What is the future demand for shipping?

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1. Introduction

Within the context of Low Carbon Shipping, a key driver for future emissions from the sector must be the demand for shipping – both local and global. Predictions of shipping flows underpin forecasts of their likely environmental impacts, and policy debates to develop technologies and operational strategies to manage and regulate emissions. To evaluate policy strategies designed to deliver low carbon shipping requires realistic forecasts of future movements of different types of ships. In the Low Carbon Shipping: A Systems Approach project, WP1 is modelling global flows and drilling into the detail of particular flows and commodities as required; WP4 is studying UK wet and dry bulk flows and links between bunker prices and spot freight rates; and WP3 is concentrating on box trades, links with inland and port logistics and the detail of UK flows. Initially WP1 collated global transport demand for different ship types (dry and wet bulk, general cargo, and containers) and examined historical relationships with GDP (Gross Domestic Product), using GDP forecasts to project out to 2050, but this approach did not define the trade flows required for more disaggregated model analysis.

This paper focuses on the socio-economic drivers, and particularly those with a Low Carbon future perspective, primarily of the wet and dry bulk trades. Further publications by the authors will address more completely other major trades, in particular containerised goods, and drivers related to supply chain optimisation, port configuration and choice, technological development, ship operations, and policy and regulation. Predictions of shipping flows underpin forecasts of their likely environmental impacts, and policy debates to develop technologies and operational strategies to manage and regulate emissions. This paper summarises analyses of patterns of wet and dry bulk flows involving the UK, and forecast flows to 2050. Drivers of future shipping flows include economic growth, market changes, haul lengths and energy demands identified in trade press articles which fashioned a Delphi instrument to build consensus regarding future market trends. Two panels of experts (wet bulk and dry bulk with long term industrial commitments were recruited to study expert perceptions of likely trends and flows. Market volatility, legislative uncertainty and behavioural change contribute to conservative estimates but invite spatial analysis of flows forecasts and interlinking of flows and their impacts within a holistic systems model. This paper looks at the socio-economic, political, institutional, and market-based drivers, and particularly considers those with a Low Carbon future perspective or impact, and primarily related to the wet and dry bulk trades. Further publications by the authors will address more completely other major trades, in particular containerised goods, and drivers related to supply chain optimisation, port configuration and choice, technological development, ship operations, and policy and regulation.

2. Data Sources & Assumptions

NEA (a transport research organisation and member of the Panteia group) data for inter-region trade flows and port volume flows was aggregated to quantify the tonnes traded by sea and tonne-km of maritime transport demand for a range of commodities (disaggregated using NSTR [EUROSTAT Standard Goods Classification for Transport] codes) for all country pairs. This data was then aggregated into regional and commodity group transport demands to generate a 2005 base year database of historical data. Using NEA's agent-based model, forecasts were generated to 2050, along with data describing UK imports and exports for a range of commodities. Testing of NEA data and corroboration of their forecasts with other sources is ongoing. When the model has been tested UK-centric flows will be extracted. To supplement these forecasts of global and UK transport demand, CCC (The Committee on Climate Change) have presented an aggregate transport demand forecast for the UK for scenarios which include high mitigation, consistent with 80% UK emission reduction by 2050. WP1 is preparing NEA data for the UK which may offer a comparison. These forecasts will be combined with work which has estimated the impact of bunker prices on freight rates, tests for consistency between an exogenous transport demand forecast and a forecast generated by endogenising transport demand, and testing of how demand forecasts react to different fuel/carbon price scenarios for selected commodities and flows. This will require an estimate of demand/freight rate elasticity, to be combined with work on bunker price/freight rate elasticity. Future publications will link these higher level analyses with detailed work in WP3 (Logistics and Ports).

Research in WP4 (Economics) of the Low Carbon Shipping Project has concentrated on the most polluting types of ship, measured by total volume of fleet emissions, namely wet and dry bulk (Ref: IMO 2nd GHG Study, 2009 for more information). The availability and comparability of secondary maritime statistics is problematic, with global and national data emanating from both official and private sources (e.g. UNECE, UN, BP, EIA, DfT, Dukes, MDS Transmodal Ltd). Changing trade classifications may frustrate serial commodity comparisons, where for example official UK oil products flow data incorporated liquefied gas until 2000. Varying aggregated spatial units are a perennial problem complicated by volatile commodity sourcing policies and political changes which redefine trading boundaries including perhaps China and/or Hong Kong, and individual EU accessionary states. Northern Ireland is the principal exclusion when comparing data collations for Great Britain with the UK. Further, port commodity arrivals data which does not identify transhipment flows or an ultimate source or destination, hampers maritime flow reporting and denies end-to-end supply chain mapping.

