A systems perspective on decarbonising the UK energy system – the impacts on shipping CO_2 emissions

Dr Sarah Mander[1]**, Dr Conor Walsh*[1]*, Dr Paul Gilbert*[1]*,*
Michael Traut[1] *and Dr Alice Bows*[2]

[1] Tyndall Centre for Climate Change Research, School of Mechanical, Aerospace and Civil Engineering, University of Manchester, M13 9PL
Email: s.mander@manchester.ac.uk; Conor.Walsh@manchester.ac.uk, Paul.J.Gilbert@manchester.ac.uk, Michael.Traut@postgrad.manchester.ac.ukc

[2] Sustainable Consumption Institute, School of Mechanical, Aerospace and Civil Engineering, University of Manchester, M13 9PL
Email:alice.bows@manchester.ac.uk

** corresponding author*

Abstract

The UK's climate change mitigation policies require reductions in CO_2 emissions of 80% by 2050 within specified emission budgets. Meeting these objectives necessitates the deployment of low carbon technology across the whole UK energy system for the provision of electricity, heat and energy for transport. A shift to electricity, for example, is envisaged for heat and surface transport, with decarbonisation of the grid by 2030. Current energy supply relies heavily on the shipping of fossil fuels in the form of coal, gas, oil and transport fuels; these imports contribute 46% of UK imports by weight. The future energy system may take many different forms, and different supply options will have a knock-on effect on the patterns of fossil fuel trade into the UK, with a corresponding impact on the demand for shipping. This paper uses two contrasting future energy scenarios devised out by the UK's Department of Energy and Climate Change to explore future demand for fuel and demonstrates that different scenarios imply differing patterns of imports and a corresponding impact on the CO_2 emissions from the shipping of that fuel.

Keywords: energy system change; CO_2 emissions; demand for shipping

1. Introduction

Whilst the emissions from international transport are currently excluded from UK emission budgets, the UK Government is to review the exclusion of international shipping and aviation emissions towards the end of 2012. The UK Government's independent advisor on climate change, the Committee on Climate Change (CCC), has recommended that these emissions are included within the targets (Committee on Climate Change 2011). Under an emission budget, all sectors of the economy have to contribute to the achievement of an overall target. If one sector does less, or is less able to reduce its emissions, other sectors must make greater reductions to remain within the budget. The inclusion of the emissions from international transport into the 2050 target will thus place greater pressure on other sectors of the economy to reduce emissions whilst at the same time necessitating reductions in the emissions from international shipping and aviation.

The shipping sector provides a service to other sectors and is strongly influenced by other sectors in terms of the demand for its services (Van de Voorde 2005; Stopford 2009). Demand for shipping reflects the demand for goods which in turn reflect the state of the economy, changing tastes and broader structural changes. One such structural change on the horizon, is the decarbonisation of the UK energy system necessitated to meet the UK challenging climate change targets of an 80%

reduction by 2050, within specified emissions budgets (Department of Energy and Climate Change 2008; Department of Energy and Climate Change 2011). Achieving the UK's climate change objectives requires the deployment of low carbon technology across the whole energy system for the provision of heat, electricity and energy for transport. The current UK energy system is predominately fossil fuel based, and as an island, heavily reliant on imports arriving in the UK by ship. The future energy system may take many different forms, and different energy supply options will have a knock-on effect on the patterns of UK fuel trade, with a corresponding impact on the demand for the shipping of fuel and the associated CO_2 emissions. This paper uses the decarbonisation of the UK energy system as a case study to explore how demand for fuel impacts on the CO_2 emissions resulting from the shipping of that fuel.

