A comparison of alternative decarbonisation scenarios for UK shipping.

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Abstract

Despite accepting the need to respond to the challenges posed by climate change, the shipping sector has, thus far, failed to agree on appropriate measures to significantly reduce its emissions. In the absence of a global mechanism, it is argued that individual states have a greater onus to seek the means of reducing the shipping emissions attributable to them. Given the anticipated growth in shipping demand and the prospect of an associated increase in emissions, this study develops shipping scenarios for the UK up to 2050 that are bound by an emission reduction target of >80% relative to 2006. Through the development and use of an emission accounting tool, a suite of alternative assumptions on both the demand for, and supply of, freight work are presented within three scenarios. Through differing assumptions on traded quantities, trading partners, ship size, type, technological and operational emission reduction measures, these scenarios present different pathways for the decarbonisation of UK shipping. The results highlight how a suite of changes to demand, technology and operations, as opposed to a focus on one aspect, are required to remain within the desired emissions pathway. This also reinforces the view that there are numerous opportunities for intervention available, each leading to distinct futures, in terms of how emissions are mitigated. A key message is that decarbonising an open system such as the shipping sector will not be achieved in isolation but requires the combined efforts of all stakeholders within the supply chain, including ship builders, owners, operators, port managers, logistical support as well as consumers.
Keywords: Shipping Emissions, Scenarios, Emission Thresholds

1. Introduction

Despite recent economic fluctuations, the pivotal role played by the maritime sector in economic development remains incontestable. The globalised character of modern trade means that economic development is contingent upon the ability to strengthen linkages with existing trading partners as well as capitalise on emerging markets. Whilst the impact of the global recession precipitated a reduction in the quantity of global seaborne trade in 2009, the United Nations Conference on Trade and Development estimates that total global trade increased by 4% in 2011 (UNCTAD, 2013). This is comparable with historical data as Stopford (2009) demonstrates that between 1950 and 2005, the productivity of the shipping industry (in this instance, the quantity of seaborne imports) increased on average by 4.7 % per annum. Its economic importance notwithstanding, it is estimated that international shipping contributed to 2.7 % of global anthropogenic CO_2 emissions in 2007 (Buhaug et al., 2009). While this proportion may appear trivial given that over 90% of global trade is facilitated by the shipping sector, such estimates should be viewed within the context of the continued growth of shipping, even in periods of economic uncertainty. A number of studies have estimated historical shipping emissions (Eyring et al. 2005a) highlighting its consistent growth. Similarly, other studies have projected future global shipping emissions with varying underlying assumptions for the increase in the demand for shipping and the presence of emission mitigation measures (Eyring et al. 2005b).

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1.1 Study objective

This paper seeks to generate alternative emission pathways for UK shipping which are informed by key emission thresholds. This is achieved through the generation of alternative scenarios which represent different projections for how the demand for, and supply of the service of shipping may change within the context of wider decarbonisation commitments. This is facilitated through the development of a shipping emission scenario generation tool: “Ask for ships” Walsh (2012a). In this regard a scenario should not be viewed as a prediction, but rather as a narrative tool through which potential futures are projected, based on a consistent logic and the quantification of their core characteristics. Such an undertaking is considered particularly appropriate to the shipping sector given its inherent complexity and the uncertainties involved. Specifically, scenarios are useful in illustrating and quantifying some of the key economic, technological, and operational variables which are likely to affect future emissions (Buhaug et al., 2009). Scenario generation at sub-global level allows country specific considerations to be taken into account. This is considered important as specific changes to the pattern of shipping can be reflected in ways which, arguably, are less visible when presenting a global representation of shipping, i.e. through generalised projections in transport demand without reference to specific regions or commodities.