Published UK maritime commodity flow data is limited and secondary statistics are often incomparable (Glen and Marlow, 2009). Subject to inevitable measurement errors (Dinwoodie and Bhatia, 2004), global flow data emanate from official (e.g. EC, 2008) and private sources including BP's Statistical Review and Energy Outlook (www.bp.com), Exxon Mobil's Outlook for Energy (www.exxonmobil.com) and Shell's Energy Scenarios (www.shell.com), as do national data (e.g. EIA, 2011; DfT, 2009; Dukes, 2009; MDS Transmodal Limited, 2007). In addition aggregate trade flow data is available but changing classifications may frustrate serial commodity comparisons, where for example official UK oil products flow data incorporated liquefied gas until 2000 (DfT, 2009). Aggregations of spatial units vary, commodity sourcing policies are volatile and political changes redefine trading boundaries perhaps as new states accede to the EUs. Data collated for Great Britain (GB; MDS Transmodal Limited, 2007) differs from the UK (e.g. DECC, 2009) principally excluding Northern Ireland which receives one-fifth of UK arriving tanker dwt (Dft, 2009, table 3.6). Port commodity arrivals data which typically fails to identify transhipment flows or an ultimate source or destination further hampers flow reporting and thwarts end-to-end supply chains mapping.

Demand for tankers originating in, destined for, or visiting UK ports varies with the UK supply and demand for crude oil and products. UK crude oil imports peaked in 1973, before declining as North Sea production transformed the UK into a net exporter. By 2010, the UK was again a net importer. Eventually UK flows to Europe will decline as North Sea production diminishes. As UK refineries age, UK crude imports will reduce and as new long range products tankers transport supplies from modern refineries in producing countries, UK products imports, LNG and biofuels will rise. The distribution of ports which handle major oil products reveals outflows dependant on the location of refining capacity. Reducing numbers of smaller regional distribution centres exist as policy changes to tax oil ex-refinery rather than ex-distribution centre coupled with scale economies which favour larger coastal tanker fleets closed many smaller port facilities and increased mean road haul lengths.

3. Energy Scenarios

The impact of global energy scenarios on the future demand for shipping is an important element. A large percentage of wet and dry bulk cargoes are to meet energy demand, and all shipping energy input, currently met almost exclusively by fossil fuel sources. Three potential energy demand scenarios have been considered; the first two can be characterised as 'do nothing' and 'slow & steady', they encompass those considered by oil majors, such as in BP's Statistical Review and Energy Outlook 2030 (www.bp.com), Exxon Mobil's 2012: The Outlook for Energy 2040 (www.exxonmobil.com) and Shell's Energy Scenarios to 2050 (www.shell.com), and also the 'very low carbon future' scenario as put forward by the Tyndall Centre as the minimum required to meet 2050 global warming targets set out in the Kyoto agreement (Saltmarsh, 2010). The energy scenarios examined by these 3 major oil producers address the question of where can we go from today, how far and how fast? The focus of work by the Tyndall Centre for Climate Change Research (Bows & Gilbert, 2012) however, considers where we need to get to, and therefore how that could be achieved, and what actions are therefore necessary. UNCTAD's (2009) Expert Meeting on Maritime Transport and the Climate Change Challenge highlighted that timeframe was a real concern:

> "Current trends in terms of energy consumption and carbon path suggested that if no action were taken within the following two years … the world would forever miss the opportunity to stabilise emissions at "manageable" levels [and] a global and concerted solution was urgently required. … [N]egotiations towards regulation of CO2 emissions from international shipping should be pursued with all due speed."

The difference in approach is striking: one says "this is where we are and what we know, what level of change is acceptable to industry, and particularly to society as a whole?" Against this is the Tyndall Centre Approach, typified by projects such as that described in Anderson et al (2006): *Decarbonising Modern Societies: Integrated Scenarios, Process and Workshops*, and *Behavioural Response and Lifestyle Change in Moving to Low Carbon Transport Futures* (Pridmore et al, 2003). Indicative longer term forecast techniques span statistical time series and growth models, scenarios, and Delphi methods. Twenty-year quantitative meta-models typically highlight baseline, high growth and low growth scenarios, perhaps with a range of oil price assumptions, focused on interdependencies between exogenous input and resulting output, expressed primarily as elasticities. To construct alternative plausible futures, scenarios may draw on objective, quantitative forecasts or qualitative behavioural foresight amongst experts.

