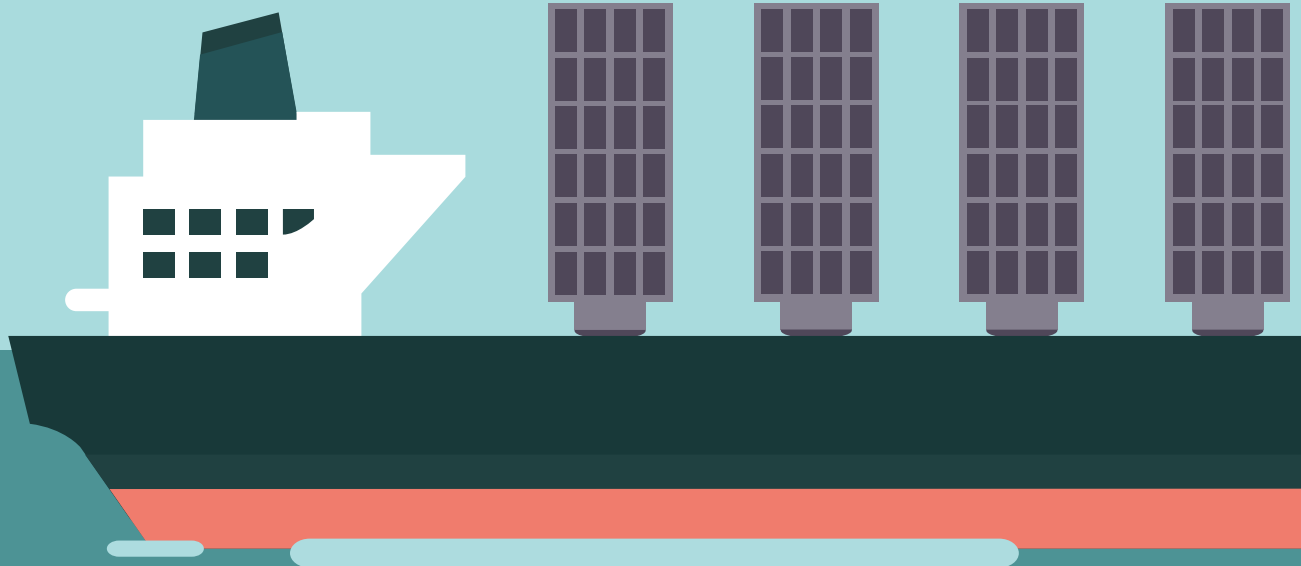
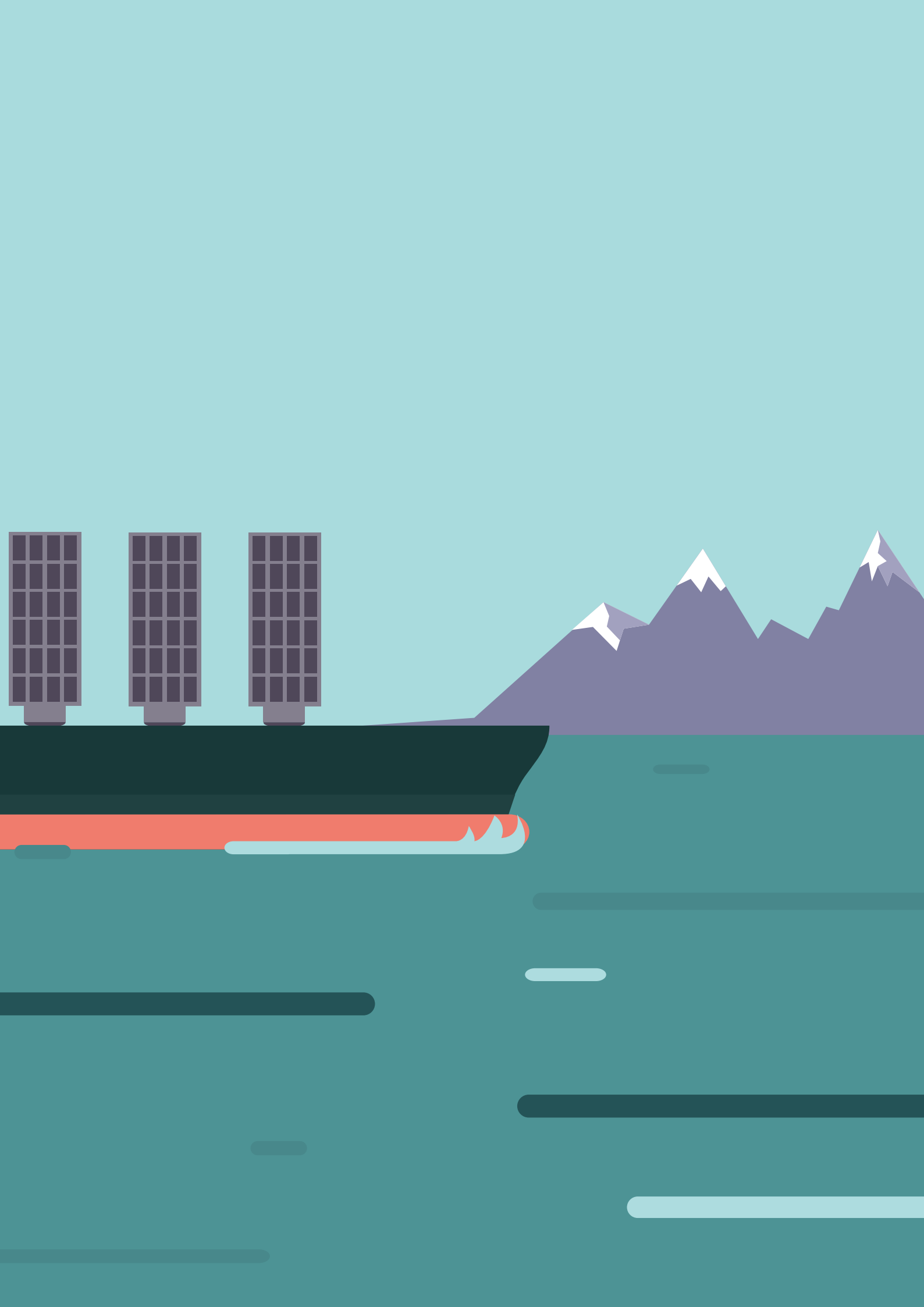


HIGH SEAS, HIGH STAKES

HIGH SEAS PROJECT FINAL REPORT

TYNDALL CENTRE FOR CLIMATE CHANGE RESEARCH
UNIVERSITY OF MANCHESTER





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INTRODUCTION

The international community has committed to “hold the increase in global temperature below 2°C, and take action to meet this objective consistent with science and on the basis of equity”¹. This technical report explores options available to the shipping sector in order to support strategic decisions consistent with this commitment.

It is clear that the science of climate change places stringent emissions constraints on all sectors if the 2°C commitment is to be met. Fortunately, in the case of the shipping sector, there is a range of options for achieving significant decarbonisation within appropriate timeframes. Nevertheless, debate focused on how to support the sector in making a ‘Scharnow turn’² to achieve step-change decarbonisation measures is low down the policy agenda in the UK, EU and across the globe.

This report serves to raise the profile of shipping decarbonisation by highlighting key research outputs from the EPSRC-funded High Seas Project. The report aims to:

- Illustrate implications of the quantitative framing of climate change for shipping
- Describe the shipping-specific policy and broader context
- Present a range of methodological approaches for quantifying shipping emissions
- Summarise opportunities and scenarios for rapid and significant decarbonisation in shipping
- Consider the policy implications of the High Seas Project research

During the High Seas Project, the research team have produced and disseminated a broad array of academic and policy-relevant outputs. This technical report summarises these outputs with links to detailed published work for those seeking more in-depth analysis.

1. United Nations Framework Convention on Climate Change, The Copenhagen Accord. 2009 FCCC/CP/2009(L.7)
2. A Scharnow turn is a maneuver used to swiftly bring a ship back to a position previously passed through

CONTEXT

Despite ongoing climate negotiations aimed at preventing a rise of 2°C above pre-industrial levels, growth in global fossil fuel emissions continues across all sectors. While the energy and industrial sectors are generally at the heart of mitigation policies, the increasing urgency of the climate challenge is leading to increased consideration of mitigation options across all sectors, including international aviation and shipping.

In response, the International Maritime Organisation (IMO) and the International Chamber of Shipping (ICS) have stated the “shipping industry is committed to playing its part in further reducing its CO₂ emissions”, and that it “must be proportionate to shipping’s share of the total global emissions” (less than 3 per cent). The ICS also suggest that shipping’s CO₂ emission cuts “should be at least as ambitious as the CO₂ emissions reduction agreed under any new UN Climate Change Convention”.

The High Seas Project undertook detailed quantitative analysis to translate high-level statements into what they mean in terms of absolute reductions in emissions, as well as rates of mitigation.

Working with global carbon budgets and emission reduction pathways commensurate with 2°C, equivalent pathways for the shipping sector were derived. These were then compared with the scenarios developed by the IMO and presented in the 2nd Greenhouse Gas Study,³ which included mitigation measures such as the Energy Efficiency Design Index (EEDI) introduced in 2013.

Results show that an approximate 50:50 chance of avoiding 2°C demands around a 70-80 per cent reduction in emissions by 2050 from 1990 levels, with rates of reduction of at least 6 per cent per year following a peak date before 2020. By contrast, IMO scenarios project emissions rising by approximately 300 per cent between 1990 and 2050 (Figure 1).

If shipping is to drive down emissions in line with a small and rapidly reducing carbon budget accompanying the 2°C commitment, then the climate change agenda for the industry is much more challenging than the IMO analysis suggests. For shipping to make a ‘fair and proportional’ contribution towards avoiding 2°C, a fundamental change in its decarbonisation policy is necessary.

*For more detail see: Anderson & Bows, **Executing a Scharnow Turn: reconciling shipping emissions with international commitments on climate change**, Special mini focus issue of Carbon Management, 3, 615-628, 2012.*

Sector-specific challenges

International shipping has enjoyed a long history of growth. Typically, global trade in terms of tonne-kms has grown at over 4 per cent p.a. since the 1990s. While shipping facilitates increasingly diverse trade patterns, such buoyant growth in a sector reliant on fossil fuel combustion has led to trends in CO₂ emissions above the global cross-sector average, with growth of an estimated 3.7 per cent per year since 1990 (Figure 2).

There is an array of features specific to shipping that differentiates it from other sectors. These features make encouraging and incentivising decarbonisation pathways a particular challenge. For a start, there are many different actors within the complex market structure that spans nations and regions. Those with a potential role in influencing the emissions associated with ships or trade routes include ship owners, operators,

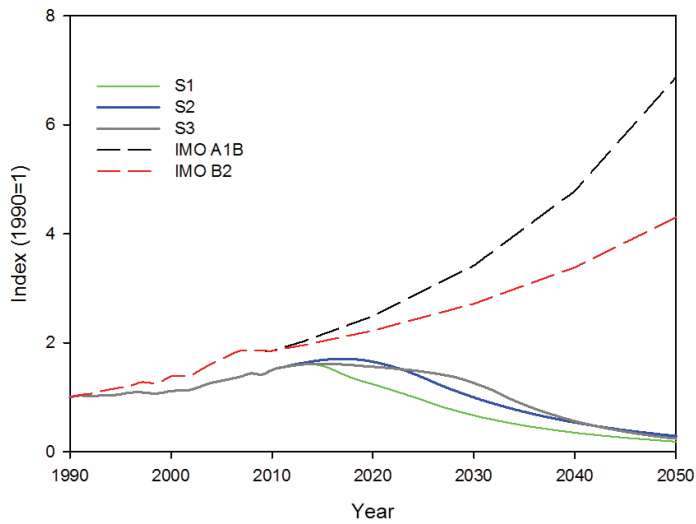


Figure 1: Comparison of '2°C' emission pathways with IMO scenarios, indexed to 1990=1. Published in Carbon Management 3, 6, doi:10.4155/cmt.

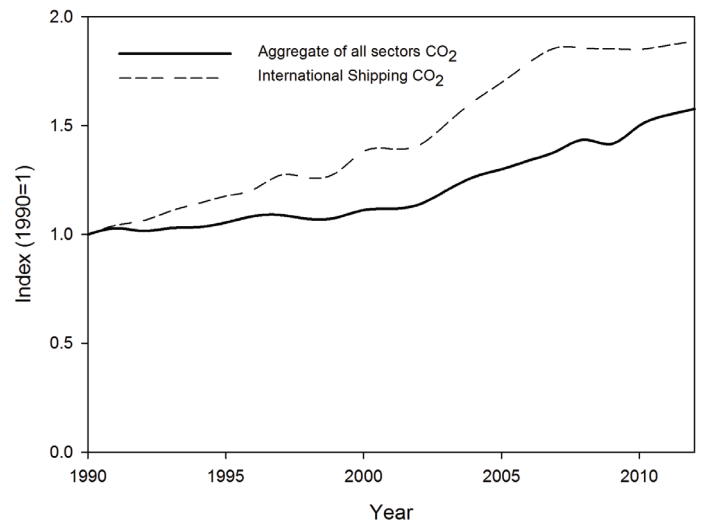


Figure 2: Comparison of the global average growth in CO₂ emissions compared with the growth from the international shipping sector, indexed to 1990=1 using data from the International Energy Agency.

charterers, shippers and port authorities. Added into this mix are the various governance channels that primarily operate through the IMO, influencing global shipping activity and ship construction. Nation states or unions of states, such as the EU, can influence shipping activity in local waters and ports. Finally, port authorities have some agency, for example through fee-setting policies.

