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Decarbonizing China's coastal shipping: The role of fuel efficiency and low-carbon fuels

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Summary

At the 75th UN General Assembly in September of 2020, Chinese President Xi Jinping announced that China's overall carbon dioxide (CO_2) emissions will peak by 2030 and that carbon neutrality will be reached before 2060 (China Dialogue, 2020). This is a huge commitment for China as the world's largest emitter of greenhouse gases (GHG) in 2019 (UCS, 2022) and as the second largest economy. One year later, China released an action plan designed to cap its CO_2 emissions before 2030 (National Development and Reform Commission (NDRC) People's Republic of China, n.d.). But the world is still waiting to learn what "carbon neutralization" means for the country, and what an action plan for reaching this target by 2060 will look like.

Informing these goals is a study by the Institute for Climate Change and Sustainable Development at Tsinghua University (ICCSD), which offers insight into China's long-term, low-carbon development strategy and transition pathways (Tianjie, 2020; ICCSD, 2021). For the transportation sector, the report concluded that an 83% reduction in the sector's overall CO_2 emissions by 2050 compared to 2020 would be needed to align with the 1.5°C cap on global temperature recommended by the 2015 Paris Agreement. As we await the unveiling of official level of ambition by 2060 and a long-term action plan for the shipping sector, the ICCT takes a first look at China's domestic coastal shipping sector and provides recommendations for actionable long-term decarbonization pathways designed to avoid exceeding its current share of transportation-sector CO_2.

Specifically, we used the sector's 2019 activities, energy consumption, and CO_2 emissions as the study's baseline and projected those out to 2060 under three scenarios: a) Business-as-usual (BAU), which assumes that the sector's energy consumption will be governed only by adopted policies, with no new policies proposed and implemented after 2019; b) a 2°C-aligned scenario, which assumes coastal shipping maintains its 2019 share of a 2°C transportation sector CO_2 budget in future years; and c) a 1.5°C-aligned scenario, which assumes that the sector maintains its 2019 share of the 1.5°C CO_2 budget for the transportation sector. The 2°C-aligned and 1.5°C-aligned scenarios require 44%,

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and 83% reductions, respectively, in CO_2 emissions in 2060 compared with the 2019 baseline. We considered two broad categories of policy actions in addition to adopted policies to reach the goals of 2°C-aligned and 1.5°C-aligned scenarios: improving energy efficiency and reducing the carbon intensity of shipping fuel.[1] Finally, because fuel carbon intensity regulations (or low-carbon fuel regulations) are crucial to decarbonizing the shipping industry and are currently less mature and more costly than energy efficiency improvements, we considered two different implementation schedules for each of the 2°C-aligned and 1.5°C-aligned scenarios, while keeping their targets intact.

We found that:

- In 2019, China's coastal shipping sector emitted about 45 million tonnes of CO_2, or roughly 4.5% of total CO_2 emissions from China's transportation sector. With no additional policies, CO_2 emissions from China's domestic coastal shipping would more than triple to more than 162 million tonnes in 2060.
- With the help of mandatory energy efficiency standards as well as low-carbon fuel regulations, CO_2 emissions from China's domestic coastal shipping could peak by 2040 and fall significantly by 2060. We proposed two possible pathways for achieving this:
  - With mandatory energy efficiency standards tightened every five years between 2025 and 2045 for newbuild ships, and with low-carbon fuel regulations slowly phasing in from 2030, CO_2 emissions could peak by 2040 and decrease by 56% in 2060 relative to the 2019 baseline, which is aligned with the 2°C-target set for the transportation sector in the ICCSD report. The average carbon intensity of the fleet could fall by 79% relative to the 2019 baseline.
  - With more stringent mandatory energy efficiency standards to be implemented between 2025 and 2045, and with low-carbon fuel regulations phasing in five years earlier (beginning in 2025), CO_2 emissions could peak by 2035 and decrease by 83% in 2060 relative to the 2019 baseline, which is aligned with the 1.5°C-target set for the transportation sector in the ICCSD report. The average carbon intensity of the fleet could fall by 92% relative to the 2019 baseline.
- It is essential that low-carbon fuel regulations be implemented no later than 2030. If delayed until 2046 after expiration of mandatory energy efficiency standards, the required rate of fuel carbon intensity reduction would be dauntingly high for the industry.

Background

The International Maritime Organization's (IMO) Fourth Greenhouse Gas study shows that shipping accounted for about 2.89% of global anthropogenic CO_2 emissions in 2018. Emissions are projected to grow by up to 30% by 2050 compared to 2008 levels in a business as usual scenario (Faber et al., 2020). To support the United Nations' Sustainable Development Goal 13 (SDG 13), which calls for urgent action to combat climate change and its impacts, IMO has adopted mandatory measures to reduce GHG emissions from international shipping under IMO's pollution prevention treaty (MARPOL). In 2018, IMO adopted an initial strategy to reduce total annual GHG emissions from ships by at least 50% by 2050 compared to 2008 levels and to reduce ship carbon intensity by at least 40% by 2030 (Rutherford & Comer, 2018).

