Vessel Technology Advice and Support for Fuel Efficient Shipping

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Summary

Since 2017, global companies BMT and Black & Veatch, sponsored by the Energy Technologies Institute (ETI), have been working in close collaboration to bring a new service to market entitled; Vessel Technology Advice and Support (VTAS).

VTAS seeks to provide ship owners, operators, charterers and financiers with independent and impartial knowledge that assists them in justifying future investment in Energy Saving Technologies (EST`s). VTAS also provides opportunities for EST manufacturers to market test their products and understand its performance with the independence that VTAS brings.

The paper briefly describes the background and context to achieve an environmentally friendly modal shift in shipping. A brief summary of available ESTs will be presented and an illustrative case study discussed. The paper concludes by discussing some of the on-going research and thinking that the VTAS team are engaged in.

Keywords: Fuel Efficiency, Energy, Technology, Shipping, VTAS, Climate

1 Global Environmental Context

According to NASA analysis, the earth's global surface temperature in 2018 was the fourth warmest since modern recordkeeping began in 1880. Global temperatures in 2018 were 0.83ºC warmer than the 1951 to 1980 mean. Globally, 2018's temperatures rank behind those of 2016, 2017 and 2015 but the past five years are, collectively, the warmest years in the modern record. (Reference 1)

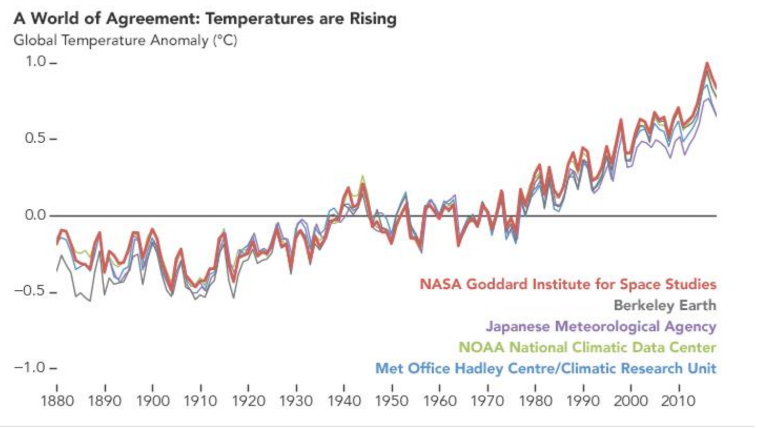

Figure 1. Temperature change (oC) between 1880 and 2018 (Source: NASA's Earth Observatory)

The Intergovernmental Panel on Climate Change (IPCC) view regarding climate change is;

"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen". (Reference 2)

"Human influence on the climate system is clear, and recent anthropogenic emissions of Greenhouse Gas (GHG) are the highest in history. Recent climate changes have had widespread impacts on human and natural systems". (Reference 2)

GHG warms the earth by absorbing energy and slowing the rate at which the energy escapes to space. Carbon dioxide (CO_2) released to the atmosphere and the burning of fossil fuels (e.g. coal, natural gas and oil) is the largest global contributor currently to GHG emissions (>60%). Reducing global GHG emissions is a key enabler to avoid the most significant impacts of climate change.

2 Global Commitments to Reduce GHG Emissions

A vast majority of countries have committed to reducing their GHG emissions under the Paris Agreement. The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 ºC above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 ºC. Additionally, the agreement aims to increase the ability of countries to deal with the impacts of climate change, and at making finance flows consistent with a low GHG emissions and climate-resilient pathway (Reference 3). Significantly, the Paris Agreement excludes international shipping.

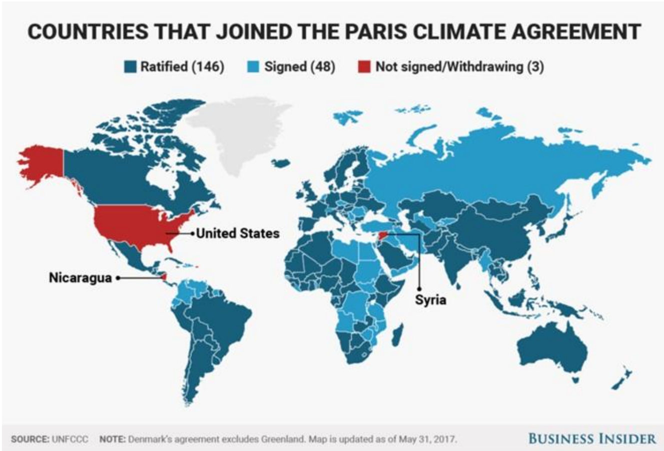

Figure 2. Paris Agreement Signatory Status (Source: Business Insider)

3 Shipping and Emissions

3.1 Key IMO Led Energy Efficiency & Emission Reduction Initiatives

The International Maritime Organization (IMO) is developing its own strategy to reduce GHG emissions from ships. The IMO predict that CO_2 emissions from shipping will be 50-250% higher in 2050 than in 2012, based on the assumption of steep rises in transport demands. Without concerted action, the share of global CO_2 emissions from maritime shipping will grow drastically (Reference 4). Some estimates suggest that compared to current maritime shipping CO_2 emission levels (of around 3%) shipping could be responsible for 17% of global CO_2 emissions in 2050 if left unregulated.

In April 2018, the IMO Marine Environment Protection Committee (MEPC) 63 adopted an initial strategy on the reduction of GHG emissions from ships setting out a vision to achieve at least a 50% reduction in emissions compared to 2008 levels by 2050, while, at the same time, pursuing efforts towards phasing them out entirely. The strategy sets out a range of other objectives, including to reduce the carbon intensity (i.e. Grams per tonne-nm) of shipping by 40% by 2030 and at least 70% by 2050, compared to 2008 levels and to generate a list of possible short, mid and long term emission reduction measures with a commitment to develop a work-plan for implementation to deliver emission reductions before 2023.

The Energy Efficiency Design Index (EEDI) was made mandatory for new ships at the IMO MEPC 62 (July 2011). It is a non-prescriptive, performance-based mechanism that leaves the choice of energy efficient technologies to use in a specific ship design to the industry so they are free to use the most cost-efficient solutions for the ship`s overall design, including energy efficient technologies, that complies with the regulations. The EEDI provides a specific figure for each individual ship type design expressed in grams of CO_2 per ship's capacity-mile (i.e. the smaller the EEDI the more energy efficient the ship design) and is calculated by a formula based on the technical design parameters for a given ship. The CO_2 reduction level (grams of CO_2 per tonne mile) for the first phase is set to 10% and will be tightened every five years to keep pace with technological developments of new efficiency and reduction measures. Reduction rates have been established until the period 2025 to 2030 when a 30% reduction is mandated for applicable ship types calculated from a reference line representing the average efficiency for ships built between 2000 and 2010.

In addition, key IMO regulations relating to SOx emissions from ships have been progressively tightened. From January 1, 2020, the limit for sulphur in fuel oil used on board ships operating outside designated emission control areas will be reduced to 0.50 percent m/m (mass by mass). This will significantly reduce the amount of sulphur oxides emanating from ships and should have major health and environmental benefits, particularly for populations living close to ports and coasts.