2. Method

The approach to assessing CO_2 emissions from shipping is based on previous analysis conducted at Tyndall Manchester, focusing on the whole energy system (Mander, Bows et al. 2008) and aviation (Bows, Anderson et al. 2009). The following 5 step process is followed:

1. CO_2 emissions associated with current imports are quantified using the 'ASK for ships' model to provide a baseline against which to assess future emissions. The model and its approach to quantifying CO_2 emissions are described in (Walsh, Bows et al. 2012)
2. Contrasting DECC energy scenarios, for 2050, are used to illustrate alternative visions of the UK energy system and to quantify fuel imports in (Department of Energy and Climate Change 2011; Department of Energy and Climate Change 2012).
3. A set of trade assumptions are outlined to specify import distances for each fuel. To simplify the emission and distance calculations, and given the uncertainty of knowing how much fuel would be imported from a particular source in 2050, the 'what if' scenario assumption is that UK demand is divided equally between the major trading partners highlighted.
4. Freight work is calculated for each scenario; freight work is the quantity of freight transported multiplied by the distance travelled
5. The CO_2 emissions are calculated using the 'ASK for ships' model.

3. Energy baseline

The UK Energy Digest provides estimates of total final energy demand at 1972 TWh (for baseline year 2006) (Department of Energy and Climate Change 2007). Figure 1 shows a breakdown of final energy demand by end-user.

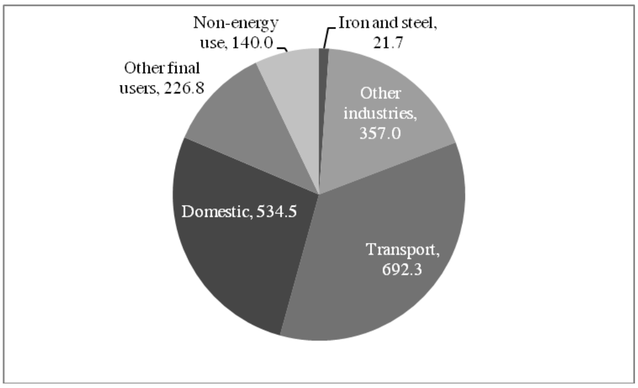

Figure 1. UK final energy demand by end user in 2006 in TWh
Source: Department of Energy and Climate Change (2007)

Figure 2 is a breakdown of final UK energy demand by fuel, highlighting the importance of the combustion of natural gas for space, water and process heating and the use of petroleum for transport.

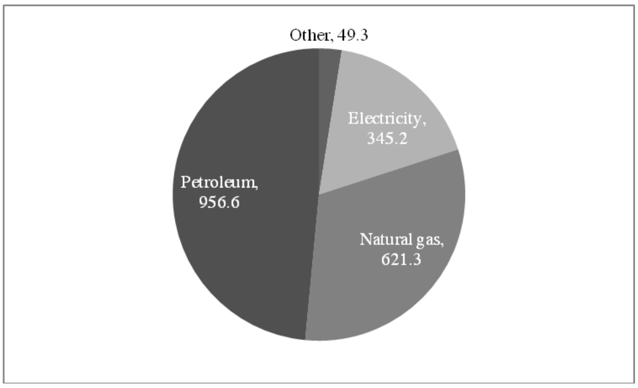

Figure 2. UK final energy demand by fuel in 2006 in TWh
Source: Department of Energy and Climate Change (2011)

Whilst the UK is a significant producer of oil, coal and natural gas, it is a net energy importer as illustrated in Figure 3.

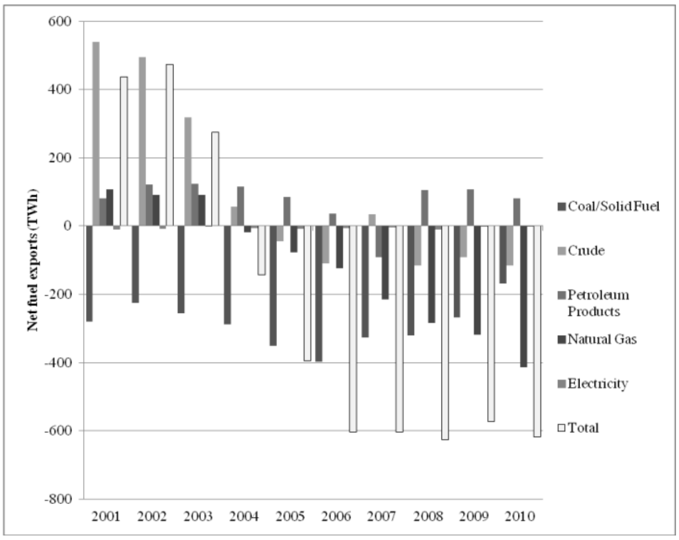

Figure 3. UK net fuel exports in Twh between 2000 and 2010
Source: Department of Energy and Climate Change (2011)