As part of the short-term measures of the initial strategy, IMO has been updating the Energy Efficiency Design Index (EEDI) for new ships and recently adopted the Energy Efficiency Existing Ship Index (EEXI) for the in-service fleet, as well as the Carbon

1 The metric of fuel carbon intensity is the measure of life-cycle greenhouse gas emissions per unit energy from burning transportation fuel, in g CO_2 eq/MJ (Baral, 2009). For this study, we estimated only CO_2 emissions, so the metric is modified to g CO_2/MJ.

Intensity Indicator (CII) rating scheme to address operational efficiency. More aggressive policy actions are in process in the European Union (EU). To help meet the EU's climate neutrality goal by 2050 and an interim target of at least 55% net GHG reduction by 2030, relative to 1990 levels (*Fit for 55*), the EU proposes to include CO_2 emissions from ships in its Emissions Trading System (ETS) starting in 2023, and will set a maximum limit on the GHG content of energy used by ships calling at EU ports starting in 2025 (EC, 2021; T&E, 2021).

Although decarbonization is seldom discussed within the shipping sector in China, monitoring and improving energy efficiency has long been favored by both government and industry. In 2012, the Ministry of Transport of the People's Republic of China (MOT) released industry standards called *Limits and verification methods of* CO_2 *emission for commercial ships* (JT/T 827-2012) which requires ships navigating major inland waterways to calculate an adapted version of the IMO EEDI. Although this is mandatory, it does not require any improvement of the EEDI over time. In 2014, MOT released an incentive program to reward ships with verified attained-EEDI at least 30% better than the baseline EEDI required in JT/T 827-2012.[2] In 2015, the Ministry of Finance of the People's Republic of China (MOF) implemented a ship scrappage plan to promote the early retirement and replacement of old river, coastal, and oceangoing commercial cargo-carrying ships, as well as old fishing vessels.[3] This program was wrapped up in 2019. At the end of 2019, the China Classification Society (CCS) released the *Green River Vessel Guidelines 2020* which certifies ships with advanced energy performance.[4]

Despite these efforts, data is still lacking on the actual energy efficiency and associated CO_2 emissions for different types of ships. In the past, MOT would release statistics on energy efficiency[5] per ship type for coastal and oceangoing ships, but they stopped doing so in 2014, instead releasing a single generic average fuel efficiency number for the entire shipping sector each year. Environmental regulations on shipping fuel have focused on reducing fuel sulfur content. The only exception is the intense promotion of shore power, which allows ships to plug into electricity while berthing in ports, cutting conventional pollutants as well as GHGs.[6] In 2017, MOT planned to equip 493 specialized berths with shore power facilities within the Domestic Emission Control Area (DECA) by 2020 (Ministry of Transport of the People's Republic of China, 2017) which was completed by the end of 2020, with total usage of more than 740,000 hours of onshore electricity in 2019.[7]

Current policies are unlikely to lead to a meaningful decarbonization of China's shipping sector any time soon. But the country's newly announced carbon peaking and neutralization ambitions could spur the creation of additional policies to help with the transition. A first step to development of such policies is to gain a clear understanding of the shipping sector's current activities, energy consumption and efficiency performance, a quantified level of ambition given the country's 2060 carbon neutralization pledge, and a pathway that sets a reasonable pace and defines actionable policies to reach that ambition. This study begins by probing the above inquiries for the domestic coastal shipping sector. A similar exercise focusing on the inland waterway shipping sector is being addressed in another ICCT-commissioned study (forthcoming).

2 The policy notice is available on MOT's website at: https://zjhy.mot.gov.cn/zzhxxgk/jigou/ysfwc/201910/t20191009_3280196.html.

3 The policy notice is available on MOF's website at: http://jjs.mof.gov.cn/tongzhigonggao/201512/t20151217_1618410.htm.

4 The policy notice is available on CCS's website at: https://www.ccs.org.cn/ccswz/articleDetail?id=201900001000010576.

5 The statistical indicator for energy efficiency used in China's statistical system was expressed as kgce per 1000 tonnes-nm.

6 Depending on the carbon intensity of electricity used, the GHG reduction level varies.

7 MOT released the implementation progress of shore power by the end of 2019: http://info.chineseshipping.com.cn/cninfo/News/202004/t20200427_1336443.shtml

The remainder of the paper is organized in three parts. First, we introduce the methods and data used in the study. We then present the results and discuss their implications. Finally, we conclude with our findings and discuss needed future work.