3.2 Other Efficiency & Emission Reduction Initiatives

Other initiatives aimed at improving energy efficiency and reducing emissions include the IMO Energy Efficiency Operational Indicator (EEOI), IMO Ship Energy Efficiency Management Plan (SEEMP), EU Monitoring, Reporting and Verification (MRV) and the EU Emission Trading System (ETS).

3.3 Implications for the Shipping Industry?

Noting the aforementioned measures targeted at improving energy efficiency and emissions reduction the shipping industry is going through a period of significant challenge and change. Further, with the planned 2020 sulphur limit likely leading to price increases of low sulphur distillate fuels, additional pressure will be created for ship owners and operators to improve vessel efficiency.

Vessel efficiency is now of even greater importance with a need for ship specifiers, designers, owners and operators to consider options such as (1) alternative fuels, (2) improved energy efficient propulsion and adjunct propulsion concepts (3) maximise vessel operations (i.e. slower speed operations), and (4) improve fleet utilisation amongst others to improve energy efficiency and emissions reductions.

4 A Quick Look at Transport in the UK

In 2017, transport continued to be the largest GHG emitting sector in the UK at 27%, followed by energy (24%), business (17%) and residential (15%) with the remainder split across agriculture, waste management and other emitters (Reference 5). Cars, vans and HGVs remain the three most significant sources of emissions, accounting for 87% of domestic transport emissions (Reference 6).

In 2015, just over three quarters (76%) of all goods in the UK were moved by road, with the remainder by water (15%) and rail (9%). (Reference 7).

Enabling transport in the UK is costly. Table 1 shows total transport expenditure for the UK from 2016-2017 was around £29.1b (Reference 8)

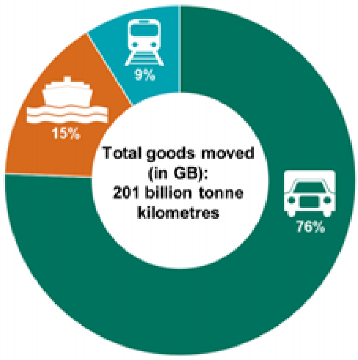

Figure 3. Goods Moved within Great Britain by Mode of Transportation, 2015 (Source & Reference

Transport Mode	Percentage Spend (2016/17)	Spend in Billion £ (2016/17)
Rail	54%	16
Local Roads	19%	6
National Roads	14%	4
Public Transport	8%	2
Other	5%	1.1
	Total Spend 2016/17	***29.1***

Table 1. Total UK Transport Expenditure by Function 2016/17 (Adapted from Data Source, Reference 8)

4.1 Road Network

As previously stated, roads continue to be the primary method of transporting goods and freight within the UK. The UKs road network (national and local roads) has the highest traffic density within Europe (Reference 9). A recent Department for Transport (DfT) study (Reference 9) into future road traffic estimates that the number of vehicles on the road could increase by between 17% - 51% percent in the 35 years from 2015 to 2050. Traffic growth on the Strategic Road Network (SRN) is forecast to be strong, with growth ranging between 32% and 66% by 2050. Growth on principal roads and minor roads is estimated at between 10%-47% and 11%-50% respectively. Car traffic is forecast to grow between 11% and 48% by 2050, whilst LGV traffic is forecast to continue growing significantly also (between 23% and 108%). HGV traffic growth is forecast to range from 5% to 12% by 2050. Our reliance on roads clearly comes at a cost also with total transport expenditure in the UK on roads at £10b (33%) (Reference 8). Further, our road network continues to be under pressure with significant investment required to keep pace with growth. It is highly likely that congestion will become an even more critical issue in the UK in years to come and the costs to maintain and improve our roads will increase.

4.2 Rail Network

As previously stated, rail only accounts for about 9% of total UK domestic freight movements (Reference 7). One could speculate that there could be capacity to move freight from roads to our rail network. However, a recent report focused on the Congestion Challenge produced by The Royal Academy of Engineering (Reference 10) articulates the challenge extremely well. The problem is that the parts of the rail network most suitable for the take-up of freight are also those parts of the network under most pressure from passenger transport. Given the need for the rail network to absorb more passenger traffic, not least because of the partial modal shift which efficient pricing would stimulate, this puts this measure in direct conflict with other recommendations to ease congestion. One option would be to retime rail freight delivery to the night time, so that it competes less with peak-time passenger traffic. Nevertheless, the scale of modal shift towards rail freight that would be needed to make a significant national contribution to congestion reduction would require substantial investment in infrastructure. Because freight tends to be moved by road for the last mile of its journey, a national network of new multi-modal termini would still need to be built at railway stations in order to transfer palettes on to Lorries and HGVs. Such a network would take a significant amount of time to build and probably run up against the same investment challenges as restructuring towards ports-centric logistics.

4.3 Maritime Transport

It has been recognised for some time that when compared to other forms of transport, maritime transport CO_2 emissions are typically significantly lower (Figure 4). The authors recognise that the level of difference is dependent on ship type, route and operational factors but the ability of maritime transport to move large quantities of freight & goods remains.

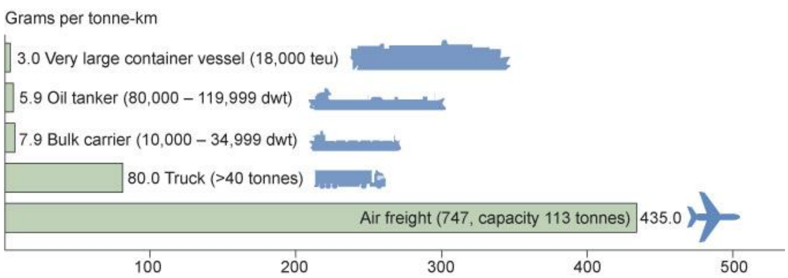

Figure 4. Comparison of Typical CO2 Emissions between Modes of Transport (Source - https://www.open.edu/openlearn/ocw/mod/oucontent/view.php?id=68906&extra=thumbnailfigure_idp3055056, IMO GHG Study 2009 and A.P. Moller - Maersk 2014)

About 90% of goods imported to the UK arrive by sea, with some 75% containerised. The UK's two major container ports handle more than seven million Twenty-Foot Equivalent Unit (TEUs) containers per annum. Only 30% of this volume is transported inland by rail (a comparatively less congesting mode) and often the final movement of that volume is conducted by road: so the vast majority of container movements occur by road. (Reference 10).

Looking to the future, recent UK Foresight Reviews examined the maritime freight transport system in the UK (Reference 11) and trends in the transport of goods by Sea (Reference 12). They envisage that UK maritime freight flows in 2050 would be characterised by:

- A flexible (on and offshore) ports sector with automated handling capabilities and linked (physically and digitally) to its hinterland – serviced by a network of inland ports and intermodal transport connections; there will be increased use too of coastal shipping and inland waterways;

- Green and smart ‘future proof’ ships servicing a global shipping network characterised by inter-hub connections serviced by mega-ships, with more flexible smaller modular ships connecting these hubs to diffuse regional port networks;
- Product flows within self-thinking supply chains characterised by global flows of lighter and higher-energy products in a connected global economy, with ships acting as both rolling warehouses and floating factories with capacity to both process/customise products on board and react to both real-time and predicted demand.