Taken individually, different energy commodities reflect different patterns of trade. The oil crisis in the Middle East precipitated a shift towards Europe in particular Norway and Russia for imports of oil and oil products (Eurostats 2011). In the past decade the main source of imported crude has been Norway, due to its proximity and compatibility between Norwegian crude and domestic production. Significant quantities of crude are also shipped from Russia (Department of Energy and Climate Change 2011). Refined petroleum products represent a more diverse range of exporting countries (Department of Energy and Climate Change 2011). Diesel is mainly imported from Europe whereas aviation fuel is imported from Asia. The imports of natural gas demonstrate an important shift in trade patterns, increasing 24 fold between 2010 and 2000 (Eurostats 2011), reflecting new trade with Qatar. The past decade has seen a gradual decrease in South African and Australian coal imports in favour of Russian, Columbian and American imports.

4. UK 2050 energy system scenarios

This paper focuses on 2 contrasting DECC energy system scenarios for 2050, the ‘higher energy efficiency, more renewable energy’ scenario (RE) and the ‘higher carbon capture and storage, more bioenergy’ scenario (CCS) (DECC, 2011). A more detailed analysis focusing on the 4 DECC energy system scenarios outlined in the ‘Carbon Plan’ (DECC, 2011) can be found in Mander, Walsh et al (2012). In the ‘RE’ scenario, there has been a step change in behavior and reductions in the costs of renewable energy technologies and energy storage technologies. This results in large reductions in per capita energy consumption; 55% of electricity consumption is met by renewable technologies. The ‘CCS’ scenario is characterized by a step change in CCS technology; biomass is used with CCS (BECCS) to generate negative CO_2 emissions, allowing emission space for the continued use of fossil fuels. Per capita reductions in energy consumption are lower in the CCS scenario than in the RE scenario. The scenarios are described in detail in DECC (2011). Figures 4 and 5 illustrate energy demand and energy supply for the 2 scenarios, compared to a baseline[1].

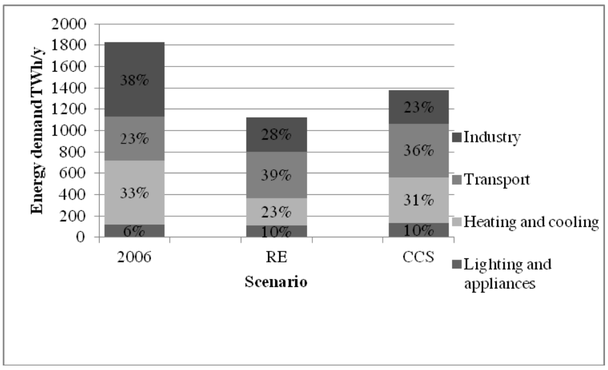

Figure 4. 2050 Primary Energy demand (TWh/y) for the RE and CCS scenarios
Source: Department of Energy and Climate Change (2007); Department of Energy and Climate Change (2011)

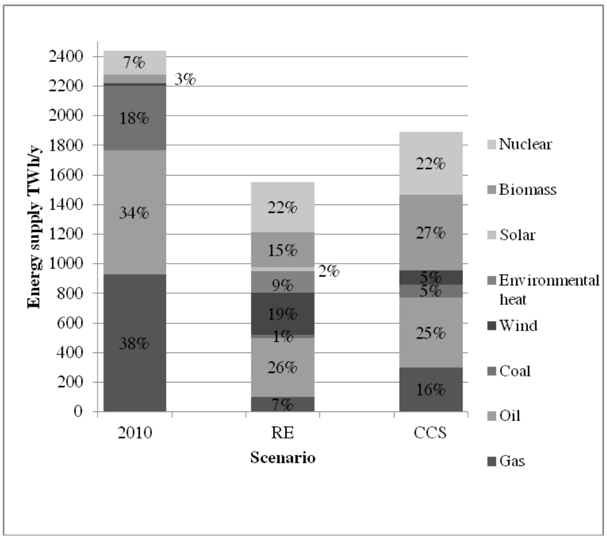

Figure 5. 2050 Primary Energy supply by fuel (TWh/y) for the RE and CCS scenarios
Source: Department of Energy and Climate Change (2011)

---

[1] Energy demand is compared to 2006 and energy supply to 2010. This is due to a lack of consistent energy supply data being available for 2006. The energy supply system was similar, however, in the 2 years.

