What is a fair measurement and apportionment scheme?

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Abstract

An apportionment strategy is a necessary mechanism to understand and scale the greenhouse gas (GHG) emissions produced by international shipping. This is a sector that exceeds national boundaries and an apportionment strategy should be in place to attribute those emissions to nations. A number of alternative strategies have been identified and discussed in the literature. These include apportionment based on fuel sale, ship movements, national emissions, etc. To be an appropriate strategy, it is suggested that a measurement and apportionment strategy to be fair and feasible to implement. In this paper, apportionment strategy is based on demand share of individual countries. Based on this strategy, Global maritime model (GloTraM) will be used to generate emission levels apportioned to countries.

Keywords: Apportionment, GHG emissions,

1 Introduction

One of the difficulties faced by the IMO has been determining both the actual level of emissions from international maritime activity and finding an instrument, which allows responsibility for these emissions and for emission reduction efforts to be allocated to nations. The IMO second GHG report (Buhaug et al., 2009) has accomplished the first task by establishing a consensus estimate of international maritime CO2 emissions. The second task, however, has proven more difficult for several reasons, not least of which is the complex nature of ownership and control in the maritime sector.

This current paper follows from the work of Smith and O’Keeffe (2012) where a number of apportionment strategies were discussed in detail.

2 Literature review

Subsidiary Body for Scientific and Technological Advice (SBSTA, 1996) contains a number of options for possible allocation of shipping emissions. Some of the methods are simple and rely on smearing shipping’s global emission across states according to a proxy for responsibility. Other methods are more complicated and rely on details about emissions associated with a specific voyage or the geographical location of a ship. The options include:

1. No allocation
2. In proportion to national emissions
3. According to where the bunker fuel is sold
4. According to the nationality of the transporting company, where the vessel is registered or to the country of the operator
5. According to the country of departure or destination of a vessel or some split between arriving and departing countries
6. According to the country of departure or destination of a vessel’s cargo, or some split between arriving and departing countries
7. According to the country that owns the cargo or origin of the passengers (dismissed by SBSTA)
8. According to emissions generated in a country’s national space (dismissed by SBSTA)
Besides option 1, which is to continue with the status quo and is therefore deemed unacceptable, these two overarching approaches (simple and complicated) can better be categorized as top down and bottom up methods.

A number of authors have conducted studies to calculate the emissions produced according to one or more of the different allocation options (Heitmann and Khalilian, 2010 and Gilbert et al, 2010). Gilbert et al (2010) compare estimates of the UK’s share of emissions from different options. Heitmann and Khalilian (2010) look at global emissions allocated to countries (and aggregated back up to regions) according to a number of the different SBSTA options (Options 2-6). The findings indicate no consistency between the options. Whilst for some regions (e.g. Europe), all options provide at least some degree of consistency, for other regions (e.g. Central America) the difference between options is frequently an order of magnitude or more.

Options 7 and 8 were dismissed by SBSTA in the same report that they proposed them. Option 7, because of the data burden and method complexity, and Option 8 because it left emissions occurring in the high seas unallocated.

In a study by Smith et al (2012), the fairness and effectiveness of a number of apportionment strategies were discussed. Variants of bottom-up options associated with ship movements (option 5 above) and trade (option 6) were found to be the most credible mechanism for emissions allocation. Details of method and data collection required for a bottom-up method was examined to determine the feasibility of such approach.

The main objective of a system for MRV is to provide reliable data on GHG emissions from maritime transport. A robust MRV system is the foundation for implementation of any measure reducing GHG emissions of ships at EU or global level and facilitates results based monitoring of progress. Therefore, its implementation is useful, even without an MBM in place.

According to the results of the Impact Assessment, the implementation of MRV provides – to some extent – environmental and economic benefits of up to 2% reductions in annual GHG emissions and of up to € 1.2 billion annual net savings for the sector in 2030 due to reduced fuel bills. The predicted fuel cost savings is expected to outweigh the costs for monitoring and reporting (European Commission, 2013).