Methods

The study comprises three analytical parts:

1. A CO_2 emissions inventory of China's coastal shipping sector for 2019, including:
   a) Ship activities in terms of total distance travelled
   b) Fuel consumption
   c) CO_2 emissions and the fleet's average carbon intensity
2. Projections of CO_2 emissions of China's coastal shipping sector out to 2060, under three scenarios:
   a) A BAU scenario: assumes that only adopted policies targeting the sector's energy consumption profile would be proposed and implemented after 2019
   b) A 2°C -aligned scenario: assumes that additional policies proposed and implemented after 2019 are consistent with maintaining coastal shipping's 2019 share of the 2°C transportation carbon budget[8]
   c) A 1.5°C-aligned scenario: assumes that additional policies proposed and implemented after 2019 are consistent with maintaining coastal shipping's 2019 share of 1.5°C transportation carbon budget.[9]
3. A sensitivity analysis of the timing of introducing low-carbon fuel regulations for shipping.

Before introducing the details of the three analyses described above, we describe our data sources.

Data

We used three main datasets in this study: (1) terrestrial and satellite Automatic Identification System (AIS) data from exactEarth Ltd., (2) ship characteristics data from a purchased IHS ship database, and (3) additional ship characteristics data from Global Fishing Watch (GFW)[10] and the chinashipbuilding.cn website. According to IMO's Fourth GHG Study (Faber et al., 2020) , the AIS data includes four types of ships: Type 1&2, which can be matched to the IHS ship database[11] and are mostly oceangoing vessels; Type 3, which cannot be matched to the IHS ship database and are mostly ships engaged in domestic navigation; and Type 4, which are listed in the IHS ship database as in-service fleet but which are missing their AIS data.

8 According to the ICCSD report (2021), the 2°C-aligned transportation carbon budget is about 550 million tonnes in 2050. To reflect the principle of Common But Differentiated Responsibilities (CBDR) for countries with varying levels of economic growth, we moved this target to 2060 for China.

9 According to the ICCSD report (2021), the 1.5°C-aligned transportation carbon budget is about 172 million tonnes in 2050. To reflect the principle of Common But Differentiated Responsibilities (CBDR) for countries with varying levels of economic growth, we moved this target to 2060.

10 GFW data is publicly available at https://globalfishingwatch.org/datasets-and-code.

11 Type 1 ships can be matched via a ship's IMO number while Type 2 ships can be matched via a ship's MMSI number. The IHS ship database is commercially available from IHS Markit. Details can be found here: https://ihsmarkit.com/products/maritime-ships-register.html.

In this study, we focused on Type 3 ships that are registered in China.[12] Among these ships, we identified those most likely engaged in coastal navigation based on their AIS signals' spatial pattern (Mao & Rutherford, 2015). We found 444 ships[13] with ship records (ship type, ship name, deadweight tonnage, and year of build) available at chinashipbuilding.cn and randomly sampled another 63 ships that matched with the GFW database. We used our Systematic Assessment of Vessel Emissions (SAVE) model (Olmer et al., 2017) to estimate their fuel consumption, CO_2 emissions, and travel distances in 2019, which was used to characterize the entire China coastal shipping fleet and activities that year.

2019 CO_2 emissions inventory estimation as baseline

We calculated the CO_2 emissions from the entire China coastal shipping fleet using Equation 1. The carbon intensity of a ship, measured via the Energy Efficiency Operating Indicator (or EEOI, in g CO_2/tonne-nm), was calculated from the 507 sample ships for each major ship type. In determining the actual cargo tonne nautical miles of a ship (denominator of EEOI, abbreviated as tonne-nm), we used a generic utilization rate—the percentage of how much of a ship's maximum cargo-carrying capacity[14] is loaded with cargo—of 0.72.[15] Total transport work[16] per ship type was estimated by multiplying the actual annual cargo moved per ship type collected from China's annual statistical yearbook in 2019[17] with average voyage distance calculated from the 507 sample ships for each major ship type (See Appendix A for more details).

Equation 1

$$CO_2\ \ Emissions = \sum EEOI_i \times Transport\ work_i$$

Where:

EEOI$_i$: Average carbon intensity of ship type *i*, measured in g CO_2/tonne-nm.

Transport work$_i$: Total transport work of ship type *i*, measured in tonne-nm.

Projecting CO_2 emissions out to 2060

The method for projecting CO_2 emissions from China's coastal shipping sector comprises six steps:

1. Build a detailed description of the fleet and its activity in the base year, 2019.

2. Project transport work for fossil-based energy products.

3. The method used to project transport work related to the transportation of fossil-based energy products is based on demand projections for four main products: coal,

12 The nationality of a ship is indicated by the first three digits of the ship's MMSI number. The International Telecommunication Union (ITU) assigned "412", "413" and "414" to China: https://www.itu.int/en/ITU-R/terrestrial/fmd/Pages/mid.aspx. China's Ministry of Transport authorizes provincial transport departments to assign those MMSI numbers when ships register with them.

13 Among the matched ships, we found only container ships, bulk carriers, and oil tankers. This is likely due to the fact that the ship records available on chinashipbuliding.cn are incomplete and only include the major ship types. According to 2020 fleet capacity updates released by MOT, the three ship types make up about 98% of the coastal shipping cargo-carrying capacity. See details here: http://www.gov.cn/xinwen/2019-09/19/content_5431312.htm.