1.2 Projected shipping emissions

In the second greenhouse gas study published by the International Maritime Organisation (IMO), global shipping emissions are projected to 2050 (Buhaug et al., 2009). Such projection are assisted through the development of differing scenarios which are principally informed by the assumptions of global development in the Intergovernmental Panel on Climate Change (IPCC) SRES storylines (Nakicenovic et al., 2000). The SRES scenarios are informed by the competing dynamics of globalization and regionalisation, and the influence of economic or conversely, environmental considerations. Different scenarios are developed which project future demand for shipping (in terms of tonne-nautical miles) as well as any mitigation efforts, including both technological, operational measures as well as the sources of fuel. The results of the main scenarios for 2050 which refer to CO_2 released through international shipping are presented in Table 1. The results presented in the table reflect the base case as well as the upper and lower bound estimates associated with each scenario family.

Table 1. Projected global international shipping emissions for 2050, taken from Buhaug et al. (2009)

Scenario Name	Descriptions	Base case	Upper bound	Lower bound
A1FI	Economic and global focus, fossil intensive.	2,648	7,228	692
A1B	As above but balanced across energy sources.	2,681	7,344	693
A1T	Technologically advanced, less fossil reliant.	2,668	7,341	688
A2	Economic and regional focus.	2,194	5,426	637
B1	Moderate economic focus, local suitability.	2,104	5,081	616

As be seen from Table 1, while there is a significant range in emissions between the minimum and maximum values, the base cases for each scenario do not demonstrate the same levels of variability. Given that international shipping emissions are estimated at 870 MT CO_2 in 2007, these results would suggest that scenarios which reflect more conventional projections in transport demand and emission mitigation are nonetheless, expected to result in a significant increase in emissions from current levels by 2050.

1.3 The importance of emission thresholds

Anderson and Bows (2012) stress that, in principle, the IMO accepts that the shipping industry “will make its fair and proportionate contribution” to the levels of mitigation deemed necessary to reduce the likelihood of a global mean temperature rise commensurate with averting dangerous climate change. However there remain fundamental differences in position between the principles which underpin both the IMO and the United Nations Framework Convention on Climate Change (UNFCCC). The former expresses the view that shipping, as a sector, should be treated as a distinct regime, akin to a separate sovereign state and that all sections of the global fleet should be treated equally. Anderson and Bows (2012) reiterate the scale and urgency of the climate change mitigation challenge, suggesting that by 2050 emission reductions greater than 80% (relative to 2010 levels) will be necessary. This is seen as a proportional contribution to global efforts to affect an even probability of stabilising the global temperature at 2°C above pre-industrial levels.

2. Methodology

Similar to CCC (2011) within this study, UK shipping is defined as the freight work between country of loading and unloading for both imports and domestic shipping. This definition is predicated on the need to adequately reflect the link between domestic material consumption and demand for shipping by allowing changes to both the traded quantities and the geographic distribution of trading partners to be reflected. Imports were chosen as the UK is a net importer of material and are arguably a better representation of UK shipping demand. The method applied to estimate recent UK shipping emissions is presented in Walsh et al. (2012a). In order to estimate the transport work associated with UK, annual trade quantities at national level is taken from Eurostats (2011) in tandem with the transport distance between trading partners is estimated using online port distance calculators such as www.seadistances.com and www.vesseltracker.com, representing the shortest sailing distance between trading partners. The energy intensity of seaborne freight work is estimated based using List intelligence (LLI) ship calling dataset (LLI, 2010) as well as ship calling data published in DfT (2011). Additional data per is allocated to the appropriate ship size and type using data taken from Buhaug et al. (2009).

$$\mathrm{kWh/tkm} = \frac{\sum_{i=1}^{nME}\left(ME_{(i)} \times Lf\right) + \sum_{i=1}^{nAE}\left(AE_{(i)} \times Lf\right)}{\left(Cp \times Uf\right) \times \left(V \times 1.85\right)} \qquad (1)$$