The recent EU proposal on monitoring, reporting and verification (MRV) of emissions (European Commission, 2013) advised all EU related voyages shall be monitored for amount and type of fuel consumed. The report did not discuss or dismiss an apportionment philosophy and the proposed data to be captured does not preclude the use of Option 5 or Option 6. However, by only capturing traffic data and not the origin or destination of the cargo the report is implicitly advocating against a trade based apportionment philosophy (option 6). Notwithstanding this, the authors of this paper believe it remains important not to dismiss Option 6 as it serves, at the very least, as a comparison for option 5 apportionment. Moreover, National Emission Inventories (NEI) are submitted annually by countries party to the UNFCCC on a production basis. Trade based estimates of apportionment are more compatible with this approach as they facilitate easy conversion from production to consumption based estimates as some authors are calling for (Willing & Vringer, 2007 and Peters, 2008). Although it is not currently clearly defined, the forthcoming discussions at IMO MEPC (MEPC IMO, 2013) with respect to MRV may also have an impact on the data collection methodology development that in turn could have a bearing on the practicality of different apportionment mechanisms.

3 Statement of the problem

A number of options have been proposed for national emissions allocation. It is clear from the existing literature that the allocation is highly sensitive to the option chosen. There is therefore a significant consequence to a nation and/or region’s implied responsibility associated with the selection of an option and this makes the issue politically sensitive, a situation made more difficult because many of the assessment criteria (e.g. fairness) are subjective and hard to evaluate.

Alongside the politically contentious selection of an option is its feasibility from a method and data perspective. Data for top down calculations can be sourced from existing and long established internationally recognized sources (e.g. national GDP or emissions calculations). The methods are simple, involving little more than the calculation and application of percentage shares. Whereas bottom-up methods require a method or data collection programme, which can resolve detail on a per-ship and often per-voyage level. There is no existing international obligation for shipping data reporting that can be deployed to meet this level of detail.
The remaining sections of this paper are intended to:

- Provide a brief outline of GloTraM and models used in the analysis.
- Explore further the implications of deploying trade/freight movement (option 6) for allocating emissions to nations.
- Investigate some of the simplified apportionment models, particularly with respect to their appropriateness for use in a rebate mechanism for potential market based mechanisms.

4 Description of the method and approach

There remain limited datasets describing international shipping’s emissions in sufficient detail and levels of disaggregation, to allow quantification of emissions apportionment. One of the few data points is included in Buhaug et al. (2009), expanded in further detail in IMO MEPC 60 WP.5. Both are for global aggregates of emissions. Ricardo AEA (2013) estimated the share of international shipping’s emissions attributable to the EU, however this is for the EU in isolation – the same method was not applied to enable quantification of other global regions, for the purposes of comparative analysis.

In the absence of data, the approach taken in this paper is to use bottom-up, disaggregated model derived estimates of shipping’s activity and associated emissions and apply these to apportionment frameworks. The two principle drivers of shipping’s CO₂ emissions are:

- the transport demand (e.g. tonne nm)
- the transport carbon intensity (e.g. gCO₂/tonne nm)

The model used for estimation of both of these variables is GloTraM, developed through the project “Low Carbon Shipping – A Systems Approach”. The model uses data derived baseline year assumptions and then a time-domain simulation to estimate how shipping activity and emissions will evolve over time.

The model decomposes global trade and the shipping fleets servicing that trade into ship type categories. In this paper, the three ship types that dominate international shipping’s emissions are focused on: wet bulk, dry bulk and container ships. Domestic shipping emissions are not included (these are assumed to be accounted for in national emissions inventories). The model time-scale is from a baseline year of 2010 out to 2050.

The assumptions most pertinent to this analysis are described in greater detail below. Reports outlining the model’s input assumptions and method can be found in Smith et al. (2013a) and Smith et al. (2013b) respectively.