With such a level of institutional complexity, the sector's emissions are extremely challenging to influence. Moreover, climate change has typically been lower down the IMO's agenda than issues surrounding safety and minimising local pollutants during the combustion of marine fuel. Focusing on recent changes to sulphur regulations highlights the relatively low position of climate change on the political agenda.

Marine fuel oil has a high sulphur content, and when combusted, releases sulphur oxides (SO_x) that increase the acidification potential of the surrounding atmosphere. To address this, the IMO devised Emission Control Areas (ECAs) stipulating that from the 1st January 2015, the maximum allowable sulphur content of marine fuel combusted in an ECA will

be 0.1%. UK shipping will be included in the North West European Waters ECA.

Three principal options are open to ship owners to comply with the regulations – using low sulphur distillates, liquefied natural gas and SO_x scrubbers. The recent strengthening of sulphur standards is essentially encouraging a shift away from marine fuel oil, yet by focusing on sulphur in isolation, the regulations are incentivising changes that ignore opportunities to address the climate challenge at the same time.

As this legislation is likely to lead to a widespread change to the type of fuel burned in marine engines, an opportunity exists to explore co-benefits of sulphur and carbon reduction. Instead, regulators appear to be taking a short-sighted approach that seems to give little strategic thought to devising a co-ordinated suite of measures to address local and global pollution in unison.

Such an approach could provide an incentive to support more radical, step-change forms of propulsion from the outset, reducing the risks of infrastructure lock-in and preventing lock-out of technologies, such as wind propulsion,

that could significantly reduce the sector's carbon as well as sulphur emissions.

*For more detail see: Gilbert, **From reductionism to systems thinking: how the shipping sector can address sulphur regulation and tackle climate change**, Marine Policy, 43, 376-378, 2014.*

MEASURING SHIP EMISSIONS:

Industry insight:

“A reflection on the industry at this moment in time is that views are polarised as to whether we face an imminent quantum change in fuel supply (like we saw when coal was replaced by fuel oil). Or a more measured transitory mutation, of more fuel efficient propulsion and ‘scrubbing’ of emissions.”

(International Bunker Industry Association Annual report, 2012/2013, page 5).

It is widely accepted that shipping must reduce its CO₂ emissions, but the actual size of its global carbon wake is uncertain. Typically, it is estimated to account for about 3 per cent of global CO₂. If combined with CO₂ from aviation, this is similar to the total CO₂ produced by the African or Latin American continents, according to IEA statistics.

While the 3 per cent figure is generally accepted, methods established in the literature (for instance, using activity-based models; estimates derived from bunker fuel sales etc.) that are generally used to derive this number, make many assumptions and generalisations. Perhaps more importantly, most are unable to account for increases in energy efficiency through, for instance, slow steaming.

More generally, any useful tool for quantifying shipping emissions should fulfil a set of criteria to give a clear picture of shipping’s contribution to annual emissions.

Propulsion accounts for the bulk of energy used and CO₂ produced by ships. Thus, fuel consumption can be derived from individual ship movements. This in turn can be used for estimating fuel combusted from a large proportion of the world’s

ships because at frequent and regular time intervals, all large ocean-going vessels must send Automatic Identification System (AIS) messages. These messages include information about the vessel’s location and speed (Figure 3). Satellites can pick up these AIS messages. There are already receivers in Earth’s orbit, with many more planned.

Working with AIS data gathered by both satellite and shore-based receivers to track a sample of cargo vessels, a model for reconstructing vessel movements and estimating their fuel consumption has been developed for the High Seas Project. Taking an example vessel, model results can be compared with fuel consumption data recorded in noon reports (Figure 4). Results suggest that the method provides more accurate estimates than others currently used. Crucially, it can give geographically and temporarily resolved estimates, in near-real time, allowing operational efficiency to be monitored. Further work will refine the method and apply it to estimates of global shipping emissions.

*For more detail see: Traut, M., **Monitoring shipping emissions via AIS data? Certainly,** Low Carbon Shipping Conference 2013.*



Figure 3: Track of a vessel reconstructed from both terrestrial and satellite AIS data over the course of the year 2012. Data: LuxSpace Sarl. (satellite) and JAKOTA Cruise Systems (terrestrial).

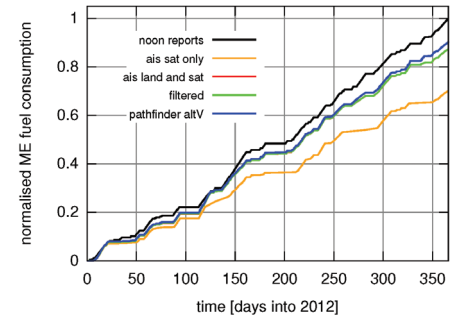


Figure 4: Main engine (ME) fuel consumption estimated by a new AIS model, compared with the fuel consumption as recorded in sample vessel's noon reports. (Noon reports: Reederei Buss. AIS data: JAKOTA Cruise Systems and LuxSpace Sarl).

Supply chain accounting

Ship emission estimates also have an important role to play in supply chain accounting, although this requires an altogether different approach. Instead of methods that can monitor and aggregate shipping emissions, lifecycle accounting involves estimates for the fuel consumed per tonne-km. Existing tools tend to provide only very generalised estimates, often for just three ship types, each of a typical size. In reality, the CO₂ emissions associated with shipping freight can vary significantly depending on a range of circumstances, such as ship size, type, speed, loading and so on.

There is a huge variety in the CO₂ intensity of different ship types and sizes. Moreover, although shipping is the least carbon-intensive mode of freight transport, the vast distances involved mean that choosing an emission factor that is too low can lead to a significant underestimate of the supply chain emissions associated with particular goods. While vessel type depends on the commodity being shipped, vessel size is often more difficult to ascertain. By correlating emission data with ship type, research within High Seas highlights the non-linear relationship between ship

size and CO₂ emissions (Figure 5). The specific shape of this curve is different for different ship types but for most types the CO₂ emissions intensity is relatively high for small ships, decreasing rapidly, to a point beyond which an increase in ship size results in only a marginal decrease in CO₂ intensity (measured in CO₂ per tonne-km).

Data analysis by the project team demonstrated that it is very difficult to presume a reasonable “average” ship CO₂ intensity estimate. There are two reasons for this. Firstly, not all ships have a good fit with the expected CO₂ intensity vs size relationship. Secondly, through this non-linear relationship it is not possible to identify if a ship is travelling at full capacity.

High Seas analysis suggests that someone using carbon accounting tools should be directed by the accounting software towards emission data with more highly resolved granularity and specificity. Knowledge of the specific market within which trade takes place may provide enough information for an informed choice to be made about both ship type and size, offering a better estimate than available from

using most existing tools. For example, manufactured products are more likely to be transported on a container vessel and knowledge of where the material is sourced can indicate a suitable size range.

*For more detail see: Walsh & Bows, **Size Matters: Exploring the importance of vessel characteristics to inform estimates of shipping emissions**, Applied Energy 98, 128-137, 2012.*

Apportioning emissions

Even more subjective than the processes of estimating shipping emissions and supply chain accounting is the debate around how to apportion the responsibility for international shipping emissions to nations or regions. If greenhouse gas targets are to be meaningful at a sub-global scale, all sectors must be accounted for.

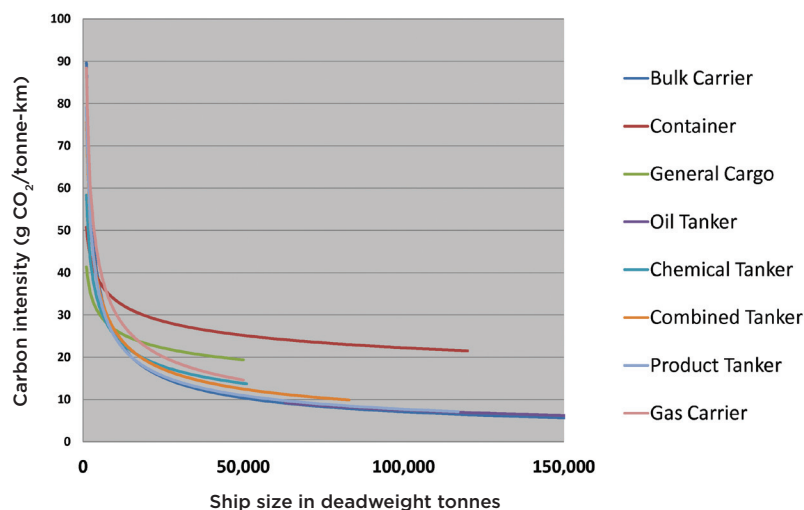


Figure 5: Illustration of how CO₂ intensity of different ship types becomes saturated as size increases.

Most nations rely on the IMO to deliver mitigation policies, but progress is slow.

Nonetheless, the legacy of the Kyoto Protocol excludes emissions produced within international waters (and airspace) from national targets, which poses a significant challenge for mitigating emissions. Essentially, most nations and regions rely on the IMO to deliver appropriate mitigation policies rather than bringing shipping in line with their own national (or regional in the case of the EU) carbon-reduction efforts. And the debate at IMO meetings has been moving very slowly.

One aspect hampering progress through the IMO is the delay in agreeing a global carbon cap within the United Nations Framework Convention on Climate Change (UNFCCC) negotiating process.

Moreover, the UNFCCC's framing of 'Common but Differentiated Responsibility' (CBDR) is a significant challenge for the shipping sector, which operates under 'No More Favourable Treatment' – a maritime principle to ensure shipping standards apply equally to all nations. Therefore, while some nations – notably China and India – advocate consideration of different treatment for emerging economies in mitigating shipping emissions, overall

there remains strong support from many IMO member states for policies aimed at all nations.

Dissatisfied with the slow progress to mitigate shipping emissions through the IMO, the EU considered implementing its own sub-global policies, and in 2013 announced an EU-wide legal framework for collecting and publishing verified annual CO₂ data from all large ships (over 5,000 gross tonnes) that use EU ports, irrespective of where ships are registered. The rules are proposed to apply from 1 January 2018. The industry had feared shipping would be included in the EU's Trading Scheme, but at present, this looks unlikely.

Nationally, the UK Government has been debating how to address CO₂ from shipping. For instance, the Climate Change Act notes that by the end of 2012, international shipping (and aviation) CO₂ should be included in the 2050 target or else justification to Parliament will be required. During 2012, the UK's Committee on Climate Change (CCC) advised that these emissions should be included in the 2050 target and in its short-term carbon budgets. This would lead to shipping being monitored

and the UK would be making unilateral adjustment to its national carbon budgets to account for its share of international shipping CO₂.

However, following a decision by the EU to suspend the full inclusion of aviation within its emissions trading scheme, the CCC reneged on their advice. Subsequently, the UK Government took the decision in 2012 to exclude these international emissions from the budgets and 2050 target, deferring a decision until agreement of a fifth carbon budget in 2015.

*For more detail see: Bows et al, **Aviation and shipping privileged – again? UK delays decision to act on emissions**, Tyndall Briefing Note 47, 2012.*

Conducting research while these debates at global, EU and UK scales were ongoing, the High Seas project team argued that the urgency and scale of addressing climate change, as well as the shipping system's complex nature, required a broad suite of bottom-up measures targeted at regions, nations and organisations to complement global top-down measures implemented through the IMO (for instance the Energy Efficiency

Design Index). The research highlighted that several aspects of the shipping system are more directly influenced at a national rather than global scale, offering opportunities that are difficult to exploit through conventional IMO channels.

For instance, 'port states' (coastal nations) can influence the amount, source and destination of freight imported and exported as well as the energy efficiency of ships within national waters and at national ports, which could lead to more efficient technologies and operational practices being developed. Nations could indirectly influence technological innovation too if sub-global polices are adopted across multiple nations.