Wet Bulk

Delphi survey methodology was used to predict likely trends in oil tanker flows to 2050. Discussion of the results highlights volatility, and legislative and behavioural uncertainties, this explains the conservative predictions of the experts, and conversely supports the use of holistic systems research when addressing the problem (Dinwoodie et al, 2012). Table 1 shows selected drivers which may underpin future demand for shipping wet bulk.

Table 1 Selected drivers which may underpin future demand for shipping wet bulk

	Socio-economic effects
SE1	How responsive is worldwide demand for maritime transportation to shipping cost changes?
SE2	How significant are transport costs per unit weight for imports into different regions?
SE3	Spatially differential rates of population growth will proportionately redistribute oil demand.
SE4	Spatially differential rates of industrial output growth will proportionately redistribute oil demand.
SE5	Reducing oil or energy intensities (oil or energy used per unit output) in industrial nations will persist
Ships and shipping markets	
S1	Will tankers be re-deployed as water carriers as drought risks increase with global warming?
S2	Will world oil tanker tonnage continue to remain constant whilst dry bulk tonnage trebles?
S3	Will large tankers be used for carbon storage and smaller ones transport liquid CO_2 to storage sites?
S4	Will regionalisation of oil supplies shorten supply chains and reduce demand for shipping? Will pipelines from Russia oilfields supply NE Asia and Canadian tar sands/ Brazilian oilfields the US?
S5	Will technical optimisation of ships reduce CO_2 emissions by 20% with scope for retrofitting?
Political and institutional changes	
P1	Will damage to BP's reputation and exposure to unlimited liability post *Deepwater Horizon* oil spills deter offshore exploitation in the US and stimulate re-sourcing of supplies?
P2	Will new trading relationships in the Russian Arctic reconfigure oil supply chains?
P3	Will droughts induced by global warming create more failed states causing piracy to proliferate; sub-optimal ship routing to avoid trouble spots; longer maritime hauls, and tie up more tonnage?
P4	Will scope to cut EU GHG emissions by up to 90% by 2050 create pressure to reduce emissions?

Oil tanker movements vary with the supply and demand for crude oil and oil products, dependent on demand for transport, traditionally related to GDP. All scenarios predict global oil demand peaks with timing varying from Shell's *Scramble* scenario in which climate shocks necessitate oil substitution post-2020 to ExxonMobil's forecast (op. cit.) of no oil demand decline pre-2040, as GDP growth in developing countries exceeds 240% of European rates. Longer term forecasts predict reducing

European GDP growth and energy consumption and EU demand for freight transport decoupling from GDP growth as economies dematerialise. European oil production will decline (EC, 2008; EIA, 2011). Given that shipping costs comprise small proportions of crude oil import values, worldwide demand for maritime transportation of oil and freight rates have been relatively inelastic to bunker price changes (UNCTAD, 2010).

Perceptions of how particular developments will affect total demand are crucial. As global warming heightens drought risks, will more tankers be deployed as water carriers (Hammer, 2009)? Similarly, how will shorter sea routes arising from Arctic ice-melt (Ho, 2011), or an enlarged Panama Canal (Stott and Wright, 2012) impact tanker tkm? How will new Energy Efficiency Design Index (EEDI; IMO, 2012; MEPC.1/Circ.681) ship design regulations to encourage improvements in new ship fuel consumption affect demand or rising demand for new fuels including LNG and nuclear power? How will pipeline investments impact oil import mode splits as more pipelines link supply routes (Hammer, 2009)? Regulation of the type of fuel that ships may consume in particular areas and undefined future ECA designations may promulgate ship re-routing to avoid them (IMO, 2012). To reduce carbon emissions, an Energy Efficiency Operational Index for ships in operation or Ship Energy Efficiency Management Plan imply shorter hauls to reduce tkm (IMO, 2012). However, multi-sourcing strategies to ensure secure energy supplies may impact haul lengths (Dinwoodie et al, 2012).

