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Mitigation of CO_2 emissions from international shipping through national allocation

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Abstract

Neither international treaties nor domestic policies control carbon dioxide (CO_2) emissions from international shipping. To enhance mitigation, a new multilateral mechanism could allocate these emissions to national carbon budgets, where different options could be used based on the location of industry actors and ships. We analyze five allocation options, showing that a clear majority of CO_2 emissions would be distributed to ten countries under each option; however, the top ten countries vary across allocation options and the amount of CO_2 emissions allotted to individual countries could increase their carbon budgets thousand-fold or more. We further examine how the different objectives, principles for decision-making, and geographical coverage of the United Nations Framework Convention on Climate Change (UNFCCC) and the International Maritime Organization influence the design and implementation of an allocation mechanism under each of these two bodies. We find that the allocation mechanism that best meets criteria related to effectiveness and equity would be one in which emissions are assigned to countries of ship owners, and which operates under the UNFCCC.

1. Introduction

To meet the 2015 Paris Agreement's goal to limit global average temperature increases to well below 2°C above pre-industrial levels, and to pursue efforts to limit them to 1.5°C, it is central that all human-induced greenhouse gases (GHGs) are counted and mitigated (Traut *et al* 2018). The 1992 United Nations Framework Convention on Climate Change (UNFCCC) stipulated that only domestic sources of GHG emissions should be included in country-based calculations of emission totals. The Intergovernmental Panel on Climate Change in 1996 recommended that carbon dioxide (CO_2) emissions from domestic shipping should be included in national carbon budgets, while emissions from international shipping should be reported separately (IPCC 1996). The 1997 Kyoto Protocol obligated industrialized countries to pursue limitation or reduction of GHGs from marine bunker fuels, but it delegated further discussion on CO_2 emissions from international shipping to the International Maritime Organization (IMO). In the 2010s, international shipping was responsible for approximately 2% of global annual CO_2 emissions (IMO 2020).

Despite over two decades of discussion, the IMO has failed to design a strategy to appreciably reduce CO_2 emissions from international shipping. The IMO initiated its first legal measures on CO_2 emissions in 2011 through amendments to Annex VI on air pollution to the 1973 International Convention for the Prevention of Pollution from Ships (MARPOL) (Tanaka 2016, Kopela 2017). The 2011 amendments, together with further action in 2016, introduced mandatory energy efficiency and fuel reporting measures through the Energy Efficiency Design Index and the

Ship Energy Management Plan, respectively (Lister *et al* 2015). In 2018, the IMO adopted an initial strategy on reducing GHG emissions from international shipping with the goal that they should peak as soon as possible, and be reduced by at least 50% from 2008 levels by 2050, while pursuing efforts to phase them out completely. Discussions are continuing among IMO members, but existing measures are not nearly enough to meet this goal (Doelle and Chircop 2019). In the absence of more ambitious mitigation, CO_2 emissions from international shipping may increase by up to 50% above 2018 levels by 2050 due to an expansion in maritime trade (IMO 2020).

International political debates and analyses about how to address CO_2 emissions from international shipping date back to the 1990s (Oberthür 2003, Anderson and Bows 2012, Hackmann 2012, Harrison 2013, Bows-Larkin 2015, Zhang 2016). One previously identified policy option is for the world's countries to agree on a collective mechanism for allocating these emissions to national carbon budgets, including a mechanism that is based on the national location of a particular shipping industry actor or a ship (SBSTA 1996, Gilbert and Bows 2012, Shi and Gullett 2018). There are multiple actors who play different roles in the shipping industry, and discussions of any national allocation scheme for CO_2 emissions from international shipping are influenced by the fact that these actors as well as ships are registered in countries all over the world (Poulsen *et al* 2021). There is also a long history of complex and opaque ownership structures in the shipping industry (Harlaftis 2019). In addition, the national location of industry actors and ship registrations can easily change over time (DeSombre 2006).

Taking into consideration options outlined by a UNFCCC subsidiary body in 1996 (SBSTA 1996), a few previous studies have quantified outcomes of allocation options based on the country location of shipping industry actors and ships (den Elzen *et al* 2007, Faber *et al* 2009, Heitmann and Khalilian 2011). Heitmann and Khalilian (2011) most recently calculated how much CO_2 emissions would be added to different countries and regions. Their analysis was based on estimates of CO_2 emissions for the year 2007 using assumptions about ship type and annual average fuel consumption. Heitmann and Khalilian carried out the analysis in the context of the Kyoto Protocol (which required GHG reductions only from industrialized countries) and the 2009 Copenhagen Accord (which included participation also by some developing countries). Based on their analysis, considering environmental and legal efficiency and burden sharing relate to the Kyoto Protocol and the Copenhagen Accord, Heitmann and Khalilian concluded that CO_2 emissions should be allocated to the country of the ship operator.

Both the global institutional context and the availability of shipping data have changed since the earlier quantitative studies were conducted. The Paris Agreement introduced a flexible approach to country-based mitigation of GHGs that includes participation by all the world's both industrialized and developing countries through their own nationally determined contributions (NDCs) (Falkner 2016, Romera 2016). All parties to the Paris Agreement are mandated to regularly update their NDCs with the intent of increasing mitigation efforts and policy goals over time. The changing nature of national sources of GHG emissions also no longer reflects a strict division between high-emitting industrialized countries and low-emitting developing countries (but many developing countries have relatively low per capita emissions). In addition, previous analyses of national allocation schemes were limited by data availability on the national location of industry actors and inventories of CO_2 emissions from ships.

Here, we evaluate the implications of different national allocation options for CO_2 emissions from international shipping. We use spatially-resolved data based on detailed ship movements for estimating CO_2 emissions. Further analysis using such data was called for by Heitmann and Khalilian (2011). We use data on ship movements and bunker fuel sales to calculate outcomes related to five national allocation options: (a) the country where the ship is flagged ('flag country'); (b) the country of the ship owner ('owner country'); (c) the country of the ship manager ('manager country'); (d) the country of the ship operator ('operator country'); and (e) the country where bunker fuel is sold ('bunker fuel country'). Our results differ from earlier quantitative analyses, including the one by Heitmann and Khalilian (2011) calling for a national allocation scheme based on the country-specific location of the ship operator. Taking into consideration the Paris Agreement and effectiveness and equity issues, we argue that CO_2 emissions from international shipping are most appropriately allocated to the country of the ship owner. In addition, we propose that such an allocation scheme is most appropriately designed and implemented under the UNFCCC.