However, one of the main stumbling blocks cited for developing sub-global mitigation polices for the shipping sector is the perceived difficulty with their implementation. In order to allocate responsibility for an appropriate share of global international shipping emissions, it is assumed a method of apportioning emissions to nations is required. In conducting an in-depth analysis of the practical and philosophical considerations surrounding emission

apportionment, many complications were identified during High Seas. Firstly, there is a wide range of apportionment regimes available that lead to substantial variation in emission estimates. Moreover, with high data cost and the absence of transparent fuel consumption and freight data, all regimes that estimate emissions from the bottom up have limited sensitivity, rendering them obsolete for monitoring purposes. Simplified top-down regimes do exist, but, as proxies, they do not offer any monitoring of mitigation policy success over time. This is because they do not measure anything directly. Thus, the aspects of the shipping system over which national or sub-global policy may have influence are currently not sufficiently captured even by the extensive range of existing regimes.

It is clear that complications surrounding apportionment have stalled the debate. But, more importantly, it has also postponed any consideration of sub-global polices and indicators that can be activated without the need for apportionment. Research within High Seas makes a case for putting the apportionment debate aside in the short-term to open out the full span of

options. Policymakers and organisations should instead consider: the influence they may have over aspects of the shipping system; the implications of measures that could be employed to control emissions; and, how success could be monitored.

*For more detail see: Gilbert & Bows, **Exploring the scope for complementary sub-global policy to mitigate CO from shipping**, *Energy Policy*, 50, 613-622, 2012.*

*Gilbert, Bows & Starkey, **Shipping and climate change: scope for unilateral action**, *Tyndall Centre Policy Report*.*



Figure 6: Screenshot of the ASK-C scenario tool

Modelling future emissions

To explore what options may be available to decarbonise the shipping sector from a UK perspective, a new scenario tool has been developed within High Seas. It can calculate the emissions that result from scenarios of future shipping activity associated with UK imports, including choices over technologies, operations and the demand for trade. The timeframe of the scenario model called ASK-C (see Figure 6) is from 2006 to 2050.

The physical quantity of material transported is split into 19 categories. Future trade can be projected by specifying an annual growth rate, while a specific energy-focused module has been developed to allow the user to choose one of the DECC energy scenarios, which will have a significant impact on the future trade of fossil fuel (see Shifting Demand, page 17). Changes in trading distances are reflected by specifying an annual change in the baseline transport distance or by allocating changes in traded quantities to a specific source. These particular choices allow transport work (in terms of tonne-km) to be estimated for a specific year.

Each commodity category is allocated an appropriate ship type. Given the non-linear relationship between ship size and emissions (Figure 5), the model allows the user to choose either a single ship size per ship type or alternatively transport work can be allocated to a range of sizes. For each ship type, a choice of vessel characteristics is used to generate energy consumption estimates per unit of transport work (kWh/tonne-km). These estimates can be further modified to reflect the presence of technologies that reduce energy consumption including the use of renewable propulsion, as well as operational changes. Both retrofit and new-build technologies can be included, with retrofit rates and the penetration of new build ships taken into account.

The specific combination of technologies chosen gives an amount of energy required for the shipping of imports into the UK that needs to be satisfied by some form of marine fuel. For each type of ship, a choice of engine type, fuel type, and bio-derived fuel content generates a CO₂ emission factor.

This, in conjunction with the transport work projections allows absolute CO₂ emissions to be estimated. Taking this

one stage further, cumulative emissions can be calculated by considering how the shipping system will make the transition between the baseline year to a radically different one in 2050.

ASK-C captures the pattern of UK imports, which at present includes a large proportion of trade within the EU. The trade of energy commodities figures prominently in the UK's demand for shipped imports, contributing to approximately half of all transport work in the base year (2006).

For more detail see: Walsh et al., A comparison of alternative decarbonisation scenarios for UK shipping, Low Carbon Shipping Conference, 2013.



OPTIONS FOR DECARBONISING SHIPPING:

Industry insight:

“We need a shift in how the industry is financed....at the moment there is a lot of interest in green technologies but you have to persuade the banks to give you the money.”

(Technology developer, interview)

Armed with tools to quantify the CO₂ emissions associated with shipping activity, and an in-depth understanding of the current shipping system, the High Seas researchers articulated a suite of low-carbon shipping scenarios or visions of the future. The intention from the outset was to consider the full system, including technological, operational and demand-side aspects. This approach builds on similar scenario exercises conducted within Tyndall Manchester (Figure 7), where methodologies have been developed that acknowledge that all these aspects can interact with and influence each other.

Scenarios are not predictions or forecasts, but tools to explore a range of plausible futures. The particular type of scenario used within High Seas is known as backcasting. In backcasting, the process begins by setting a strategic objective – in this case a significant cut in the CO₂ emissions associated with shipped UK imports. All scenarios are designed to meet this objective, but each scenario will include different choices regarding technological development, rates of change, shifts in the demand for products and where they are sourced from, as well as differences in operational practices.

The scenarios parameters are not only quantified in terms of energy consumption and emissions using the ASK-C tool, but are also informed by expert stakeholders through workshops and interviews. This ensures that the scenarios, while optimistic in terms of CO₂, will be plausible and of relevance to industry and policy decision makers.

While a considerable amount of research around operational change was available to draw upon in the literature, detail on how the wide variety of technological interventions could impact on ships was less readily available and few demand-side assessments pay attention to the impending shift in the trade of fossil fuel resources. To address this, the High Seas team delivered new analysis with regard to both these key aspects. These are explained over the following 14 pages.

Technology change

Technology offers huge potential for decarbonising the shipping sector, even in the short- to medium-term. But, if the sector is to step up to the decarbonisation challenge, then the scale of change offered by the technologies and any co-benefits or trade-offs necessary needs

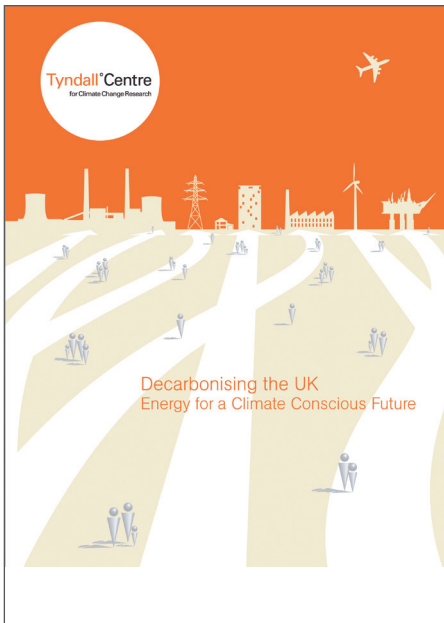


Figure 7: Decarbonising the UK publication containing Tyndall’s first energy system scenarios.

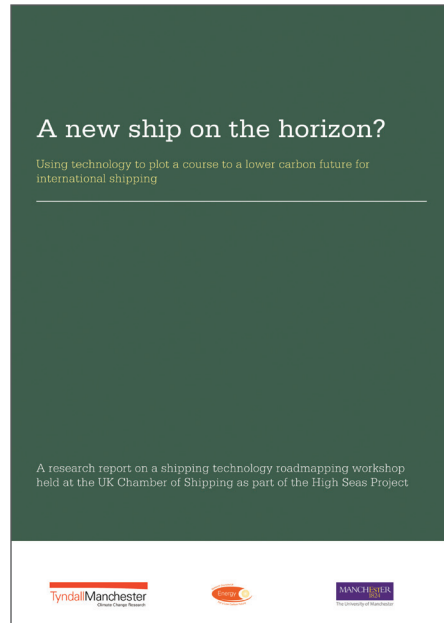


Figure 8: The High Seas Project’s roadmapping report



Figure 9: Extract from the High Seas Project’s roadmapping report

to be examined in detail. Research within High Seas highlights that it is technically feasible to significantly decarbonise both new builds and retrofits. However, many technologies that could be drawn upon are under-researched, not fully commercialised or considered to be too ‘niche’ to warrant consideration or investment at an appropriate scale.

During a technology road-mapping stakeholder workshop in January 2013, 2050 visions for a range of radically decarbonised vessels were articulated (Figures 8 and 9). While the roadmaps were essentially qualitative in nature, information was translated into emissions savings using the ASK-C model.

Perhaps surprisingly, results from the workshop demonstrate that the combination of the technology measures for the 2050 visions are able to deliver considerable (>90%) cuts in CO₂ from today’s levels for both retrofitted and new-build ships.

However, several barriers stand in the way of realising such futures. Ways of overcoming barriers to technology change identified in the workshop are presented in the following eight points; this is not,

however, an exhaustive list as there will likely be additional barriers associated with economics, markets, governance and social acceptability.

For a copy of the workshop report visit www.mace.manchester.ac.uk

1. With its complex system of markets, services and vessel types and a wide range of technology measures to match, the sector would benefit from market- or service-specific roadmaps, including tailored policy instruments to support progress towards high levels of decarbonisation in the near-term.
2. When considering alternative fuels, there needs to be a reliable supply to match demand, as well as infrastructure capable of production, distribution and storage.
3. For widespread adoption of new fuels, economies of scale need to be enhanced, as many fuels are yet to be commercialised.
4. With a lifespan of 30-40 years, vessels entering operation today are likely to be in service near to 2050. This

highlights the importance of retrofit options, but limited political will, feasibility issues and financial constraints need to be overcome.

5. Uncertainty surrounding performance and functionality of renewable forms of propulsion in real-life weather conditions supports a need for full-scale demonstration.
6. Practical challenges in installing, deploying and operating renewable technologies require a systemic analysis for each new technology.
7. Pursuing co-benefits of addressing CO₂ and SO_x emissions would likely reduce the impacts of infrastructure lock-in, as well as reducing potential lock-out of future low carbon fuels (see Sector-specific challenges, page 6).
8. The cumulative nature of CO₂ emissions means that implementing mitigation measures in the short-term makes the challenge easier in the long-term. While potentially offering short-term CO₂ mitigation, LNG can only ever be an interim part of a more radical transition towards a decarbonised sector.

Industry insight:

“...GIS data will help, as will getting more information about what the weather patterns actually are. Investing in that technology route may be more effective, using the existing ships more effectively.”

(Technology developer, interview)

The technology roadmaps articulated by the stakeholders suggest that the technologies that are considered feasible in the short-term (i.e. <10 years) and have long-term viability are: Wind-assisted propulsion (kites, sails and Flettner Rotors), small-scale (1MW) fuel cells as well as a partial penetration of biofuels.

Wind propulsion

So is there an opportunity for a wind revolution for shipping? With shipping facing the challenge of reducing its dependence on fossil fuels and cutting its CO₂, this renewable energy source, freely available on the world's oceans, offers an attractive alternative. Shipping has changed a great deal since the days when it was entirely wind-powered. Smaller crews on larger ships transport more goods, often within a 'just-in-time' logistics system. Consequently, the desirability for wind power technologies, which are considered to be slower or less reliable, has diminished within commercial trade. Yet as just one component of modern-day cargo shipping, wind-assist technologies could, when coupled with sophisticated computer-controlled systems, constitute a complementary source of propulsion. While various concepts

do exist already, the High Seas project identified knowledge gaps in relation to performance, feasibility and cost.

In order to assess the carbon abatement potential of wind power, numerical models of wind power technologies were linked with wind data along international trade routes. In particular, performance models of a Flettner Rotor and a kite were analysed along five shipping international trade routes representing various trades. Results revealed that the average power contribution of the modelled towing kite along the routes considered ranged from 127kW to 461kW, while a single Flettner rotor's power ranged from 193kW to 373kW.

The power contribution from the towing kite is more volatile, both over time and geographic location, than that from a Flettner rotor. Furthermore, the power is lower than the power that could be harnessed from two or more Flettner rotors. Nevertheless, one rotor has the advantage of taking up very little deck space and could feasibly be retrofitted onto existing vessels. The analysis conducted underlines the hypothesis that the wind power contribution from a kite or Flettner rotor is too low and variable for the industry to consider wind as the



A big switch to renewables is an important element of UK energy system decarbonisation



Will there be a wind revolution in shipping? (Photo US Navy)

sole power source for cargo. Nevertheless, wind power could make a significant contribution when vessels operate in hybrid mode and even provide a major share of required propulsive power under some conditions.

Using this method, the analysis outlines steps towards grasping the emission reduction opportunities presented by wind power, both as a technology providing a step change in emissions and as part of a wider transition to a decarbonised shipping sector.

*For more detail see: Traut et al., **Propulsive power contribution of a kite and a Flettner rotor on selected shipping routes**, *Applied Energy*, 113, 362-372, 2014.*

Shifting demand

While developing technologies fit for purpose is an essential element of the low-carbon transition, demand for shipping services and how it may shift in the future should also be considered.

The UK's current energy supply relies heavily on shipped imports of fossil fuels, yet as the energy system decarbonises, UK shipping patterns will alter. Analysis

by High Seas shows that if a cut in energy demand and a big switch to renewables are important elements of UK energy system decarbonisation, then the need for imported fossil fuels will fall.