Oil products tanker movements involving the UK depend on demand for various oil products, the capacity and location of refineries, export demand and the availability of other modes such as pipeline networks. In 2010, UK consumption of oil products comprised mainly transport fuel including petroleum and increasingly diesel by road users, dependent on car ownership levels and use; kerosene for air travel; and some heating kerosene (Dukes, 2011).

Dinwoodie et al (2012) aims to analyse patterns of oil tanker flows involving the UK and by synthesising experts' opinions, to forecast flows to 2050 for this ship type. Largely because of the sheer size of the fleet, wet bulk carriers (primarily oil tankers) generate the highest volumes of carbon dioxide emissions (Buhaug et al., 2009). The demand for shipping crude oil and oil products derives from macro-economic demands for shipping which fluctuate with global economic activity and the dynamic role of shipping in moving raw materials, semi-processed or finished products in fluctuating supply chains (Stopford, 2009). Further, because measures of shipping demand combine tonnage lifted (t) and distance hauled (km), changes in both affect demand in tonne-kilometres (tkm) creating equifinalities. Tanker flows remain concentrated but increasing ship sizes have necessitated more offshore terminal developments of loading and discharging facilities. In the North Sea, offshore oil production has generated offshore transfers from production vessels or an undersea oil production facility. Near urban areas atmospheric emissions may influence decisions to establish Emissions Control Areas (ECA; IMO, 2012).

A Delphi panel used to canvas expert opinions and synthesise perceptions of future demand for wet bulk shipping flows to 2050 by Dinwoodie et al (2012) identified diverse stakeholders spanning the supply chain. International Shipping is a complex, holistic interconnected system, requiring a range of stakeholder inputs. Panellists' predicted increased total global demand (tkm) solely due to increased demand for water carriers, an enlarged Panama Canal and rising demand for LNG. Demand would reduce due to EEDI regulations, nuclear power and shorter Arctic sea-routes, implying 4% net growth from the drivers listed. They also expected oil pipelines to reduce the proportion of US, European and Chinese oil imports moved in ships. Taken individually, no single driver would radically impact voyage lengths globally, but cumulatively their impacts mount. By 2050, predicted shortening of tanker haul lengths to counter rising bunker costs, ocean routing, multi-sourcing to ensure secure energy supplies and ECA-avoidance impacts imply cumulative reductions of 22%.

Dinwoodie et al (2012) summarise the impact on wet bulk flows as follows: Overall, expected global tanker demand to 2050 will rise only modestly despite increasing demands to ship more water, avoid pirates and ECAs and satiate rapidly developing economies. Perceptions of modest global change coupled with reducing energy intensity of UK industrial output imply a rapidly diminishing UK tanker market share. Perceptions of accelerating global preferences for pipelines over maritime flows and increasing demand for nuclear power, combined with reducing tolerance of fossil fuels in UK energy production may signify that as an advanced industrial nation, the UK will lead on systemic post-oil dependence behavioural shifts. However, based on this evidence, Kuznets curve concepts remain speculative stated intentions. Longer term, tanker movements in UK waters may vary with unknowns such as ice-strengthened hull availability, the incidence and political fall-out of oil spills incidents in Arctic waters, and the accessibility and cost of pipelines from Russia and MEG.

Dry Bulk Flows

Some of the uncertainties in predicting flows of coal, the current main UK dry bulk flow (and second globally) include assessing the likelihood and possible effects of changes in:

1. Regulation – EEDI, EEO1 and market based measures.
2. Supply chain resourcing?
3. Piracy including costs of sub-optimal re-routing and re-sourcing supplies using less vulnerable routes?
4. Shipping networks such as opening of a NE passage due to climate change?
5. Technological efficiency such as reduced transport intensity?
6. Technical relationships in advanced economies such as dematerialisation or Kuznets curves (exponential reduction in acceptance of major pollutants)?
7. Industrial structure including new ones (carbon capture and transfers, biofuels) or decline of e.g. coal?

All these unknown factors will act together to shape future demand for shipping. A key challenge was to establish what constitutes 'foreseeable' future transport demand scenarios ranging from 'Business As Usual', through varying degrees of mitigation, which can then be modelled to assess the implications on the emissions of the shipping industry. A Delphi survey was used for this purpose, as reported in Dinwoodie et al (2011b).

Dinwoodie et al (2011b) presents an independent prediction of maritime dry bulk movements to 2050, finding that even though the tonnage of goods moved is expected to grow substantially, this is partially offset by expectations of shorter hauls. Realistic forecasts of future ship movements for different types of ships underpin policy formulation and evaluation in maritime logistics, including strategies to deliver low carbon shipping.