2. Methods

We use one set of data to calculate CO_2 emissions for the 'flag country,' 'manager country,' 'owner country,' and 'operator country' options and another set of data to calculate CO_2 emissions for the 'bunker fuel country' option. Table 1 summarizes and defines the five allocation options as well as lists the associated data sources that we use for our analysis of each allocation option. All data are for year 2015. Figure 1 in supplemental materials illustrates the data that we use and our methodological approach.

For the allocation options of 'flag country,' 'manager country,' 'owner country,' and 'operator country,' we conduct a bottom-up estimation for CO_2

Table 1. Allocation options and data sources.

Allocation option	Description	Data source
Flag country	The country where a ship is officially registered. A ship flies the flag of the country where it is registered.	World Register of Shipping from IHS Maritime & Trade
Owner country	The country where the entity that is the owner of the ship is legally registered. The owner is defined as the asset owner, e.g. the entity which ultimately benefits financially from the employment of the vessel.	World Register of Shipping from IHS Maritime & Trade
Operator country	The country where the entity that operates the ship is legally registered. The operator is defined as the commercial decision maker concerning the employment of the vessel and therefore decides how and where that asset is employed.	World Register of Shipping from IHS Maritime & Trade
Manager country	The country where the entity that manages the ship is legally registered. The manager is defined as the entity who is responsible for the daily running of a vessel. Management may be sub-contracted to a third party or undertaken as an internal function by the owner or operator.	World Register of Shipping from IHS Maritime & Trade
Bunker fuel country	The country where a seller of marine bunker fuel is located. Bunker fuel sellers are typically located near major ports.	International Energy Agency

emissions using an integrated dataset of terrestrial and satellite automatic identification system (AIS) data along with a global-level ship parameter database. We differentiate between ships used for international shipping and domestic shipping based on their geographical range, a distinction not explicitly made in previous studies. We use our own ship emission inventory model; a detailed description of this model is provided by Zhang *et al* (2019). The ship activity data that we use for emission estimates are collected from the AIS dataset.

We use data on the country where a ship is flagged as well as the national location of ship owners, operators, and managers from the World Register of Shipping (WRS) operated by IHS Maritime & Trade. Industry structures of ship owners, operators, and managers can be complex (Poulsen *et al* 2021). Industry actors also sometimes look to maintain anonymity to avoid liabilities in instances of accidents and spills. However, any allocation mechanism based on the national registration of a ship or an industry actor would likely use data from publicly accessible sources such as the WRS. An individual IMO number is required for all propelled international sea-going merchant ships over 100 GT (IMO 2016), and we base our calculations and analysis on the ships with an IMO number that are listed in the WRS database.

To identify individual ships, we use terrestrial and satellite AIS data that contain more than 896 million rows of AIS records of global ship activity for 2015. We assume that AIS signals are from the same ship if they have identical static messages in the AIS database related to the ship's IMO number, maritime mobile services identity, ship name, call sign, and ship type. If a ship is reflagged during the year, we consider it a different ship. Similarly, where any static messages change during the year, we also count this as a new ship. Identified in this way, there are a total of 433 940 ships in the AIS database for 2015, including 69 399 ships that are identified as having a valid and unique IMO number.

We distinguish between domestic and international voyages using AIS activity data and spatio-temporal analysis to identify a ship's geographical range. We use geographical shapefiles from the Flanders Marine Institute (2014), which provides the boundaries of the world's countries and their exclusive economic zones (EEZs). An AIS signal has spatial messages of latitude and longitude and can be associated with a specific country in the geographical dataset. If a ship has more than 95% AIS signals located within only one country's EEZ for the whole year, we classify it as a domestic ship; otherwise, we include it as a ship employed in international shipping. In addition, we assume that the purpose of a ship does not change over the year, but that it was used exclusively for international or domestic shipping. We categorize 44 304 IMO-identified ships as engaged in international shipping, of which 44 103 ships have country information associated with their owner, operator, manager, and flag state.

We calculate CO_2 emissions as a function of engine power demand, activity time, and emissions factor. The engine power demand for propulsion engines is based on engines' maximum power, ships' real-time speed, and ships' design speed. The power demand of auxiliary engines and auxiliary boilers are determined according to their corresponding ship class, ship capacity, and activity mode. Necessary technical parameter data for ships such as engine machinery details are available if the ship is listed in the WRS database. For ships that could not be identified in the WRS database, we estimated their engine specifications using the categorical regression method described in Zhang *et al* (2019). There is not always full coverage of AIS records per hour for ships. If a ship has at least one AIS signal in a day, missing values of its speed and coordinates are interpolated to an hourly frequency, using linear interpolation and nearest neighbor methods, respectively. The interpolated data points represent 32% of total coverage hours.

Of relevance to our calculations and analysis, emission factors are associated with both ship engines and local regulations. Ships with high-speed main engines, and ships sailing within emissions control areas (ECA) and among EU ports, are assumed to use marine gas oil or marine diesel oil. Other ships are assumed to use heavy fuel oil as default. Our emission factors are consistent with those reported in the IMO's third GHG study (IMO 2015). The total amount of CO_2 emissions from international shipping for 2015 were calculated at 690 million tonnes, of which 656 million tonnes are associated with IMO-identified ships that could be allocated to national carbon budgets under the 'flag country,' 'manager country,' 'owner country,' and 'operator country' options.

For the 'bunker fuel country' allocation option, we use data from the International Energy Agency (IEA) that reports international maritime CO_2 emissions per country based on the calculated combustion of the total volume of bunker fuel sold within each country (IEA 2018). The total amount of CO_2 emissions reported by the IEA for international maritime shipping was 662 million tonnes. We use this total number to calculate additions to carbon budgets under the 'bunker fuel country' allocation option. This is close to, but not identical to, the 656 million tonnes of CO_2 emissions that we use for the 'flag country,' 'manager country,' 'owner country,' and 'operator country' allocation options.

To calculate changes to national carbon budgets as well as the EU's carbon budget, we use national CO_2 emissions data for 2015 excluding land-use change from the Global Carbon Budget 2018 (Ritchie and Roser 2019). To align data sets with each other and with the list of UNFCCC parties, we combined some territories with countries (see table 1 in supplementary materials (available online at stacks.iop.org/ERL/16/045009/mmedia)). Most of these involve overseas territories of European countries. The EU data and calculations include the current 27 member states. There were 28 EU members in 2015, but we exclude the United Kingdom, which left the EU in 2020, as our focus is on implications of future allocations. We first calculate the total amount of CO_2 emissions from international shipping that would be allocated to the carbon budgets of individual countries and the EU under each of the five allocation options. Next, we calculate the percentage increase to these carbon budgets when adding the CO_2 emissions from international shipping under each allocation option.