The scenarios are characterised by different requirements for indigenous and imported fuels based on assumptions about the availability of domestic supply. Figure 6 illustrates the quantities of imported fuel.

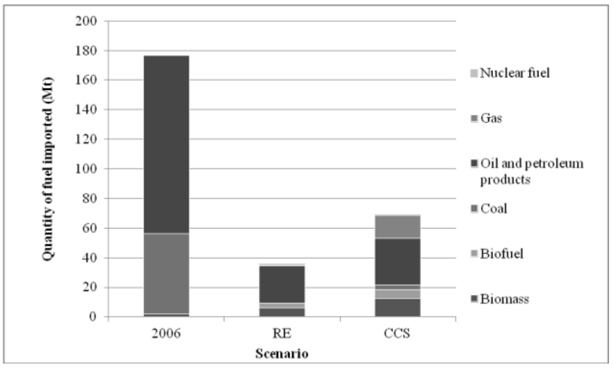

Figure 6. Quantity of fuel imports

Source: Department of Energy and Climate Change 2007; Department of Energy and Climate Change (2012)

5. Fuel trade assumptions for 2050

The import assumptions propose continued imports from existing key suppliers. In 2050, there will be reduced demand for petrol and diesel due to the penetration of alternative fuels, such as electricity within the transport sector, but continued high demand for aviation fuel, due to a lack of low carbon alternatives (Department of Energy and Climate Change 2011; Department of Energy and Climate Change 2011). In this light, and given that OPEC countries' share's of world oil production is set to rise (British Petroleum 2012) high levels of imports from OPEC countries with large refining capacity for aviation fuel, predominately Kuwait and Saudi Arabia, as well as crude oil imports from Norway are maintained. Piped gas imports continue from Norway. At present, imports of shipped LNG are dominated by imports from Qatar (Department of Energy and Climate Change 2011); to reduce dependence on a dominant source for shipped LNG, UK imports of LNG are diversified to include Australia (British Petroleum 2012; Financial Post 2012). Coal imports continue from Russia, the US and Columbia. Whilst small in 2010 relative to imports of fossil fuels, imports of solid biomass and liquid biofuels are likely to be significant in 2050. Solid biomass is imported as pellets from Canada, which has invested in pellet production facilities, and as olive cake from Spain (Junginger, Bolkesjo et al. 2008). Liquid biofuels are imported from Brazil and South Africa (Smeets, Faaij et al. 2004; Junginger, Bolkesjo et al. 2008). The implications of these assumptions in terms of import distance are illustrated in Figure 7.

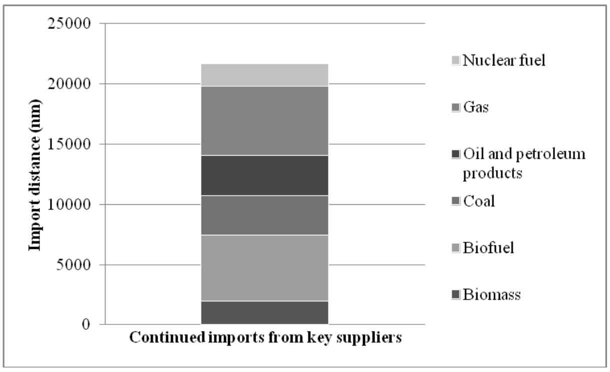

Figure 7. Fuel import distance

Source: www.seadistances.com

6. Results

Figure 8. illustrates the freight work associated with the import of fuels in 2050.

