A new method for estimating national-scale CO_2 from shipping: preliminary results from a UK study.

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Abstract

The shipping sector facilitates over 90% of global trade and is essential to the UK given its geographic setting. However the anticipated growth of shipping, despite its efficiency in relative terms, has implications for a carbon constrained future. The UK's Committee on Climate Change has recently discussed the methodological options for including shipping emissions within existing national targets and budgets. Any rational target requires establishing a credible baseline for current emissions, which is dependent on defining what is meant by "UK shipping." Previous research by Tyndall Centre researchers estimates UK annual shipping emissions at 7-42 Mt CO_2 depending on the apportionment regime applied. Adopting a new bottom-up approach, this study seeks to contextualise this range through the development of a new method to estimate the emissions associated with UK trade by sea (including imports and exports) over the past decade. Annual emission estimates vary from approximately 15 Mt CO_2 in 2002 to 20 Mt CO_2 in 2008. This study reinforces the point that operational and technological measures are essential in reducing shipping emissions. However meeting the UK's 2050 emission reduction target of 80% on 1990 levels will depend on both stronger policies at global and sub-global level in addition to managing the demand for shipped at the national scale.

Keywords: Shipping, Emissions model, Imports, Exports,

1. Introduction

The increasingly globalised nature of modern trade means that economic development is contingent upon the ability to reinforce linkages with existing trading partners as well as capitalise on emerging markets. The shipping industry is seen as being pivotal to economic growth within industrialising countries as their shipping activity represents approximately 60 and 56 % of total goods unloaded and loaded respectively (UNCTAD, 2011). Its economic importance notwithstanding, it is estimated that shipping contributed to 2.7 % of global anthropogenic CO_2 emissions in 2007 (Buhaug et al., 2009). While this may appear small given its dominance in supporting international trade, it should be viewed within the context of the continued growth of shipping. 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. Given the widely recognised need to decarbonise the global economy, the anticipated growth in shipping (and its associated emissions) may offset carbon reductions in other sectors. The repercussions of this growth on shipping emissions in the future, including both CO_2 and other pollutants, have been reviewed in a number of studies (Eyring et al., 2005a, Eyring et al., 2005b, Corbett et al. 2007, Endresen et al., 2007, Gilbert and Bows, 2012). Similarly, Buhaug et al. (2009) present a number of emission trajectories towards 2050, for which emissions (due to international shipping) range from 68 %, and 840 % of 2007 levels. While these represent more extreme scenarios, more moderate projections predict emissions will increase by 1.9-2.7 % annually, which result in overall emissions that are 220-300 % of 2007 levels (Buhaug et al., 2009). Given its geography, the UK is fundamentally dependent on shipping. Comparing the tonnage of UK seaborne and overall trade (Eurostats, 2011a) demonstrates that, for the past decade, over 90 % of traded material was transported onboard ships. It is unlikely that this reliance on shipping will be displaced in the future, with some commentators predicting an average annual increase of 1 % in the tonnage handled by UK ports between 2005 and 2020 with an annual increase of 3.3 % for unitised goods (Garratt, 2011). In light of such anticipated growth, meeting the current commitment to have reduced UK emissions by 80% from 1990 levels in 2050, (which itself is a contested value) is anticipated to be particularly challenging for the shipping industry, if it is decided to include the shipping sector in this target. The aim of this study is to present a new tool for estimating recent CO_2 shipping emissions associated with UK trade and in doing so identify the impact of changes in trade patterns. A greater awareness of the contributing factors to recent emissions will inform the development of future scenarios for UK shipping emission scenarios.