14 This is measure via ship's deadweight tonnage, abbreviated as DWT.

15 According to the Medium- and Long-term Special Plan for Transportation Energy Conservation (2005-2020) released by MOT, the utilization rate for coastal and oceangoing vessels by 2020 was set at □72%. So, we took 0.72 as a conservative estimate for 2019 utilization rate. The document can be accessed here: http://www.gov.cn/gzdt/2008-11/04/content_1139571.htm.

16 According to the Fourth IMO GHG study (Faber et al., 2020), transport work is measured by factual cargo tonne miles or passenger miles undertaken by a ship.

17 Data was collected from the National Statistics Yearbook 2019 (http://www.stats.gov.cn/tjsj/), and the Statistical Communique of the Development of Transportation Industry 2019 (http://www.gov.cn/xinwen/2020-05/12/content_5510817.htm).

oil, natural gas, and non-energy products. The ICCSD report (2021) assumes declining transport demand for energy products and rising demand for non-energy products, with the rate of energy decline accelerating across its strengthened policy scenario, 2°C-aligned policy scenario, and 1.5°C-aligned policy scenario (ICCSD, 2021). We matched those assumptions with our BAU, 2°C-aligned and 1.5°C-aligned scenarios respectively (See details in Appendix B).

4. Project transport work for all other products.

By plotting the historical data of coastal shipping transport work for all other products and China's overall GDP per capita for the years 2010 to 2019, we found that the annual growth rates for these two parameters trailed each other and the ratio of the two (the denominator is the annual growth rate for GDP per capita) had remained relatively stable at 1, with a slight downward trend in recent years. This ratio, or the elasticity between growth of transport work and GDP per capita, is a measure of freight productivity evaluated in China every year for each freight mode, which we assume will decrease slowly (due to higher productivity) in the future. As a result, the product of the annual growth rate of GDP per capita (ICCSD, 2021) and decreasing elasticity between the growth rate of transport work and GDP per capita was assumed, and used to project transport work for all other products (see details in Appendix B).

1. Project the future fleet composition based on a literature review and a stakeholder consultation. The details of a fleet turnover model can be found in Appendix C.
2. Project future average carbon intensity of the fleet, influenced by natural efficiency improvements (efficiency improvements caused by market competition), and by policy interventions including energy efficiency standards for newbuild ships and low-carbon fuel regulations for the entire fleet. (See details in Appendix D).
3. Combine results from the steps above to project shipping emissions each year, also using Equation 1.

For each year from 2020 to 2060, transport work and average carbon intensity of the fleet were projected using Equations 2 and 3. We considered three broad types of policies that might cut future CO_2 emissions of China's coastal shipping sector: limiting demand for transport work, improving energy efficiency, and reducing fuel carbon intensity. According to the ICCSD report (2021), limiting demand for transport work could take place only for fossil-based energy products given that China will transition away from them. Demand for transport work for other products would grow as the economy at large grows. Policies to improve energy efficiency can be achieved by enacting energy efficiency standards on newbuild ships and tightening them every five years. This is similar to IMO's EEDI standards except that in using lower carbon shipping fuel is not considered compliance in our study. Instead, they are required separately by low-carbon fuel regulations similar to the FuelEU Maritime Initiative. In addition, natural efficiency improvements were adapted in our study from the Fourth IMO GHG study (Faber et al., 2020) except that using lower carbon shipping fuel is not considered natural. Assumptions of key parameters related to these policies under different scenarios are presented in Table 1.

Equation 2

$$Transport\ work_{i,y} = \sum Transport\ work_{i,y-1} \times (1+g_{i,y})$$

Where:

$g_{i,y}$: Annual change of demand for transport work provided by ship type *i* in year *y* (unit-less); note that $g_{i,y}$ for ship types moving fossil-based energy products is different from $g_{i,y}$ for ship types moving other products (See Appendix B for details).

Equation 3

$$EEOI_{i,y} = \frac{N_{newbuild_{i,y}} \times EEOI_{newbuild_{i,y}} + N_{existing_{i,y}} \times EEOI_{existing_{i,y}}}{N_{i,y}} \times FC_y$$

Where:

$N_{newbuild_{i,y}}$: Number of newbuild ships within ship type *i* in year *y*.

$EEOI_{newbuild_{i,y}}$: Average carbon intensity of newbuild ships within ship type *i* in year *y*, measured in g CO_2/tonne-nm. It is impacted by energy efficiency standards for newbuild ships as well as natural efficiency improvements like slow steaming.

$N_{existing_{i,y}}$: Number of existing ships within ship type *i* in year *y*.

$EEOI_{existing_{i,y}}$: Average carbon intensity of existing ships within ship type *i* in year *y*, measured in g CO_2/tonne-nm. This is impacted by natural efficiency improvements and the deterioration rate of designed efficiency.[18]

$N_{i,y}$: Total number of ships within ship type *i* in year *y*.

