A spatially explicit data-driven approach to calculating commodity-specific shipping emissions per vessel

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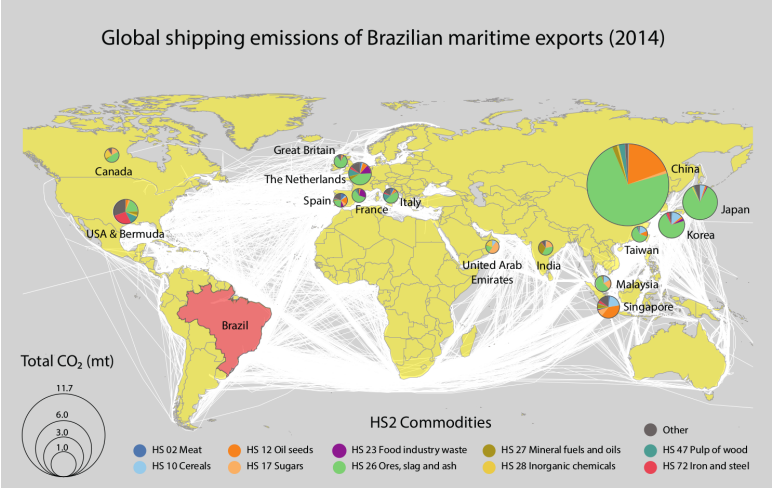

Figure 1. *Global shipping emissions from Brazilian exports in 2014.*

Ocean-going ships carry approximately 80% of the world's traded goods by volume, which translates into more than 10 billion tonnes in shipped traded volumes per year. Despite its importance, the maritime shipping sector has been traditionally overlooked in climate mitigation discussions, since this sector was largely neglected in the 1997 Kyoto Protocol. Key barriers for successful implementation of CO_2 abatement measures in the sector include the lack of reliable emissions data and the inherent difficulty of attributing responsibility for international shipping emissions to the involved countries, companies and commodities, as well as the threat to global trade interests. We argue that the data paucity on maritime emissions from international trade can be addressed by linking and integrating a large wealth of data, previously used in isolation. By linking per vessel cargo composition data, individual vessel journeys from the Automatic Identification System (AIS) and a bottom-up methodology to estimate emissions, this paper describes and demonstrates this new approach for the case of Brazil's shipping manifests.

The manifests used in this study included the shipment of 350,734 cargo-specific trades, shipped on 4,089 vessels, describing 124,173 voyages moving goods from Brazil to 112 countries. Most importantly, they specified the departure and arrival port, as well as the date of travel. For the individual ship movement, we scoped all AIS messages for the year 2014. Extending the methods from Jia et al. (2017), we classified a port call based on whether a vessel is stationary for a sustained period of time at a location close to a port and found a total of 1,387,859 stops for 28,948 vessels. Following the methodology described in the Third IMO GHG Study, CO_2 emissions for each vessel and its trajectories were estimated based on a ship's calculated fuel consumption and operational voyage data from its AIS messages (see Smith et al (2015)). By matching the exported cargo composition with the appropriate sailed voyage, we were able to obtain the spatially-explicit shipping emissions associated with the transportation of each traded commodity and arrival country. Our process of linking the datasets contained different degrees of stringency in matching criteria, which resulted in higher levels of uncertainty for 8.1% of shipping manifest records. We accepted this to provide an estimate of the total emissions associated with all Brazilian maritime exports in 2014.

We found that the maritime transportation associated with these trades is responsible for 25.99 million tonnes of CO_2, an addition of 5% to Brazil's total CO_2 emissions of 2014 (reported by the World Bank, currently excluding international shipping and aviation). Over 90% of Brazil's maritime exports is made up of 8 HS2 chapters [1] and transported to 28 countries, which illustrates Brazil's nature of being a major exporter of commodities in bulk of relatively low value, to major production countries and/or transhipment hubs. By analysing commodity- and voyage-specific emissions in conjunction, the above-described strong allocation to a very limited number of products and actors became evident (figure 1). Figure 2 shows the top 20 commodities contributing to Brazilian export shipping emissions, where the largest emissions are those of ore, slag and ash (HS 26), contributing 14.67 million tonnes of CO_2 (56.5% of the total), with 73% of this amount emitted on voyages to China (8.5 million tonnes of CO_2) (figure 1). The export of oil seeds and oleaginous fruits, grains and seeds (HS 12) and cereals (HS 10) come 2nd and 3rd with their transportation emitting 3.17 (12.2%) and 1.46 (5.6%) million tonnes of CO_2, respectively. With regard to destination-specific accounting, Brazilian exports to China account for the largest proportion, with 11.6 million tonnes of CO_2 emissions (45.6% of total), while this represents only 19.1% of Brazil's outgoing trade in value. Japan and South Korea follow, representing 8.43% and 4.56% of shipping

1The HS is an international nomenclature developed by the World Customs Organization for the classification of goods (WCO, 2017).

emissions respectively. Discrepancies between total weight, value and associated emissions are notable (see figures 2(a) and 2(b)), which emphasises the importance of considering both emission accounting criteria.

Overall, our observed emissions per weight lie between 48,000 and 70,000 grams of CO_2 per tonne of shipment (g/t), while this range is 32,000 to 113,000 g/t for destination-specific results. By factoring in the average distance travelled by a given commodity, it is possible to somewhat dissociate emissions from distance and take into account that some commodities show different demand in relation to transport distance, which lead to the formation of a notable cluster where emissions per tonnage range between 18 and 24 g/t nautical mile (nm) travelled (g/tnm) (figure 2(d)). When looking at the entire dataset, instead of only the top 20 emitting voyages, we found that 95 routes of 112 emit CO_2 between 11 and 48 g/tnm. A similar cluster can be observed in figure 2(c).