1.2 Defining UK shipping emissions

The urgency with which emissions from all sectors must be mitigated drives policies aiming to cut the emissions from shipping towards addressing aspects of the shipping system where actors most readily have influence and can monitor success (Gilbert & Bows, 2012). For instance, national ports could implement an efficiency standard for docking ships, or set a limit on the CO_2 emitted per tonne-km within local waters. If such policies were applied at all ports within the vicinity, this could lead to improvements in, for instance, operational efficiency, with data on fuel use collected and monitored by port authorities. Nevertheless, if an emission target is to be established as part of a comprehensive national emission reduction objective, a credible baseline for emissions is needed, which is dependent on defining what is meant by “UK shipping”. This is predicated on the necessity in not just estimating emissions, but understanding the reasons why shipping emissions are estimated at current levels. Given the extent and interconnectivity of modern supply chains, allocating shipping emissions to an individual country or region is inherently uncertain (if not arguably contentious) and may require a degree of arbitration. Gilbert and Bows (2012) demonstrate different apportionment regimes in order to estimate emissions which are appropriate to the UK’s demand for shipping. The regimes are based on a range of approaches such as using estimates for national bunker fuel sales, or a top-down method which scales global shipping emissions using a suitable proxy. This presents an array of potential emission estimates, ranging from 7 to 42 Mt CO_2 in 2006, based on the apportionment regimes mentioned above (Gilbert and Bows, 2012). The UK Committee on Climate Change (CCC) allocates UK shipping emissions based on the tonnage of imports, which is further scaled based on the relative distance travelled by UK imports. This results in an annual emission estimate of 16 Mt CO_2 (CCC, 2011). One of the rationales of applying an apportionment regime such as a proxy to estimate shipping emissions is that it negates the potential for double counting of emissions as well as allowing for emissions to be allocated to land-locked countries. However such an exercise raises the question of deciding upon the most suitable and equitable proxy or scalar. Furthermore, top-down methods using proxies or scalars are insensitive to changes in, for instance, fuel efficiency or carbon intensity, limiting their use within a comprehensive national carbon reduction package (Gilbert and Bows, 2010). An alternative allocation method may be based on estimating the actual transport work done in facilitating a country’s seaborne trade. This can be based on ship movement or trade data. Using ship movement data, the CCC (2011) estimate that 12 Mt CO_2 were emitted in supplying goods to and around the UK in 2006. Schrooten et al. (2009) use existing trade patterns to estimate the number of vessels required to ship the resulting cargo tonnage. Emissions are estimated based on the duration of sailing and power required by marine engines. They then assign national responsibility based on halving the sailing distances between trading partners.

This study is developing an energy and emissions model (provisionally entitled “ASK-Ships”) to allow both recent and prospective emissions associated with the UK to be assessed. A similar approach as Schrooten et al. (2009) is adopted, with two main distinctions. Within this study UK shipping is defined as the transport work associated with both imports and exports. (This mimics the treatment of aviation within the EU emission trading scheme, whereby in absence of a global agreement, both flights to and from EU destinations are taken into account.) The emissions during vessel manoeuvring and while at berth are excluded, whereas emissions due to auxiliary boilers are included.

A further key distinction is that within this study transport work is translated into emissions by estimating average emissions per tonne-km for specific ship types. The main rationale for this decision is that this allows country specific emission factors to be explicitly generated which can be compared more readily across time, amongst different ships or with other modes. The generation of such emission factors also allows the potential impact of changing assumptions in ship size, type or utilisation etc. to be more easily incorporated into existing overall emission estimates. It is anticipated that readily accounting for such factors will allow for more meaningful and targeted scenario generation in estimating future emission estimates.

2. Recent trends in UK shipping.

Both Eurostats (2011a) and the UK Department of Transport (DfT 2012) provide data on the quantity of material moved through UK ports. Figure 1 illustrates the quantity of foreign imports unloaded at UK ports over the past decade, excluding domestic trade. Prior to 2007, international seaborne imports to the UK demonstrated an average annual growth of 1.73 % (inclusive of a decline in 2001 and 2002). The visible impact of the recent economic downturn means that despite earlier growth, imports in 2010 are approximately 10% lower than in 2000. (The impact of the downturn is also evident when overall UK trade is examined in monetary terms, where imports in 2009 demonstrate a 10% decrease from the previous year, while returning to previous levels in the following year.) With the exception of 2007 and 2010, the quantity of material loaded in UK ports has decreased annually, demonstrating an average annual reduction rate of 2.54% across the decade. The most pronounced decline is seen in crude oil exports which have decreased annually by an average of 7.8%. Examining the country of (un)loading demonstrates both gradual and drastic changes in trading partners. For example, between 2000 and 2008, ores imported from Brazil supplant Australian imports. By contrast, between 2008 and 2010 imports of liquid gas grew by over 500%, admittedly from a relatively low tonnage.