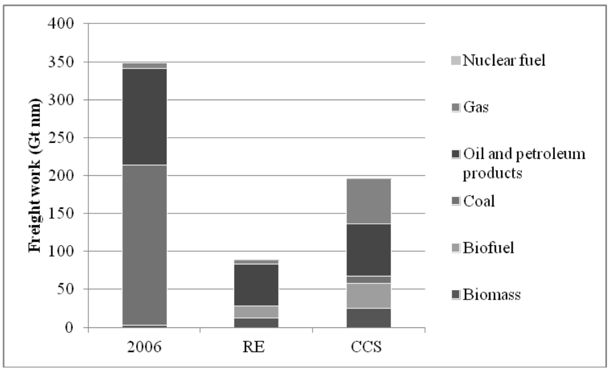

Figure 8. Freight work (in Gt nm) for fuel imports in 2050
Source: authors

Figure 8 demonstrates that the form of the energy system in 2050, and hence demand for fuel, has implications for shipping. Not only is the total amount of freight work arising from the shipping of fuel reduced by either 75% or 44% depending on the scenario, but the make-up of that demand has changed significantly. For the baseline year (2006) coal, oil and petroleum products are the dominant contributors to freight work; this changes, however, according to the assumptions made within the energy scenarios. Overall, by 2050, there is expected to be less need for the shipping of coal, oil and petroleum products, but new requirements for shipping biomass and biofuels. In the 'higher renewable, more energy efficiency' scenario 'RE' there is low energy demand due to a reduction in per capita energy consumption of 53% , delivered through a high penetration of demand reduction approaches in buildings and a large switch to public transport (Department of Energy and Climate Change 2011). The low level of demand, coupled with the high proportion of primary energy supply from renewables, (Figure 5) results in the lowest demand for imported fuels in 2050, and the lowest amount of freight work. The small amounts of coal that are used in this scenario can be sourced domestically. The highest freight work in 2050 arises in the 'higher CCS, more bio-energy' scenario, 'CCS' due to the considerable quantities of gas, oil and bioenergy that are shipped. The extensive deployment of CCS allows for the continued use of gas for thermal generation, hence LNG imports that are higher than in 2006.

The CO_2 emissions associated with fuel imports in 2050 are illustrated in Figure 9. At this stage, no assumptions have been made with respect to the abatement of shipping CO_2 emissions due to operational or technical measures

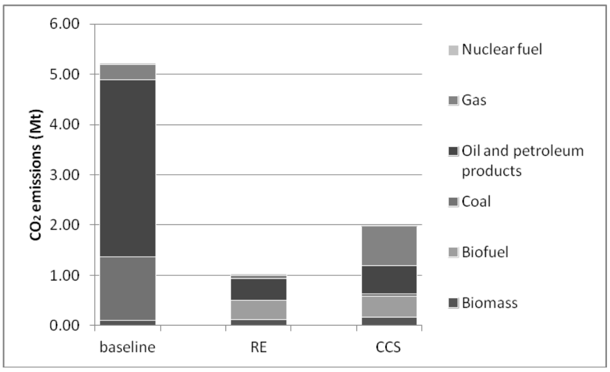

Figure 9. CO_2 emissions (in Mt) for fuel imports in 2050
Source: authors

Figure 9. demonstrates that the form of the energy system in 2050, and the associated shipping of fuels, has implications for the CO_2 emissions arising from the shipping of fuel. In 2006, 68% of CO_2 emissions from fuel shipping are a consequence of the shipping of oil and petroleum products and a further 24% arise from the shipping of coal. CO_2 emissions from shipping are dependent on the quantity of commodity shipped, the distance it is shipped and the emission factor of the ship. The shipping of coal represents 60% of freight work, yet only 24% of shipping CO_2 emissions due to the low emission factors (6 gCO_2/tnm) associated with the large (in the region of 163,000 dwt) ships commonly used to transport coal (Buhaug Ø 2009; Stopford 2009). Whilst oil is shipped in large ships with low emission factors (110,000 dwt and 10 gCO_2/tnm), oil products are shipped in smaller ships where the need for auxiliary boilers to keep fuel viscose leads to higher emission factors (78,000 dwt and 45 gCO_2/tnm) (Buhaug Ø 2009; Stopford 2009). This leads to the shipping of oil and oil products representing 34% of freight work and 68% of shipping CO_2 emissions respectively in 2006.