3. Results

We present our results in three steps. First, we outline findings from our quantitative analysis on how national allocation of CO_2 emissions from international shipping influences national carbon budgets in different ways under the five allocation options. Second, we detail how the operations of the UNFCCC and the Paris Agreement versus the IMO influence the development of a global approach to a country-based allocation scheme, focusing on their objectives, principles for decision-making, and geographical coverage. Third, we explore how effectiveness and equity issues are important to the design of a national allocation scheme under the Paris Agreement model of climate change mitigation.

3.1. National allocations and differences

International shipping moves many different kinds of goods across countries and regions. Figure 1 shows major shipping routes as well as their CO_2 emission intensity, derived from global ship movements based on AIS data. If these CO_2 emissions were allocated to individual countries, different allocation options would have varying implications for how much CO_2 emissions would be transferred to countries' carbon budgets. We calculate the additional CO_2 added to national carbon budgets under the 'flag country,' 'owner country,' 'manager country,' 'operator country,' and 'bunker fuel country' allocation options. We do the same calculations for the EU-27. In this section, we first discuss the total amounts of CO_2 added to countries' carbon budgets under each allocation option. We then examine percentage changes to national carbon budgets under each allocation option. Full results for all countries are provided as supplementary data.

3.1.1. Total amount of CO_2 emissions allocation by country

All allocation options would distribute a majority of CO_2 emissions to a small number of countries. Table 2 shows the 20 countries which have the largest total amounts of CO_2 emissions added to their carbon budgets under each allocation option (which we refer to below as the countries with the largest allocations) as well as the EU. The top ten countries would be allocated between 69% and 75% of total CO_2 emissions for all five options, and the top 20 countries would be allocated between 88% and 90% of CO_2 emissions. Figure 2 shows the percent of the total amount of CO_2 emissions that would be allocated to the top ten countries, the next ten countries, and all other countries under each allocation option. For three of the allocation options ('owner country,' 'operator country,' and 'manager country') members of the Organization for Economic Co-operation and Development (OECD) would be allocated more than

Table 2. Top 20 countries and the EU27 for all five allocation options, ranked by the total amount of CO_2 emissions (ΔE, MT) allocated to carbon budgets.

	Bunker fuel		Flag		Owner		Operator		Manager	
Rank	Country	ΔE	Country	ΔE	Country	ΔE	Country	ΔE	Country	ΔE
1	Singapore	141	Panama	119	Japan	84	Japan	68	Greece	81
2	China	57	Liberia	74	Greece	79	Greece	60	Germany	67
3	United States	54	China	61	Germany	67	China	55	Japan	65
4	United Arab Emirates	49	Marshall Islands	57	China	63	United States	50	China	59
5	Netherlands	45	Singapore	47	United States	51	Germany	48	Singapore	53
6	Russia	42	Malta	36	United Kingdom	40	Singapore	39	United States	38
7	South Korea	30	Bahamas	35	Singapore	25	Denmark	39	United Kingdom	33
8	Spain	24	United Kingdom	34	South Korea	25	South Korea	35	South Korea	29
9	United Kingdom	20	Greece	18	Denmark	22	United Kingdom	32	Denmark	25
10	Belgium	19	Denmark	13	Norway	19	Switzerland	27	Norway	22
11	Iran	15	Italy	13	Chinese Taipei	18	Chinese Taipei	25	Chinese Taipei	17
12	Japan	14	Cyprus	13	Switzerland	15	Norway	22	Switzerland	16
13	Brazil	13	Netherlands	11	Netherlands	11	France	17	Netherlands	15
14	Panama	12	Antigua and Barbuda	10	Italy	10	Italy	14	Italy	13
15	South Africa	11	Norway	10	Turkey	10	Netherlands	14	France	10
16	Saudi Arabia	10	Japan	9	France	9	Russia	9	Turkey	9
17	Germany	8	Germany	8	Russia	9	Turkey	9	Russia	8
18	Italy	6	United States	8	Monaco	7	Belgium	8	United Arab Emirates	8
19	Sweden	6	South Korea	7	Canada	7	United Arab Emirates	6	Cyprus	7
20	Greece	6	Portugal	6	Belgium	6	Qatar	5	Belgium	6
	EU27	132	EU27	136	EU27	230	EU27	220	EU27	243

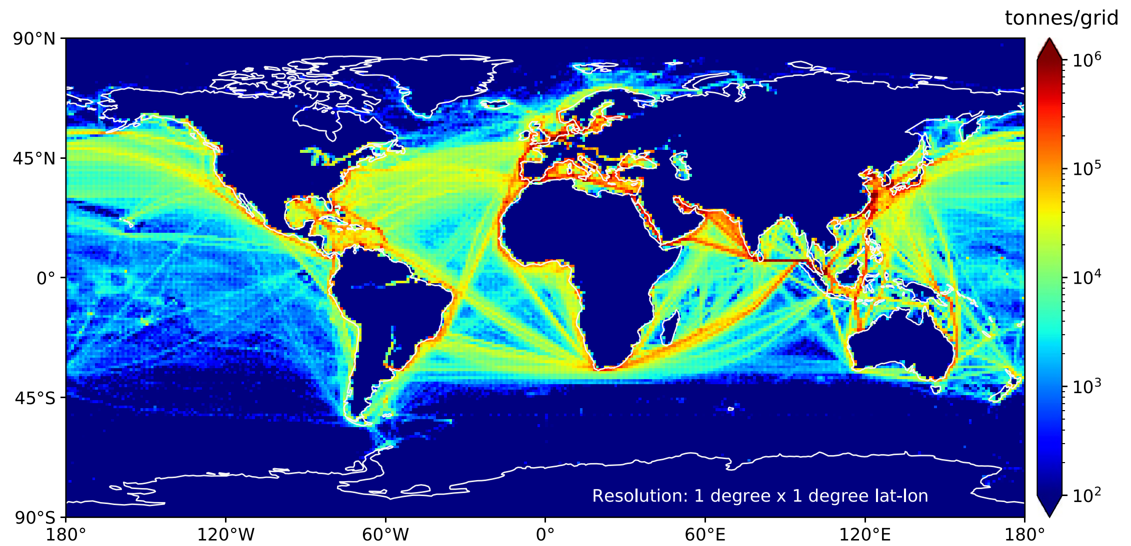

Figure 1. Global CO_2 emissions from international maritime shipping routes in 2015.