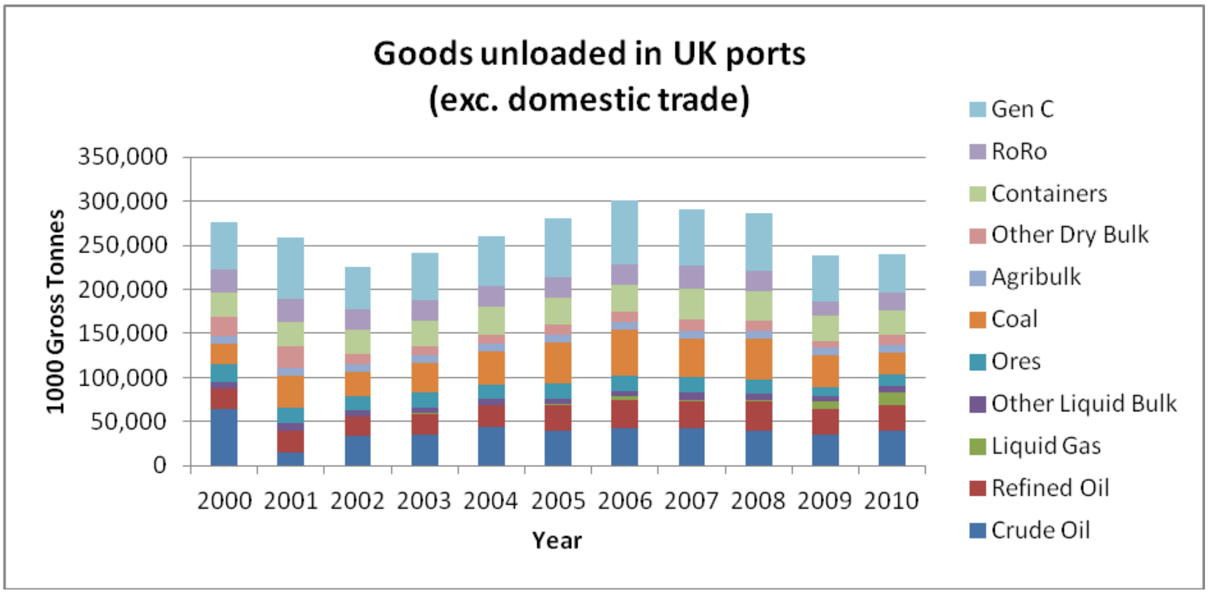

Figure 1: UK seaborne imports by commodity type,
Source: Eurostats (2011a) and DfT (2012).

The quantity of goods loaded in UK ports is shown in Figure 2. In terms of exports, the materials that show drastic changes in the distribution of trading partners are generally those goods exported in smaller volumes, such as coal and forestry products. Approximately 50% of imports by tonnage are sourced within the EU and the majority of overall seaborne exports are traded within the EU.

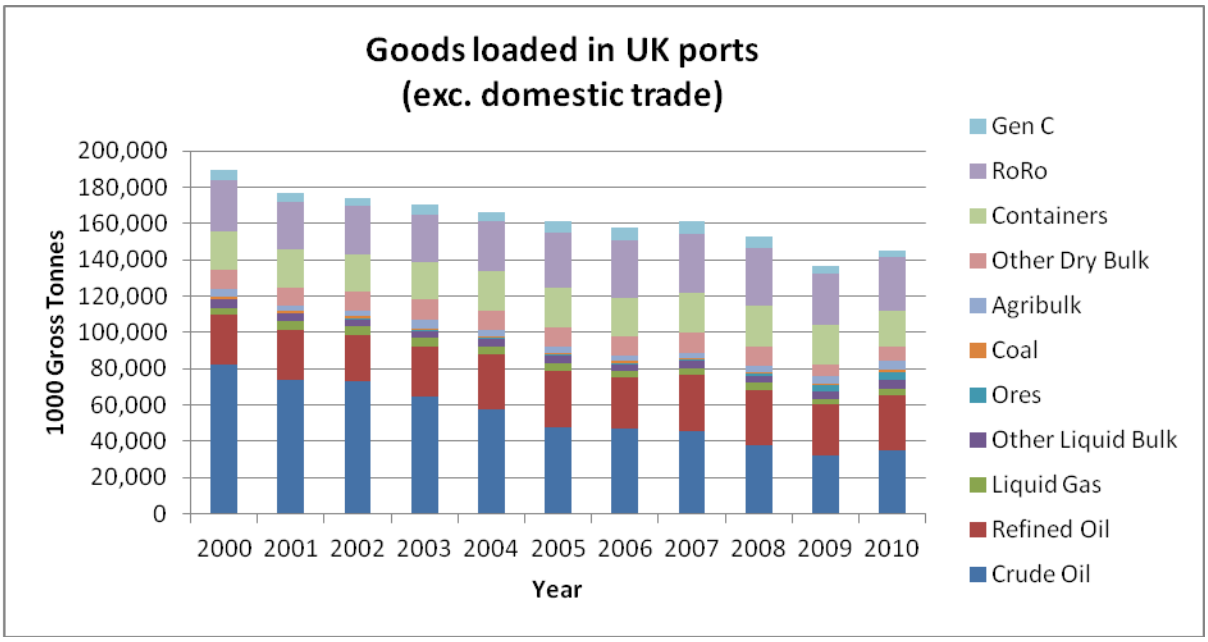

Figure 2: UK seaborne exports by commodity types.
Source: Eurostats (2011a) and DfT (2012).

Eurostats (2011b) publishes data on vessel traffic arriving in UK ports. Between 2000 and 2011 the aggregated tonnage of vessels visiting the UK has grown on average by 0.1% per annum. In contrast, the associated number of vessel visits declined by an annual average rate of 3.62%. This has resulted in an average annual increase in vessel size (per visit) of 3.94%. The growth in average vessel size is shown in Figure 3.