Once values for the energy intensity of transport are generated, they can be used in conjunction with estimates of transport work to generate the overall primary energy demand associated with UK import and domestic seaborne trade for the study year. Alternatively, such estimates can be modified to reflect additional emission mitigation measures at the ship level. These are grouped into 4 main categories: additional operational measures, new build technologies, retrofit technologies and onboard renewable energy technologies. These modifications are represented by % reductions to the energy intensity of transport. These reduction estimates may represent an individual technology, a number of (compatible) technologies, or a compound energy reduction estimate which represents a number of distinct technologies or additional operational measures (in addition to a reduction in speed) operating in tandem. Individual energy reduction estimates for specific technologies and operational measures are presented as averages and are based on estimates on ship level fuel/energy savings published in Hobson et al. (2007), EMEC (2009), McCollum et al. (2009), Crist (2009), Lockley and Martin (2011), Buhaug et al. (2009) and Mortensen (2009). (It should be noted that the model reflects the fact that the overall impact of any group energy efficient technologies on board a vessel will not be additive.) These estimates are further augmented to reflect the proportion of the fleet which is undertaking these measures. This is more complicated for new build technologies which will only be applicable to new builds. As an approximation, the percentage of the merchantable fleet that is comprised by new builds is estimated based on the year at which efficient ships are assumed to enter the market and the percentage additions and percentage removals (in term of capacity) in the intervening period between market entry and the study. Once the primary energy demand associated with UK shipping is augmented to reflect the above measures, it is converted into the estimates of fuel necessary to supply this demand. This is facilitated using estimates for specific fuel consumption (g/kWh) for each ship type based on the fuel used, engine type and the anticipated efficiency gains (Olsesen et al., 2009), choice of engine type and the fuel for main, auxiliary engines and boilers. This method also allows the fraction of the fuel that is supplied from renewable sources to be assigned. It is assumed that the bio-derived fuel is effectively carbon neutral. The method used to generate shipping emissions is presented in a simplified manner in Figure 1.