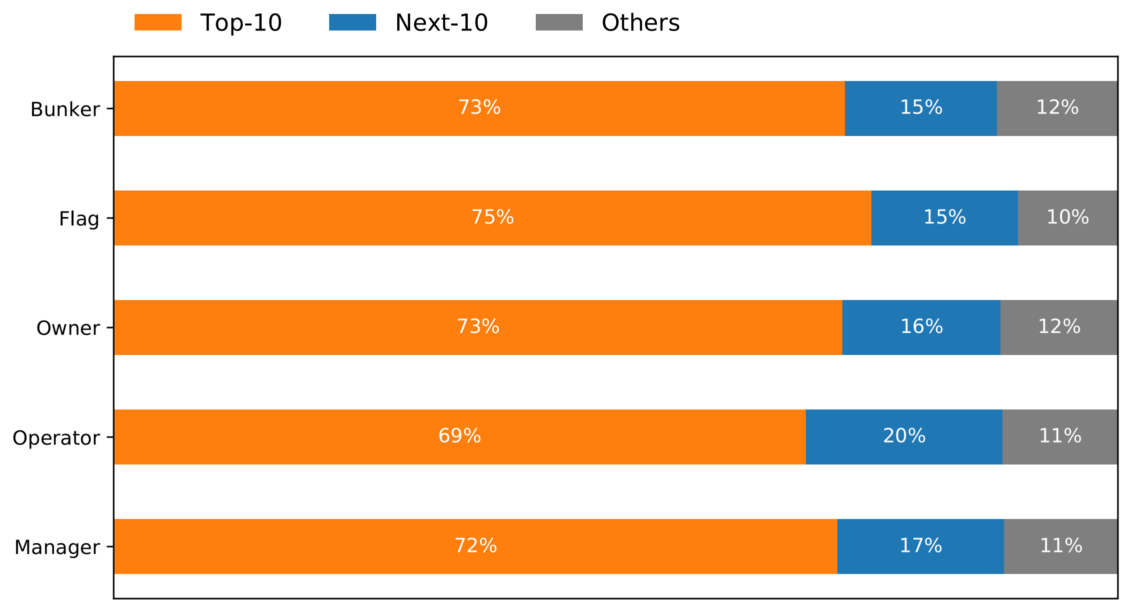

Figure 2. Relative allocation of the total amount of CO_2 emissions to the top ten countries, the next ten countries, and all other countries under each allocation option.

70% of CO_2 emissions, and for the other two options ('bunker fuel country' and 'flag country') non-OECD countries are allocated more than 60%. Figure 3 shows the relative percentage of CO_2 emissions that would be allocated to members of the OECD versus non-OECD members for all allocation options.

A total of 35 countries are in the top 20 for the total amount of allocated CO_2 emissions across the five allocation options. Eighteen of these countries are OECD member states (see also table 1 in supplemental materials). The EU and nine countries are among the top 20 in all five (China, Germany, Greece, Italy, Japan, Singapore, South Korea, United Kingdom, and the United States). Five countries are among those with the largest allocations in four different options (Belgium, Denmark, Netherlands, Norway, and Russia). Five others are among the largest for three different allocation options (France, Switzerland, Chinese Taipei, Turkey, and the United Arab Emirates). Three countries are among the largest in two different allocation options (Cyprus, Panama, and Sweden), while 13 countries are in the top 20 under only one allocation option (Antigua and Barbuda, Bahamas, Brazil, Canada, Iran, Liberia, Malta, Marshall Islands, Portugal, Qatar, Saudi Arabia, South Africa, and Spain).

The 35 countries that are that in the top 20 for the total amount of allocated CO_2 emissions in at least one of the five allocation options are spread across the world's regions, but not evenly. In

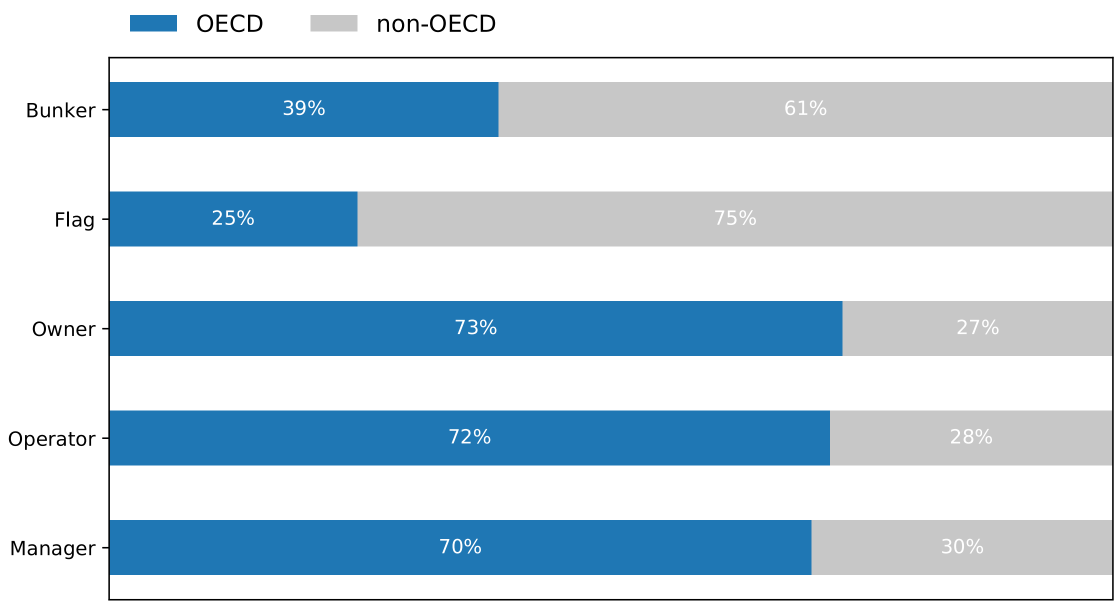

Figure 3. Percentage of CO_2 emissions that would be allocated to members of the OECD members versus non-OECD members for all allocation options.

particular, European countries are overrepresented. Sixteen of the 35 countries are located in Europe (Belgium, Cyprus, Denmark, France, Germany, Greece, Italy, Malta, Monaco, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom), and 12 of those countries are EU members. Ten of the countries are located in Asia and the Middle East (China, Chinese Taipei, Iran, Japan, Qatar, Saudi Arabia, Singapore, South Korea, Turkey, and the United Arab Emirates). Six of the countries are located in the Americas (Antigua and Barbuda, Bahamas, Brazil, Canada, Panama, and the United States). Of the remaining four countries, two are located in Africa (Liberia and South Africa), one in Oceania (Marshall Islands), and the other is Russia.