FC_y: Fuel carbon intensity reduction target for year *y* (unit-less).

Table 1. Key policy-related assumptions used in three scenarios

		Scenarios					
		BAU		2°C-aligned		1.5°C-aligned	
Transport work (annual change)[a]		**2020-2030**	**2030-2060**	**2020-2030**	**2030-2060**	**2020-2030**	**2030-2060**
$g_{i,y}$	**Coal**	-0.3%	-2.2%	-1.5%	-5.3%	-4.1%	-9.2%
	Oil	1.2%	-1.5%	-0.2%	-1.7%	-2.4%	-7.4%
	Natural gas	6.1%	-0.5%	5.1%	-1%	4.4%	-4.2%
	Non-energy products	4.7%	2.9%	4.4%	2.5%	4.2%	2.2%
		BAU		**2°C-aligned**		**1.5°C-aligned**	
Energy efficiency standards (reduction target of newbuild energy efficiency relative to 2019 baseline)[b]		2020-2060		2025-2045, five-year steps		2025-2045, five-year steps	
Container ships		—		-10%, -25%, -35%, -40%		-20%, -35%, -45%, -50%	
Other ship types		—		-10%, -20%, -30%, -40%		-20%, -30%, -40%, -50%	
		BAU		**2°C-aligned**		**1.5°C-aligned**	
Low-carbon fuel regulation (reduction target of fuel carbon intensity relative to 2019 baseline)[c]		2020-2060		2030-2060, five-year steps		2025-2060, five-year steps	
FC_y		—		-2%, -6%, -13%, -26%, -59%, -65%		-2%, -6%, -13%, -26%, -59%, -75%, -85%	
		BAU		**2°C-aligned**		**1.5°C-aligned**	
Natural efficiency improvements (annual change relative to previous year)[d]		2020-2030	2030-2060	2020-2030	2030-2060	2020-2030	2030-2060
$Market_y$		-0.8%	-0.6%	-0.8%	-0.6%	-2.5%	-0.4%

Notes: [a]. These assumptions are sourced from the ICCSD report (2021). [b]. Energy efficiency standards will bring improvement in operational carbon intensity, but not directly. For simplicity, we assumed that the designed efficiency requirement will translate 100% to ships' operational carbon intensity improvement when first introduced. All in-service fleet will experience an annual degradation rate of 0.2% in future carbon intensity. [c]. The stepwise low-carbon fuel regulations are sourced from the FuelEU Maritime Initiative, which spans 30 years. For the 2°C-aligned scenario, the final fuel carbon intensity reduction target by 2060 was modified to align with the 2°C target. For the BAU scenario, fuel carbon reduction targets beyond 30 years were interpolated to align with the 1.5°C target. [d]. These assumptions are sourced from Table 75, 77, and 78 in Faber et al. (2020). To avoid double-counting, we excluded data related to natural fuel carbon intensity development from these tables.

18 The annual carbon intensity deterioration rate is assumed to be 0.2%, which applies to all ships that are "existing" for a particular year.

Sensitivity analysis of the timing for introducing low-carbon fuel regulations

For the 2°C-aligned and 1.5°C-aligned scenarios, low-carbon fuel regulations for shipping are introduced on a stepwise schedule, with a strengthening of measures every five years over a total span of 30 and 35 years, respectively. This design is similar to the FuelEU Maritime Initiative but incorporates time for industry to transition to low-carbon shipping fuels (see details in Appendix D). As a result, the policy would be implemented over a long period, which means it needs to kick off no later than 2030. We did a sensitivity analysis of a delayed schedule for introducing this policy for the 2°C-aligned and 1.5°C-aligned scenarios while keeping their 2060 targets intact. The delayed schedule assumes these policies will be implemented from 2046 to 2060, after the mandatory energy efficiency standards expire in 2045. The resulting annualized reduction target of fuel carbon intensity relative to the previous year was calculated using Equation 4. Finally, the reduction targets for fuel carbon intensity relative to the 2019 baseline can be calculated cumulatively for a given year.

Equation 4

$$AFC_y = \left(\frac{CO_2\ Emissions_{2060}}{CO_2\ Emissions_{2045}}\right)^{1/15} - 1$$

Where:

AFC_y: Annualized fuel carbon intensity reduction in year y relative to the previous year. y is a value between 2046 and 2060.

Results and discussion

2019 Baseline ship activities and CO_2 emissions from China's coastal shipping sector

In 2019, we estimated that China's coastal shipping fleet emitted approximately 45 million tonnes of CO_2, much of which (45%) was contributed by container ships, followed by bulk carriers (22%) and oil tankers (6%). However, bulk carriers did the most transport work (tonne-nm) in 2019 (46%) followed by container ships (31%) and oil tankers (6%). This reflects the fact that in general, bulk carriers have relatively lower (better) carbon intensity than other ship types.