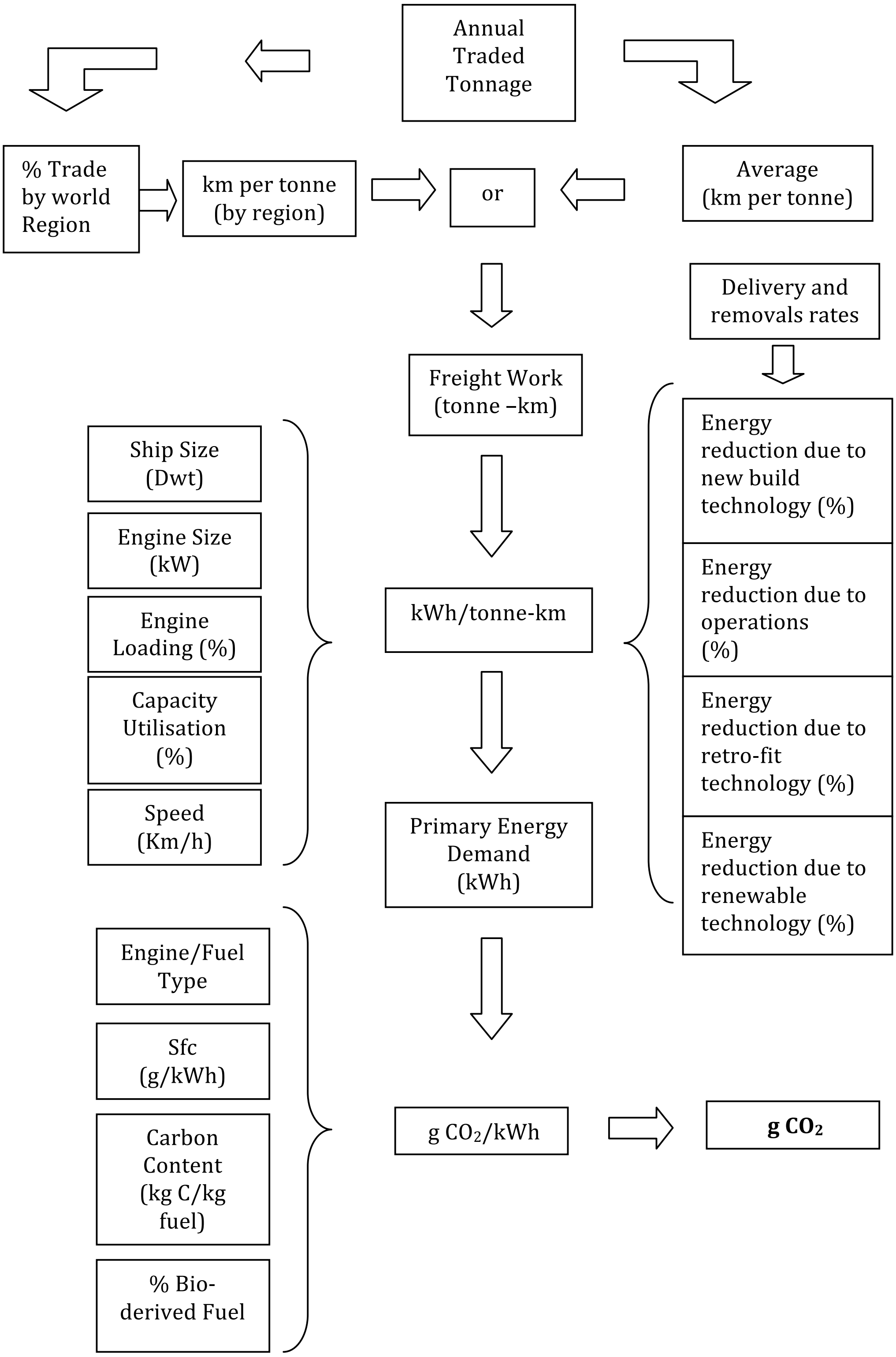

Figure 1. Emission generation method

3. Shipping emission scenarios

This method has been applied to assess the potential impact of the successful implementation of UK decarbonisation policies as envisioned by UK Department of Energy and Climate Change (DECC 2012). The results demonstrate how adhering to a decarbonisation strategy can affect drastic reductions in the emissions associated with national energy trade (Mander et al., 2012). However, given the need to decarbonise all sectors of the economy, this paper presents three contrasting scenarios which project demand for all commodity types.

Three scenarios were developed through an iterative process of review and consultation with an advisory group as well amongst the authors. The process through which these scenarios are generated can be broadly differentiated into projecting the energy demand for the UK shipping sector (as defined by this study) and the means by which such demand can be satisfied. The former includes specific assumptions on the quantities of material required by 2050 as well as where they may be sourced. Meeting this demand requires methodological choices as the type, size, speed etc. of ships that might be employed as well as the nature of any emission mitigation measures.

It was decided that where possible, the scenarios should project distinct accounts of the demand for shipping as well as ensuring that decarbonisation itself is not overly dependent on identical (or excessively similar) mitigation measures. In order to reflect the need to affect a significant reduction in emissions it was decided that an emission reduction target of 80% on existing levels was chosen. Given the apparent decline in trade in the latter years of the previous decade 2006 was chosen as the emission base year. This has been estimated at approximately 17 MT CO_2 based on data updated from Walsh et al. (2012a). The main characteristics of each scenario are presented in Table 2.