4.1 Assumptions on the technical and operational parameters describing the ships servicing the transport demand (baseline year)

GloTraM is calibrated to a baseline year, 2010. The transport demand derivation and ship-route matching is defined below. Calculations of carbon intensity of different ship types and sizes are given in Buhaug et al. (2009) however these are derived from 2007 data, a year prior to the global financial crisis and the adoption by many ship operators of slow steaming. As a result, for 2010, GloTraM uses estimations of ship speed (a constituent of a ship’s total transport supply) and the corresponding effect on fuel consumption, based on the data presented in Smith et al. (2013c). This approach uses Satellite AIS observations of shipping activity on different routes, which is similar to the approach taken for model derived estimates of the EU’s carbon emissions Ricardo AEA (2013).

The world fleet in 2010 is taken from Clarkson’s World Fleet Register. A number of ships are laid-up from this fleet, in the event that the transport supply exceeds the transport demand.

4.2 Assumptions on the technical and operational parameters describing the ships servicing the transport demand (future years)

Transport carbon intensity is a function of the evolution of a fleet’s composition (ships) and their technical and operational specifications. These are determined by combining consideration of regulation, economics and technology performance, availability and cost and applying to models of how the fleet evolves both through stock turnover (newbuild and scrappage) and existing fleet management (lay up, retrofit and operation). The choices that are made to determine technical and operational specifications of newbuild and existing ships are driven by the profit maximization of the ship’s owner, and regulatory compliance. A number of technical and operational interventions options, for both energy efficiency and alternative fuels are used in the model. An
The important feature of the model is its representation of the interaction between technical and operational specifications and the inclusion of technology additionality and compatibility. For description of the detail applied in the engineering characterization, see Calleya et al. (2011).

The regulatory, economic and technology development backdrop to the model is described by a number of “exogenous factors” which define a scenario for global economic development (including GHG and non-GHG regulation of shipping, fuel prices and carbon prices). For this paper, the business as usual scenario defined in Smith et al. (2013a) is used, however it should be noted that the carbon emission trajectory is sensitive to these input assumptions and a range of different global emissions scenarios are feasible.

### 4.3 Trade scenario

#### 4.3.1 Wet, dry and containerised transport

Derivation of trade (tonnes and teu) between origin and destination countries in the form of an origin-destination matrix for each vessel type is based on the Newton et al. (2009a) proportions of total trade flows using the WORLDNET tool. The WORLDNET tool is based on the traditional four-stage model (FSM) used in transport modeling. Base year flows are taken from EUROSTAT and COMTRADE and supplemented by other national data where gaps exist. Data is output as country-to-country commodity flows (value and tonne/teu) by transport mode. The base year for the data is 2005; the trade module uses aggregate income data from the economic model to expand the base year flows (Newton et al., 2009b).

The total trade flows are scaled by the IMO Second GHG Report projections on transport demand growth based on the IPCC A1B scenario (Nakicenovic, N. & Swart, R., 2000). The baseline year (2010) is scaled by UNCTAD reported data to account for the discrepancy between the NEA 2010 modelled trade flows and the actual 2010 trade flows.

At the UK level, trade is further scaled in line with the CCC Central Scenario. Adjusting UK trade is not considered to significantly affect total global trade (approximately 5% of global trade flows), so the discrepancy between the dataset after adjusting UK would still broadly be inline with the IMO estimates. The overall process is outlined in Figure 1.