As a knock-on impact, shipping CO₂ emissions arising from energy imports could decrease by up to 80%, if current trading patterns are maintained. Oil and oil products used in refineries and as transport fuels currently comprise around one third of UK shipped imports (by weight) and are responsible for the highest share of shipping CO₂ emissions of all imported fuels.

Decarbonisation of the transport sector will significantly reduce demand for oil products. As a result, in a low carbon future, it is envisioned that biofuels and solid biomass become increasingly important, with emerging markets requiring new or retro-fitted ships travelling between Europe and centres of production in America and Africa.

The future role of coal in the UK energy system is contingent on the successful deployment of carbon capture and storage (CCS), but even if CCS is successfully deployed, the demand for the shipping of coal will likely be lower in the future, leading to a cut in coal's contribution to

shipping CO₂. The distance that fuels travel is a further crucial factor in determining future emissions. It is clear from the analysis that the greatest absolute reductions in shipping CO₂ emissions are achieved when there is a reduction in both fuel and the distance travelled.

Add these changes in demand to the potential shifts in operations and technology, and near-term step-change cuts in CO₂ start to appear feasible. The full impact of decarbonisation may also have a spillover influence on other sectors facing similar challenges.

Of course, the penetration of technical and operational change will be driven by national and global policy, the application of energy efficiency-focused initiatives such as the EEDI and SEEMP, as well as the anticipated increase and variability in fuel price. Nevertheless, the shipping sector currently faces less pressure to decarbonise than sectors within the EU ETS or UK climate change targets. Should the policy framework strengthen, step-change decarbonisation could materialise.

*For more detail see: Mander et al., **Decarbonising the UK energy system and the implications for UK shipping**, *Carbon Management*, 3, 601-614, 2012.*

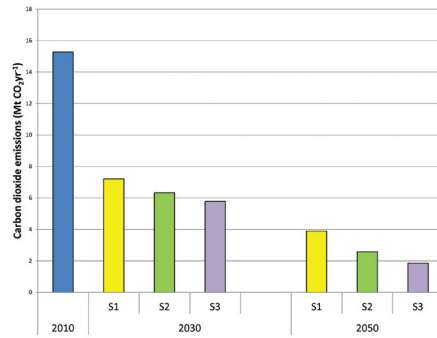


Figure 10: Baseline and scenario levels of CO₂ emissions in 2010, 2030 and 2050.

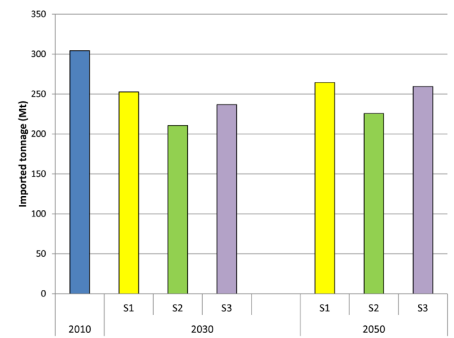


Figure 11: Baseline and scenario levels of imported tonnage into the UK in 2010, 2030 and 2050.

DECARBONISATION SCENARIOS:

Industry insight:

“Pooling ships is key to maximising the efficiency of operation and in those situations I think you can make quite a lot of savings in fuel per tonne carried as you can minimise the time in ballast.”

(Technology body, interview)

Drawing together insights from across the team as well as through a dedicated engagement process with industry and policy shipping stakeholders, three future scenarios were developed. All three focus on potential changes affecting the imports of goods to the UK under a strict decarbonisation agenda, capturing a range of decarbonised visions of the shipping system. Each scenario is described by a narrative as well as quantitative indicators represented in graphical form. Prior to presenting the scenarios individually, selected headline parameters are highlighted here first.

Scenario summary

Each scenario is given a neutral name capturing a sense of its overall theme. They are: Big World (S1), Full Steam Ahead (S2) and Small Ships Short Trips (S3). Big World paints the picture of a thriving globalised shipping industry where ship size continues to grow.

Full Steam Ahead contrasts with Big World to highlight a different future where technology in the form of nuclear power has offered an alternative low-carbon route for the sector, allowing high speeds to be maintained despite the decarbonisation agenda.

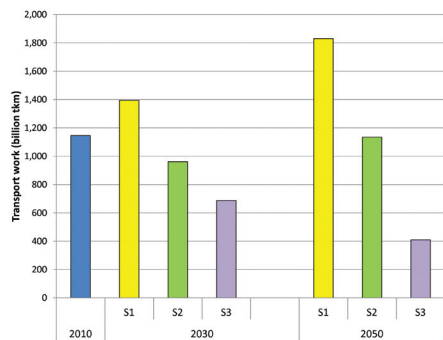


Figure 12: Baseline and scenario levels of transport work associated with UK imports in 2010, 2030 and 2050.

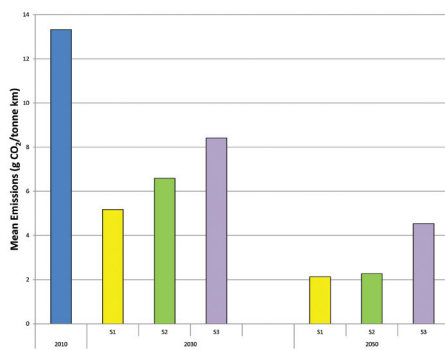


Figure 13: Baseline and scenario levels of emissions intensity per freight tonne-km in 2010, 2030 and 2050.

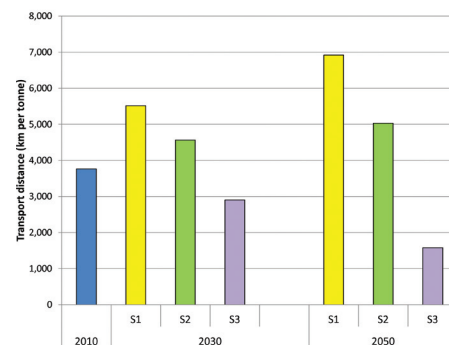


Figure 14: Baseline and scenario levels of average transport distance in 2010, 2030 and 2050.

Finally, Small Ships Short Trips considers a future where the port infrastructure within densely populated nations like the UK presents a barrier to ever larger container vessels, driving a need for smaller feeder ships able to more readily take advantage of the UK's future leading renewables industries.

The scenarios differ in almost every way apart from the fact that all achieved significant decarbonisation between 2010 and 2050 under constrained carbon budgets (Figure 10) and capture a material fall in the overall tonnes imported into the UK (Figure 11) although tonne-kms did not fall in all cases (Figure 12).

The primary driver for the reduction in overall tonnage is the very significant change experienced by the UK's own energy system, which as a result of decarbonisation, no longer requires the very high levels of fossil fuel imports by 2050 (see Mander et al., 2012).

Parameters that vary across the scenarios include: levels and types of goods traded; trading partners - which in turn lead to a change in the average distance travelled by tonne of good imported; the range of new build and

retrofit technologies penetrating the fleet; modifications to operations including slow steaming.

As a result, some scenarios achieve decarbonisation with more of an emphasis on the demand-side than others. For instance, in Small Ships Short Trips (S3) the emissions intensity (CO₂ per tonne km) is higher than in the other scenarios, but the overall number of tonne-km travelled is much lower (Figures 12 and 13).

This means that measures to improve energy efficiency and the level of CO₂ produced by the fuel mix are less demanding than they are in the other two scenarios. Note that the greatest change from the baseline in terms of CO₂ intensity is a reduction from over 13 g CO₂ per tonne-km to just over 2 g CO₂ per tonne-km within the Big World scenario (S1) (Figure 13).

This is necessary to provide enough carbon space for the growth in distance travelled per tonne rising from just under four thousand km per tonne to just under seven thousand (Figure 14).

The next section describes the scenarios in more detail including

information on the specific technology penetration required for the level of CO₂ reduction attained.

	BIG WORLD (S1)	FULL SPEED AHEAD (S2)	WHERE THE WIND BLOWS (S3)
Context out to 2050			
Global Backdrop	Globalisation continues apace.	Security becomes a more pressing concern with increasing risks of piracy at known conflict points.	Western economies focus on regional.
UK Energy System	UK energy system decarbonised in line with the DECC "high CCS" scenario.	UK energy system decarbonised in line with the DECC Markal scenario; Bio-fuels used for aviation and for domestic energy provision.	High penetration of renewable technologies as the UK decarbonises according to DECC "high renewable, high efficiency" scenario. No coal imports; significant imports of bio-derived energy; 90% reduction in LNG imports; while oil imports 50% of 2010 levels. (inc domestic trade).
UK Shipping			
UK Shipping Market	Increased importance of deep sea trade.	Both deep and short sea shipping important.	Decline in deep sea trade routes.
UK Demand for Imported Goods	Continuing increases in demand for manufactured goods	Equivalent to base year for non-energy commodities.	Marginal increase in demand for non-energy commodities.
Drivers for Decarbonisation of the Shipping Sector	Regulation and competition to incentivise fuel efficiency gains.	Increase in costs of marine fuel.	Decline in deep sea trade routes.
UK Imports	40% reduction in wet and dry bulk imports (2010) as a consequence of energy scenario. Doubling of quantity of containerised goods.	26% reduction in overall tonnage relative to 2010.10% increase in demand for non-energy commodities.	15% reduction in overall tonnage relative to 2010. 27% increase in non-energy goods, mostly associated with RoRo and containerised trade.
Trading Partners	Extension of trade routes to encompass new markets; increased trade with Central and South America, the Caribbean, North East Asia and India; reduced trade with Europe and Africa.	Increased trade with America for certain commodities but no drastic change in trading partners. Some routes are longer as a precaution against piracy.	Regionalisation results in dominance of short sea shipping; increased trade within the EU.
Freight Work	60% increase on 2010 levels; 45% freight work arising from shipping of containers increased from 28%.	Negligible change relative to 2010.	64% reduction relative to 2010 levels.

	BIG WORLD (S1)	FULL SPEED AHEAD (S2)	WHERE THE WIND BLOWS (S3)
	Vessels in 2050		
Size of Vessels	Container ships approximately 3 times current size; other ships double in size.	Bulk and container ships size doubles by 2050.	Ship size decreases by at least 50% for vessels > 5,000 dwt.
Ship Speed	40% reduction for container vessels; 20% reduction for other vessels.	20% reduction for containerised vessels.	20% reduction for all vessels.
Load Factors	30% increased in utilisation of container vessels.	Increased utilisation capacity of container vessels post 2040 from 7 to 10 Tonnes/TEU.	No change.
Fleet Replacement	90% turnover of fleet by 2050.	90% turnover of fleet by 2050.	100% turnover of fleet by 2050.
New Build Technology	Container vessels - 10% reductions in energy demand per tonne-km; technology is not as important when ships slow steam. Other vessels - 30% energy saving (propeller optimisation and hull design).	Nuclear ships emerge 2030-2035. Gradually penetrate fleet. Majority of tankers and approximately 30% of container and dry bulk fleet assumed to be nuclear powered. Non nuclear new builds assumed to be 30% more energy efficient.	All ships assumed to benefit from a suite of technologies such as contra-rotating propellers, refinement of hull lines etc.
Retrofit Technologies	Approximately 11% reduction in energy intensity for all container ships and 20% reduction for other ships. This is a compound value reflecting a combination of technologies including waste heat recovery, engine tuning, fuel injection, improved rudder propeller integration, etc.	Approximately 20 % reduction in emission intensity applied to all non - nuclear ships. As in Scenario 1 reflects overall impact of multiple individual measures.	Large array of diverse technologies such as hull coating, variable speed pumps and fans, waste heat recovery, engine tuning, fuel injection, improved rudder efficiency monitoring, hybrid energy systems, etc. Rapid uptake of new technologies as these come onboard. Results in approximately 11 (dry bulk -20% (container) reduction in energy intensity of transport work.
Renewable Propulsion	Wind powered or wind assisted is assumed to reduce energy demand by approximately 10% across all vessels.	Wind powered or wind assisted is estimated to reduce energy demand by approximately 10% across non-nuclear vessels.	Wind powered or wind assisted is assumed to reduce energy demand by approximately 10% across all vessels.
Fuel	HFO with 10% biofuel (main engines and boilers); MDO with 10% biofuel for auxiliary engine.	HFO (main engines and boilers); MDO with for auxiliary engine. 50% bio-derived fuel for RoRo.	HFO with 20% biofuel (main engines and boilers); MDO with 20% biofuel for auxiliary engine. 50% bio-derived fuel for ships transporting bio-energy. All Auxiliary boilers supplied by bio-fuel.
Operational Measures	8% reduction in energy intensity for containers and 14% reduction for other ships. Reflects to a combination of measures including weather routing, optimised trim/draft, condition based maintenance etc.	14% reduction in energy intensity applied to all non-nuclear ships. As in Scenario 1 reflects overall impact of multiple individual measures.	As in Scenario 1 reflects overall impact of multiple individual measures. 14% reduction in energy intensity applied to half the fleet.
Emissions Estimates 2050	3.9MtCO₂	2.58MtCO₂	1.86MtCO₂

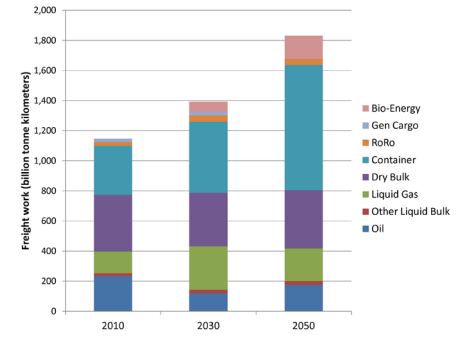


Figure 15: Levels of transport work associated with UK imports in 2010, 2030 and 2050 in the S1 scenario.