Table 2. Summary of main scenario characteristics

	Scenario 1	Scenario 2	Scenario 3
Scenario Context-by 2050			
Global Context	Globalisation continues apace. Competition between shipping companies and greater regulatory incentivises consistent fuel efficiency gains.	Security becomes a more pressing concern with increasing risks of piracy at known conflict points. Continued increase in marine fuel price.	Reversal of globalisation processes. Western economies focus on self reliance and domestic manufacturing. Decline in deep seas trade routes.
UK Context†	UK decarbonises according to DECC "high CCS" scenario. Demand for manufactured goods increases.	UK decarbonises according to DECC "Markal" scenario. Increase in onland nuclear power demand. 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. Focus on circular economy and domestic production.
Demand for UK Shipping-by 2050			
Drivers for demand	Continued demand for goods manufactured in distant regions and increased importance of deep sea trade.	Similar to current situation with both deep sea and short sea shipping important.	Consolidation/ regionalisation of manufacturing within EU-27.
Imported and Domestic Tonnage	20% reduction in overall tonnage relative to 2006. Doubling of Container demand.	28% reduction in overall tonnage relative to 2006. Equivalent demand for non-energy commodities	23% reduction in overall tonnage relative to 2006. 18% increase in non-energy goods, mostly associated with RoRo and containerised trade.

† Decarbonisation pathway data taken from Department of Energy and Climate Change (2012)

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Trading Partners	Continuation of globalisation, increased trade with Americas and Asia at the expense of Europe.	Increased trade with America for certain commodities but no drastic change in trading partners. Some routes are extended as a precaution against piracy.	Contraction of trade routes results in dominance of short sea shipping.
Imported and Domestic Freight Work	38% increase on 2006 levels. 45% of freight work associated with containerised demand.	15% reduction relative to 2006 estimate, equivalent to 2010 estimate.	70% reduction relative to 2006 levels.
Characteristic of Shipping Supply-by 2050			
Ship Size	Containerships 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 all vessels except those that are normally less than 5,000 dwt.
Ship Speed	20% reduction for non-containerised vessels. 50% reduction for containerised vessels.	20% reduction for containerised vessels.	20% reduction for all vessels.
Utilization	Increased utilisation capacity of container vessels.	Increased utilisation capacity of container vessels post 2040.	No change.
Ship Replacement and New-build Technologies	A high turnover rate insures full replacement by 2050. Container ships assumed to consume 10% less energy while other ships are assumed to require 30% less energy. This is a compound emission estimate based on a number of distinct technologies.	Nuclear ships emerge 2030-2035. Gradually penetrate fleet. Majority of tankers and approximately 30% of container fleet assumed to be nuclear powered. Non nuclear new-builds assumed to require 30% less energy.	A high turnover rate results in full replacement by 2050, all ships assumed to benefit from a suite of technologies such as contra-rotating propellers, refinement of hull lines etc.
Further 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 emission intensity applied to all non-nuclear ships. As in Scenario 1, reflects overall impact of multiple individual measures.	As in Scenario 2 but applied to half the fleet.
Retrofit Rates and Technologies	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.	20 % reduction in emission intensity applied to all 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. Results in 11-20% reduction in energy intensity.

Renewable Onboard Technologies	Wind powered or wind assisted is estimated to reduce energy demand by approximately 10% across all vessels.	As in Scenario 1.	As in Scenario 1.
Fuel Type and bio-derived mix	Remaining energy demand satisfied by distillate fuel with a 10% bio-derived fuel mix.	Remaining energy demand satisfied by distillate fuel with a bio derived fuel mix of 50% for RoRo vessels.	Remaining energy demand satisfied by distillate fuel bio derived fuel mix of 20%. This increases to 50% for ships transporting bio-energy.
Emission Estimate 2050	**3.21 MT CO_2**	**2.74 MT CO_2**	**1.86 MT CO_2**

4. Comparing scenario results

The impact of the different scenarios on the quantity of material unloaded at UK ports by 2050 is presented in Figure 2. Comparing the projected estimates for the freight work demand reinforces the importance of transport distance. In particular, the choice of trading partners is pivotal. Specifically, comparing the first and third scenario demonstrates how similar quantities of trade can pre-empt significant divergence in the eventual freight work demand. The predominance of the container category is the result of both the quantity traded but, more importantly the transport distances involved.