![Diagram](image)

**Figure 1:** Approach to generating trade estimates

#### 4.4 Approach used for modeling the allocation of ship type and size to trade flow (Eoin/Solmaz)

Allocation of trade to ship types and sizes consists of, i) allocating the commodity to a particular ship types, and ii) allocation of trade to route and ship size. For the latter, there are two algorithm types which reflect the nature of the industry. Container transport is allocated according to a liner type network while wet and dry bulk trades follow a tramp network. The details of the methods are outlined below.
4.4.1 Allocation of commodities to ship types

GloTraM considers the detailed technical and operational characteristics of ships, and also the transport demand for which their activity is derived. Therefore, an added complication to determining an appropriate disaggregation is that the ship categories match with disaggregation of the trade and transport demand data. For example, crude oil is predominantly transported in crude oil tankers and so there is a one-one mapping of the transport demand to the transport supply. However, some chemicals are carried in product tankers and some in chemical tankers and substitution might occur between the ship types. To achieve this balance and whilst matching the constraints in the input data, the following disaggregation has been selected:

- wetbulk
  - wet crude (referred to as wet_crude)
  - wet product and chemical (referred to as wet_prod_chem)
- drybulk
  - dry (inc. general cargo) (referred to as dry)
- unitised
  - unitised containers (referred to as unit_cont)

Appendix A and B provide the mapping of individual commodity codes to the aggregations of ship types and the matching of low level ship types into the higher level ship types. The table shows the high-level ship type and low-level ship type (naming as used in the Clarksons World Fleet Register data product). Additionally, the table matches those ship types to different commodities and groups of commodities. The IMO literature uses different ship type taxonomy to the Clarksons World Fleet Register, and these can be seen mapped onto the low-level ship types.

4.4.2 Containership to TEU flow route matching

Allocation of trade in TEU’s to routes consists of two main processing components: Container assignment module and vessel size allocation module. Container assignment involves the allocation of container traffic flow to origin-destination pairs. The allocation algorithm starts by identifying major hubs around the world using the Liner Shipping Connectivity Index of the country (UNCTAD, 2013). The set of hub countries through which trade is route is first identified by setting a parameter, alpha, where countries with an LSCI index above this value are designated as hub countries. All other countries have their trade routed through the nearest hub country. In this paper, alpha is set to 30.

\[
Trf_{ij} = \begin{cases} 
0 & \text{if } i, j \in \text{non} - \text{hub} \\
\sum_{non-hub}^{\text{non-hub}} Trd_{ij} + Trd_{ik} & \text{if } j \in \text{hub}, i \in \text{non} - \text{hub} \\
\sum_{non-hub}^{\text{non-hub}} \sum_{non-hub}^{\text{non-hub}} Trd_{ij} + Trd_{ik} + Trd_{ij} + Trd_{kl} & \text{if } i, j \in \text{hub}
\end{cases}
\]  

(1)

Where

- \(Trf_{ij}\) Amount of traffic from country \(i\) to country \(j\) (TEUkm)
- \(Trd_{ij}\) Volume of trade between country \(i\) and country \(j\) (TEU)
- \(k, l\) Country of transhipment
- \(i, j\) Country of origin and destination

Exports from each country are directed first to nearest hub (if itself is not a hub country). The flow is then transshipped to another hub country nearest to the destination (or straight to the destination country if it is a hub country). This iterative process generates a traffic flow (in TEU’s and TEUkm’s) and is visually displayed in Figure 2, further details are available at (Haji et al, 2013).
4.4.3 Bulk (wet and dry) to tonne flow route matching
Allocating vessels to routes is based on Kendall (1972) where the optimum vessel is that which minimises the total shipper’s costs as shown in (2 to 4).

\[ TC_s = S(Q_s) + S_h(Q_s) + H + P_c \]  
(2)

\[ S(Q_s) = \frac{Q_s V I}{200q_y} + \frac{FU}{q_y} \]  
(3)

\[ S_h(Q_s) = d \alpha Q_s^\beta \]  
(4)

Where
- \( TC_s \) = total cost for ship size \( s \) (\$/tonne)
- \( S(Q_s) \) = Inventory and storage cost (\$/tonne)
- \( Sh(Q_s) \) = Shipping cost (\$/te)
- \( H \) = Handling cost (\$/tonne)
- \( P_c \) = Port costs (\$/tonne)
- \( V \) = FOB commodity value (\$)
- \( I \) = Interest rate/cost of capital
- \( Q_s \) = Vessel size (dwt)
- \( Q_y \) = Annual volume on route (te)
- \( FU \) = Cost per tonne to store cargo (\$/te)
- \( d \) = Voyage distance (km)
- \( \alpha, \beta \) = Cost coefficients