4.4 A Future Multi-Modal Transport System

Even with the promise of alternative fuels and/or powering technology for land based transport modes, congestion is likely to remain a dominant factor in limiting transport effectiveness in the UK. However, the UK is fortunate as an island nation to have a coastline that provides an opportunity to significantly increase the level of goods and freight transported around the country via Short Sea Shipping (SSS).

SSS is assumed to cover maritime transport services which do not involve an ocean crossing. It also includes maritime transport along the coasts and between the mainland coasts and islands of the European Union, as well as sea-river transportation by coastal vessels to and from ports in the hinterland. Typically transport mediums are Ro/Ro HGVs, Containers and bulk. A number of SSS potential benefits and challenges are shown at Table 2.

Potential Benefits	Explanation	Potential Challenges
Improved freight mobility (i.e. increased freight capacity and availability of modal choice)	At a basic level, incorporating SSS into a more balanced & integrated multi-modal transport system should add net capacity to the UKs transport capability because it provides modal alternatives. SSS operations may also help increase capacity in other ways, such as helping remove containers from busy ports.	Port infrastructure (berths, electrical infrastructure, link spans, cranage, etc) is likely to require dedicated increased investment to enable significant growth. Integrated logistics management tools and systems would need to be developed to maximise utilisation of the integrated multi-modal transport system of systems. Multiple economic and commercial barriers to overcome. Shortage of LGV/HGV drivers.
Improved freight mobility (i.e. less congestion)	By taking a proportion of HGVs off the road, SSS may help alleviate congestion, particular on the SRN. This could lead to SRN maintenance cost savings as a consequence of reduced HGV use on the SRN also.	The impacts of an increase on non-SRN roads and particularly local roads near ports would be required. Note: It is assumed that in parallel to investment in SSS ongoing improvements to reduce emissions on land based modes on transport would continue.
Improved air quality and reduced emissions	Coastal ship services may be more fuel efficient than trucking, and one coastal ship may be able to carry as much freight (for example one barge carrier’s capacity equivalent to 58 trucks.). Removing these trucks from the road and using a more fuel-efficient option may reduce emissions, improve air quality and, in addition, reduce noise and road accidents.	Optimised ship design would require development in many cases. Further work to determine a "standard" optimised ship design for different goods suited to SSS switch would need to be undertaken.
Reduced CAPEX need to build roads and rail lines with corresponding net OPEX savings relating to reduced maintenance costs	By reducing the pressure on existing transportation infrastructure, SSS can reduce the need to build new infrastructure and corresponding maintenance costs. Large infrastructure projects, such as new roadways and rail lines, are expensive, time consuming, and in some cases may be limited because of population density or land costs.	Investment in infrastructure, rail and roads is likely to still be required in areas local to ports.

Table 2. SSS Potential Benefits and Challenges (Reference 13)

As part of a wider shift towards a more balanced and integrated multi-modal transport system, maximising the utilisation of SSS infrastructure and extending the SSS network has the potential to bring significant benefits, none the least (1) reducing congestion and (2) reducing GHG emissions and improve air quality. Inevitability for any SSS expansion there will be increasing regulatory and public pressure to deliver environmental benefits and ultimately significant motivation to introduce more clean air solutions. More efficient and "cleaner" ships enabled by the introduction of new Energy Saving Technologies (ESTs) will be a key factor in making this shift.

5 Vessel Technology Advice and Support (VTAS)

5.1 VTAS Overview

Since 2017 global companies BMT and Black & Veatch, sponsored by the Energy Technologies Institute (ETI), have been working in close collaboration to bring a new service to market entitled; Vessel Technology Advice and Support (VTAS).

The core purpose of VTAS is to accelerate the adoption of ESTs within the commercial shipping market. VTAS seeks to provide ship owners, operators, charterers and financiers with independent and trusted impartial knowledge that assists them in justifying future investment in Energy Saving Technologies (EST`s) and strategies.

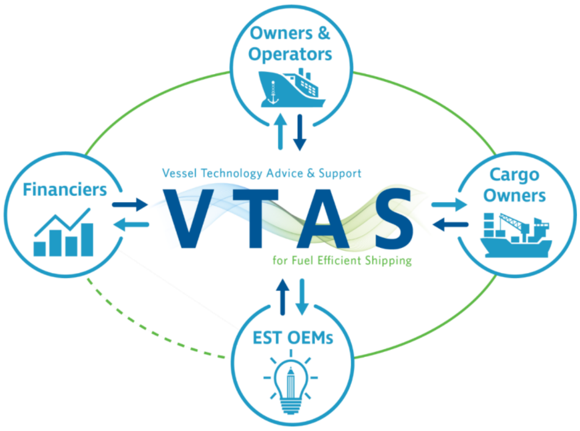

Figure 5. VTAS Engagement Nodes

5.2 Barriers to Adoption

EST`s are gradually being adopted by ship owners and operators, but one significant barrier limiting wholesale adoption is the lack of sufficiently reliable and validated information on fuel efficiency benefits, operational impact and life-cycle costs.
VTAS seeks to address this barrier.

Over the last 12 months as part of a stakeholder consultation package of work, the VTAS team have identified a set of leading considerations that stakeholders need to be addressed. They are complex, interdependent in many cases, not exhaustive and depend very much on the attitude of each stakeholder. However, they provide a level of insight into the issue and have helped the VTAS Team to target its capability to address such barriers. A "spaghetti diagram" that reflects these needs is presented at Figure 6.

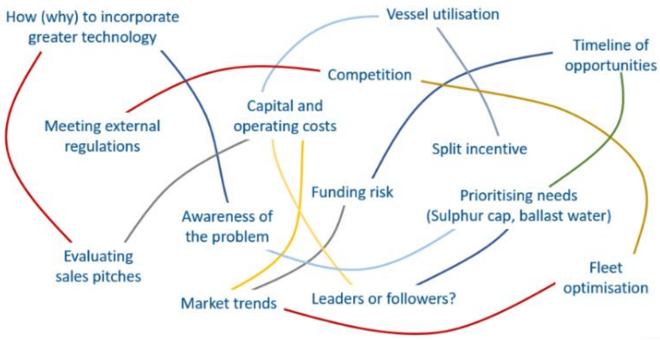

Figure 6. Barriers and Considerations to EST

5.3 Motivators for Adoption

Alongside the work completed by the VTAS team to identify the **barriers to** adoption, typical **motivators for** adoption were also established as shown at Table 2 below.