BIG WORLD (S1):

Industry insight:

“The slower ships go, the easier it is for renewably powered ships to compete”

(NGO, interview)

The shipping sector has thrived within an increasingly globalised world. Despite volatility, energy prices have increased. The realities of addressing climate change have gained political acceptance with the carbon emission space becoming increasingly constrained. This has led to some form of energy monitoring/carbon accounting becoming prevalent along established supply chains as a means of identifying opportunities for cost savings (assuming carbon pricing is in operation). Within the shipping sector the impact of globalisation, competition and increasing costs is manifested in the emergence of economies of scale in terms of ship size, as well as a reduction in speed.

UK energy context

In this scenario, carbon capture and storage technologies have been commercially deployed across the electricity generating sector and for the sequestration of industrial emissions of CO₂.

The overall generation mix for electricity is a balanced mix of renewable, CCS and nuclear power. Heating is provided by heat pumps and networked infrastructure such as CHP and district heating. Widespread

use of biomass with CCS (BECCS) and the use of gas for electricity generation results in significant imports of both these fuels, though quantities of gas imports are lower than in 2010. The use of BECCS enables the continued use of fossil fuels for transport. Fossil fuel imports reduce by 58% in terms of tonnes and by 16% in terms of tonne-km. By 2050 the energy demand of UK shipping has reduced by 70% compared with 2010 (Figure 17). Within the wider system, the quantity of energy imports has reduced by 50% relative to 2010, while the associated transport work demand is equivalent to 2010 levels.

UK consumption

Material efficiency has become a central component of management systems with the waste hierarchy being adhered to as far as is feasible. However within a globalised, technologically literate world there remains a strong demand for manufactured consumer goods (such as electronics or clothing) with over double the quantities of containerised goods imported by 2050. Within the UK, there is large-scale region-centric production that has a focus on repair and reuse. In general terms, most goods are transported further than at present, particularly dry bulk,

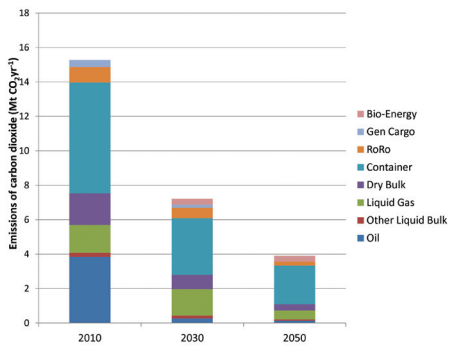


Figure 16: Levels of annual CO₂ emissions associated with UK imports in 2010, 2030 and 2050 in the S1 scenario.

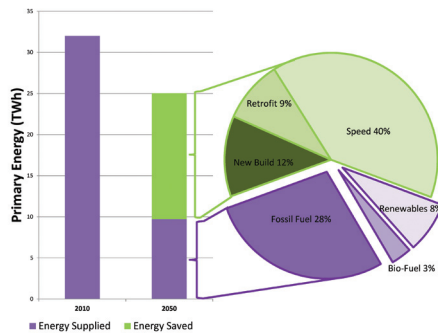


Figure 17: Baseline and scenario primary energy supplied by fuel and measures used to mitigate CO₂ emissions through energy demand-side savings in the S1 scenario.

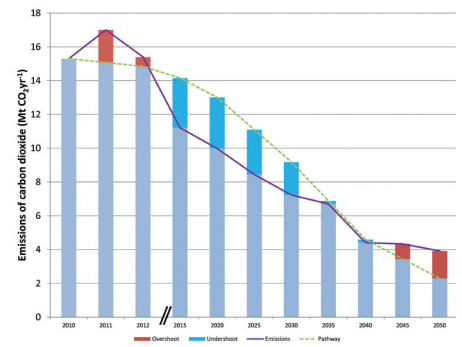


Figure 18: Annual and cumulative CO₂ emissions from the baseline year out to 2050 in the S1 scenario.

liquid gas and containerised freight. The demand for traded dry bulk (such as ores) remains at current levels but due to large cuts in the trade in energy commodities, the absolute quantity of imported goods is approximately 13% less than 2010 levels (Figure 11). Overall transport work has increased by 66% (Figure 15), while the average distance traded has increased by 83%.

Shipping technology

Ship removal rates are comparable to current levels but the delivery rate (in terms of existing capacity) is higher as the demand for more efficient new builds is driven by a buoyant shipping sector. Based on assumed replacement rates, efficient new builds enter the system in 2020, fully penetrating the fleet by 2050. Through new build technologies alone, bulk ships entering the market in 2035 are 30% more energy efficient than current vessels, whereas containers are 10% more efficient, with operational changes more important in the containerised sector. In addition to new build technologies, the retrofit of vessels has become routine with dry dock schedules accommodating the widespread inclusion of retrofit and renewable technologies, supported by

changes in the regulatory environment. This has led to a wider uptake of new technologies with efficiency measures becoming commonplace. Following the EU's lead, ships are required to measure fuel efficiency/emissions in a standardised and transparent manner. Regular audits are used to ensure compliance with regional/port based standards with records requested on a mandatory basis when ships are sold.

Shipping operations

Advances in logistical infrastructures (such as satellites) and related services allow for more extensive, interconnected and adaptable supply chains. The geographic range of AIS systems has transformed the logistical landscape.

The sharing of information along the supply chain coupled with the ubiquitous provision of weather routing services and dedicated berthing has supported slow steaming in becoming the norm, enshrined within "slow steaming clauses" in time and voyage charters. By 2050 container vessels travel at 40% of the speed of current ships, while other ships are 20% slower. This is accompanied by a consistent

increase in ship size, particularly for container vessels. Container vessels arriving in the UK are approximately three times the size of the current average and there is 30% more material inside the containers.

This increase in size is assumed to offset the need for additional ships while maintaining delivery rates. However, the relative size of marine engines is kept as safety is paramount for such large vessels and underpowered engines are considered hazardous. By 2050, engines are capable of operating a variety of load profiles without a drastic reduction in fuel efficiency.

FULL STEAM AHEAD (S2):

Industry insight:

“....bunker fuel consumption might have fallen even though the fleet has grown dramatically in the last few years, which is not something you would have predicted, but high fuel costs and low freight costs have caused that to happen..”

(Industry analyst, interview)

After two decades of a stagnating global economy, political instability and tensions between trading regions, the 2030s onwards are characterised by greater co-operation and a determination to address global threats such as climate change. This co-operation has seen the rapid deployment of new technology initially developed for land-based power applications, such as small modular nuclear reactors, into the marine sector. This technological revolution has been driven in part by high fuel prices, but also as a means of facilitating the rapid transport of goods between nations, in contrast to the previous decades of slow steaming. By 2050, shipping energy demand has reduced by 40%.

UK energy context

The UK energy system uses a mix of fuels, with coal and nuclear delivering the majority of UK electricity and renewables having also increased significantly in share. Heating demand has been shifted onto electricity so gas is no longer used for heating in buildings, but instead meets the back-up requirements of an electricity grid with a high penetration of wind and marine energy. A diverse range of fuels

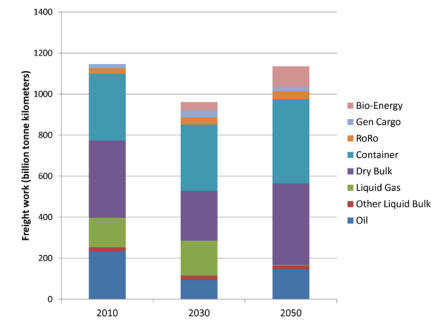


Figure 19: Levels of transport work associated with UK imports in 2010, 2030 and 2050 in the S2 scenario.

power transport; batteries, biomass-to liquids and hydrogen-fuelled vehicles all play a role. The UK imports coal and oil products, though at significantly reduced levels compared to 2006, while gas is no longer imported by sea. Imports of bio-derived fuels have risen considerably compared with 2006, with fuel imports reducing by 65% in terms of tonnes and by 45% in terms of tonne-km.

UK consumption

By 2050, a vibrant global economy supports balanced trade between all regions. Instability and uncertainty prior to 2030 caused a drop in container trade prior to 2030, and while trade has boomed post-2030, UK containerised imports in 2050 are the same as in 2010. A degree of repatriation of activities back to the UK, particularly an increase in indigenous food production over a four-decade timeframe, results in a reduction in agri-bulk imports. There is a diversification of energy suppliers, with increasing imports from North America and Canada, at the expense of Middle Eastern nations.

By 2050 overall tonne-km has reduced by 18% relative to 2006, (Figure 19) traded

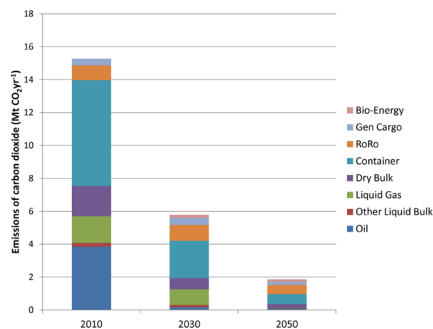


Figure 20: Levels of annual CO₂ emissions associated with UK imports in 2010, 2030 and 2050 in the S2 scenario.

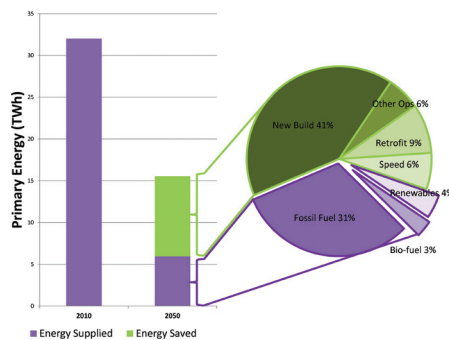


Figure 21: Baseline and scenario primary energy supplied by fuel and measures used to mitigate CO₂ emissions through energy demand-side savings in the S2 scenario.

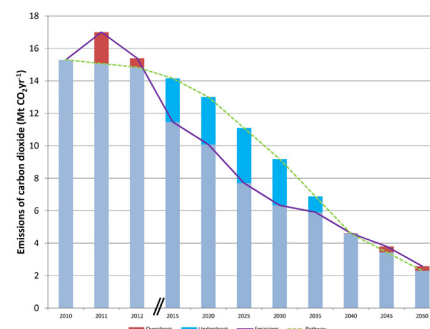


Figure 22: Annual and cumulative CO₂ emissions from the baseline year out to 2050 in the S2 scenario.

tonnage decreased by 38% and average distance traded decreased by 30%.

Shipping technology

After an initial slow uptake of measures to reduce the climate change impact of shipping, the sector has been able to benefit from the technology developments that have taken place in other sectors, particularly for onshore power and transport applications. The early involvement of far-sighted technology companies in research consortia, focusing on land power applications, allowed these technology firms to be early movers in marine applications in the late 2020s, as the shipping industry sought to maintain its competitiveness as the price of marine fuel continued to rise. The development of small modular reactors for marine applications has been facilitated by the deployment of the technology on land, including the introduction of regulation and the addressing of safety concerns.

Shipping and nuclear regulators have worked together to develop ownership and finance models, ship classification codes and the supporting manufacturing, repair and

decommissioning infrastructure that has allowed nuclear marine technology to move out of military niches. Designs are specified to ensure the integral safety of reactors, both from the perspective of safeguarding against accidents, but also to reduce the risk of piracy and the use of vessels as weapons by terrorists. Nuclear isn't the only new development, a diverse range of technologies are now used onboard ships depending on market and application, with even conventionally fuelled vessels benefiting from wind assistance where appropriate. Biofuels are not used extensively in the marine sector with the exception of roll-on/roll-off ferries (ro-ro) where biofuels supply 50% of the fuel combusted to meet EU carbon regulations.