3.1.2. Percentage changes to carbon budgets

The carbon budgets of many countries that are in the top 20 of total allocation under all five options would change only modestly. Table 3 shows the countries that have the largest percentage increases to their carbon budgets under each allocation option together with the percentage increase to the EU's carbon budget.

The world's two largest country emitters of GHG emissions from domestic sources—China and the United States—would see less than 1% increases to their carbon budgets across all five allocation options. Four other countries in the top 20 for total allocation under all five options would also only see single-digit increases to their carbon budgets. South Korea would see a 1%–6% increase and Japan a 1%–7% increase. Italy and Germany would see 3%–4% and 1%–9% increases in their carbon budgets, respectively. The EU's carbon budget would increase by between 4% and 8%. In addition, the United Kingdom would see its national carbon budget increase in the range of 4%–10%.

Other countries' carbon budgets would see further increases under some allocation options. The other two countries in the top 20 for total allocation under all five options—Greece and Singapore—could see an increase of up to 108% and 232%, respectively. The largest percentage increases in national carbon budgets occur under the 'flag country' option where the Marshall Islands would see a 51 203% increase, followed by Liberia (8143%), Tuvalu (2450%), Malta (2061%) Antigua and Barbuda (1798%), Bahamas (1388%), Panama (1234%), Vanuatu (792%), St. Vincent and the Grenadines (743%), Kiribati (600%), Niue (370%), and St. Kitts and Nevis (276%). Two of these countries would also see major increases to their carbon budgets under other allocation options. The Marshall Islands' carbon budget would increase by 610% under the 'owner country' option and by nearly 400% under both the 'operator country' and the 'manager country' options. Under the 'bunker fuel country' option, Panama's carbon budget would increase by 121%.

Another 20 countries would see at least a 50% increase to their carbon budgets under one or more allocation options. Seven of these are located in Latin America and the Caribbean (Antigua and Barbuda, Bahamas, Belize, Dominica, Panama, Saint Kitts and Nevis, and Saint Vincent and the Grenadines). Six countries are small island states in the Pacific (Kiribati, Marshall Islands, Niue, Palau, Tuvalu, and Vanuatu), five are European countries (Cyprus, Denmark, Malta, Norway, and Switzerland), and two countries are in Africa (Comoros and Liberia). An additional six European countries (Belgium, Iceland, Latvia, Luxembourg, Portugal, and Sweden),

Table 3. Top 20 countries and the EU27 for all five allocation options, ranked by percentage increases to carbon budgets after allocation (ΔE, %).

	Bunker fuel		Flag		Owner		Operator		Manager	
Rank	Country	ΔE (%)	Country	ΔE (%)	Country	ΔE (%)	Country	ΔE (%)	Country	ΔE (%)
1	Malta	281%	Marshall Islands	51 203%	Marshall Islands	610%	Marshall Islands	398%	Marshall Islands	399%
2	Singapore	232%	Liberia	8143%	Greece	105%	Denmark	108%	Greece	108%
3	Panama	121%	Tuvalu	2450%	Cyprus	79%	Greece	79%	Cyprus	98%
4	Netherlands	26%	Malta	2061%	Denmark	61%	Switzerland	70%	Singapore	87%
5	United Arab Emirates	22%	Antigua and Barbuda	1798%	St. Kitts and Nevis	46%	Singapore	64%	Denmark	71%
6	Mauritius	21%	Bahamas	1388%	Norway	44%	Norway	50%	Norway	50%
7	Belgium	19%	Panama	1234%	Singapore	42%	St. Kitts and Nevis	49%	St. Kitts and Nevis	49%
8	Sweden	13%	Vanuatu	792%	Switzerland	40%	Cyprus	38%	Switzerland	42%
9	Cyprus	11%	St. Vincent and Grenadines	743%	Bahamas	39%	Vanuatu	36%	Vanuatu	36%
10	Gabon	11%	Kiribati	600%	Seychelles	27%	Barbados	24%	Barbados	23%
11	Latvia	11%	Niue	370%	Liberia	24%	Seychelles	20%	Liberia	17%
12	Spain	9%	St. Kitts and Nevis	276%	Malta	23%	Malta	17%	Malta	15%
13	Uruguay	8%	Cyprus	186%	Vanuatu	23%	Bahamas	16%	Bahamas	14%
14	Jamaica	8%	Comoros	185%	Samoa	15%	Liberia	14%	Seychelles	13%
15	Suriname	8%	Belize	173%	Sweden	14%	Iceland	11%	Sweden	12%
16	Greece	8%	Dominica	120%	Belize	12%	Chinese Taipei	10%	Iceland	10%
17	Denmark	7%	Palau	101%	Iceland	10%	Sweden	9%	Netherlands	9%
18	Sri Lanka	6%	Singapore	77%	United Kingdom	10%	Belgium	8%	Germany	8%
19	Oman	6%	Barbados	45%	Germany	8%	Finland	8%	United Kingdom	8%
20	Estonia	6%	Denmark	37%	Panama	8%	Netherlands	8%	Micronesia	8%
	EU27	4%	EU27	4%	EU27	7%	EU27	7%	EU27	8%

five African countries (Gabon, Mauritius, Togo, Seychelles, and Sierra Leone), three Middle Eastern and Asian countries (Cambodia, Chinese Taipei and the United Arab Emirates), and one small Pacific island state (Samoa) would receive between a 10% and 49% increase to their carbon budgets under at least one allocation option.

3.2. Developing a global approach

International maritime shipping and trade are central to the global economy and to advancing human well-being (UNCTAD 2017), but it is important to expand efforts to control CO_2 emissions from international shipping. Given the lack of progress to reduce CO_2 emissions from international shipping, together with an absence of substantive IMO measures to meet the GHG reduction goals under the 2018 strategy (Doelle and Chircop 2019), there is a need to develop a more comprehensive global approach. Here we examine how differences in three important factors related to the UNFCCC and the IMO—the two multilateral fora most central to debates on how to address CO_2 emissions from international shipping (Hackmann 2012, Shi and Gullett 2018)—shape efforts to develop a global approach for country-based allocation of CO_2 emissions. These three factors are the objectives, principles for decision-making, and geographical coverage of the UNFCCC and the IMO.