Motivator Group	Characteristics
"the Carrot" 	• Clear performance benefits can be achieved through adoption of the technology and risks can be understood and managed • Safety and availability of the vessel is maintained • Impacts on normal vessel operations (i.e. including unloading/loading) are minimised • CAPEX and OPEX costs and savings are well understood and can be justified • The net asset worth of the vessel can be increased • Charter rates can be increased and otherwise inaccessible Charter markets opened • Green credentials are improved and green funding initiatives can be accessed • Port tariffs/charges can be reduced • Competitive advantage

Table 2. EST Adoption Motivators

“the Conscience” 	• Individuals “Green” interests and desires are met • “Fair trade” push similarities. Willingness of some customer groups to “pay a premium” • Increasing pressure from shareholders on Companies to play their part in tackling climate change issues
“the Club” 	• Legislative and regulatory compliance • Port access requirements are met • Contract obligations and needs are met

Table 2. EST Adoption Motivators (Cont)

5.4 Energy Saving Technologies (ESTs)

EST`s are described as those technologies that have the potential to bring fuel efficiency benefits to a ship. ESTs generally fall into one of three categories, euphemistically referred to as “windy”, “wet” and “warm”. A description for a selection of ESTs is provided at Appendix 1 and Reference 14.

- **Windy:** Devices that harness wind energy and typically provide an additional means of auxiliary propulsion
- **Wet:** Devices that provide hydrodynamic efficiency improvements, typically reducing resistance and/or providing enhanced propulsive conditions.
- **Warm:** Devices that utilise the waste heat generated from on-board machinery which would otherwise have been lost to sea or atmosphere.

5.5 EST Selection

For new build ships the ship owner will usually make a decision to specify (or not) the incorporation of an EST into a new build vessel specification. The decision will be based on a number of factors including vessel usage, typical operators/charterers and required legislative/regulative requirements. Even if the owner does not want to fit the EST immediately to ship, and would prefer to defer installation it is likely to be advantageous in most cases for the owner to “build into” the ship any required infrastructure to support the EST (e.g. power, structure) as part of a “fit for and not with” approach. The authors see adoption of this approach increasing over the next few years. For more invasive ESTs in most cases, fitting the vessel with an EST during its build is likely to be more cost effective than retrofit (e.g. large heat recovery based ESTs, ancillary equipment and foundations for some wind devices)

For retrofit cases the vessel owner will again have to satisfy themselves that the required CAPEX to support the EST fit can be justified by the expected pay-back period, the impact on the vessel schedule for EST installation can be accommodated and operational impacts on the ship can be mitigated. Certain ESTs lend themselves well to be treated as a removable asset and have been designed with that in mind and for some ship owners/operators this will be seen as advantageous (i.e. enabling lease arrangements). However, in almost all instances a justified and credible CAPEX versus pay-back business case will underpin whether or not to fit an EST.

5.6 VTAS Capability

The VTAS capability comprises tools, processes and the VTAS team’s knowledge and experience. Core to the VTAS capability is the Integrated Techno-Economic Model (iTEM). The proceeding section will use a case study to articulate some of the VTAS capability. The iTEM

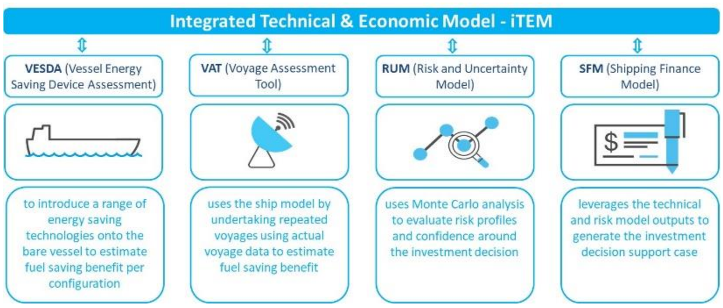

Figure 7. Integrated Technical and Economic Model

permits modelling to be undertaking for a range of given input data depending on what is available (i.e. basic ship and EST characteristics at one extreme to the other than would include comprehensive ship and performance data obtained through on-board measurement systems).

6 VTAS Case Study – Technical Assessment (i.e. VESDA)

6.1 EST Modelling

A wide variety of EST`s exists to choose from, but not all are necessarily suited for use on every vessel type or in conjunction with each other, depending on the peculiarities of the proposed installation and the vessel operation. The initial decision on what EST to consider and thus what to model depends on a number of key areas that are initially gauged by the professional experience of the assessor in consultation with the Client, such as:

- the interest and practical guidance of the owners/operator/charterer or financier;
- power & propulsion arrangement;
- operating speed & profile;
- size, hullform, and superstructure arrangements;
- anticipated environmental conditions.

6.2 Study Vessel

The vessel modelled in this example is a RoRo ferry of ~17,000 tonnes displacement, with the following principal particulars:

- Length overall 186.4m
- Length waterline 181.9m
- Beam 25.6m
- Draught 6.8m

The vessel is powered by 2x ~10.8 MW two-stroke diesels operating on Heavy Fuel Oil (HFO), with 3x ~1.8 MW generator sets. This particular vessel is equipped with a pair of shaft generators which have not been included in this model due to a lack of information in the public domain regarding their type and operation, however in future iterations these could be included when more information becomes available on their operating set-up, the ships electrical load, and propeller combinator curves, which would improve the confidence in the final result.

For this particular case study, the ferry has been modelled to include 3x Flettner rotors (18m high by 3m wide) for auxiliary propulsion, and 2x Organic Rankine Cycle (ORC) units (110kW each) for waste heat recovery.

6.3 Model and Results

The ship has been modelled over a 24 hour period, based on publicly available AIS data to provide its location, speed, heading and other related parameters. The period presented below was chosen as it represented a fairly "average" day at sea for the vessel, not for any specific energy saving reasons. The model period represents one of dozens that are modelled to build a broader view of the combined ship and EST performance, which are aggregated to form an estimate of overall fuel savings and thus allow for an economic analysis.

6.4 Ship Model

The ship is modelled in a bare condition (i.e. without an EST) to provide a baseline to compare against, illustrated as Option 150 in the results figures. The model ship has been defined using its known principal particulars and power & propulsion arrangements, then via the use of various derived hull-form coefficients and factors the vessel resistance and powering requirements have been calculated across a range of conditions. The ship model relies upon the estimation of key parameters such as wake fraction and thrust deduction factor as model test reports are not available in this case. For example, when the ships draught is away from the design point, as often is the case, the tonnes per centimetre (TPC) factor is used to determine the actual displacement. The ship resistance is calculated through standard empirical relationships used by Naval Architects, i.e. Holtrop & Mennen for calm water resistance, and the Alexandersson method for added resistance in waves. Where appropriate an allowance for hull roughness & fouling is applied. On-board machinery and engine performance at these points are modelled using the ship and environmental conditions with the best information available, such as the manufacturer Specific Fuel Consumption (SFC) curves, electrical load requirements for example.

6.5 Environmental Model

Environmental conditions are an important factor when estimating ship and EST performance, as particularly for wind based devices the performance is linked to factors such as vessel speed, air temperature, wind speed and direction etc. The AIS data available does not provide such wind and weather data, and for this study there is no access to the vessels on-board data or Fleet Performance Monitoring software. To combat this, publicly available meteorological data from the European Centre for Medium Range Weather Forecasts (ECMWF) has been correlated with the AIS time and location data to provide environmental conditions for modelling.