Chowdhury and Dinwoodie (2011) assess the effect of bunker fuel prices on spot dry bulk freight rates, principally coal, and how a carbon tax on bunker fuels could affect spot freight rates for these dry bulk markets. They take a top down approach, probing some of the assumptions regarding market structure and competition on routes. In 2010, the transportation of dry bulk cargo comprised more than one-third of all international seaborne trade (approximately 3.3 billion tonnes). Iron ore is the largest dry bulk trade by volume, and coal is second with imports of 904 million ton in 2010. As a major input to the shipbuilding process, supply of coking coal to produce steel has the potential to affect shipping markets as both a supply and demand driver. Since 2005 China and India have capitalised on the sharp increase in oil and gas prices to build new power plants that utilise coal, resulting in significant growth in the steam coal trade. In the global market for steam coal, China is a major importer and Australia is the largest exporter (Chowdhury & Dinwoodie, 2011). Australia, South America, southern Africa and Eurasia are expected to expand their international coal trade by 2030. Coal will continue to play a key role in the world's energy mix, with demand in certain regions set to grow rapidly. Growth in both the steam and coking coal markets will be strongest in developing Asian countries, where the demand for electricity and the need for steel in construction, car production, and demand for household appliances will increase as income rises. The estimates of UK coal production for the period 2005-2030 show that production will fall from about 22 million tonnes in 2005 to over 2 million tonnes in 2030. Therefore coal fired power stations will have to depend on imported coal (Chowdhury & Dinwoodie, 2011).

Table 2 Steam Coal Requirement in the UK up to 2030

	2010	2015	2020	2025	2030
Steam Coal required (tonnes)	45.8	29.8	27.4	27.4	27.4
UK coal production	21.2	14.3	6.9	2.2	2.2
Import requirement for power generation	24.7	15.5	20.5	25.2	25.2

Source: Adapted from MDS Transmodal (2007)

Predictions of global shipping movements to 2050 underpin forecasts of their likely environmental impacts, and hence policy debates to develop technologies and operational strategies to manage and regulate emissions. However, Stopford (2009) spurns long-term forecasts noting that prediction should aim to clarify risk rather than create certainty. Dinwoodie et al (2011b) report a Delphi survey which aimed to predict likely trends in dry bulk shipping movements (DBSM), the second most polluting ship-type (by trade volume; Buhaug et al, 2009), to 2050. Secondary data sources including UK government, supranational and private statistical sources were deployed to identify baseline dry bulk movements in 2010. Based on drivers of future shipping movements such as Arctic ice melt, an upgraded Suez canal, piracy, resourcing and changed mode splits identified in trade press articles and academic opinions, an instrument was devised to test for consensus regarding future market trends. A Delphi panel comprised of 51 experts with long term industrial commitments was recruited and their agreement with various quantitative statements was canvassed. Mean estimates were fed back in a second round of questioning along with an opportunity to revise initial opinions. Coal is the second largest global dry bulk trade, and the major one for the UK. Reserves are estimated to last for 122 years, is easy to store with low obsolescence, but high inventory costs (WCI 2005). The development of technologies for 'clean' power stations has improved the potential performance of coal as a fuel from a climate change perspective, but it remains some way from the level of emissions required if we are to meet Kyoto Agreement levels for reduction in CO_2 emissions by 2050. Growth in the use of biofuels, renewable and even nuclear energy, and dematerialisation of western economies will temper significant growth in maritime tonne kilometres.

Issues which do not on the surface appear to have much impact upon the decarbonisation of global shipping, such as tackling piracy, could also achieve significant reductions, through the reduction of distance hauled. Detailed modelling of shipping emissions and the effectiveness of potential regulatory and operating procedures to mitigate them are predicated by realistic estimates of the future demand for shipping. Estimates revealed expert perceptions that bunker price changes impact DB spot freight rates substantially. The considered mean short run spot freight rate elasticity for coking coal in relation to bunker fuel prices was 0.95 with long run estimates of 0.92. Similarly the estimated short run spot freight rate elasticities for steam coal in relation to bunker fuel prices rise was 0.534.

