable investors to assess the best technology for their fleet profiles. Once again, the most dynamic segments of the wind industries (e.g. in Germany) show the way.

Establish standards

Once the best practice of the industry is written and recorded, either in technology safety or in the logistics component, standards have to follow.

One important first step is to introduce the idea of “Wind Propulsion Compatible” among the builders, in order to render possible retrofits in several technological options, such as kite or rotors. It is possible to mandate certain structural strengthening that is low cost at build but much dearer when added later.

One option is to adapt the principle of deferment used in the US, in which a ship owner can defer compliance with short term regulations if he commits to a more radical –but later- step. If well enforced, this is a powerful tool to avoid “half measures” in the fleet evolution.

Include carbon gains

Mandating the adoption of Carbon accounting systems for all commercial shipping companies is an important step for regulators, and this should include some specific measures of zero carbon propulsion in fleets. This will capture data from all vessels and enable wind savings/performance to be monitored and improved. Beyond this, inclusion of wind propulsion in Clean Development Mechanisms or for eligibility to the Green Funds, notably through official submissions by parties at UNFCCC, IMO or World Bank Institutions is a key step in particular for the small ship segment linked with development issues.

Discuss safety early

A safety forum for users such as harbors, crews, suppliers and insurance companies has to be set, in order to start a dialogue early on. Such forum can be organized as a side-event of larger bodies such as the IMO but have to be volunteer-based. One specific issue is the SOLAS regulations (Safety of Life at Sea) that have to be renewed in 2016.

Other fora can be organized with the appearance of more models, to start and sustain the discussions on maintenance for example.

Bring the logisticians on board

Another issue for wind assisted shippers or designers stems from the need to listen to the logisticians. Shipping should always be assessed as part of the complete chain, therefore circular economy aspects are assessed – e.g. embodied energy, full lifecycle footprint, recyclability, seafarer welfare and safety etc., reduction of land-based emissions from use of smaller vessels and smaller ports etc. This integration of final and intermediate users is a key aspect of the systemic learning curve, in order to ensure cost reductions and smooth operations. It is also an essential part of development of a “Wind Propulsion” preference.

Establish in academia and research

Finally, professionals have to prepare the integration of wind propulsion and sailing techniques into maritime training academies and qualifications. This will prepare commercial companies for the uptake of sail technology and start to build capacity within the industry.

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Appendix I

E&E Consultant made estimates for sectoral emissions in negotiation zones, using material from IPCC AR5 scenarios. These results show the key importance of international maritime transport and also the difficulty of abating emissions beyond the present set of measures in discussions. Graphs are presented in the text.

Emissions in transport segments in the RCP 4.5 IPCC scenario (in MtCO2)							
	2005	2010	2020	2030	2050	2080	2100
Domestic Aviation	295	295	460	566	803	859	862
International Aviation	451	451	507	483	532	619	684
Domestic Waterways	122	122	172	201	287	465	608
International Maritime	**553**	**553**	**715**	**773**	**908**	**962**	**999**
2-3 wheelers	79	129	153	152	208	225	215
Bus	273	384	435	375	430	493	309
Autos	2239	2408	2511	2572	2243	2193	2145
Passenger Trains	37	60	89	112	185	287	327
Rail Freight	50	62	79	88	124	174	143
Road Freight	1975	2267	2890	3236	4005	4173	4354
E&E Consultant 2015 with GCAM and IPCC AR5							

Emissions in transport segments in the RCP 2.6 IPCC AR5 scenario (in MtCO2)							
	2005	2010	2020	2030	2050	2080	2100
Domestic Aviation	295	295	402	458	643	324	0
International Aviation	451	451	446	446	485	246	0
Domestic Waterways	122	122	157	195	272	269	57
International Maritime	**553**	**553**	**609**	**666**	**751**	**669**	**147**
2-3 wheelers	79	129	159	152	179	112	0
Bus	273	384	464	524	698	279	0
Autos	2245	2415	2262	2108	1302	21	0
Passenger Trains	37	60	138	212	426	499	115
Rail Freight	50	62	81	106	163	150	0
Road Freight	2078	2275	2761	2852	2655	741	10
E&E Consultant 2015 with GCAM and IPCC							

Appendix II

The Poster next page was presented by SAIL and E&E Consultant at the Tyndall “Radical Emission Reduction Conference”. This conference intends to provide an evidence-base for developing radical-mitigation strategies, hosted by the Tyndall Center for Climate Change Research (London UK)[75].

75 *Tyndall Conference : http://www.tyndall.ac.uk/radical-emission-reduction-conference-10-11-december-2013*

Factors of hybrid sailing re-emergence in the transition to a low carbon economy

Introduction : We investigate the conditions of the "re-transition" from steamships to (hybrid) sailing technologies (including kites, flettner rotors, turbo sails…) through a systems approach in a carbon constrained economy

1 A need for radical innovations to reduce shipping sector's global and local emissions

Approved International Maritime Organization regulations :

- By 2015, fuel sulfur content reduced from 0.5 to 0.1 % in ECA (Emission Control Area : Baltic Sea, North Sea, North American area and US Caribbean sea)
- By 2020, fuel sulfur content reduced from 3.5 to 0.5 % outside ECA

NOx and PM emissions under discussion

⇒ Short sighted approaches to the problem limited to alternative fuel or scrubbing

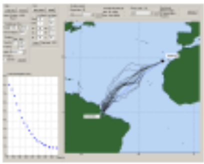
⇒ Very few voices calling for seizing the opportunity to explore co-benefits of sulfur AND carbon reduction

If global economic growth continues at the current rate, emissions from Marine industry are set to rise of nearly 200% by 2050

How to radically cut ship carbon intensity ?