With respect to their objectives, the UNFCCC has an explicit focus on addressing GHGs while the IMO has a more multifaceted agenda. The objective of the UNFCCC centers on stabilizing atmospheric GHG concentrations. This goal is further developed in the Paris Agreement's temperature goals, and more ambitious climate change mitigation is central to the periodic review mechanism of each party's NDC under the Paris Agreement (Falkner 2016). In contrast, the IMO is tasked to integrate objectives to facilitate international shipping and ensure maritime safety and efficiency of navigation with controlling pollution from ships. The Conference of the Parties to the UNFCCC has a more explicit and singular mandate to prioritize the development of a stronger legal framework for reducing CO_2 emissions from international shipping than the IMO Assembly. Addressing the issue of CO_2 emissions from international shipping under the UNFCCC process, with the IMO as a partner organization, could help ensure a more sustained focus on counting and mitigating those CO_2 emissions moving forward.

Designing a national allocation scheme under the UNFCCC would send an important political signal that efforts to reduce CO_2 emissions from international shipping is addressed in a global forum dedicated to climate change mitigation. This would not be an easy political process, as shown by earlier debates in the IMO. Shortly after the adoption of the Paris Agreement, a group of European and African countries together with some small island states argued that IMO members needed to take tangible steps to define the shipping sector's 'fair share' to the international community's efforts to curb global GHG emissions in line with the Paris Agreement (King 2016). The EU is also stepping up its regional efforts, including by moving to add CO_2 emissions from shipping to its Emissions Trading System. In contrast, some major emerging economies including China, Brazil, and India as well as the United States rejected the idea of setting GHG reduction targets for international shipping. These countries instead insisted that IMO only focus on energy efficiency and data collection measures, arguing that the Paris Agreement did not cover international transport (Darby 2016, King 2016).

Principles for decision-making in the IMO and the UNFCCC differ primarily in their treatment of differentiation of national responsibilities (Wang 2010, Zhang 2016). Equal treatment of all members is a core principle for decision-making in the IMO. In comparison, the UNFCCC principle of common but differentiated responsibilities, which allows for variations in national contributions to climate change mitigation, provides a more flexible basis for negotiating a collective approach where obligations may not necessarily be uniform across all countries. This is consistent with language in the Paris Agreement that all parties shall pursue domestic mitigation measures, but that developed countries should continue taking the lead. Parties to the Paris Agreement are also free to determine their own approaches to GHG mitigation under their NDCs. Some differentiation of national responsibilities in absorbing and addressing CO_2 emissions from international shipping will likely be important to reaching broad agreement on the design and implementation of a durable global approach.

The broader geographical coverage of the UNFCCC than that of the IMO, with 195 UNFCCC country parties compared to 174 IMO member states, is important to limit free-riding (Hackmann 2012). The EU is also a UNFCCC party but not an IMO member. The UNFCCC parties that are not IMO members are Afghanistan, Andorra, Bhutan, Burkina Faso, Burundi, Central African Republic, Chad, Eswatini, Kyrgyzstan, Lao, Lesotho, Lichtenstein, Mali, Micronesia, Niger, Niue, Rwanda, South Sudan, State of Palestine, Tajikistan, and Uzbekistan. None one of these are in the top 20 of the total allocation, and only one of these countries could see a large percentage increase to the national carbon budget (Niue, under the 'flag country' option). Risks of free-riding stem from the fact that the location of the owner, operator, and manager as well as a ship's flag country can be moved from one national jurisdiction to another to avoid controls (DeSombre 2006). Thus, a globally designed scheme for national allocation would benefit from the largest possible participation of countries and the EU.

A global approach under the UNFCCC for counting and addressing CO_2 emissions from international shipping would establish the broadest possible framework for a system of national allocation. Shipping industry actors often oppose new mandates, but typically prefer regulations at the global level rather than having to navigate a patchwork of different regional and local standards and controls (Lister *et al* 2015). Policy consistency is also important for efficient shipping operations (Zhang *et al* 2018). National allocation would create a stronger incentive for national governments to work more actively with shipping industry actors to reduce CO_2 emissions from marine transport. This may involve the design of a combination of further regulatory, technical, and/or economic measures to advance mitigation. If a greater focus on reducing CO_2 emissions from international shipping results in industry-based emission cuts, fewer emissions from this sector would then be allocated to national carbon budgets over time. This would help countries meet national and regional emission targets included in NDCs while ensuring that the international shipping sector contributes more to collective efforts to meet the temperature goals included in the Paris Agreement.

3.3. Effectiveness and equity

Issues of effectiveness and equity are central to international climate change debates (Zenghelis 2017). A national allocation scheme for CO_2 emissions from international shipping requires broad participation to be effective. Yet, countries often pursue negotiation strategies that aim to limit their own obligations while increasing those of others; this behavior has influenced past discussions about how to address CO_2 emissions from international shipping (van Renssen 2012, Bows-Larkin 2015). Countries that would see large changes in the amount of CO_2 emissions added to their carbon budgets under different allocation options may prefer an option that gives them a comparatively smaller increase. This is also the case for individual EU member states as the EU as a whole would need to decide which allocation option to support. At the same time, some countries and industry actors are more able than others to drive a process toward reduced CO_2 emissions from international shipping in terms of shouldering burdens and helping to drive technological change.

Most of the top 20 countries for the total amount of CO_2 emissions allocated under the three options of 'owner country,' 'operator country,' and 'manager country' are wealthier OECD countries that can help lead politically on designing and implementing a national allocation scheme. It is relatively common that entities that are listed as ship owner, operator and manager are headquartered in the same country—according to WRS data, 74% of all ships that are deployed in international shipping are owned, operated, and managed by entities that are located in the same country (and some may be part of the same company). Of the ships that are owned, operated, and managed by entities from the same country, most of these entities are located in China, followed by Greece, Japan, Germany, and Singapore. These ships are responsible for 61% of CO_2 emissions from international shipping. Across these three allocation options, there is an average increase in carbon budgets of 18%–26% for the top 20 countries. Yet, some of the top 20 countries are smaller countries including the Marshall Islands that would see significant percentage increases to their carbon budgets.

Ship owners, who are mainly registered in OECD countries, have the capacity to introduce the technological improvements to ships that are at present the main way in which CO_2 emissions reductions from this sector could occur. The typical commercial lifespan for a ship is 25 years (Lister *et al* 2015). Because the ship owner makes decisions on ship purchasing and technology upgrades, the owner has a relatively large role to play in determining the carbon footprint of the industry by altering emissions factors. Reducing CO_2 emissions from shipping will to a large extent depend on the development and application of new technology and fuels, including more efficient engines and ships that eventually can run on zero-carbon energy. There currently is no readily available fuel option that could significantly reduce CO_2 emissions without worsening other environmental impacts (Gilbert *et al* 2018). In addition, private sector efforts like the Poseidon Principles, where major financial institutions are looking to align their ship finance portfolios with CO_2 emission reduction goals and the Paris Agreement, engage with ship owners (Rebelo 2020).