It is assumed that per unit of cargo, handling cost, port costs and storage cost do not vary with vessel size, reducing the equation to inventory costs and transport costs (freight rate), resulting in a convex function of cost vs. dwt. This is complicated by the existence of more than one route between countries where there are vessel size restrictions, resulting in a stepped function. The optimum vessel size is that which minimises the total cost for each bilateral commodity flow.

The main assumptions for this method are that a single vessel type and size is used to transport the cargo from origin to destination. Within the vessel size category that the flow is associated with, there are no significant deviations that would alter the route distance outside the bounds of the track efficiency. To some extent this is supported by work from Kaluza et al. (2010), who found the average number of the minimum number of port calls between all pairs of ports to be extremely small at 2.5. Comparing the container network, dry bulk and wet bulk networks they found the mean journeys per link to be low at 4.65 and 5.07 for dry bulk and wet bulk respectively while containers ships were at 24.25. This suggesting more direct country to country flows in dry and wet but a hub and spoke type network dominating the container trade. The method also assumes there is no mixing of commodities for the determination of optimum vessel size.
4.5 Apportionment philosophy

Using GloTraM, the fleet’s activity is calculated on an annualised basis and statistics produced for the average ship in each type, size and age category (fuel consumption, carbon emissions, transport supply etc.). This is then applied to the route-matching algorithm’s results which categorises the different ship types and sizes servicing the disaggregated trade flows (inter and intra region flows for different ship types). From this, national and regional statistics can then be obtained for CO₂ emissions according to different allocation philosophies.

In Figure 4, the apportionment philosophies for Option 5 (ship movement, CCC in blue) and Option 6 (trade, LCS in red) are described for a consumption-based approach. The quantifications in this paper are for Option 6, a trade based approach that attributes a nation or region’s trade flow’s carbon emissions with either a production (export) or consumption (import) based approach.

Figure 3 – An example of a voyage with two transshipment hubs.

5 Results

The import and export flows in tonnes are displayed in Figure 4 and Figure 5. The trade scenario does not include any domestic trade (i.e. transport demand within countries). Container flows in TEU have been converted to their equivalent tonnes using a uniform conversion factor of 6.9 tonne/teu. The conversion factor is mean tonne/teu for the global trade in teu and is low as it includes empty containers that are in transit due to repositioning. Nonetheless, the trade scenario is dominated by continued strong imports to Asia developing economies and strong exports in manufactured goods.
Figure 4: Import scenario for all commodities by region.

Figure 5: Export scenario for all commodities by region.

Figure 6 and Figure 7 show the evolution of the trade scenario together with the relative demand for commodities. In the trade scenario, the demand for manufactured goods increases, most notably for Asian populations. As outlined earlier, the model does not include any market-based mechanisms resulting in continued increases in emissions of greenhouse gases albeit not at the same rate as the increase in trade (by any of the metrics shown).
Figure 6: Change in CO2 emissions, transport demand in value distance and tonne distance, trade in values (USD) and tonnes lifted and also average distance over which goods are traded weighted by value of goods where 2010 values are indexed to 1.