Shipping operations

Nuclear vessels primarily move high value cargo on container ships and product tankers, with a significantly smaller number of dry bulkers moving less valuable cargo. Dedicated nuclear ports with advanced logistics systems ensure that cargoes are loaded and unloaded as swiftly as possible, to facilitate the rapid turnaround of vessels required by

the owners of these expensive vessels. Onward shipping of goods is via a network of smaller feeder vessels. As the global economy rises out of recession and operators look to maximise profits by increasing ship speed, nuclear-powered ships are able to meet this operational requirement without the carbon emissions of fossil-fuelled vessels. High ship speeds facilitate a continuation of just-in-time logistics. Ship size has increased by an average of 2% each year, resulting in ships that are two and a half times bigger compared to ships docking in 2006. The exception is the fleet of product tankers delivering liquid biofuels that have grown at 5% each year. Security is important for specific trade routes, and some routes (such as the Suez route) are avoided to reduce the risk of nuclear vessels falling into the wrong hands.

SMALL SHIPS SHORT TRIPS (S3):

Industry insight:

“.....there are some things happening which may act to reduce long haul trade, like shale gas in the US.....and more local production...”

(Trade body, interview)

Global shipping is impacted by carbon constraints and sulphur standards, strictly enforced at an EU level but influential globally. The IMO continues to incentivise incremental shifts towards low carbon technology, but has not significantly changed its position since the 2010s. The trend towards greater globalisation, supporting a global shift towards larger container vessels stalled in the 2010s as Western nations struggled to improve existing land-side and port-side infrastructure to accommodate the throughput from increasingly large container ships.

Thus, by 2050, container ships are no bigger than the average in 2010, with a prevalence for somewhat smaller ships where short-sea shipping dominates. This has opened up opportunities for renewable propulsive power, which is more effective in smaller vessels, as well as fuel cells and batteries that are viable over short distances.

UK energy context

Widespread deployment of low cost renewable electricity generating technologies, and innovations in energy storage technologies, have resulted in a strongly renewable electricity grid with

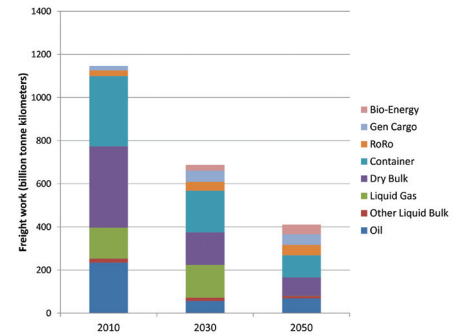


Figure 23: Levels of transport work associated with UK imports in 2010, 2030 and 2050 in the S3 scenario.

nuclear and coal- and gas-fuelled CCS plants providing baseload capacity. There have been high levels of demand reduction across the whole economy and the deployment of CCS to capture industrial emissions to further reduce the carbon impact of a steadily growing industrial sector. All domestic heating is electrified, and cars and buses powered either by batteries or hydrogen fuel cells. The UK has become more energy independent, with little in the way of gas, coal and biomass imports. In terms of energy trade, the tonnage and transport work associated with fossil fuel imports are reduced by 64% and by 83% respectively.

UK consumption

Although there has been a step-change in shipping technology for smaller ships, this is not mirrored globally. Thus for goods traded over longer distances in large container ships, consumption levels have fallen or are substituted by markets closer to the UK in order to keep within strict carbon limits. Trade of ores with South America and Australia declines as does containerised trade with Asia; trade with north Africa, Europe and Baltic states increases, particularly immediate materials carried on ro-ro. By 2050, the UK re-manufacturers

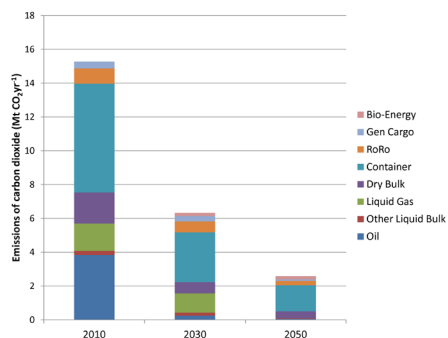


Figure 24: Levels of annual CO₂ emissions associated with UK imports in 2010, 2030 and 2050 in the S3 scenario.

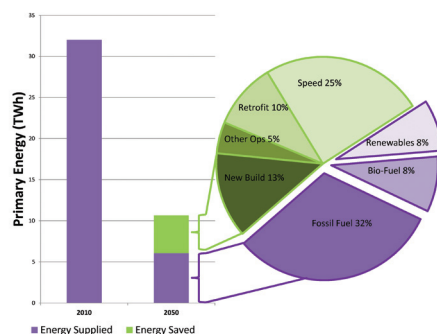


Figure 25: Baseline and scenario primary energy supplied by fuel and measures used to mitigate CO₂ emissions through energy demand-side savings in the S3 scenario.

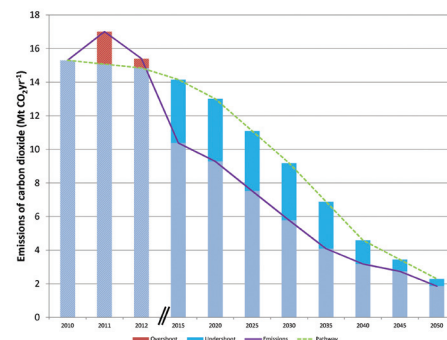


Figure 26: Annual and cumulative CO₂ emissions from the baseline year out to 2050 in the S3 scenario.

more for its own consumption (high up the waste hierarchy), with a higher reuse/more circular economy than in 2013, reductions in imports of final products, and growth in material servicing. Waste is treated as a valuable commodity. Overall tonne-km associated with UK imports have reduced by 70%. Bulk exports of foods for rising global demand, such as wheat, have risen while the imports of processed, packaged and manufactured goods remains EU-dominated. Relative to 2006, total tonne-kms have reduced by 70%, total tonnes by 27% and average distance traded by 61%.

Shipping technology

Although shipping technology has developed incrementally at a global scale, with implementation of improvements such as the widespread use of microbubbles to reduce drag, emergence of new hull designs etc, more radical change has been seen in UK and EU waters, with dual-fuel hybrid engines, Flettner rotors and solar panels (particularly for tankers) as well as kites and sails (particularly for dry bulk) commonplace. Strict efficiency standards at ports encourage only the most fuel efficient or low-carbon ships to dock. Retrofitting renewable technologies became widespread from 2015 onwards through a process

whereby routine inspections allowed for new equipment to be added incrementally. Many new ships used for short-sea shipping within EU waters are designed with integrated renewables. For long-haul journeys, larger ships primarily switch to more expensive biofuel as they approach EU waters, while ships for which this is not possible could pay to be pulled through national waters by renewably powered tugs. A very high proportion of ships by 2050 have integrated renewable technology and fuel cells and batteries are more common given a rise in short-sea shipping and subsequently shorter journey times. Rates of new deliveries and removal of old stock increased between 2010 and 2050 to deliver fleet-wide change.

Shipping operations:

Logistics has undergone a step-change in technology, with real-time information systems continually updating operators regarding timing for offloading. New systems facilitate inland ports and multi-modal shifts onto the advanced freight rail and inland waterway infrastructure around the UK. Through explicit efforts to develop regional port infrastructure nationwide, coupled with advanced logistics systems, the UK has cut port waiting times to a minimum, lowering

congestion and improving energy efficiency. The industry is more resilient than in the 2010s, when it relied on a small number of larger container ports. Supporting logistics infrastructure linking ports to rail/waterways, coupled with a reduction in imports of manufactured goods has reduced dramatically containerised freight on roads.

Slow steaming is common and enforced around the waters surrounding the UK and EU. This allows further benefits from renewables, the development of which has been encouraged by the inclusion of shipping within the EU's emissions trading scheme, which has imposed a high carbon price within local waters. The distributed network of smaller ports has resulted in a further skew towards more small ships serving the UK, as well as a revival in the ship building industry for renewable propulsion powered ships, with supporting industries manufacturing renewable technologies also buoyant.

Due to the prominence of short-sea shipping, average ship size declines from 2020 by 0.5% to 1% annually up to 2040. This, coupled with the UK's new port systems has reinvigorated the UK's pride in shipping.

CONCLUSIONS FROM HIGH SEAS:

Combining the insights from the three scenarios presented in the chapter *Decarbonisation scenarios*, with the analysis and implications drawn from the more focused research summarised in the first two chapters (*Context and Measuring ship emissions*) the following conclusions are drawn from this EPSRC-funded High Seas project.

Need for a step-change

Quantifying the challenge for shipping posed by climate change shows that avoiding a 2°C global temperature rise requires a radical rethink of the shipping system. The scale of this change is beyond anything yet countenanced in the current mitigation debate. Emissions from international shipping are expected to grow indefinitely in coming decades and be over 200%-300% higher by 2050. In contrast, if global shipping is to make its “fair and proportionate” contribution to avoiding 2°C, emissions need to be cut within the next 10 years and continue to decline to at least 80% of their 1990 baseline by 2050.

Intensity improvements need to outstrip growth

Both technology and operations offer huge scope for decarbonisation but must more than offset emissions that are driven by a rise in demand. By considering and quantifying emissions for the full shipping system, meaningful decarbonisation pathways can be articulated. In recent years, the significant growth in containerised transport has upheld the CO₂ intensity

of shipping. Coupled with a rise in demand, CO₂ emissions are travelling in the wrong direction.

Overturning these trends requires a full appreciation of the existing system, as well as the scope for change. Improving the CO₂ intensity of shipping will not be sufficient for the industry to make its “fair and proportionate” contribution to avoiding 2°C; trade routes, levels of demand, storage and timing, all have roles to play when seeking to avoid 2°C.

Couple sulphur & CO₂ targets

Measures implemented by the industry to tackle other pollutants, such as sulphur emissions, need to be integrated with the climate change agenda. Recent legislation to enforce a reduction in the sulphur content of fuel used for ship propulsion may incentivise the use of Liquefied Natural Gas (LNG). LNG is a fossil fuel, albeit with a lower CO₂ intensity than heavy fuel oil for direct combustion. If shipping is to decarbonise in line with 2°C, solutions that can tackle both sulphur content and CO₂ in unison are desirable, thereby avoiding lock-in or stranded assets. Wind-assist propulsion is one option that offers scope for addressing both.

Absence of data transparency is a barrier to change

Making data public and transparent is highly desirable to support change. For many aspects of emissions mitigation, publicly available information is of crucial importance – and often it is lacking. Currently, there is no mechanism in place for monitoring shipping emissions accurately over time. Improving fuel consumption accounting could support a range of stakeholders in their efforts to mitigate emissions. For example, it could assist policymakers when designing regulations, help businesses when trying to cut their fuel bills, or shippers in driving progress as they make their supply chains more energy efficient. While significant abatement potential is widely claimed by a range of new technologies, the continued absence of information on performance and cost will undermine their uptake.

AIS for monitoring emissions

The advent of satellite-based Advanced Information System (AIS) receivers offers an opportunity for improving the measurement accuracy of fuel consumption for ships in international waters. With their real-time, global

coverage of international shipping, High Seas research demonstrates that this new method can improve the accuracy compared with more conventional alternatives. Based on actual ship movements, the method is sensitive to emission reduction measures such as slow steaming, estimating emissions savings in near-real time. AIS data also has the scope to alleviate some of the existing issues over data transparency.

Improve ship representation in accounting tools

Shipping data within carbon accounting tools is inadequate for estimating supply chain CO₂. Different ship sizes and types have very different CO₂ intensities (emissions per tonne-km), but the limited choice within accounting tools does not currently capture the non-linear relationship between size and emissions. The smaller the ship, the higher its CO₂ intensity, yet for each ship type, once ships reach a particular size, this intensity changes very little. This relationship makes it difficult to ascertain the ‘typical’ CO₂ intensity for a particular ship type. Carbon accounting methods and tools can be improved by increasing the range of options available, using the established relationship between ship size and CO₂

intensity for each ship type. For example, as the UK has a prevalence of short-sea shipping, its ships tend to have a higher emission intensity, leading to an underestimate in the CO₂ associated with some supply chains.

Apportionment not necessary

Apportionment is regarded by many decision-makers as a prerequisite to enable sub-global policy. The absence of agreement over how to fairly and appropriately apportion emissions to nations has been a significant barrier to meaningful policy development. While apportionment may be useful if nations wish to account for their share of shipping emissions in national budgets and targets, nations are still in a position to take unilateral action to reduce their share of international shipping emissions if so desired, even without apportionment. The main problems with existing methods to apportion emissions are the quality, poor data availability and high cost of data and the use of top-down measures that can not monitor the success of any policy measure put in place. A chosen regime may also not fairly reflect a nation’s share of global emissions. The urgency with which shipping needs to start down a 2°C-type emission pathway

gives no leeway for further delay. Beginning a process of data gathering to improve the transparency of fuel consumption statistics is a first step towards improving the data issue taken by the EU, but other policy avenues can be pursued in parallel.