Energy system changes will have a considerable impact on the CO_2 emissions associated with the shipping of fuels in 2050, with CO_2 emissions reducing by 81% under the 'RE' scenario and 62% under the 'CCS' scenario. The CO_2 emissions from fuel shipping in the 'CCS' scenario are nearly twice as large as those in the 'RE' scenario. Clearly, the quantities of imported fuels implied by the assumptions previously outlined about demand reduction, penetration of renewable technologies, deployment of CCS and so on influence CO_2 emissions in the same manner as they do freight work. Ship size and emission factor also comes into play, however. The energy system changes will result in changes in the markets for shipping of particular fuels. Thus the market for the shipping of coal may reduce significantly, but new markets will emerge for the shipping of solid biomass and liquid biofuels associated with particular countries or regions; the quantities of commodity shipped is likely to impact on ship size and emission factor ((Buhaug Ø 2009; Stopford 2009).

At present biomass is shipped as general cargo, on small ships (7,000 dwt) with emission factors in the region of 36 gCO_2/tnm (Buhaug Ø 2009; Stopford 2009). In the future, new or retro-fitted ships will be required to meet the demands for the shipping of bioenergy commodities and the size of these ships is a key factor in ensuring that these commodities are shipped in as carbon efficient manner as possible. In the 'RE' scenario, some 6 Mt of biomass and 3 Mt of biofuels are required in addition to domestic resources; this rises to 13Mt of biomass and 6Mt of biofuels in the 'CCS' scenario. In the 'RE' scenario, due to the size of the market, the assumption is made that biomass is transported in dry bulk ships of 60,000 dwt with an emission factor of 9 gCO_2/tnm; biofuels is transported in product tankers of 30,000 dwt with an emission factor of 24 gCO_2/tnm (Mander, Walsh et al. 2012). The larger market suggested in the 'CCS' scenario leads to the assumption that ships are larger, 120,000 dwt and 100,000 dwt for biomass and biofuels respectively, leading to lower emission factors of 7 gCO_2/tnm and 13 gCO_2/tnm (Mander, Walsh et al. 2012). Achieving the scale of reductions in shipping CO_2 emissions suggested is dependent on the emergence of new markets for the shipping of bio-energy commodities that use the most appropriate vessel. If ships that currently serve the bio-energy market continue to do so, the CO_2 emissions from the shipping of that fuel would effectively be doubled.

Up to this point, the analysis does not consider the abatement of CO_2 emissions from the shipping sector as a result of the deployment of operational and technical measures; the impact of changing demand is clearly demonstrated. The shipping sector does, however, face pressure to take steps to reduce its climate change impact. Taking the UK as an example, whilst shipping is not currently included in climate change policies, this exclusion is to be reviewed in late 2012 and the independent body that advises the UK Government on climate change, the Committee on Climate Change (CCC), has recommended that the emissions from international shipping and aviation should be included in the 2050 targets and emission budgets (Committee on Climate Change 2011). Options to abate CO_2 emissions from shipping, include increasing ship size, fuel substitution, additional wind propulsion systems (Traut et al, 2012) and speed reduction but not all may be applicable to all ships types (Buhaug Ø 2009; Crist 2009; Committee on Climate Change 2011). The CCC considers 3 levels of abatement: 22%, 48% and 65% (Committee on Climate Change 2011). The 22% abatement would be achieved with limited abatement beyond that required to achieve the Energy Efficiency Design

Index (EEDI). A 65% abatement would be achieved with full take-up of potential technical and operational measures, and fuel substitution of 5% LNG and 15% biofuels. Applying these figures across the 'RE' and 'CCS' scenarios, suggests that with high abatement, CO_2 emissions from the shipping of fuel could be reduced by 93% in the case of the 'RE' scenario, and by 83% for the 'CCS' scenario. Were a lower level of abatement to be achieved (e.g. 22%). CO_2 emissions would reduce by 85% for the 'RE' scenario, and by 70% for the 'CCS' scenario.