Policy issues consequent on predictions of substantial growth in DB tonnes lifted to 2050 partially offset by expectations of shorter hauls include fleet expansion and scope for design upgrades via EEDI to ensure a stock of low carbon DB carriers. Drivers such as growth in biofuel use and localised production, and dematerialisation of the UK economy will temper growth in maritime tkm in developed economies and consequent carbon emissions, and measures to tackle piracy proffer significant reductions. If global DBSM demand slows, carbon emissions also grow less rapidly, but global demand will increase, even for coal, to satiate raw materials demand in rapidly developing economies. Despite increasing dematerialisation of more economies, research into reducing energy intensities and raising the technical efficiency of production to minimise raw materials input is urgent. Although freight rates are estimated to respond elastically to bunker price changes, this analysis ignores cost pass-through considerations where substantial rises in delivered unit prices may drive a search for alternative fuels to thermal coal, or non-metal material substitutes to steel for car making. Further, in this analysis, EEDI regulations alone were expected to reduce total global tkm slightly, although coal hauls will shorten slightly due to localised and multi-sourcing. New Arctic passages caused by ice-melt will shorten N.E. Asia-W. Europe hauls, and even if increased piracy lengthens hauls in the Indian Ocean, this impacts a reducing proportion of hauls. International agreements to manage Arctic developments sustainably and tackle piracy could reduce shipping's carbon emissions. For UK hauls, slight reductions in haul length due to rising bunker costs, offset by increased re-routing to avoid ECAs and piracy imply a dwindling source of quick win-win carbon reduction operational strategies. Major changes would stem from growth in biofuel demand, increasing self-sufficiency in biofuels, intolerance of fossil fuels, carbon capture and dematerialisation of the UK economy.

A Sustainable Shipping Industry

Sustainable approaches are becoming the norm throughout industry, and shipping can be no exception. The concept of a sustainable industry or economy is an interesting one; oil is the major energy source powering the global economy and supplying 95% of the total energy fuelling world transport. Maritime transport relies heavily on oil for propulsion, and is not yet in a position to adopt effective energy substitutes, however, fossil fuel reserves are finite. The implications of rising and volatile oil prices for transport costs and trade will be very important, especially for developing countries (Landamore, 2011). If the shipping industry is to effectively and sustainably reduce its environmental impact, a model for assessing that impact against a cost base will be required. The full cost accounting sustainability assessment model (SAM), although designed for assessing the impact of an individual project, may be able to be adapted and applied to the shipping industry as a whole, a national industry (e.g. the UK's) or to individual companies shipping activities, even to an individual ship or voyage.

Low Carbon Shipping – A Systems Approach aims to develop a holistic systems model for world shipping capable of identifying pathways for the reduction of (primarily) carbon emissions from global shipping, through the design, powering, operation, routing, regulation and financing of the global shipping industry. Development of the economic imperative available via holistic measurement of the 'triple bottom line' of economic, environmental and social impact can signpost the way in which global shipping can contribute to a lower carbon future for all. The sustainability agenda has been applied to many areas of economic activity for a decade or so but it is only relatively recently that the scope for applying sustainability models has been applied to shipping. Landamore & Campbell (2010) approached the issue of sustainability using a 'full-cost' lens to analyse the scope for sustainability assessment of shipping operations using an existing model (the 'SAM' – Sustainability Assessment Model; Davies, 2009) that has been conceptually employed in other contexts, including petrochemicals and construction.