As shown in Table 2, the estimated carbon intensity of bulk carriers is one-third that of container ships. Liquified gas carriers showed the worst performance in ship carbon intensity for China's coastal fleet in 2019 on a tonne-nm basis. The resulting average fleet-wide carbon intensity was 25 g CO_2/tonne-nm in 2019. According to the ICCSD report (2021), the transportation sector is estimated to emit about 990 million tonnes of CO_2 in 2020; the Chinese coastal fleet would account for 4.5% of that. In projections to future years, we assumed that this CO_2 emission budget remains constant.

Table 2. 2019 baseline fleet activity (voyage length and transport work) and CO_2 emissions

Ship type		Share of total transport work	Share of fleet-wide CO_2 emissions	EEOI (g CO_2/tonne-nm)	Mean voyage length (nm)
Bulk carrier	**Coal**	31%	15%	12.0	743
	Non-coal bulk cargo	15%	7.5%		
Container ship		31%	45%	36.2	573
Liquified gas carrier		0.20%	0.50%	71.6	713
Oil tanker		5.8%	6%	27.4	935
Other		17%	26%	37.3	675
Average		—	—	25	668

Future CO_2 emissions from China's coastal shipping sector

1. Demand for transport work

We expect transport work in China's coastal shipping sector to grow in step with the economy, except for shipping of fossil-based energy products, namely coal, oil, and natural gas, which the country is transitioning away from. Under the BAU scenario, transport demand for shipping coal would be halved by 2060 with existing policies. Under the 2°C-aligned and 1.5°C-aligned scenarios, coal shipping's contribution to total coastal transport work would further decrease from 46% in 2019 to less than 2% in 2060. Transport work for oil and natural gas would experience a somewhat smaller decrease, from a share of 6% in 2019 to approximately 1% in 2060 in 2°C-aligned and 1.5°C-aligned scenarios.

Such a drastic decrease in transport work for fossil-based energy products would be picked up by shipping other products, such as containerized cargo and bulk cargo like iron and ore. The contribution to total coastal transport work of the container shipping sector alone could grow from 31% in 2019 to about 48% in 2060 under the 2°C-aligned and 1.5°C-aligned scenarios. The demand composition of transport work in selected years is shown in Figure 1. Total transport work more than triples in 2060 relative to the 2019 baseline under the BAU scenario, and the growth would be suppressed somewhat under the 1.5°C-aligned scenario, to around 2.2-times that of the 2019 level, even with nearly-vanishing demand for fossil-based energy products.

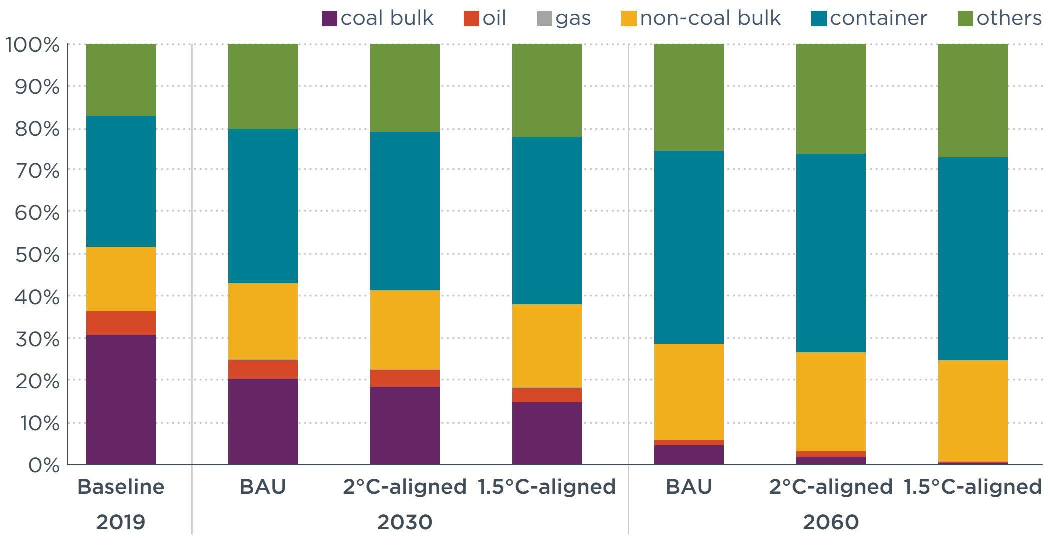

Figure 1. Transport demand composition in 2019 and predicted for 2030 and 2060 under each scenario

2. Total number of ships and average carbon intensity of the future China coastal shipping fleet

The average carbon intensity of the fleet improves with the introduction of newer and more efficient ships. Our fleet turnover model estimates the number of newbuild ships and existing ships for the years 2020 to 2060. Although the total cargo-carrying capacity of the fleet should grow to supply the growing demand for transport work, the projection of fleet size each year is impacted by different assumptions about the capacity of newbuild ships. In the BAU scenario, in which newbuild ship capacity grows relatively slowly, the total number of ships increases over time to meet the growing demand for transport work (Figure 2). Under the 2°C-aligned scenario, the total number of ships first increases slightly, then falls steadily as newbuild ship capacity grows slowly over time, as fewer ships perform the same amount of transport work. For the

1.5°C-aligned scenario, in which newbuild ship capacity grows even more, the total number of ships falls year over year (see details in Appendix C).