6.6 EST Models

As this case study utilises two different ESTs, it also incorporates two different EST models. At each time period, each EST model is provided with the vessel and environmental conditions from the ship model and return their calculated benefits. The ship model then automatically adjusts the power & propulsion machinery based on this feedback. The FR model determines the useful forward FR thrust for given sea states and wind heading, which is passed back to the primary ship model to assess the reduction in main engine loading and consequent fuel saving, as well as potentially increased loading on the generator sets. An example of the calculated thrust output can be seen at Figure 8.

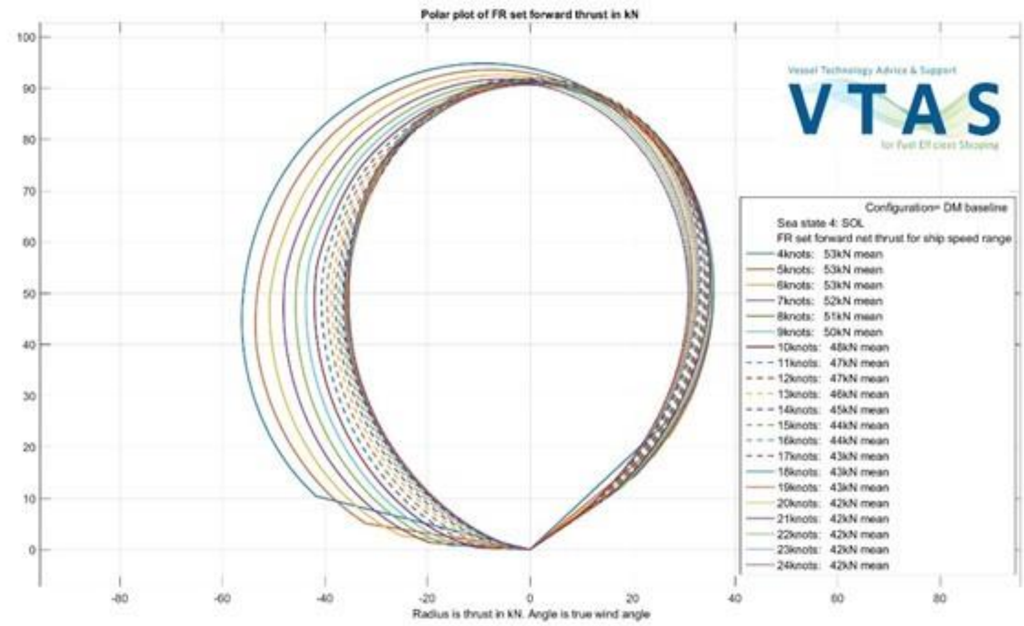

Figure 8. Example of FR Thrust in kN Based on Input conditions (e.g. SS4)

The ORC model determines the electrical power generated based on manufacturer data for the jacket water/exhaust gas temperature conditions, and returns this value to the ship model which reduces the auxiliary generator set power accordingly, reducing fuel consumption. An example of this is illustrated at Figure 9.

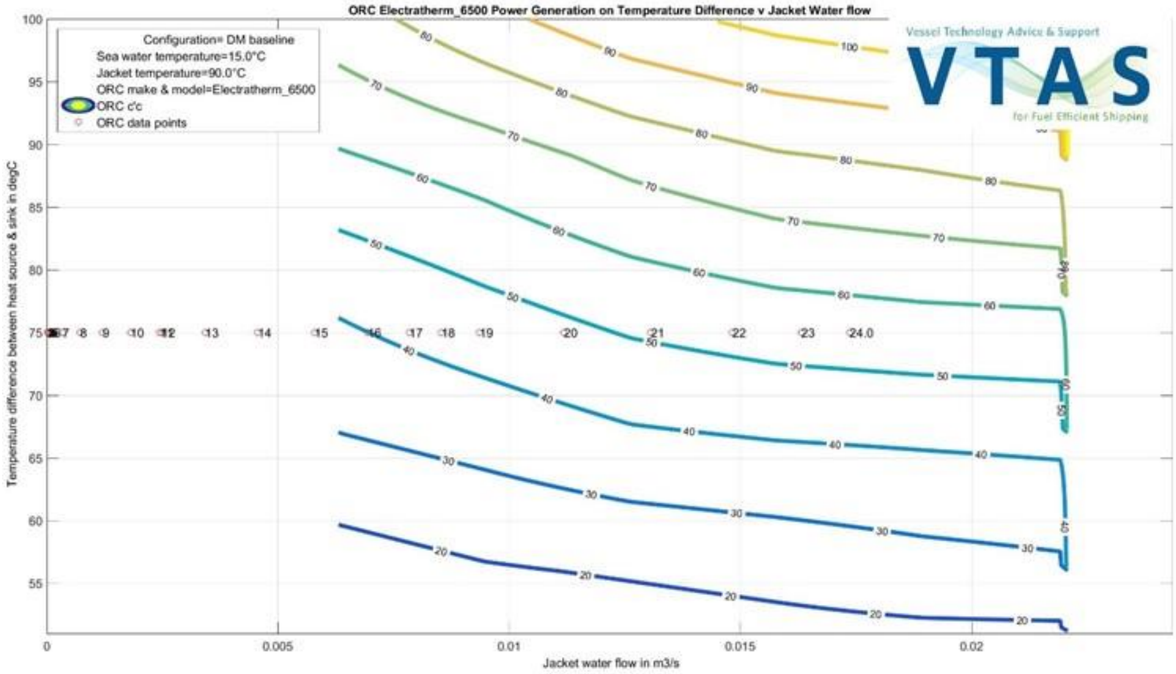

Figure 9. Example ORC Power Outputs for Varying Input Conditions

6.7 Results

The following figures represent the results of the combined ship and EST models over the presented period. Figure 10 illustrates the propeller shaft speed (rpm) change over the period, the baseline ship shown in red. The pronounced dip is due to the vessel slowing and subsequently accelerating again. Option 155 (Green behind blue) and 1503 (blue) are the same, as the FR has reduced the required shaft speed but the ORC has no effect when added.