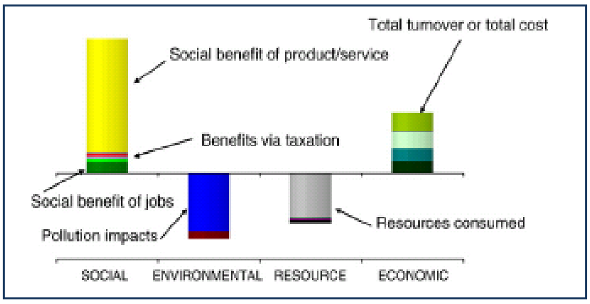

Figure 1: The SAM signature. Source: Bebbington et al, 2006:229

The notion of environmental sustainability is well-established as an aspirational concept in a range of commercial and non-commercial contexts, where "sustainability refers to the long term maintenance of systems according to environmental, economic and social considerations" (Crane and Matten, 2007). Companies are being encouraged, and will increasingly be forced, to take 'cradle-to-grave' responsibility for their products, which of course includes shipping. These pressures have seen an increasing move towards 'life cycle thinking'. Landamore & Campbell (2010) specifically considers a range of issues concerning accounting for these concerns. In doing so, it extends the SAM and applies it to the context of shipping. Following the work of the likes of Bows & Gilbert (2012) and Corbett et al (2007) we can assume that a business as usual approach will not work, and that a future scenario for energy use and emissions must follow one of the other routes, designed to deliver meaningful reductions in global emissions, and at a rate sufficient to prevent global warming above 2% by 2050. In this context, a sustainable shipping industry must be one that can adapt to operate within the new global paradigm, and balance its economic, environmental and social responsibilities to ensure survival. The impact this will have on future demand for shipping will be presented in a future publication by the authors. It is important to remember that this approach is not prescriptive: we do not yet know what a 'full cost' price would look like, but we do acknowledge that economies must move towards generating an *increasingly full cost*. Achieving even a reasonably sustainable position will require 'the most profound, fundamental and visionary change' (Bebbington et al, 2001).

Ship owners, operators and designers are beginning to seriously consider the emissions generated by their operations as they take note of the political shift towards a focus on reducing the impact of activity on climate change (Landamore & Campbell, 2010). There are many models available in the literature compare the carbon emissions of different methods of transporting a specified cargo (e.g. Kuhlwein & Fiedrich, 2000; Corbett & Koehler, 2003&2004; Corbett et al, 2007; Endresen et al, 2003; MOSES Project, 2007; IAPH, 2009; Faber et al, 2010; Browne et al, 2009; Leonardi and Browne, 2009; ESPO, 2009; McKinnon, 2010) although they are often narrow in focus. Simplified assessment of the emissions from shipping (e.g. TRL, 2010; Argonne National Laboratory, 2009; ARTEMIS Project, 2003), and is consequently rarely tailored to the characteristics of shipping. *Low Carbon Shipping – A Systems Approach* focuses primarily on emissions during operation, a necessary limitation in scope which can be defended by the existing research which shows that, at least for conventional and existing ships and ship designs, from an environmental point of view, the emissions during transit generally dwarf other impacts (Landamore, 2006;2007;2009&2010). When looking beyond the immediate future, however, it is important that an assessment of overall impact is included, to identify the true cost to society, industry and the environment, and this is work WP4 is currently undertaking, allowing for proper comparison of options for reducing the impact of shipping.

Conclusion

We expect a likely spatial momentum of future CO_2 emissions arising from bulk movements involving the UK which reflects geographically inert configurations of deep-water ports but volatile domestic production and use of oil, coal, steel and other materials. As more sustainable products such as biomass are imported ahead of local production for energy consumption, cargoes may change radically, but tonnages handled will only reduce as energy or transport intensities reduce significantly. Forty-year projections are necessarily speculative and market volatility implies unknown but potentially substantial variations in the magnitude of both movements and emissions. Other movements are spread nationwide, engaging many small ports and often small ships with high CO_2 emissions per unit handled. Because of this complexity, maritime flow forecasts are interlinked with macro-economic decisions, developments in marine technology, logistical and supply chain sourcing, mode choice and routing decisions, micro and macroeconomic developments, regulatory changes and operational strategies which all affect the reduction of shipping's CO_2 emissions. Each theme defines a specialist work package which draws together five universities and twenty industrial collaborators to assist the process of accessing operating data and ensuring realistic market assessments, within a unique holistic systems framework. Because long term maritime flow forecasts for one sector are inevitably interdependent on complex operating and regulatory decisions taken across and beyond the shipping sector, complex scenario dependent testing of various combinations of technologies and operational strategies is needed to guide future work.

Implicit within, and underwriting, the European Commission's call for FCA are two assumptions: that current prices do not reflect the 'ecological truth', that is they do not reflect the true cost to society or the planet of the product, process or service; and secondly that if the market price of a product, for example, were to reflect accurately the environmental cost of that product, then market forces would encourage consumers to switch to 'more ethical' choices through financial incentives (Bebbington et al, 2001). Recognition of the social and environmental costs of key activities associated with the international shipping industry will serve to deliver a different future energy scenario, one where external costs are properly incorporated into the decision making. Assuming that, as expected, a key driver would be the reduction of emissions to address climate change, then behavioural shifts would focus around actions which massively reduce the need for energy from fossil fuels, and where use is unavoidable in the short term, monetisation of negative impacts would encourage efforts to maximise efficient use and to capture harmful emissions where they can't be avoided. It is likely that any successful attempt to significantly and quickly reduce the emissions from shipping, in line with those required by the most stringent future scenarios (Bows & Gilbert, 2012) to 2050 would result in a significantly different global fleet to that which we see today, and furthermore, the quantity of goods being shipped globally would also have to reduce, resulting in fewer journeys by fewer ships. One consequence of rising bunker fuel prices (and by extension, a likely initial reaction to the introduction of Carbon price fuel levies) is slow steaming. Whilst still delineated by ship type (primarily design speed and cargo value dependent), operators of wet and dry bulk carriers are increasingly turning to reduction in operating speed to save on operating costs (Claudepierre et al, 2012).