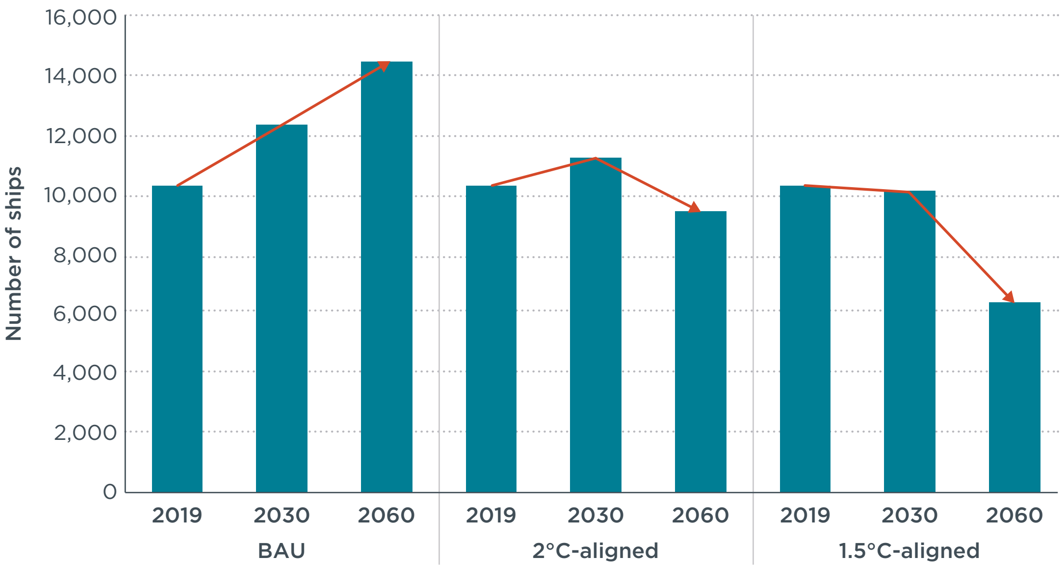

Figure 2. Total number of ships in 2019, 2030, and 2060, under each scenario.

Under the BAU scenario, natural efficiency improvements and the change in fleet composition would impact the fleet's average carbon intensity, resulting in minor but positive EEOI improvement over time for each ship type. However, fleet average EEOI could increase by 7% in 2060 relative to the 2019 level (Figure 3). This is because container ships, which are less efficient than bulk carriers (Table 2) gradually replace bulk carriers' dominance in China's coastal fleet composition over the years. Under the 2°C-aligned scenario, additional policies are introduced including near-term energy efficiency standards on newbuild coastal fleet from 2025 to 2045, and long-term low-carbon fuel regulations from 2030 onward. This addition could bring about a 79% reduction in fleet average EEOI by 2060 (Figure 3) relative to 2019 baseline. Under the 1.5°C-aligned scenario, with more stringent energy efficiency standards and earlier transition to low-carbon fuel regulations, we could see an even further reduction in fleet average EEOI—about 92% lower than the 2019 baseline (Figure 3).