The ship operator and the ship manager are two other categories of shipping industry actors who are predominantly located in OECD countries and whose varying decisions impact CO_2 emissions from individual ships. The ship operator decides on operational issues including the routing of a ship, as the more and longer a ship sails the more CO_2 emissions it emits. The ship manager is responsible for the day to day running of a ship, including determining ship speeds and the purchasing of fuel oils; both of these decisions influence the amount of CO_2 emissions coming from an individual ship. However, decisions by the ship operator and the ship manager are less impactful for achieving large-scale CO_2 emission reductions than the capital investment decisions in engine upgrades and the purchasing of new vessels made by ship owners. This makes the ship operator and manager less able than the ship owners to drive an industry wide transition to zero CO_2 emissions.

A national allocation scheme based on the 'bunker fuel country'—similar to the allocation options based on ship owner, operator, and

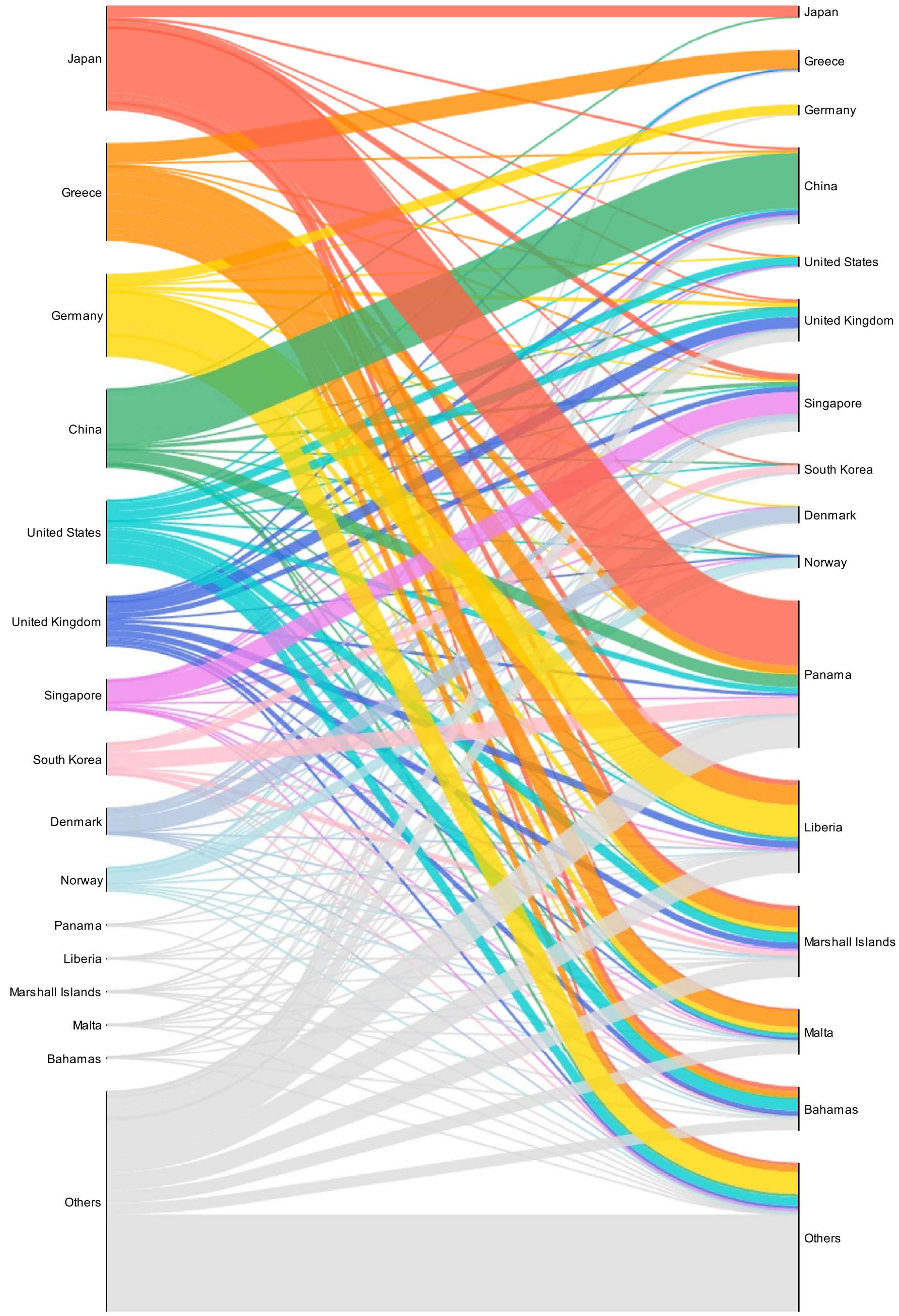

Figure 4. CO_2 reallocation between ship owner countries and flag states. Left column shows CO_2 allocations for top ten countries of ship owners; right column shows the amount of CO_2 emissions which would be reallocated to each flag state.

manager—would transfer CO_2 emissions to the carbon budgets of countries where profit-making firms are registered. Unlike the allocation options focused on ship owners, operators, or managers, only a minority of CO_2 emissions would be allocated to OECD members under the 'bunker fuel country' option (see also figure 3). The firms selling bunker fuel also do not control decisions on engine performance standards, shipping routes, and ship speeds that directly affect levels of CO_2 emissions. This gives bunker fuel sellers less influence over a transition towards reduced CO_2 emissions than actors who are connected to specific ships, especially the owners. Under the 'bunker fuel country' option, the average percent increase in carbon budgets for the top 20 countries is 24%, but a few smaller countries, especially Malta, Singapore, and Panama, would see much larger percentage increases to their carbon budgets.

Allocating CO_2 emissions from international shipping based on the 'flag country' option is the option that puts the most burden on the carbon budgets of non-OECD members, including several smaller developing countries (see also figure 3). Under international law as well as IMO rules, the flag country is legally responsible for ensuring that a ship meets all relevant domestic and international standards. However, many of the major flag countries, both individually and collectively, lack the political power to lead a global change towards greater mitigation of CO_2 emissions from international shipping. The design of a comprehensive approach to reducing CO_2 emission from international shipping ultimately requires broad participation and support from all politically influential countries that are engaged in, and benefit economically from, international maritime transport and trade. Under the 'flag country' option, there is an average increase of 3310% to the carbon budgets of the top 20 countries, with the Marshall Islands seeing an increase of 51 203% to its carbon budget.