7. Conclusions

Under current climate change legislation UK shipping will experience a massive change in the types and quantities of fuels transported. Overall, there is a reduction in freight work of 75% in the case of the 'RE' scenario and a 44% reduction in the 'CCS' scenario. Whilst coal and oil and oil products are currently the biggest contributors to freight work and CO_2 emissions, under a suite of low carbon energy system scenarios biomass and biofuels become increasingly important. Continued use of coal within the UK energy system is contingent on the successful deployment of CCS technology, and there will be little or no market for the transport of coal without CCS. The importance of bio-energy commodities is such that in the future, transport in dedicated carriers is essential to that transport does not contribute significantly to CO_2 emissions. Even without technological abatement, changing demand for fuels can reduce the CO_2 emissions from the shipping of fuel by between 81% and 62%, depending on the assumptions made about the future energy system.

8. Acknowledgements

This research was funded by the EPSRC Energy Programme through the *High Seas* Project and the Sustainable Consumption Institute.

9. References

Bows, A., K. Anderson, et al. (2009). "Aviation in turbulent times." Technology Analysis & Strategic Management 21(1): 17-37.

British Petroleum (2012). Energy Outlook 2030. London.

Buhaug Ø, C. J., 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 2009. London, International Maritime Organization (IMO).

Committee on Climate Change (2011). Review of UK Shipping Emissions. The Committee on Climate Change. London.

Crist, P. (2009). Greenhouse Gas Emissions Reduction Potential from International Shipping, Joint Transport Research Centre of the OECD and the International Transport Forum.

Department of Energy and Climate Change (2007). Digest of United Kingdom energy statistics (DUKES). Department of Energy and Climate Change. London, The Stationary Office.

Department of Energy and Climate Change (2008). Climate Change Act 2008. Department of Energy and Climate Change. London, The Stationary Office: 103.

Department of Energy and Climate Change (2011). The Carbon Plan: delivering our low carbon future. London, HM Government.

Department of Energy and Climate Change (2011). Digest of United Kingdom Energy Statistics (DUKES). Department of Energy and Climate Change. London, The Stationary Office.Department of Energy and Climate Change (2011). Statutory Security of Supply Report - A report produced jointly by DECC and Ofgem. London, The stationary Office

Department of Energy and Climate Change. (2012). "http://2050-calculator-tool.decc.gov.uk/pathways." Retrieved 31at May 2012, from http://www.decc.gov.uk/en/content/cms/tackling/2050/calculator_on/calculator_on.aspx.

Eurostats (2011). Quarterly trade data on marine traffic. Luxembourg, Eurostats.

Financial Post (2012). Australia says shale could double its gas resources. Financial Post. Adelaide.

Junginger, M., T. Bolkesjo, et al. (2008). "Developments in international bioenergy trade." Biomass & Bioenergy 32(8): 717-729.

Mander, S., Walsh, C., Bows, A., Gilbert, P. and Traut, M. (2012). "Decarbonising the UK energy system and the implications for UK shipping." Carbon Management (In submission).

Mander, S. L., A. Bows, et al. (2008). "The Tyndall decarbonisation scenarios-Part I: Development of a backcasting methodology with stakeholder participation." Energy Policy 36(10): 3754-3763.

Smeets, E., A. Faaij, et al. (2004). A quickscan of global bio-energy potentials to 2050 - An analysis of the regional availability of biomass resources for export in relation to the underlying factors, Copernicus Institute - Department of Science, Technology and Society.

Stopford, M. (2009). Maritime Economics. London and New York, Routledge.Van de Voorde, E. E. M. (2005). What future the maritime sector? Some considerations on globalisation, co-operation and market power. Global Competition in Transportation Markets: Analysis and Policy Making. 13: 253-277.

Traut, M., Bows, A., Gilbert, P., Mander, S., Stansby, P., Walsh, C., and Wood, R. (2012). Low C for the High Seas - Flettner rotor power contribution on a route Brazil to UK. International conference on technologies, operations, logistics and modelling for low carbon shipping. The University of Newcastle, Newcastle

Walsh, C., A. Bows, et al. (2012). Recent trends in UK Shipping Emissions: Implications for sectoral decarbonisation. International conference on technologies, operations, logistics and modelling for low carbon shipping. The University of Newcastle, Newcastle