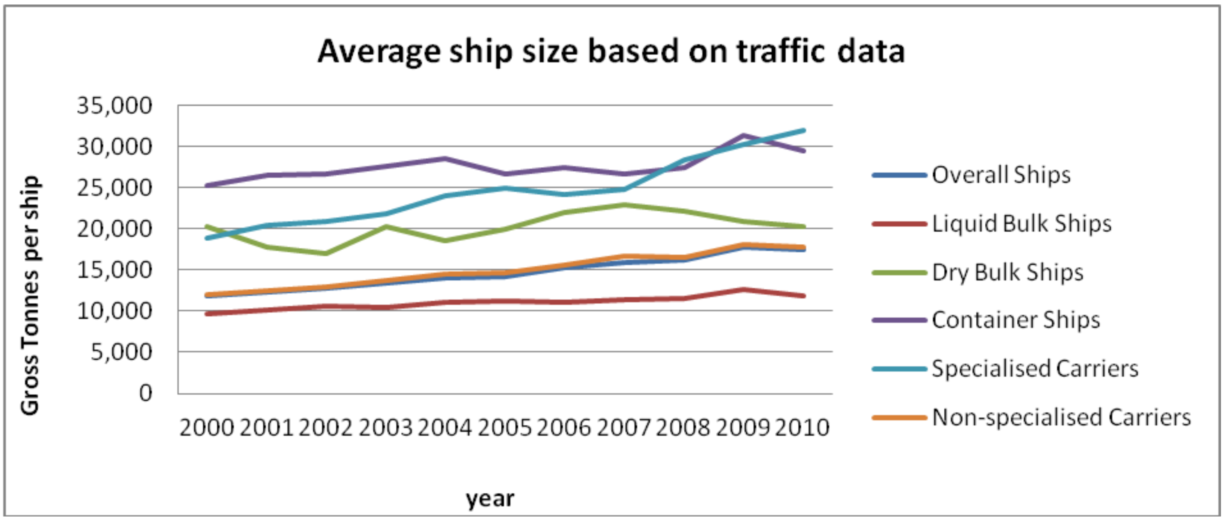

Figure 3: Average vessel size per visit based on inwards traffic data.
Source: Eurostats (2011b) and own calculations.

3. Method

This paper presents a new method for estimating the CO_2 emissions associated with shipping activity at a sub-global scale. The method is demonstrated through the use of data applicable to UK shipping. The data on cargo moved through UK ports as presented in Figures 1 and 2 are disaggregated in into individual countries of loading and unloading and used along with distance data to estimate the transport work in tonne kilometres (tkm) associated with UK seaborne trade. The distances between trading partners are estimated using online port distance calculators such as www.seadistances.com and www.vesseltracker.com. Estimates for the transport work (in tkm) associated with domestic trade are taken directly from national datasets on marine traffic along the coast (DfT, 2012). Once estimates of transport work attributable to UK shipping are available, they are mapped to the relevant ship type based on commodity type (Table 1).

Emission factor estimates for ships of differing sizes and types, measured in terms of g CO_2/tkm, are based on vessel characteristics published in Buhaug et al. (2009). These characteristics are presented in Equation 1, whereby ship capacity is expressed in deadweight tonnes (dwt). ME and AE refer to main and auxiliary engine size respectively, measured in kW. The loading factor (Lf) reflects the proportion of total engine size utilised, depending on the vessel speed. SFC refers to the fuel consumption in g/kWh and Cf refers to the carbon based fuel emission factor (kg CO_2/tonne fuel). Capacity refers to the amount of cargo that can be carried by a vessel. The utilisation factor (U_f) is expressed as a percentage and reflects the fact that a vessel will not use all of its available capacity (due to the presence of ballast, crew, fuel, or simple under loading) and/or travel a portion of the round trip while empty. V refers to average vessel speed in knots (nautical miles per hour), while 1.85 converts knots into km/h

$$g\frac{CO_2}{tnm} = \left[\frac{\sum_{i=1}^{nME}\left(ME_{(i)} * Lf * Cf_{ME(i)} * SFC_{ME(i)}\right) + \sum_{i=1}^{nAE}\left(AE_{(i)} * Lf * Cf_{AE(i)} * SFC_{AE(i)}\right)}{(Capacity * U_f) * (V * 1.85)}\right] \quad (1)$$

For ships that transport oil and petroleum products, the emissions associated with auxiliary boilers to keep cargo viscous are estimated by dividing values for annual boiler fuel consumption by the amount of transport work done (Buhaug et al., 2009). To ensure applicability, the emission factors in Buhaug et al. (2009) are at first reproduced, after which UK specific conditions are incorporated.