Port-states can influence emissions

Putting apportionment to one side and looking beyond technology, there is also the potential for influencing operations. Ships could be regulated or incentivised to be more efficient within national waters. Similarly, rethinking logistics to incorporate and encourage slow-steaming can offer a major opportunity for decarbonising the sector. Distance travelled and ship speed strongly influence shipping CO₂, and offer as much, if not more, scope for decarbonisation than ship mitigation technologies. Change within the shipping sector is therefore not only driven from within, but also by shifts in international supply chains and measures put in place by nations and multi-national organisations.

Tailor technologies to markets

Of the many possible low-carbon technologies available, their applicability and impact on delivering rapid and

urgent decarbonisation will depend on ship type and the service provided. Technology measures are at different stages of development. Wind propulsion for new ships, whether sail, hybrid or wind assist technologies, are at an advanced stage but need support to demonstrate the technology and for a commercial model for deployment to be defined. Others require more fundamental support before commercial application. Each ship type has to be considered separately, and there is stakeholder concern that different options could crowd each other out, if a strategic approach to innovation and development is not taken.

Hybrid wind-assist ships could be a retrofit option

Within the current set-up of the global shipping system, wind power can work as part of a hybrid propulsion system, with the potential to provide significant fuel savings, depending on ship type and size. In particular, dry and wet bulk carriers with free deck space are natural candidates for harnessing the wind's energy, and could feasibly be retro-fitted with wind-assist technologies in the short-to medium-term, offering a key opportunity for supporting decarbonisation in shipping.

Changing energy systems to significantly impact shipping activity

The climate change agenda beyond the shipping sector will influence the future of trade. Land-based energy system decarbonisation is likely to drive a major change in shipping. The demand for transporting fossil fuels – coal, oil and gas – will shift significantly if nations with high levels of fossil fuel combustion are to achieve strict CO₂ targets. Specific change will depend on how decarbonisation is realised. Coal trade in the future will rely on the successful deployment of carbon capture and storage.

Oil trade is set to fall significantly while new markets may emerge for biomass and biofuels. Implications for the CO₂ associated with the shipping of fossil fuels are profound. Using the UK as an example, CO₂ emissions arising from the import of fossil fuel by ship could be cut by up to 80%, if the UK adopts a low energy demand/high renewables (or nuclear) future.

It's about more than just ships

Delivering a step-change towards decarbonisation goes beyond the ships that sail the high seas. Shipping facilitates trade between the producer and

consumer: the core drivers of shipping activity. Decarbonising the shipping sector to a level commensurate with 2°C will likely involve radical change not only to technologies and operations, but to consumption and production as well.

Look beyond shipping to decarbonise the sector

Decarbonising shipping can benefit from developments elsewhere. In the energy system, low carbon efforts in other sectors (e.g. batteries or modular nuclear reactors), particularly in land-based transport, could offer spill-over benefits to shipping. Similarly, shipping will likely benefit from the deployment of infrastructure designed for other sectors, particularly the provision of energy, transport and logistics networks.

As shipping facilitates the operation of other sectors, it needs to be aware of how those sectors are themselves responding to the decarbonisation agenda.

Ships of the future could look and operate very differently

If the sector is to significantly decarbonise over the coming decades then incremental change is not the solution. Some vessel types and services will need to change fundamentally. In a low CO₂ future, dependency on heavy

fuel oil will diminish and diverse forms of propulsion must take over.

With the advent of composite materials, vessel design will need to overcome the challenges surrounding structural integrity when loading and unloading goods at ports. But change won't be limited to ship design and propulsion. If the workforce is unable to adapt to the operation and functionality of new technologies there could be a deficit of trained staff to operate a decarbonised shipping sector.

For decarbonisation to be realised, the workforce (both on the ship and in ports) must be considered from the outset. Furthermore, ship builders need to ensure their workforce is equipped to respond to this significant change.

There are numerous feasible pathways to decarbonisation. Unlike some sectors (e.g. aviation), opportunities for decarbonising shipping are manifold and stretch across technology, operations and demand.

Nevertheless, across all decarbonisation pathways articulated, slow-steaming is part of the mix. By harnessing the opportunities available both in the short-term and across technologies, operations and demand for trade, the shipping sector has the potential to be a leading sector in the decarbonisation challenge.

POLICY INSIGHTS:

Industry insight:

“In return for meeting specific low levels of greenhouse gases including carbon dioxide, sulphur oxide and nitrogen oxide, amongst other criteria, the most efficient vessels entering these harbours will receive a discount on port dues, to help encourage the use of clean ships”.

Extract from Virgin.com, Easy as A to G: green ships on the horizon, 2014.

The policy-relevant nature of the research undertaken within the High Seas project has delivered the following policy insights...

Urgency trumps uncertainty

Uncertainty is cited frequently as a reason for refraining from mitigation measures that may have damaging short-term financial implications. However, continued delays in delivering real mitigation will only serve to increase the threat posed by the climate challenges that have framed the High Seas project research. For example, uncertainty and lack of methodological standardisation associated with estimating UK shipping emissions have contributed to the exclusion of the sector from existing UK emission targets.

While accepting that uncertainty exists, there are numerous examples of published methodologies that could form the basis of a bottom-up method for quantifying ‘UK shipping emissions’. Bottom-up methods can illustrate trends in the demand for shipping in ways that bunker fuels or trade proxies cannot. Bottom-up data can identify the direction of travel of carbon intensity of

shipping, and so could play an important role in monitoring change.

Targeting the few?

In the absence of global policies for controlling emissions, ports are important channels through which shipping emissions can be influenced. Taking the example of the UK, just 10 ports dominate imports and are responsible for over 80% of the port-related CO₂ emissions. This offers scope for a focus of mitigation policy that is likely to involve close communication and cooperation with relevant terminal operators and port authorities to determine appropriate levers for change. In particular, mechanisms to prevent ships shifting their business to other ports would need to be introduced.

Scope for differentiating between markets and vessels

If the decarbonisation agenda is to deliver meaningful cuts in emissions, the range of technologies and operational practices across the shipping sector is likely to expand. Consequently, assessing the scope for targeted policies that can differentiate between markets and vessel types is desirable. The importance of market- and

vessel-specific roadmaps emerges quickly when discussing pathways to change with shipping stakeholders. With its complex system of markets, services and vessel types, solutions to decarbonisation are necessarily varied.

A decarbonised fleet will need to exploit a combination of renewable propulsion, alternative fuels and/or CO₂ removal technologies, in addition to more conventional technologies and changes to operations and practices. Not all solutions will suit all service types. Policy instruments to support decarbonisation need to be able to capture diversity and avoid locking-out potentially important niche opportunities. Existing global governance arrangements offer generic high-level incentives. Complementary bottom-up specific technology roadmaps and implementation strategies could help accelerate a low-carbon transition.

Debating apportionment delays progress towards mitigation

Disagreement over how and if shipping emissions should be apportioned geographically has hampered policymaking at the sub-global scale. Limitations, such as high up-front costs and the absence of

transparent fuel consumption and freight data, present barriers to implementing a meaningful apportionment regime within which the success of mitigation measures could be monitored. In the UK, this has led to the continued formal exclusion of UK shipping CO₂ from national budgets and targets, despite nations being able to directly influence their shipping emissions.

In several respects the shipping system is more directly influenced at a national rather than global level. For example sub-global policies can influence demand (source and destination of freight imported and exported) and operations in ports and national waters. Policymakers serious about climate change would do well to consider the influence that national jurisdiction has over several important aspects of the shipping system, the implications of measures that could be employed to control emissions, and how success could then be monitored.

Nations could build on new EU proposals

Recent proposals have been tabled by the EU commission requiring vessel owners to monitor, verify and report on the emissions and fuel efficiency

of ships calling at EU ports. Assuming approval by the European Parliament, the European Commission anticipates that the obligations associated with this scheme would apply from January 1, 2018. A quantitative understanding of greenhouse gas emissions both from individual ships and aggregate fleets is desirable given the relatively opaque nature of such data at present. Through implementation of this scheme, emissions of ships calling at national ports will be reported to both the Commission and the flag state.

In the intervening period before its implementation, it would be desirable for national governments to seek guidance on how this information may be used to incentivise or regulate for lower emissions.

Furthermore, nations could follow in France's footsteps and accelerate the timetable for delivering this policy, in line with the EU's ultimate expectations. This offers the potential advantage that, sooner rather than later, shippers and ship operators can cut their fuel costs and avoid more stringent mitigation measures that may be needed if CO₂ emissions are not cut in the short-term as dictated by carbon budgets.

Unilateral opportunities

Nations are not limited to the pace of change set by the EU or IMO. Through international supply chains and with recent economic instability and volatile fuel prices, shipping is already experiencing an increase in competition and is under pressure to improve efficiency (and hence reduce relative emissions). This period of change could offer new opportunities to adopt mitigation measures that could reduce fuel costs. One idea emerging from one of the High Seas project stakeholder workshops was for governments to purchase idle ships, lease them to shipping companies and test new configurations for reducing emissions, all with little risk to commercial fleet.

Step-change decisions require support for development and deployment

Although there is an inherent conservatism within the shipping sector, the scale of the climate change challenge highlights the need for non-incremental change. Many analyses of the shipping sector show significant carbon abatement potential, but highlight an absence of commercial development and

deployment. Although there are potential markets for new low-carbon shipping technologies, some of these technologies require commercial support, while others still need more fundamental research. Moving ahead first brings significant risks for companies. Government funding for research, development, and demonstration, and a more long-term economic assessment of cost savings offer opportunities to support the sector and spur rapid change.

There are co-benefits to tackling CO₂ and local pollutants in unison

The sector is currently taking a short-term and piecemeal approach to addressing environmental pollution. By implementing Emission Control Areas to reduce sulphur emissions, incentives to develop LNG infrastructure are emerging. Yet LNG only offers short-term and incremental benefits in terms of CO₂ emissions reductions, and is not commensurate with the reductions necessary to avoid exceeding the 2°C threshold. To address cumulative CO₂ emissions and localised SO_x emissions in parallel, more radical step-change forms of propulsion are called for. For example,

wind technologies, bio-derived fuels and fuel cells can all deliver both low SO_x and CO₂. Drawing attention to this issue within the debate can help to avoid the risk of lock-in to new infrastructure and prevent the lock-out and stranded assets of future lower carbon technologies.

Mitigation efforts can not wait

Greenhouse gas emissions accumulate over time. The more effective measures that can be implemented in the short-term, the easier it will be to avoid a temperature rise of 2°C in future. Challenges faced at IMO meetings in agreeing policies commensurate with 2°C will likely continue to mirror similar impasses at the global UN climate negotiations. As measures to tackle emissions continue to emerge slowly through IMO meetings, decarbonisation mechanisms must be established more urgently. Port-states could, for example, influence emissions and could make assessments of where and how this influence could be harnessed for reducing CO₂ emissions. Multi-national organisations engaged in supply chains also have a role in driving down CO₂ emissions within the freight transport network. Such action does not need to

wait for agreement on how to apportion responsibility for shipping emissions to nations. Instead, nations should look for new direct avenues for change, targeting ships calling in national ports or operating in national waters.

Ultimately...

There is a myriad of opportunities for enlightened governments and forward thinking companies and organisations to begin reconciling levels of shipping emissions with the 2°C mitigation agenda. Whether or not they choose to embrace such an agenda, the industry inevitably faces a future of radical change. The choice is between rapid and planned 2°C mitigation or piecemeal and unplanned adaptation to rapidly changing events and conditions.

From High Seas to Shipping in Changing Climates

As the High Seas project approached its conclusion, a new consortium of researchers under the banner of Shipping in Changing Climates (SCC) embarked from November 2013 on new research funded by the EPSRC's Energy Programme.

The consortium is an amalgamation of two teams of researchers previously funded by the EPSRC within their Low Carbon Shipping remit. The project is led by UCL, with researchers from Manchester, Newcastle, Southampton and Strathclyde involved.

There are three themes, addressing the following areas:

1. Ship as a system – investigating real-world opportunities for mitigation technologies
2. Demand side drivers – exploring how trade could be influenced by climate mitigation and adaptation

3. Interactions between demand and supply – integrating insights

The University of Manchester team, based within the Tyndall Centre, leads Theme 2 and is heavily involved in Theme 3, further developing its systems perspective and scenario approach.

A particularly exciting collaboration within SCC is the involvement of an additional Tyndall Centre partner at the University of Southampton, offering insights around future climate impacts on sea level rises, storm events and changing weather patterns and exploring the resilience of the current shipping system to disruption.

ACKNOWLEDGEMENTS:

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Next, we would like to thank the Tyndall Centre for Climate Change Research for helping to raise the profile of the work, and encouraging researchers to take their findings outside academia to wider policy and stakeholder audiences. The support of the staff at the Tyndall headquarters in the University of East Anglia adds huge value to how this research is carried out.

The School of Civil Aerospace and Mechanical Engineering (MACE) within the University of Manchester is host to Tyndall Manchester, the research group within which the High Seas team resides. MACE is unusual in its active support for interdisciplinary research, but in doing so, has allowed physical, environmental and social scientists, as well as engineers, to work closely for the benefit of the High Seas project and the low-carbon shipping endeavour, and for this we are very grateful.