Figure 7: Apportionment of emissions by ship type

Figure 8 to Figure 10 show various apportionment strategies and their relationship to modeled emissions (as defined by the bar ‘emissions import based’). At MEPC 64, WWF (2012) proposed a rebate mechanism (RM) based on value distance to mitigate cost impacts from a market based mechanism. Comparison between the modeled emissions ‘bar’ and those of each of the different metrics used, demonstrates that whilst no metric is perfect, Value distance is consistently the most well correlated metric to use in a RM if apportioning on consumption (import based) of goods. Although South America and South East Asia in the 2050 scenario would receive double the proportion than if it were based on import emissions. It is notable that the export based emissions from North East Asia (including Japan and China) is low as compared its import based emissions. By
mass, China does not dominate the export market to the extent that it dominates the import market as it is predominantly high value goods that are exported. Consequently, regions that are rich in primary resource (Australasia, South America and Middle East) have large export emissions. The figures also show, through comparison of the different metrics to the modeled emissions, that the use of value or value weighted distance, and indeed mass and trade weighted distance, are not likely to be suitable proxies for actual emissions.

Ricardo AEA (2013) calculated the emissions associated with Europe based on an activity model in 2010 and backcast to 2007 to determine the apportionment of global emissions to Europe as a percentage of global emissions calculated in Buhaug et al. (2009). They found it to be 20% which is below the 2010 value from this study of 28% (combined Europe and UK, but also including Russia and Turkey while Ricardo AEA (2013) calculated emissions for EU countries only).

Figure 8: Percentage Apportionment of emissions by region of import, region of export, value distance of imported commodities, tonne distance of imported commodities, value of imported commodities and value weighted (VW) distance of imported commodities in 2010.
Figure 9: Percentage Apportionment of emissions by region of import, region of export, value distance of imported commodities, tonne distance of imported commodities, value of imported commodities and value weighted (VW) distance of imported commodities in 2030.

Figure 10: Percentage Apportionment of emissions by region of import, region of export, value distance of imported commodities, tonne distance of imported commodities, value of imported commodities and value weighted (VW) distance of imported commodities in 2050.

6 Concluding remarks

6.1 Burden, responsibility and the rebate mechanism

The results show that value distance is the most robust proxy for emissions allocation assuming that allocation should be consumption (Option 6) based using the GloTraM maritime model. However, the model does account
for geographic variations in efficiency of vessel types and indeed using value distance as a proxy for emissions does not account for this also.

6.2 Comparison with traffic based estimates of apportionment
Following the earlier discussion regarding the EU most likely adopting option 5 apportionment, the following section briefly outlines what the expected effects on the results would be. In GloTraM, the apportionment of emissions would exactly match import based emissions for vessels arriving and exactly match export based emissions for vessels departing in the case of dry, wet_crude and wet_prod_chem as the shipping networks for these sectors assume direct traffic. However, for emissions from the container fleet, apportionment of emissions will be largely to hub countries. The liner shipping connectivity index can be used as a proxy for these major hub countries and shows 4 non-Annex 1 economies in the top 10 (China, Singapore, South Korea and Malaysia). This would suggest that apportionment of emissions, particularly if we assume the trade trajectory outlined in Figure 7 and a continued shift to Asian centric liner networks, would be heavily weighted against Asian economies.

6.3 Limitation of study
An important point to note regarding the trade dataset does not include domestic transport. Therefore, countries that have significant domestic maritime transport, particularly China, are favoured in the apportionment of emissions in Figure 8 to Figure 10.

6.4 Further work
Further work is required on apportionment of emissions to small island developing states (SIDS). The vessel to route matching and network development is robust for the larger economies where the annual flows are large enough to command shiploads for the bulk cargoes and the hub and spoke assumed network for container flows. However, for SIDS the cargoes are likely to be less than full vessels and archipelagoes are more likely to be served by multi-stop circular or pendulum network. Therefore, an empirical analysis of vessels serving SIDS, most likely based on S-AIS data, is recommended.

7 Acknowledgments
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## Appendix A – mapping of commodities to ship types

<table>
<thead>
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<th>NST2</th>
<th>Description</th>
<th>unit_co</th>
<th>dry</th>
<th>dry_reef</th>
<th>wet_cru</th>
<th>wet_pro</th>
<th>wet_oth</th>
<th>gas</th>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>Cereals (including cereals used for animal feed)</td>
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