Lloyd's List Intelligence (formerly Lloyd's marine intelligence unit) provides data on vessels callings to UK ports in 2006. This allows for average vessel size (per call) to be estimated for different ship categories. In order to establish the veracity of such estimates, average ship sizes are compared with analogous values from two other sources; averages extrapolated from Eurostats data (as shown in Figure 3) and average ship size based on the calling of ships, since 2002, which are liable to light dues[1] (Trinity house, 2008). This comparison requires average ship size to be expressed in comparable units, i.e. ship size data from Lloyd's are translated into gross weight tonnes (gwt) based on the correlation between ship weight in deadweight tonnes and gross tonnes for each ship type within the Lloyd's dataset. Ship size data from Trinity House (2008) expressed in net register tonnes (nrt) are converted into gross tonnes based on a standard equation taken from Coast Guard Marine Safety Center (2007). For some ship types, this comparison requires aggregation of individual ship types into a more generalised category such as liquid bulk. In instances where there is disagreement, ship size is chosen based on averaging the values which are in accordance. Changes in ship size (relative to 2006) are also estimated based on the trends evident in Eurostats (2011b) and Trinity house (2008).

Once an appropriate ship size is chosen, the engine size is extrapolated based on the correlation between ship size and engine size, as estimated using the Lloyd's ship calling dataset. In estimating engine loading it is assumed that the power law relation between ship speed and engine loading holds for the main engine. However many ships are built with engines which are sized to ensure minimum

[1] Light dues are charges levied on ships for the maintenance of lighthouses.

manoeuvrability and prevent engine overload. In that regard, a safety margin of 10% is assumed, resulting in a slight augmentation to the cube law as suggested in IFEU (2010).

$$Lf = \left(\frac{V}{V\,max}\right)^3 - (1 - 10\%) \quad (2)$$

As average speed and loading factors (reflective of both ship type and size) are taken from Buhaug et al. (2009), a plausible approximation for maximum speed allows the impact of a change in ship speed on engine loading (and subsequently emissions) to be estimated. The main components which determine the emission factors (in this case, for the year 2006) are described in Table 1.

Table 1: Ship characteristics for UK shipping in 2006.

	Size (dwt)	Utilisation	Engine loading	Engine Size (kW)	g CO_2/tkm
Crude Oil	110,555	48%	80%	12,685	6
Oil Products	7,836	45%	75%	2,503	25
Other Liquid Bulk	7,151	64%	75%	2,747	13
LPG Carrier	5,278	48%	70%	2,825	22
LNG Carrier	76,156	48%	70%	29,839	21
Dry Bulk	38,832	55%	70%	7,245	6
Container	30,016	70%	65%	20,733	11
RoRo	6,840	70%	65%	6,381	17
General Cargo	3,111	60%	65%	1,370	20

Source: Lloyds (2010), Buhaug et al. (2009) and Walsh & Bows (2012).

4. Results

The estimated change in transport work associated with UK imports, exports and domestic trade is shown in Figure 4. In this case, five reference years are chosen to reflect trends across the previous decade. While overall transport work has not fluctuated drastically over the past decade (Figure 4), there are visible trends. Perhaps unsurprisingly, the transport work associated with imports exceeds that of exports. This is attributable to the comparatively lesser quantity of traded materials but primarily due to the fact that the majority of export tonnage represents trade with partners located within the EU. Based on the results for the reference years, estimates for import work grows between 2002 and 2004 and remains relatively constant until returning to similar levels in 2010. In comparison, domestic transport work has consistently decreased across all reference years. Export transport work decreases between 2002 and 2006 and increases marginally thereafter. Between 2008 and 2010 the quantity of traded materials decreased by approximately 12% while the transport work decreased by approximately 9%, which equates to a marginal increase in the distance over which goods are transported (Figures 1, 2 and 4). Estimates on the average distance travelled by UK seaborne trade are equivalent to similar estimates published in CCC (2011) which also reflects both domestic and foreign trade.