- new ship efficiency standards (the EEDI)
- much greater penetration of technologies and operational practices

=> Cut in half by 2035-2040



Dam Sperrboom (Dykstra Naval Architects)

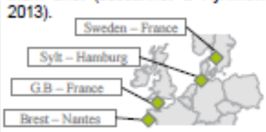
=> more step-change forms of propulsion such as wind, battery and biofuels, combined with new logistical schemes, should be introduced from the outset to achieve maximum reduction of carbon emissions

4 Develop on existing niches… or wait for future markets ?

Empirical observations and pilot projects help in the assessment of the conditions (social, political, economic, geographical,…) for new business models and markets.

- Short Sea Shipping in NSR to compete with trucks

We analyzed the peculiarities of WASP transport niches that released possible barriers to their development and make them exist (Jaouannet & Rynikiewicz, 2013).



- New markets

- Decline in fossil fuel markets in radical low carbon transitions
- Increases in biomass related trade for ex.
- …

- Isolated islands (Greenheart Project and transport for islands in South Pacific)

- Long distance shipping

Use of traditional routes with high wind potentials to offer low carbon products that match demand.

- What to expect from labelling?

Transport is the third sector after Energy and Primary industry contributing to the global French energy footprint *(Energy used in the world to satisfy French consumption by sectors, Les Cahiers du Clip n° 22)*

FairTransport label TOWT label

2 Reinforce functions of the innovation system to further develop Hybrid Freight Sailing

Key structural elements surrounding the technology are actors, networks and institutions. The functions of the Hybrid Freight Sailing innovation system need to be reinforced (Rojon & Dieperink, 2014).

We particularly focus on sharing plausible assumptions on:

- **Energy costs and carbon price**

Escalating energy costs and a real price for carbon (>100eur/tCO2) would favour Wind Assisted Sailing Propulsion (WASP) options. A real question is how to incentivise replacement of existing ships and low carbon retrofitting.

- **Associated infrastructures**

Particular interest for port infrastructure and multimodal logistics.
We also investigate specific needs related to availability of (bio)gas or LNG.

- **The role of maritime low carbon regions**

- Energy futures and marine technology development
- Low carbon infrastructure and territories development
  - ⇒ **diversification challenge and call for innovation strategies**
  - ⇒ **who are the movers and who will be the first welcome sailing ships and maintenance firms ?**

- **Policies supporting diversity**

From an evolutionary economics perspective, one policy objective, is to actively support the diversity of available knowledge to reduce the risk of infrastructure lock-in and prevent the lock-out of technologies that can meaningfully reduce absolute emissions from the sector (Gilbert, 2013 ; Van den Bergh, et al., 2006).

=> Will we see the survival of the greenest ?

3 Question change of freight demand in Low Carbon shipping Scenarios to meet the 2°C goal

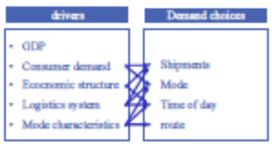
The analysis of low carbon shipping scenarios shows an increase in shipping emissions of 200 to 400% within 2050 compared to 1990.

Having a 50:50 chance to avoid a 2°C increase, would require a 80% reduction in emissions in all sectors of the economy

NIES (LCS 2050) for Japan scenario

=> Need to investigate the evolution of freight demand

- Energy trade ?
- Food trades between low carbon regions ?
- Intermodal transport
- New supply chains
- …



Drivers of Freight Transport Demand. (van de Riet, de Jong and Walker 2008)

S@IL project www.nsrsail.eu

The SAIL project is an Interreg IVB North Sea Region Project with 17 partners from 7 countries around the North Sea. The project's aim is to develop and test hybrid sailing concepts that lead to new business opportunities and a more sustainable future. The project partners are exploring the possibilities offered by alternative propulsion to renew the freight sailing industry. Those concepts have high potentials, due to rising oil prices and environmental aspects.

The Interreg IVB North Sea Region Programme

Investing in the future by working together for a sustainable and competitive region

C. Rynikiewicz (SPRU, Univ of Sussex), K. Jaouannet , A. Bonduelle (E&E Consultant).

E&E is leading activities within the SAIL project to elaborate a HFS technological roadmap until 2050.

Poster for the Tyndall "Radical Emission Reduction Conference", 10th - 12th December 2013, Royal Society, London

EU Interreg IVB SAIL partnership

1 - Province of Fryslân	11 - Ameland Shipping
3 - Plymouth University	12 - NHL Northern University of applied sciences
4 - Jade Hochschule	13 - MARIN
5 - Helmholtz-Zentrum Geesthacht	14 - E&E consultant
6 - Aalborg University	15 - Avel Vor Technology
7 - North Sea Foundation	16 - Port of Oostende
8 - Fairtransport Trading and Shipping	17 - ECO Council
9 - Municipality of Harlingen	18 - World Maritime University
10 - C-Job	

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Roadmap for Sail Transport