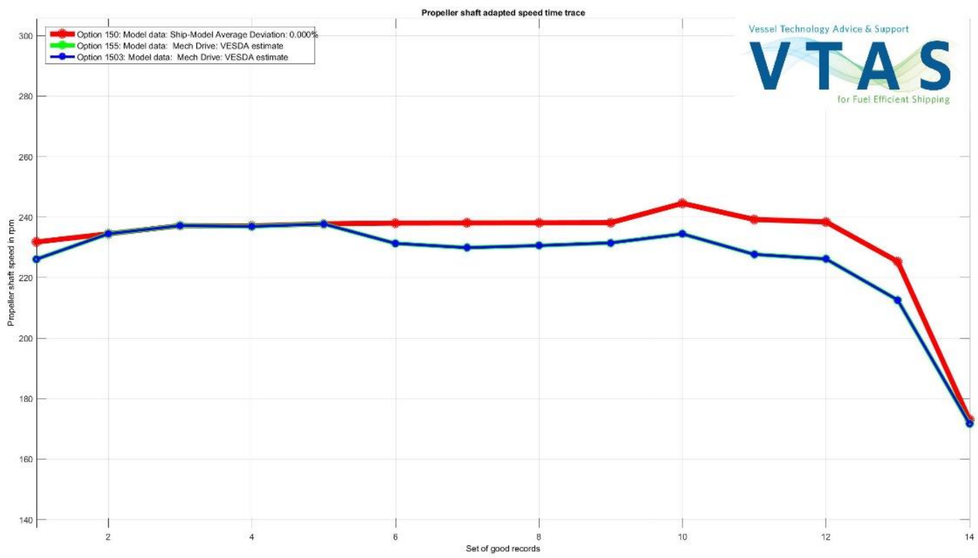

Figure 10. Propeller Shaft Speed

Figure 11 illustrates the shaft power required for the various options, and due to the cubic speed/power relationship it demonstrates a more exaggerated version of the previous figure. The reduction in shaft power required from the addition of FR is obvious (green behind blue), while yet again the effects of ORC (blue) are not visible.

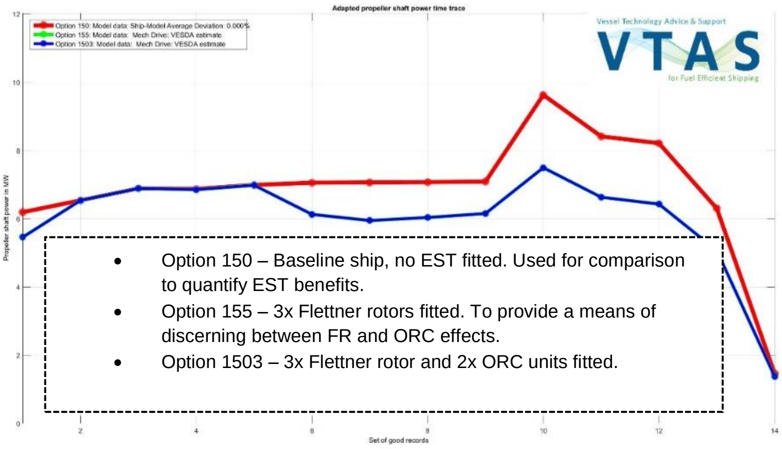

Figure 11. Propeller shaft power (kW)

In Figure 12 the baseline main engine fuel rate is shown in green. This naturally follows a similar trend to the shaft power, and is used in conjunction with the SFC to calculate fuel savings for Option 155 and 1503.

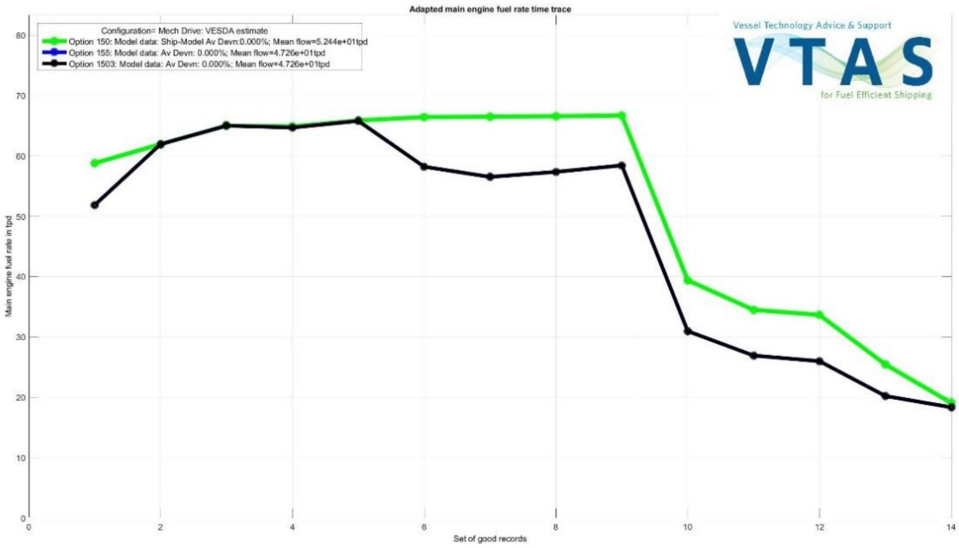

Figure 12. Main Engine Fuel Rate

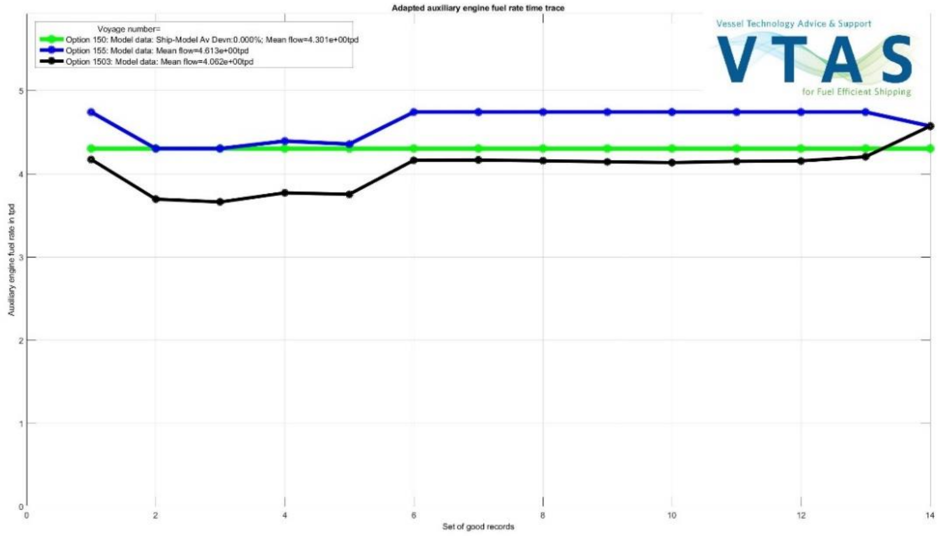

Figure 13. Auxiliary Engine Fuel Rate

Figure 13 above illustrates the difference in fuel consumption by the auxiliary generator sets, with the baseline option shown in green. It can be seen that the addition of FR (shown in blue) takes the average tonnes per day (tpd) fuel consumption from ~4.30 tpd to ~4.61 tpd. This is offset then by the addition of ORC (shown in black), which brings the generator set fuel consumption down to ~4.06 tpd.