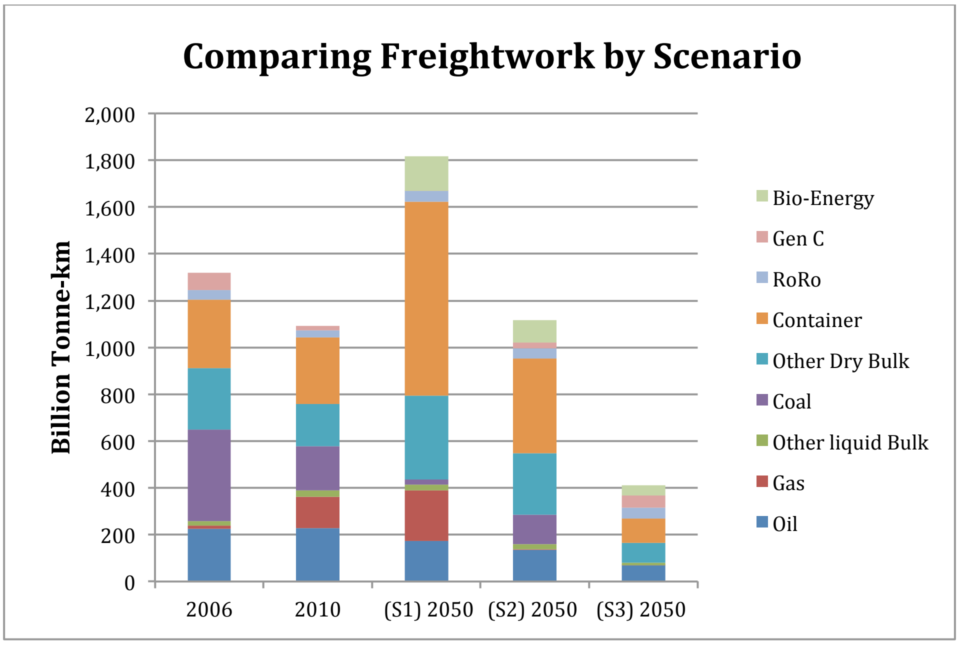

Figure 2. Comparison of freight work associated with UK imports and domestic trade

Comparing the projected estimates for the anticipated freight work demand reinforces the importance of transport distance. In particular, the choice of trading partners is pivotal. Specifically, comparing the first and third scenario demonstrates how similar quantities of trade can pre-empt significant divergence in the eventual freight work demand. The predominance of the container category is the result of both the quantity traded but, more importantly the transport distances involved. Figure 3 disaggregates the primary energy demand required to satisfy UK demand for imported and domestically traded commodities, including the relative impact of different energy saving measures.