During the High Seas project, engagement with stakeholders played a key role. In particular, the help and guidance of the advisory board and the co-operation of a range of interviewees strengthened the direction and findings of the research. We'd like to thank all those who participated in interviews, workshops and especially the advisory board for providing one-to-one guidance.

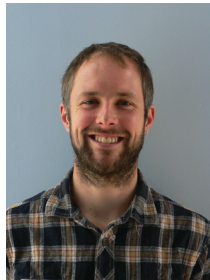
Finally, we would like to thank our immediate colleagues within Tyndall Manchester, who help bind a wide range of research questions within a climate change and energy-focused context, which helps to keep all of our projects grounded and rooted in robust methodologies.

Thanks to all from the High Seas team:

Dr Alice Bows-Larkin (principal investigator); Professors Kevin Anderson and Peter Stansby, Drs Paul Gilbert, Sarah Mander and Antonio Filippone (co-investigators); Dr Conor Walsh (core researcher); Dr Michael Traut (researcher); and Ms Amrita Sidhu (project administrator).



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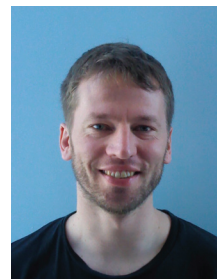
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BIBLIOGRAPHY OF HIGH SEAS OUTPUTS:

WP1: Emissions accounting and apportionment

Journal articles and book chapters:

1.1 Gilbert & Bows, 2012, Exploring the scope for complimentary sub-global policy to mitigate CO₂ from shipping, *Energy Policy*, 50, 613-622, dx.doi.org/10.1016/j.enpol.2012.08.002.

1.2 Bows, Smith, 2012, The (low carbon) shipping forecast: opportunities on the high seas, *Carbon Management*, 3, 6, 525-528. doi:10.4155/cmt.12.68.

1.3 Walsh, Bows, Size matters: exploring the importance of vessel characteristics to inform estimates of shipping emissions, 2012, *Applied Energy*, 98, 128-137, doi:10.1016/j.bbr.2011.03.031.

1.4 Gilbert, Bows, All at sea: Nations' responsibility to reduce shipping emissions, 2012, *Memoires of the Manchester Literary & Philosophical Society*, v.149.

Conference papers:

1.1 Bows, Gilbert & Anderson, Accounting for and influencing shipping emissions at a sub-global level, presented at International Conference on Technologies, Operations, Logistics and Modelling for Low Carbon Shipping, Glasgow, June 2011.

1.2 Bows & Gilbert, Emission apportionment and exploring alternative national-based policy measures aimed to reduce emissions from the shipping sector, presented at European Transport Conference, Glasgow, June 2011.

1.3 Walsh, Bows, Mander, Gilbert & Traut, A new method for estimating national scale CO₂ from shipping - preliminary results from a UK study, presented at Low Carbon Shipping Conference, Newcastle, Sept 2012.

1.4 Traut, Bows, Gilbert, Mander, Walsh & Wood, *Monitoring shipping emissions via AIS data? Certainly*, presented at Low Carbon Shipping Conference, London, Sept 2013.

1.5 Gilbert, Should have gone to Specsavers- Co-benefits of addressing sulphur and carbon emissions, presented at Low Carbon Shipping Conference, London, Sept 2013.

Stakeholder workshop and policy report:

1.1 Stakeholder workshop on emission apportionment in shipping held at Tyndall Centre, University of Manchester, November 2010. Invited industry stakeholders and academics to participate in a workshop discussing how ship emissions can be apportioned and issues of equity. Bows, Gilbert, Starkey, *Shipping and Climate*

Change: Scope for Unilateral Action, Tyndall Policy Report.

PhD Thesis:

Michael Traut: PhD thesis awarded in February 2014. Quantifying CO₂ emissions from shipping and the mitigation potential of wind power technology.

WP2: Step-change technological and operational systems

Journal articles:

2.1 Gilbert, From reductionism to systems thinking: how the shipping sector can address sulphur regulation and tackle climate change, 2013, *Marine Policy*, 43, 376-378, http://dx.doi.org/10.1016/j.marpol.2013.07.009.

2.2 Traut, Gilbert, Walsh, Bows, Filippone, Stansby & Wood, Propulsive power contribution of a kite and a Flettner rotor on selected shipping routes, 2013, *Applied Energy*, 113, 362-372, dx.doi.org/10.1016/j.apenergy.2013.07.026

2.3 Mander, Walsh & Bows, Batten down the hatches, climate change approaching: wiping the slate clean a low carbon future for shipping, forthcoming.

2.4 Walsh & Bows, Driving carbon management within the shipping sector, forthcoming.

2.5 Gilbert, Bows, Mander, Walsh, Technologies for the High Seas: meeting the climate challenge, forthcoming.

Conference papers:

2.1 Traut, Quantifying Shipping Emissions, presented at The 3rd international conference on Transport, Atmosphere and Climate (TAC), Prien Am Chiemsee, Germany, June 2012.

2.2 Traut, Bows, Gilbert, Mander, Stansby, Walsh, Wood, Low C for the high seas: flettner rotor power contribution on a route from Brazil to the UK, presented at Low Carbon Shipping Conference, Newcastle, Sept 2012.

2.3 Gilbert, Walsh, Mander, Bows, Traut, Mutiny on the high seas: exploring step-change technological mitigation in the shipping sector, presented at Low Carbon Shipping Conference, Newcastle, Sept 2012.

2.4 Traut, Out of thin air: the potential wind power contribution to international shipping, presented at 4th Marine Technology Postgraduate Conference, London, June 2013.

2.5 Mander, Bows-Larkin, Walsh, Gilbert, Anderson, & Traut, Plotting a course to 2050

and beyond: how to meet energy demand within the shipping sector, Royal Geographical Society Conference, London, Aug 2013.

2.6 Mander, Walsh & Bows-Larkin, Implications of low carbon shipping scenarios for shipping industry actors, presented at Low Carbon Shipping Conference, London, Sept 2013.

2.7 Bows-Larkin et al., Shipping visions on the horizon, Tyndall Centre Radical Emissions Reduction Conference, London, Dec 2013.

Stakeholder workshop and policy report:

2.1 Stakeholder workshop on step-change technology in shipping held at the UK Chamber of Shipping, January 2013. Invited industry stakeholders and academics to participate in a workshop discussing the potential for step-change technologies in shipping and devising roadmaps.

2.2 Bows, Bows, Mander, A new ship on the horizon? Using technology to plot a course to a lower carbon future for international shipping, 2013. Based on the discussions at a workshop held at the UK Chamber of Shipping in January 2013.

Integrated System Analysis & Assessment (IA)

Journal articles:

IA.1 Anderson & Bows, Executing a Scharnow turn: reconciling shipping emissions with international commitments on climate change, 2012, Carbon Management, 3, 6, 615-628. doi:10.4155/cmt.12.63.

IA.2 Mander, Walsh, Gilbert, Traut, Bows, Decarbonising the UK energy system and the implications for UK shipping, 2012, Carbon Management, 3, 6, 601-614. doi:10.4155/cmt.12.67

IA.3 Bows, Smith, Special Mini Focus issue of Carbon Management on shipping, Carbon Management, 3, doi:10.4155/cmt.12

Conference papers:

IA.1. Bows, Anderson and Gilbert, Quantifying the climate challenge for shipping: from incremental to step change mitigation, presentation at International Conference on Technologies, Operations, Logistics and Modelling, Glasgow, June 2011.

IA.2 Bows, Gilbert, Traut, Walsh, Wood, Towards Very Low Carbon Shipping, presentation at International Conference on Technologies, Operations, Logistics and Modelling, Glasgow, June 2011.

IA.3 Walsh, Incorporating Life Cycle elements into the energy efficiency design index, presentation at Low Carbon Shipping Conference, Glasgow, June 2011.

IA.4 Walsh and Bows, The Importance of Product Distinction in Lifecycle and Product Chain Analyses, presentation at Irish Transport Research Network, Aug 2011.

IA.5 Walsh and Bows, Assessing emission baselines for overseas freight arriving in the UK, presentation at Royal Geographical Society Annual Conference, London, Sept 2011.

IA.6 Walsh, C. and Bows, A., Implications of recent trade patterns on future UK shipping emissions. Britain and the Sea. Plymouth, Sept 2012.

IA.7 Mander, Walsh, Gilbert, Traut, Bows, A systems perspective on decarbonising the UK energy system - impacts on shipping CO2 emissions, presentation at Low Carbon Shipping Conference, Newcastle, Sept 2012.

IA.8 Bows, Executing a Scharnow turn: reconciling shipping emissions with international commitments on climate change, 2012, Invited seminar to CICERO in Oslo, Norway Dec 2012.

IA.9 Traut, Message from the masthead - elements of a transition in the shipping sector, presentation at Tyndall PhD conference - Climate Transitions: Connecting People, Planet and Place, Cardiff, April 2013.

IA.10 Bows, Pathways to low-carbon international transport: a comparison of shipping and aviation, Low Carbon Shipping Conference, Sept 2013, London.

IA.11 Anderson and Bows, Avoiding dangerous climate change: why shipping must deliver a 'Scharnow turn' in its rising emissions, Low Carbon Shipping Conference, Sept 2013, London.

IA.12 Walsh, Mander and Bows, A comparison of alternative decarbonisation scenarios for UK Shipping, Low Carbon Shipping Conference, Sept 2013, London.

IA.13 Bows, The importance of being Urgent: aviation, shipping and the mitigation debate, European Transport Conference, Frankfurt, Germany, Oct 2013.

Technical report:

IA.1 Bows-Larkin, Anderson, Gilbert, Mander, Traut, Walsh Stansby, Fillipone, High Seas Final Report, Tyndall Centre for Climate Change Research, School of Mechanical Aerospace and Civil Engineering, The University of Manchester.

Other engagement, awards and prizes:

O.1 Gilbert, What about plan B?, podcast recorded at Tyndall Centre conference, Southampton, 2010.

O.2 Knowledge Transfer EPSRC grant- Accounting on the High Seas, £10k, 2010.

O.3 Promotion to Lectureship for Gilbert, originally a named RA on the High Seas project, 2011.

O.4 Bows, Environmental Cost of Transport, paper delivered to an industry shipping audience, Short-Sea Shipping Conference, Dublin, May 2012.

O.5 Walsh, Shipping emissions and Climate change: SOS or Full Steam ahead? Talk presented at a Sustainable Future for Manchester Event, Manchester, 2012.

O.6 New collaboration - Shipping in Changing Climates- new funded proposal to the EPSRC, 2013. £4.4 million FEC.

O.7 Walsh, Public engagement talk for Cafe Scientifique, Manchester, 2013. O.8 Traut, Michael, EPSRC Doctoral Prize Award, 2013.

O.9 Bows, Shaping the future in the face of climate change: the role of shipping, National Ethical Investment Week Seminar, 2013.

Policy engagement:

P.1 Gilbert, Expert for panel on transport and environment/clean shipping coalition seminar - regulatory options for controlling shipping emissions in the EU, Brussels, 2010.

P.2 Bows, Gilbert, Anderson, Mander, Starkey, Walsh, Traut, Acknowledgement by UK Committee on Climate Change for contribution to their report on UK shipping emissions, 2011.

P.3 Bows, Walsh, Shipping emissions accounting: challenges and opportunities. 2011, Tyndall/SCI briefing note.

P.4 Dawkins, Wood, Bows, Roeder, Gilbert, Written submission to energy and climate change committee inquiry into consumption based emissions reporting, 2011.

P.5 Gilbert, Walsh, Written submission to the European Commission Consultation on including maritime transport emissions in the EU's greenhouse gas reduction commitment, 2012.

P.6 Bows, Traut, Anderson, Gilbert, Walsh, Aviation and shipping privileged- again? UK delays decision to act on emissions, 2012, Tyndall Centre Briefing Note number 47.

P.7 Traut, Making CO2 emissions visible - linking global positioning data to emissions, 2012,

Invited presentation at a stakeholder/policy event organised by Transport and Environment, Brussels, 2012.

P.8 Gilbert, Bows, Mander, Traut, Walsh, Written submission to Maritime Strategy Inquiry, 2013.

P.9 Gilbert, Mander, Oral evidence to the Maritime Strategy Inquiry, 2013.

Computer model/software:

C.1 Traut, Computer model to quantify shipping emissions from AIS satellite data, 2012.

C.2 Traut, Tool to assess the CO2 mitigation potential for wind-powered shipping, 2012.

C.3 Walsh, Excel based tool to quantify the lifecycle CO2 emissions associated with shipping.

C.4 Walsh, Excel based tool to generate future emission scenarios for UK Shipping.



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