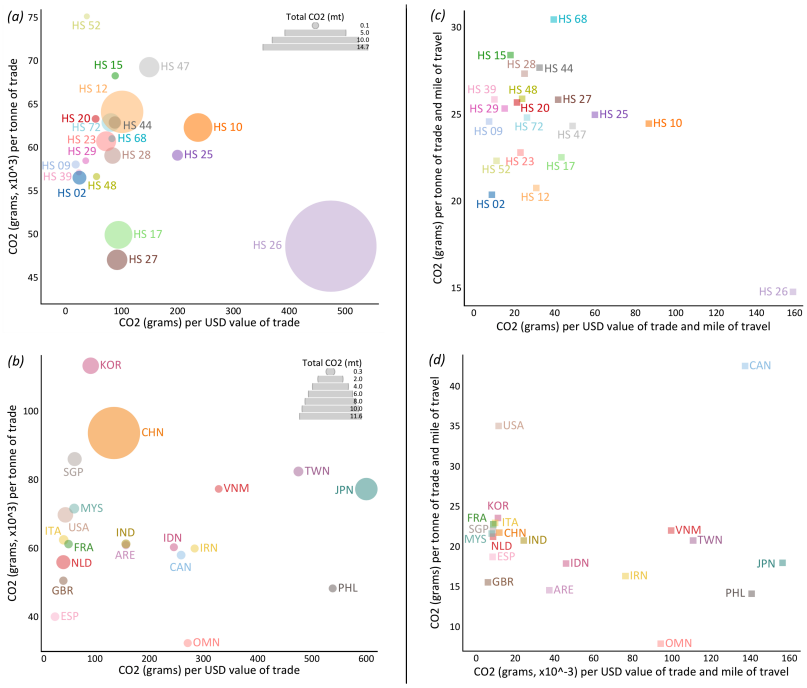

Figure 2. *(a) Top 20 Brazilian exports contributing to shipping emissions, at HS2 level aggregation; (b) top 20 destinations contributing to Brazilian export shipping emissions. Values weighted by both weight and financial value, on the y- and x-axis, respectively. Sub-figures (c) and (d) showcase these values with the distance dimension taken into account (total emissions per tonnage mile or USD mile).*

Our approach also allowed for an in-depth focus on individual commodities. Figure 3 is an example of the way our results can highlight direct geographic demand where figure 3(a) shows how the vast majority of emissions associated to soybean (HS 1201) transportation are linked to exports to China. Additionally, our method can show the geographic allocation of shipping emissions associated to some of the more valuable exported commodities, which may be of economic interest to the country in question (for example sugar (HS 1701) and coffee (HS 0901), ranked 3rd and 7th in value, as shown in figures 3(b) and 3(c)).

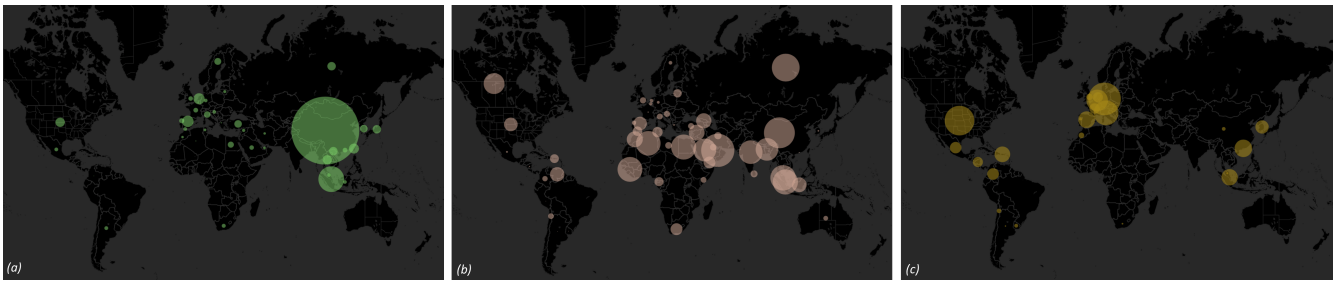

Figure 3. *Country allocation of the shipping emissions associated to the export of selected commodities: (a) soybean (HS 1201), (b) sugar (HS 1701) and (c) coffee (HS 0901)*

As shown, the data provided by our method opens the exploration of specific drivers of shipping emissions, creating entry points for targeted emission reduction interventions. The voyage- and commodity-specificity of this method allowed us to specify those commodities and trading routes which contribute the most towards this emissions account, in relation to those that are most valuable to Brazil's economy. When scaled up, this method has the potential to offer a reliable global account of trade-related maritime transport emissions. Please refer to the full paper for more discussion on further applications and perspectives with respect to global greenhouse gas abatement efforts and demand-side footprint calculations, as well as improving accountability mechanisms for the maritime sector as a whole.

Jia, H., Adland, R., Prakash, V. & Smith, T., 2017. Energy efficiency with the application of Virtual Arrival policy. *Transportation Research Part D: Transport and Environment,* July, Volume 54, pp. 50-60.
Smith, T. W. et al., 2015. *Third IMO GHG Study 2014,* London: IMO.