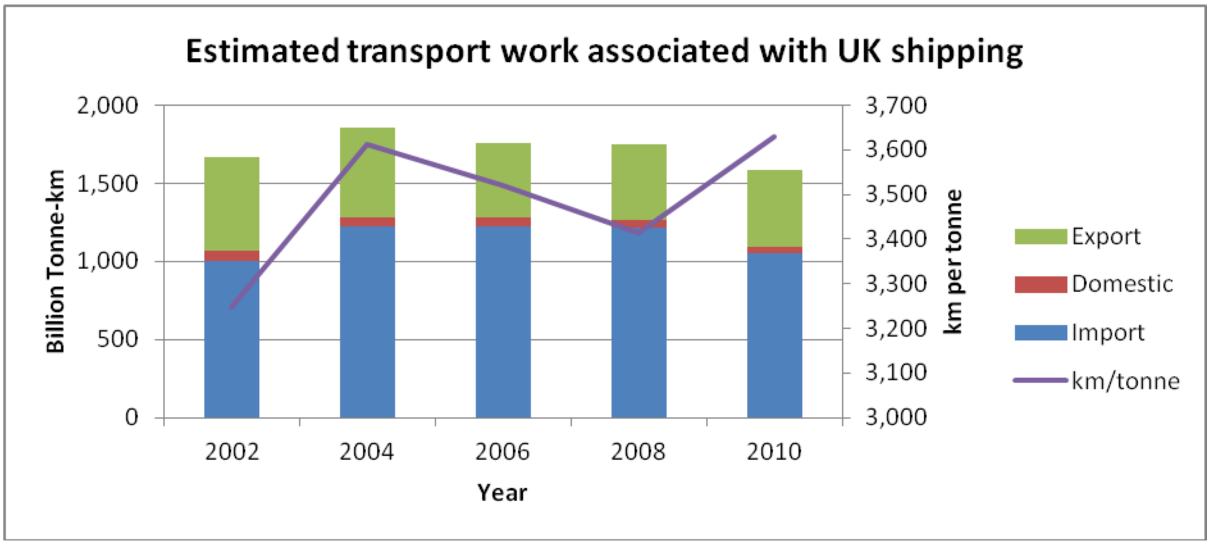

Figure 4: Absolute transport work associated with UK trade (left axis) and average distance travelled by seaborne trade (right axis).
Source: Eurostats (2011a) and own calculations.

Figure 5 shows the provisional CO_2 emissions estimate associated with UK imports, domestic trade and exports. (Note: domestic emissions are included in the import category).

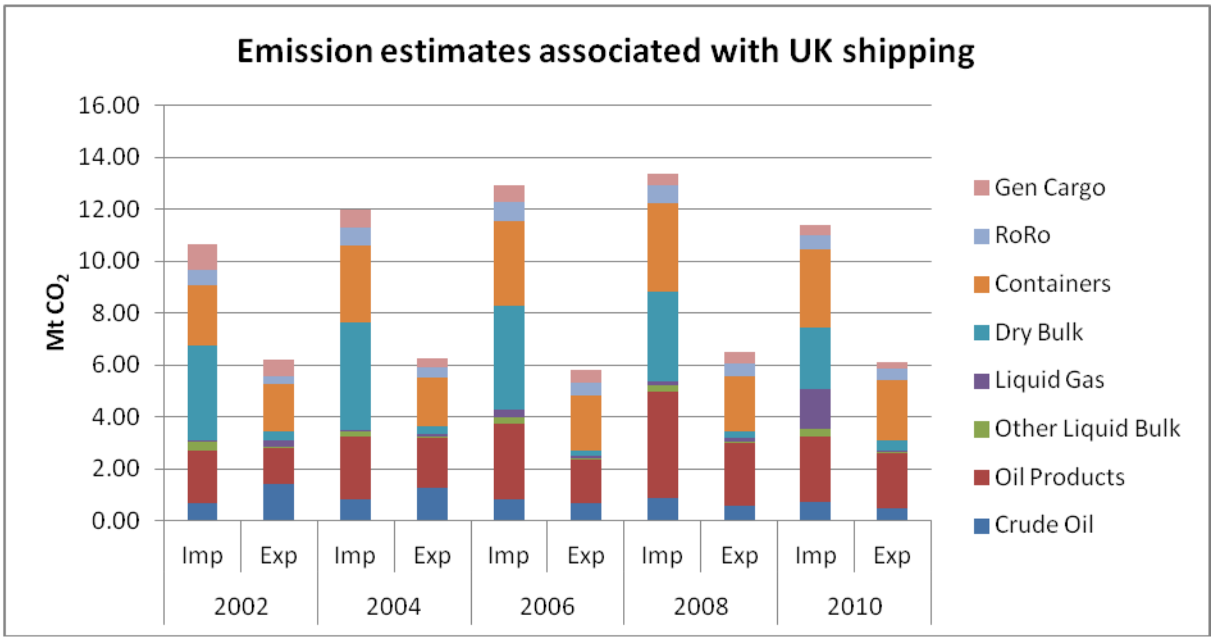

Figure 5: Emissions associated with UK imports and exports.
Source: own calculations.

In 2006 it is estimated that seaborne imports and domestic trade resulted in the emission of 12.93 Mt CO_2 in comparison to the 12 Mt CO_2 as published in CCC (2011), in reference to the same activity. As mentioned previously Schrooten et al. (2009) halve the sailing distance in order to assign national responsibility and estimate UK shipping emissions in 2005 as 8.96 Mt CO_2. If a similar method were applied within this study, comparable emissions of 9.62 Mt are estimated for 2006 (including domestic shipping which remains unchanged). Between 2002 and 2008, shipping emissions associated with both UK imports and overall trade are estimated to have an average annual growth rate of 4% and 3% respectively. In comparison, the IMO estimate that between 2001 and 2007 global shipping emissions grew by an average of 5% (Buhaug et al., 2009). Between 2008 and 2010 overall emissions fell by 12% reflecting the impact of the global economic downturn.