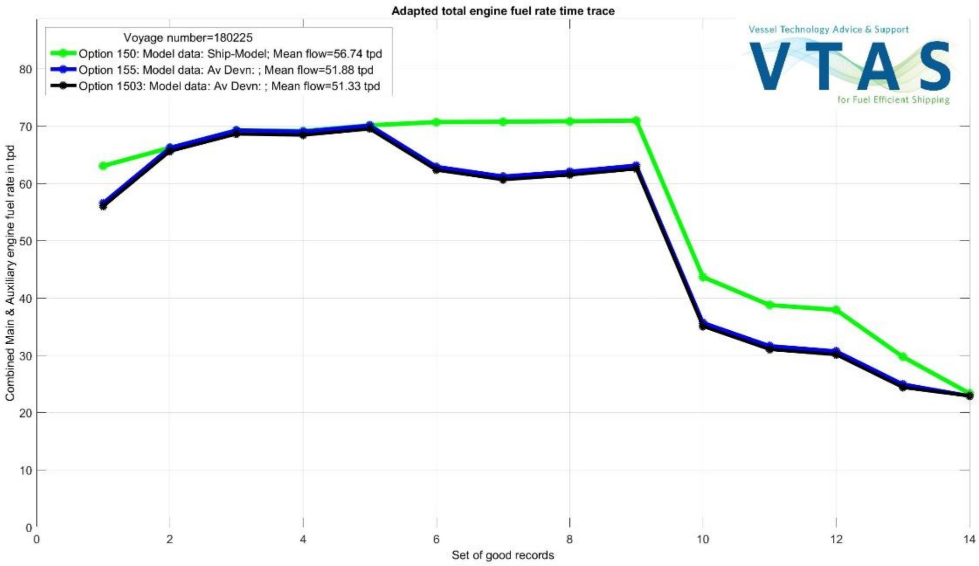

Figure 14. Total Engine Fuel Rate

The combined engine fuel rate shown at Figure 14 for the period goes from 56.74 tpd to 51.88 tpd with the addition of FR, and down to 51.33 tpd with the addition of ORC.

6.8 Technical Analysis Interpretation

Based on the case assumptions given in this example, the initial technical assessment indicates that with the addition of FR a fuel saving of 8.6% is possible for the vessel. With the addition of the ORC a net fuel saving of 9.5% is possible. This example period is one of dozens that are combined together to give an overall fuel saving picture over a wide range of operating conditions, which were then used to perform an economic analysis for a potential retrofit investment.

7 VTAS Case Study – Economic Assessment (i.e. VESDA)

7.1 Model and Results

The Integrated Techno-Economic Model (iTEM) in Figure 7 develops the technical assessment and considers that in the commercial world that owners and operators exist in. The process recognises the need to assess the holistic performance of the asset when competing for investment funds and the means by which that finance is provided. In considering the capex and opex balance in the investment decision process it is possible to evaluate the performance of the investment against expected returns for different forms of lending. These are grounded in the Internal Rate of Investment (IRR) comparisons. The IRR is a metric used in capital budgeting to estimate the profitability of potential investments. The IRR is a discount rate that makes the Net Present Value (NPV) of all cash flows from a particular project equal to zero and would be expected to comfortably exceed the cost of capital with a viable investment.

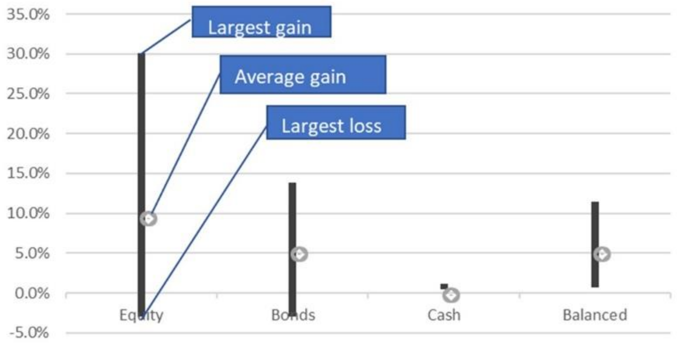

Figure 15. IRR Assumptions

By comparing the expected risk profiles against different sources of funding it is possible to compare the derived project IRR against the expected return to investors. This is shown with respect to external investment expectations as a series of annual return assumptions by asset class as depicted at Figure 15.

The early engagement phase of the projects seeks to understand the customer's appetite for risk, their funding thresholds and other pertinent information such as fuel price hedging to support the economic assessment. As with the ship's particulars, the greater the level of data the greater the confidence and therefore benefit of the output to the customer.

The economic assessment is performed utilising a Risk Uncertainty Model (RUM) incorporating a series of variables and their probabilities that feed into a Monte Carlo assessment. By considering the variables within the capital and operational phases of the EST a more comprehensive assessment can be made. This extends to the Ship Finance Model (SFM) which is then used to analyse and present the investment decision support case that can be tailored to suit specific investor's requirements. When run as part of the iTEM process a rich and informative holistic view of the technical and economic phases develops.

In the case study the CAPEX was estimated to be $2.4M which was 100% equity funded. The remaining service life of the vessel and the ESTs were taken as 15 years and the vessel had a utilisation of 45%.

Based on these case assumptions, the initial economic assessment suggests that the IRR (calculated to be 16.9%) is sufficient to attract commercial investment interest. The payback period would be 6.8 years. A positive NPV of $1.12M is generated. Encouragingly, project life fuel savings of 11,000 tonnes emerged. This represents a saving of over 34,000 tonnes of CO_2 over the project life.

Having this level of information allow customers to run ‘what-if’ scenarios to consider how they can impact the input data to enhance the business case. This may or may not be achievable but does open up greater levels of dialogue and opportunity.

7.2 Economic Analysis Interpretation

The benefit of iTEM is the information it provides through the end-to-end process of technical evaluation, through risk evaluation and into the economic model. The process of establishing the appropriate data can itself be beneficial and may challenge some pre-conceived norms.
It should be noted that there remains a wider picture. Whilst the iTEM outputs will inform the decision making process, the business imperatives will also influence the decision making process. For example, the customer’s mission statement may state a move towards a more sustainable operation. It could target carbon or fuel reductions. It could be in open competition for routes or trades that will have an increasing requirement for environmentally friendly vessels. So the iTEM outputs will inform that context with confidence. Without such a level of rigour the customers are less able to make informed decisions.

However, for the case study the outputs metrics are robust on their own. The assessed input parameters, when run through the model, demonstrate the project has an investable 17% IRR based on risk and return ratios, a reasonable payback period and will continue to save fuel and reduce carbon emissions for many years. It does indicate that additional savings in fuel and carbon emissions could be achieved with a higher utilisation or deployment on routes that have more favourable wind conditions (which may or may not be possible). Similarly, the impact on extended asset life, reductions in capex costs or the benefits of learning cost reductions could be used in building the business case. Further improvements to the IRR could be achieved if some debt financing was introduced.

8 Ongoing Research and Thinking

VTAS provides customers seeking commercially deployable energy saving technologies a platform to make sound business decisions. It does this through the holistic non-aligned assessment process. Extensive dialogue suggests the independence offered to owners and operators is valued and the opportunity for EST manufacturers - which VTAS is not – to have their offerings built into comparative performance models is a significant boost to their market entry aspirations.