Chowdhury & Dinwoodie (2011) demonstrated how a simplified method of internalising environmental cost, applying a 'carbon' levy to bunker fuel prices might impact the freight rate for a major energy dry bulk flow into the UK, coal. The results show that post 2005 estimates are more elastic and significant compared to the estimates before 2005, which are statistically insignificant. Post 2005 estimates range from 0.51 to 1.38 and are significant. Elasticity is lower the longer is the distance and is higher for coking coal, Capesize vessels (big ships) and the Pacific market than steam coal, Panamax vessels (smaller than Capesize) and Atlantic market respectively. The post 2005 estimates are similar whether the 180 CSt bunker price or the 380 CSt is used as an independent variable. The estimates are compared with the import of coal from Australia to India. The Indian study found that a 10% increase in bunker price would lead to a 15.4% increase in freight rate for coal, while Chowdhury & Dinwoodie (2011) find that a 10 per cent increase in bunker price would increase freight rate by 5.1% to 13.8%. The higher this elasticity really is, the more effective raising bunker price as a market based measure to reduce emissions from shipping will prove to be. Chowdhury & Dinwoodie (2011) did not take into account the cost pass through ratio between the producers and the consumers, or the substitutability between different alternatives. However, the study establishes that post 2004 estimates (when the world trade/economy has significantly changed, with China as a major player) are elastic and significant.

Necessarily speculative forty-year projections combine with volatile markets to amplify uncertainty. Because of this complexity, future research might usefully attempt to frame maritime flow forecasts within a holistic systems framework which encourages complex scenario dependent testing of combinations of vessel technologies, operational strategies and regulatory decisions taken across and beyond the shipping sector (Dinwoodie et al, 2012). A significant paradox in the assessment of major shipping flows, particularly in the bulk trades, in a project focussing on reducing Carbon Emissions is the fact that the cargoes themselves are significant polluters. Any full cost approach cannot ignore the impact of the cargo onboard when assessing impact, much as any assessment of the ability of the global community to meet its commitments to decarbonisation by 2050 could no more ignore emissions from energy production, as it could those from transport, whether of people, finished goods, or raw products.

> "Just over three quarters of the UK's current primary energy demand is met by oil and gas. In 2020, it is estimated that 70% of primary energy consumed in the UK will still come from oil and gas" (Oil & Gas UK, 2010)

Having said this, the focus of *Low Carbon Shipping: A Systems Approach* is to consider the emissions from global shipping itself, and particularly operational emissions as well as those pertaining to flows to and from the UK. Oil and coal are major UK sea-borne imports, and as such are likely to play a significant part in the future makeup of UK-bound global shipping trade for some time, except in the case of a major paradigm shift towards governmental (i.e. policy-driven) impetus to reach a very low carbon future scenario, such as that referred to by the Tyndall Centre for Climate Change Research (Bows & Gilbert, 2012) as the minimum necessary to meet obligations under the Kyoto agreement.

Future research

This initial paper considers the drivers for demand in International Shipping primarily associated with the major wet and dry bulk energy products: crude oil and coal. Hence future global energy scenarios are key to predicting what future demand for shipping may look like in this context. The next stage is to extend the assessment to encompass more major shipping flows, in particular containerised goods, and also to include assessment of the impact of supply chain optimisation, port developments, and technological developments. The ship design and equipment developments which are the focus of the *Low Carbon Shipping: A Systems Approach* project were selected primarily for their potential to reduce the carbon dioxide emissions from ships during operation, and as such, most of the developments address the efficiency of the drive train, or of the ship itself moving through the water. The potential to meet emissions targets afforded by combinations of these will be key to improving emissions from shipping in a 'slow and steady' energy use reduction scenario, but alone will fail to achieve the required impact for a very low carbon future scenario. Further research in this area is ongoing.

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