As Figure 5 shows, the CO_2 emissions associated with UK shipping depend on not just the transport work done (in tonne-km) but also the contribution of different commodity types. A key distinction can be made amongst goods which are traded in the greatest quantities, transported significant distances or onboard emission intensive ships. For example the distance over which dry bulk goods are transported results in this category contributing to approximately 50% of the total estimate of imported and domestic transport work. However as dry bulk carriers are (on average) less emission intensive than other cargo carriers, the category contributes to a lesser proportion (approximately 30%) of the associated emissions. In comparison, while oil products are estimated to contribute to approximately 10% of the total tonne-km value, the comparatively high carbon intensity of product tankers (also due to average vessel sizing) means that overall emissions are sensitive to trends in the trade of oil products. Similarly while containers represent approximately 12% of total traded tonnage, container ships are not only more emission intensive than dry-bulk ships but also transport goods over considerable distances. With the exception of 2008, the contribution of container ships to overall emissions has increased across the reference years, being 24% and 30% of overall emissions in 2002 and 2010 respectively. The results also illustrate the impact of drastic changes in the established patterns of trade. In 2010 emissions due to oil products and dry bulk good imports decreased relative to 2008. However this reduction has been partly offset by the emissions associated with the significant increase in imported LNG.

5. Discussion

The results included in this paper must be presented with sufficient caveats. Despite yielding results that are comparable to studies which adopt similar definitions as to what constituents "UK shipping" the model presented in this study is susceptible to high degrees of uncertainty. This is not merely a reflection of individual methodological choices but also the complexity of the shipping sector. The shipping emissions attributable to a specific country will depend, not just on the adopted definition for what constitutes national or regional shipping, but on the many individual elements which determine both the demand for, and the provision of seaborne transport work. The provisional CO_2 emissions estimated using the model, ASK-Ships, reflect underpinning assumptions on individual elements such as transport distance, ship size, type, fuel used etc. Some of these factors are discussed below.

The distance over which seaborne cargo is assumed to travel is a vital contributor to estimates of transport work (Mander et al., 2012). For the sake of simplicity both this model and Schrooten et al. (2009) assume a single origin and destination, between which ships will take the most efficient course. This is obviously a simplification as ships may dock in additional ports between the ports of loading and unloading. Although the large contribution of bulk vessels to UK transport work suggests that this issue may not be as pronounced as otherwise might be expected. Similarly the conditions at sea may necessitate deviations from the anticipated course of a journey. These factors suggest that a simplified route may underestimate the distance travelled while at sea. In contrast Eyring et al. (2010) prescribe caution when viewing generated distance estimates as such values may not accurately reflect distance across the Earth's curvature but rather reflect movement over two dimensions suggesting that such values also underestimate shipping distance.

The issue of routing is also relevant to the comparison between emissions estimated in this study and the value published by the CCC (2011). The value estimated by the CCC is based on ship movement, reflecting one journey leg from the UK port of unloading. This does not reflect the impact of transhipment, defined in CCC (2011) as the movement of cargo between ships without recourse to customs declarations and the movement of cargo onboard ships whose journey has multiple legs (i.e. liner services). CCC (2011) applies a multiplier to estimated emissions proportional to the tonnage that is assumed to be transhipped. As the method applied in this study will reflect the entire journey between countries of loading and unloading, it does not include the potential impact of the movement of cargo between ships. While CCC (2012) generate an emission multiplier by comparing UK imports in terms of the country of origin and loading, the complexity of modern supply chains implies a cautionary note. The actual impact of such transhipment on emissions will depend not just on the quantity transhipped but also the type and size of ship involved as well as the distance travelled up to the point of transhipment. While potential transhipment hubs have been identified it is likely that additional research is necessary to determine the routes, commodities and ships most susceptible to this form of transhipment.

In the interests of usability, emissions factors for transport work generated in this study represent average ship size based on the distribution of ship calls for each ship type. It should be stated that generation of such averages frustrates generating specific emission estimates (Walsh & Bows, 2012). For that reason domestic and import emissions are presented in an aggregate value. In reality it is conceivable that domestic transport work will be undertaken by smaller ships than those that service international markets. This potential variability in the emissions attributable to different shipping services suggests that more targeted definitions of shipping (e.g. the transport of agricultural bulk as opposed to total dry bulk) are susceptible to greater degrees of uncertainty. Though representative averages are used, it is likely that the instances of over and under estimation will offset each other in the aggregation process. Nevertheless it does complicate comparison of discrete emission elements. While such considerations will be examined in subsequent iterations of ASK-Ships, in the interim UK emissions are arguably best viewed collectively. However this may have unintended consequences as, for example viewing imports and exports collectively will result in double counting.