The fact that some ships that are owned by entities that are located in industrialized countries are flagged in small island states flying a flag of convenience raises important equity issues when considering allocation based on the 'flag country' option. An allocation scheme based on the 'flag country' option would put a relatively large burden on smaller countries while the income made by ship owners goes to entities in industrialized countries. Figure 4 shows how CO_2 emissions allocated to the top-ranked countries under the 'flag country' option comes from ships owned by entities located in countries that rank high under the 'ship owner' option. For example, 62% of CO_2 emissions from Japanese-owned ships are allocated to Panama under the 'flag country' option, and 44% of all CO_2 emissions from Panama-flagged ships come from Japanese-owned ships. Many ships owned by entities registered in Greece and Germany are also flagged in smaller countries. One exception, however, is China: 72% of emissions assigned to China under the 'flag country' option are from Chinese-owned ships.

Countries with larger carbon budgets are better positioned in the short term to further reduce CO_2 emissions from other sources to compensate for the emissions allocated from international shipping in the next few decades while still meeting national and regional emission reduction targets (with the goal of eventually reaching net-zero emissions). Increased mitigation in other domestic sectors is much less of a realistic option for smaller countries that would experience large percentage changes in their national carbon budgets, and it would be virtually impossible for some countries (especially under the 'flag country' option). For countries that would see very large percentage changes to their carbon budgets, the only realistic option is purchasing carbon offsets—this issue relates to the intense debate about the desirability and effectiveness of using carbon offsets in climate change mitigation (Greene and Facanha 2019). Many of the small countries that would experience the largest percentage increases to their national carbon budgets would need political and economic support from the international community.

Our analysis focuses on national allocation options involving the location of ship owners, managers, operators, and bunker fuel sellers as well as the flag country, but other industry actors could also play a role in mitigating CO_2. This includes ship charterers as cargo owners who benefit from having their goods sold in other countries (Poulsen *et al* 2021). Cargo owners can influence the shipping industry by, for example, demanding that their goods are transported on the most direct route and/or by low emitting ships. We do not include ship charterers in our analysis for two main reasons. First, there are no global-scale data on owners of all goods that are shipped or the cargo of each ship. Second, a national allocation scheme based on the location of cargo owners would involve an extremely large number of actors, making the design and implementation of such an allocation scheme infeasible at the present time. In addition, billions of consumers benefit from international shipping-based trade. The CO_2 emissions from production and consumption of goods are more easily addressed through other policy measures, including carbon pricing.

4. Conclusions

Our analysis contributes to the study and debate about how to further address CO_2 emissions from international shipping. Using a unique data set on ship movements as well as data on bunker fuel sales, we show that the creation and implementation of a national allocation scheme for CO_2 emissions from international shipping based on the allocation options of the 'flag country,' 'owner country,' 'manager country,' 'operator country,' and 'bunker fuel country' would result in a concentrated distribution of emissions to a small number of the world's countries. A majority of CO_2 emissions, up to 75%, would be allocated to only ten countries under each of the five allocation options. There would, however, be major differences in percentage changes to several countries' carbon budgets across the allocation options. In particular, the carbon budgets of some small island states in the Pacific and the Caribbean would receive very different amounts of CO_2 emissions under different allocation options, as their carbon budgets in some instances would increase by up to factors of tens of thousands. This is especially the case under the 'flag country' allocation option.

Based on our analysis of the objectives, principles for decision-making, and geographical coverage of the UNFCCC and the IMO, we conclude that there are strong reasons to move at least some debate and policy-making powers on how to further address CO_2 emissions from international shipping from the IMO back to the UNFCCC, including the creation of a national allocation scheme. The UNFCCC has a clear mandate to advance GHG mitigation, and the approach of NDCs embedded in the

Paris Agreement provides an institutional basis for expanded country-based mitigation over time. The UNFCCC and Paris Agreement's NDCs also allow for a greater differentiation in national measures than under IMO, providing important flexibility in creating and implementing a national allocation scheme. In addition, the larger membership of the UNFCCC compared with the IMO makes it a better global forum for reducing risks of free riding by industry actors re-locating to national jurisdictions outside of a national allocation scheme.

Any decision on the design of a national allocation scheme must carefully consider effectiveness and equity issues. In the global institutional context of the Paris Agreement, we argue that the creation of a national allocation scheme based on the 'owner country' option is the option that best meets effectiveness and equity criteria. Ship owners, as asset owners, are the industry actors that through their purchasing and investment decisions are best positioned to lead the transition of the world's shipping fleet to zero CO_2 emissions. Under the 'owner country' option, most CO_2 emissions would be allocated to national carbon budgets of industrialized countries. Two countries would see increases of over 100%, while 11 countries would see increases between 23% and 79%. Thus, also under this allocation option, some countries would struggle to make up for these additions by increasing mitigation from domestic emissions sources until zero-carbon fuels are available. Yet, an 'owner country' based allocation scheme would create stronger incentives for countries and ship owners to undertake more comprehensive mitigation efforts.

The relative contribution of international shipping to global annual CO_2 emissions may grow in the future if GHGs are more aggressively reduced in other economic sectors than in the shipping industry. National allocation is one option that would include CO_2 emissions from international shipping in carbon budgets and would create stronger incentives for countries and industry actors to reduce these emissions. Reaching consensus among all UNFCCC parties on the creation of a national allocation scheme of CO_2 emissions based on the 'ship owner' option, or any other allocation option, may be politically difficult, as parties have different political and economic interests related to international shipping and trade. However, the importance of addressing all CO_2 emissions sources in order to meet the Paris Agreement's goals reinforces the necessity of new and more ambitious measures to accelerate the reduction of CO_2 emissions from international shipping. A national allocation scheme based on the country-specific location of registered ship owners provides a potential mechanism for meeting these goals.

Data availability statement

The AIS data and ship parameter data (World Register of Ships) are used under license for the current study, and managed by the Institute for the Environment (IENV) and Environmental Central Facility (ENVF) of The Hong Kong University of Science and Technology (HKUST). These data are available for purchase from IHS Markit (https://ihsmarkit.com/index.html). The data obtained from the IEA and the Global Carbon Project are available for free download at their respective websites.

All data that support the findings of this study are included within the article (and any supplementary files).

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Author contributions

H S co-conceived the study, conducted the institutional analysis, wrote the first draft, and coordinated reviewing and editing. Y Z built the database on ship movements and carried out the quantitative analysis for the allocation options 'owner country,' 'operator country,' 'manager country,' and 'flag country' based on the data set on ship movements. R D co-conceived the study and carried out the quantitative analysis for the 'bunker fuel country' allocation option. N E S and A K H L contributed to data analysis and interpretation. All authors reviewed and edited the text.

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