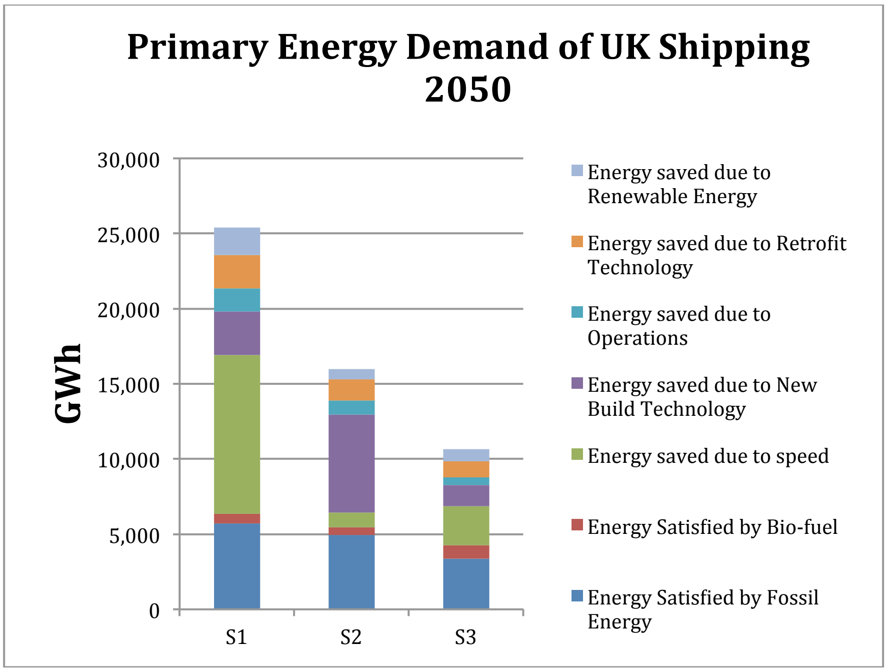

Figure 3. Primary energy demand associated with UK shipping in 2050

In essence Figure 3 demonstrates how each of the different scenarios achieves drastic decarbonisation of UK shipping. The first scenario demonstrates how a reduction in speed is the main contributor to a reduction in the primary energy demand. Alternatively the penetration of nuclear vessels (incorporated within the new builds category) is seen to affect the greatest reduction in energy demand within the second scenario. The third scenario demonstrates that while technological and operational measures remain essential, in comparison with the base year, the reduction in overall demand for shipping itself is the single most important factor.

Figure 4 compares the emissions associated with UK shipping (as defined by this study) with the baseline value for 2006. All three scenarios affect an emission reduction of over 80% relative to the base year.

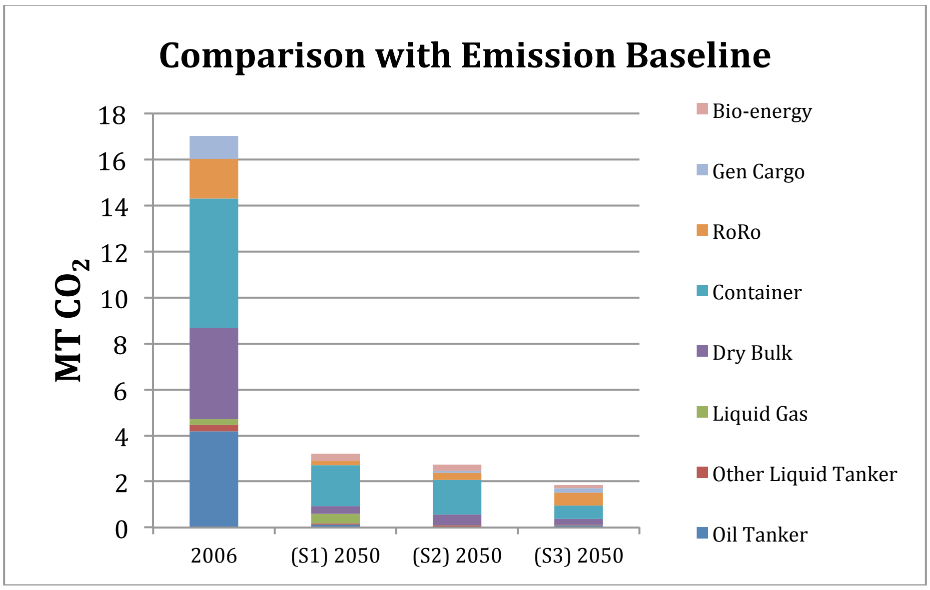

Figure 4. Emissions associated with UK domestic and import trade, by broad ship category