There is a planned development of iTEM to provide greater levels of support through the Engagement Nodes (Figure 5). These will provide a richer level of capability to enhance that in place and to further seek to open the EST market in ways that the sector is seeking:

- Working with EST manufacturers to enrich the range of depth of technologies within the iTEM model and provide them with independent validation.
- Incorporating weather routing into iTEM to support more efficient routing around optimal wind projections.
- Working with partners through the Engagement Nodes to trial the performance guarantee process. Initial trials would test the contractual basis, the enabling technologies and the factors that would be at play in the contract. Initial trials would not have binding performance guarantees to ensure open dialogue and learning was achieved. It is envisaged that iTEM would be the benchmark assessment methodology.
- Extending the model from to support multi-modal transport decisions as part of a “crop to shop” carbon initiative.

9 Conclusions

The paper has discussed the climate change challenge and the urgent need to address it. Shipping has an important part to play in reducing GHG emissions to minimise the effects of climate change. An expansion of short sea shipping, particularly around the UK coastline, could provide an additional opportunity to mitigate land-based transport congestion and in so doing reduce net carbon emissions relating to freight transport. What this will look like in 2050 is conjecture. Increasing regulations, political ambition and consumer behaviours may drive changes we do not see at present. The advent of autonomous vessels offering a carbon free port to port service around the UK coastline is possible, off-shore renewable alternative fuel terminals may emerge, a more realistic cost of carbon on a global basis could be established or the cost, land availability and planning horizons to alleviate land-based transport infrastructure investment could become insurmountable. It is inevitable there will be change and the rate of change will be significant. Through this period and beyond, ESTs will continue to provide an opportunity to reduce fuel consumption and emissions from shipping. Their rate of adoption is approaching a tipping point as push and pull factors drive the change. The methodologies outlined in this paper provide a process of independent assessment to establish the viability and business case for the right investments. Selecting the appropriate solution for the vessel and trade is a complex technical and economic process that can deliver significant results. The methodology outlined in this paper, and the contextual reasons for the need for ESTs, suggests there are viable options available. These will reduce fuel consumption and carbon emissions. They will also support the case for investment in coastal shipping in the UK as part of the multi-modal mix going forward.

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Appendix 1

Energy Saving Technology Group	Energy Saving Technology Group Definition	Energy Saving Technology	Description	Marine Application Technology Maturity Readiness	Current Estimated Efficiency Improvement
Wind Derived Devices (Windy)	Devices that harness wind energy and typically provide an additional means of auxiliary propulsion.	Flettner rotors	A Flettner Rotor (FR) installation typically comprise of a series of spinning rotors located on the ship's deck. They harness energy from the wind using the "Magnus effect", therefore, producing propulsive force allowing the engine/s to be operated at a lower load, saving fuel and reducing emissions.	8 - Examples in service now	2% to 15% depending on number, size, vessel operating conditions and environmental conditions (e.g. wind strength and direction)
		Kites	A large kite is attached to the bow of a ship by a single line via a steering gondola. It can be actively controlled to create high flying speeds, therefore, producing propulsive force allowing the engine/s to be operated at a lower load, saving fuel and reducing emissions.	7 - Trials conducted but limited take up to date	OEM claims of up to 30%. Dependant on kite size, vessel operating conditions and environmental conditions (e.g. wind strength and direction)
		Hard Sails / Wingsails / Turbo-Sails	A typical hard sail/ wing sail/ foil device comprise of a series of aerodynamic structures (i.e. sometimes similar to an aircraft wing) located on the ship's deck. Some devices (i.e. turbo-sails) also utilise powered fans to amplify the low pressure side of an aerofoil by drawing air into the device. They harness energy from the wind, therefore producing propulsive force allowing the engine/s to be operated at a lower load, saving fuel and reducing emissions.	7 - Trials conducted but limited take up to date	2% to 15% depending on number, size, vessel operating conditions and environmental conditions (e.g. wind strength and direction)
Wet Interface Devices (Wet)	Devices that provide hydrodynamic efficiency improvements, typically reducing resistance and/or providing enhanced propulsive conditions.	Static Devices	Static hydrodynamic improvement devices include pre & post-swirl stators, mewis ducts ® /nozzles, fins and other devices positioned either ahead of the propeller, fixed to the ship's hull, or behind, fixed either to the rudder or the propeller itself. They all seek to improve the propulsive efficiency of the vessel.	Variable depending on the device. Certain devices are at 8-9 now - Examples in service now and reasonable take up	Various depending on the device but typically <5%
		Dynamic Devices	Dynamic hydrodynamic improvement devices include Propeller Boss Cap Fins (PBCFs) and Grim Vane Wheels. They all seek to improve the propulsive efficiency of the vessel.	Variable depending on the device. Certain devices are at 8-9 now - Examples in service now and reasonable take up	2-7% depending on specific design
		High Efficiency Propellers	High Efficiency Propulsion Systems (HEPS) are an effective way to improve fuel efficiency. Some propeller manufactures offer improved, anti-cavitation propellers which increase thrust and improves propeller efficiency.	8-9 depending on the design	2-8% depending on specific design

Energy Saving Technology Group	Energy Saving Technology Group Definition	Energy Saving Technology	Description	Marine Application Technology Maturity Readiness	Current Estimated Efficiency Improvement
Waste Heat Recovery Devices (Warm)	Devices that utilise the waste heat generated from on-board machinery which would otherwise have been lost to sea or atmosphere.	Organic Rankine Cycle (ORC)	An ORC system uses waste heat (e.g. main engine jacket cooling water) to evaporate a fluid. The evaporated fluid is then expanded into a turbine generator to produce mechanical energy, and then electrical power. The fluid is condensed and pumped in a closed cycle. The main difference between ORC and a steam cycle is the utilisation of organic fluids that have a lower boiling point, which enables the use of lower temperature heat sources.	9 - Examples in service now and reasonable take up	5-10% depending on operating conditions and vessel energy profile
		Power Turbine Generator	Also known as an exhaust gas turbine, it is located in the main engine exhaust gas bypass. The Power Turbine is driven by part of the exhaust gas flow which bypasses the engine turbochargers. The power turbine produces extra output power for electric power production.	9 - Examples in service now and reasonable take up	3-5% depending on size and engine operating conditions
		Electric Turbo Compounding	Directly attached to the gas or diesel powered genset the device recovers waste energy from the genset exhaust to improve power density and fuel efficiency. Typically comprises (1) turbocharger, (2) Turbo generator and (3) power electronics module.	9 - Examples in service now and reasonable take up	4-7% depending on size and engine operating conditions
		Economiser/ Boiler and/or Steam Turbine	Utilises waste heat from main engine and/or auxiliary engines to produce steam. Steam is then passed to either (1) a steam turbine generator that produces electrical power or (2) directly passed to other steam users on the ship. If the electrical power is produced this can then be utilised for (a) propulsion (i.e. via shaft motor) or (b) other electrical power users (i.e. refrigerated container cooling).	9 - Examples in service now and reasonable take up	3-5% depending on size and engine operating conditions