6. Conclusion

A new model developed for determining the CO_2 emissions associated with shipping at a sub-national scale, ASK-Ships, is shown to generate emission estimates which are comparable with other published figures for the UK. Figures generated by this new model– which includes both imports, exports and domestic trade – range from 16.82 Mt CO_2 in 2002 to 19.87 Mt CO_2 in 2008, during which time emissions are estimated to have increased by 3% annually. However, given the diversity of the contributing elements, the shipping emissions associated with UK transport are susceptible to high degrees of uncertainty. This uncertainty is partially attributable to the use of averages, themselves necessary in developing a comparatively simplified (and useable) facsimile of a complex and changing system. However the results at present can demonstrate the impact of changes in trading patterns on UK shipping emissions. This has implications for the impending inclusion of shipping emissions within UK national budgets. Across the reference years the emissions associated with exports are approximately 52% of import emissions, partially demonstrating the impact of UK's demand for globally sourced products. While approximately half of import tonnage is sourced outside the EU, exports are heavily skewed towards trade with European partners. Reviewing the emission estimates shows that commodities that have comparable contributions to overall emissions will do so for different reasons. For example commodities may contribute to emissions due to the sheer quantity, distance travelled, or the emission factor of the associated ship. There are duel drivers of transformation within shipping on the horizon – a low-carbon energy transition and a rapid reduction in the CO_2 emissions produced by ships. This new model will, once refined, facilitate the production of explorative scenarios for determining the impact on CO_2 emissions of radical shifts in trade patterns, ship types and the changing demand for commodities.

References

Bazari, Z., and Longva, T., (2011) Assessment of IMO mandated energy efficiency measures for international shipping. London: DNV and Lloyd's register.

Buhaug, Ø., Corbett, JJ., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, DS., Lee, D., Lindstad, H., Markowska, AZ., Mjelde, A., Nelissen, D., Nilsen, J., Pålsson, C., Winebrake, JJ., Wu, W., Yoshida, K. (2009), Second IMO GHG Study, IMO: London.

Coast Guard Marine Safety Center (2007) Tonnage guide for simplified measurement, Marine Safety Center; Washington D.C., UK.

Committee on Climate Change (2011) Review of UK shipping emissions. CCC: London.

Corbett, J., Wang, C., Winebrake, J. and Green, E. (2007), Allocating and forecasting of global ship emissions. Prepared for the clean air task force.

Department of Transport (2011) UK port statistics. DfT: statistical releases, London.

Endresen, Ø., Sørgård, E., Behrens, H.L., Brett, P.O., Isaksen, I.S.A., (2007), A historical reconstruction of ships fuel consumption and emissions. Journal of Geophysical Research 112:(1-17).

Eurostats (2011a) Seaborne trade statistics. European Commission: Luxembourg.

Eurostats (2011b) Vessel traffic statistics. European Commission: Luxembourg.

Eyring, V., Isaksen, I. S. A., Berntsen, T., Collins, W. J., Corbett, J. J., Endresen, O., Grainger, R. G., Moldanova, J., Schlager, H., and Stevenson, D. S. (2010): Transport impacts on atmosphere and climate: Shipping, Atmos. Environ., 44, 4735–4771.

Eyring, V., Köhler, H.W., Lauer, A. and Lemper, B. (2005b), Emissions from international shipping: 2. Impact of future technologies on scenarios until 2050. J. Geophys. Res. 110, (1-18).

Eyring, V., Köhler, H.W., van Aardenne, J., and Lauer, A. (2005a), Emissions from international shipping: 1. The last 50 years. J. Geophys. Res. 110 (1-12).

Garrat, M. (2011), Latest trends in global trade and the business case for Port Centric Logistics. Mds Transmodal. PortCentric Logistics conference: Birmingham.

Gilbert, P., and Bows, A., (2012), Exploring the scope for complementary sub-global policy to mitigate CO2 from shipping, Energy Policy, in press.

Institut für Energie und Umwelt Forschung. (2010) Ecological Transport Information Tool for Worldwide Transports: Methodology and Data. DB Schenker Germany and UIC : Germany.

Lloyd’s list intelligence (2010), Ship calling dataset. Lloyd's List Intelligence: London.

Mander, S., Walsh, C., Bows, A., Gilbert, P., Traut, M.,(2012). Systems perspective on decarbonising energy – implications for UK shipping. Submitted to Journal of Carbon Management.

Nakicenovic et al. (2000) IPCC Special Report on Emissions Scenarios, Cambridge University Press; Cambridge, United Kingdom and New York, USA.

Schrooten, L., De Vlieger, I., Int Panis, L., Chiffi , C., Pastori,E. (2009). Emissions of maritime transport: A European reference system. Science of the Total Environment,408(2):318-323.

Stopford, M. (2008), Martime Economics. Routledge: London and New York.
Trinity House (2008) Report on light dues. Prepared by Raven trading on behalf of Trinity House.

Trinity house; London, United Kingdom.

United Nations conference on Trade and Development (2011), Review of shipping. UN: Geneva.

Walsh, C. and Bows, A. (2012) Size matters: Exploring the importance of vessel characteristics to inform estimates of shipping emissions. Applied Energy, 98,128-137.