5. Discussion

Reviewing the emission estimates shows both similarities as well as differences (Figure 3). The containerised goods category dominates the first and second scenario estimate, which in both instances is attributable to not just the energy intensity of containerised shipping but also the distances over which containers are shipped. The similarity in the emissions attributable to containerised transport in both scenarios should not be overstated as their respective estimate is reflects level of demands (Figure 2) and decarbonisation is acheived via different mitigation routes (Figure 3). This reaffirms that while diverse factors will determine the emissions associated with shipping a particular commodity, so too are the mitigation opportunities. In contrast, the third scenario does not demonstrate the same prominence of containerised goods, which can be attributed to the reduced transport distances involved. (As containerised goods are generally transported significant distances, a departure in trading partners is likely to have a more pronounced effect on this category.) This reduction in distance and diminution in the relative contribution of containerised goods to overall transport work means that the third scenario (as well as presenting the lowest estimate in absolute terms) also increases the relative contribution of RoRo transport to emissions by 2500. This is not unsurprising given this scenario's focus on short sea shipping and the relatively high carbon intensity of RoRo vessels (Walsh et al. 2012b).

Previous work by the authors (Walsh et al., 2012a) and others (Rigot-Muller et al., 2012) has demonstrated how the mean emission intensity of UK shipping has increased over the last decade. On a simplistic level, this increase reflects demand for dry bulk being supplanted (partly due to a reduction of coal in the energy generation fuel mix) by demand for containerised goods which are generally transported on more emission intensive ships. The implication of this is the risk of a "perfect storm" whereby both the carbon intensity of shipping as well as the absolute demand can increase in tandem.

While all three scenarios rely heavily on a central facilitator for decabonisation (namely a reduction in speed, the emergence of nuclear vessel and reduction in freight work demand, for the first, second and third scenarios respectively) none of these factors are sufficient in isolation. In that regard, meeting the necessary emission reduction will require a different "perfect storm" whereby demand for and the emission intensity of shipping will need to decrease (or be maintained) in parallel. Indeed the scale of the energy/emission reduction deemed necessary for all of the mitigation categories (new builds, operation, retrofit tech, and renewable energy) might be foreseen to be beyond what can be physically achieved. However it should be clarified that there are presently few examples of implementation of numerous different technologies and operational measures onboard a single ship. Greater experience within the shipping sector of seeking to reduce emissions through varied and diverse means will give a better indication of the extent to which such decarbonisation is technically feasible, the types of incompatibilities that will have to be addressed and the level to which an associated reduction in demand may be necessary. Achieving greater reductions in the carbon intensity of shipping through technical and operations measures will result in less stringent restraints on the future demands for shipping. This is particularly relevant to countries such as the UK which are dependent on shipping to supply many commodities which are unavailable terrestrially.

6. Conclusion

Despite differences in opinion on how it should be treated within the context of global decarbonisation efforts, the shipping sector accepts, in principle, that it must shoulder responsibility in proportion to its contribution to the challenge. A number of different studies have projected global shipping emissions into future. In some instances these projections have shown a significant absolute reduction in emissions. However such projections are generally not informed by the cumulative of impact of emissions. Adherence to an emission budget which seeks to provide an even probability of not exceeding a mean 2 °C temperature increase, requires a drastic decrease in emissions by 2050. Using 2006 as an emission base year, this study projects the carbon emissions associated with UK imports and domestic shipping to 2050 through the development of three distinct scenarios which each satisfy an emission reduction target. The results demonstrate not only that there are numerous options available to affect adequate decarbonisation of the shipping sector, but that such reductions are dependent on many factors operating in tandem. These scenarios suggest for example, that increasing fleet turnover, the ability to successfully assimilate numerous different technologies on a single ship, a drastic reduction in ship speed, near universal application of renewable technologies in conjunction a reduction in the anticipated demand are all instrumental in affecting the necessary reduction in absolute terms. However this also means that given the best available knowledge and technological prowess, the shipping sector is unlikely to adhere to the necessary emissions threshold on its own, and that decarbonisation of the shipping sector may only be achievable if paired with wider decarbonisation efforts in other sectors. This may be taken as discrediting the view held by the IMO-that the shipping sector should be treated as a distinct entity-as being contradictory to the IMO's stated acceptance of sector's shared culpability and responsibly in mitigating against the risks of dangerous climate change.

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