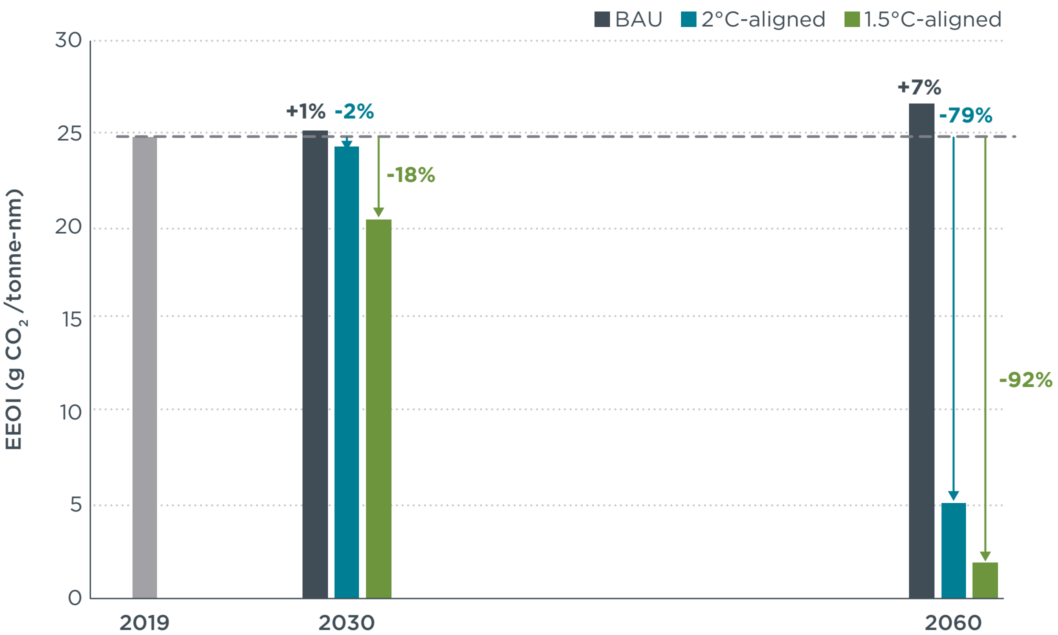

Figure 3. Fleet average EEOI change over time for China's coastal shipping fleet, three scenarios for selected years

3. Future CO_2 emissions from China's coastal shipping sector

Without additional policies to regulate CO_2 emissions from China's coastal fleet, fleetwide CO_2 emissions would more than triple, from 45 million tonnes in 2019 to 162 million tonnes by 2060, driven by increasing demand for transport work. In order to reach the 2°C-aligned decarbonization goal for China's transportation sector set in the ICCSD report (2021), China's coastal shipping sector would need to reduce its total CO_2 emissions by 56% by 2060 relative to the 2019 baseline to maintain its share of the national transportation CO_2 emission budget, which can be achieved through a pathway shown by the 2°C-aligned scenario (blue line in Figure 4). If the sector aims more ambitiously at the 1.5°C-aligned decarbonization goal set in the ICCSD report (2021), the overall CO_2 emission would need to be 83% lower than the 2019 baseline by 2060, with a potential pathway shown in the green line in Figure 4. For both pathways, fleetwide CO_2 emissions could peak before 2040, 5-10 years later than China's national CO_2 emission peaking target of 2030. Of course, peaking earlier would have the benefit of requiring less extreme reductions in later years.

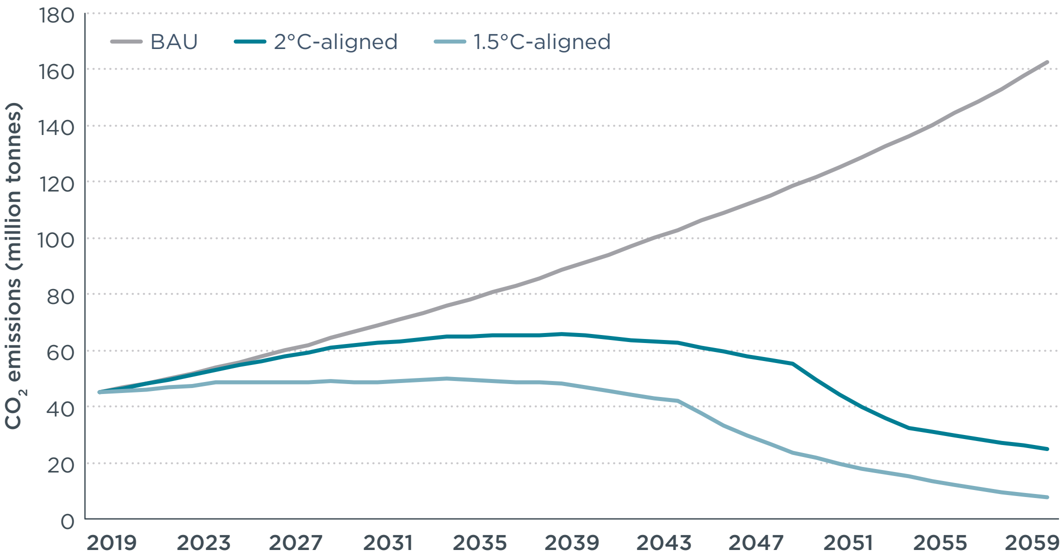

Figure 4. Combined projection of CO_2 emissions with pathways to decarbonization by 2060

We analyzed two broad types of policies that could drive down future CO_2 emissions. The first is energy efficiency standards. The impact of such policies would emerge gradually with the introduction of newbuild vessels. Beyond the period when energy efficiency standards are in place, natural1 efficiency improvements would remain a source of energy efficiency improvement without policy intervention. The second policy analyzed is low-carbon fuel regulations. In contrast to energy efficiency standards, which can be met by relatively cheap and mature technologies, the transition to lower carbon shipping fuels remains a challenge to the shipping industry. They need to phase in slowly and relatively modestly in the early years to prepare for the transition. This policy, however, would help achieve significant CO_2 emission reductions by 2060 and steer the shipping industry toward a truly decarbonized future. To illustrate the scale of impact of factors analyzed in our model on the future CO_2 emissions of China's coastal fleet, we decomposed the CO_2 emission addition/reduction potential by factor in a waterfall chart for the 1.5°C-aligned scenario as an example (Figure 5).

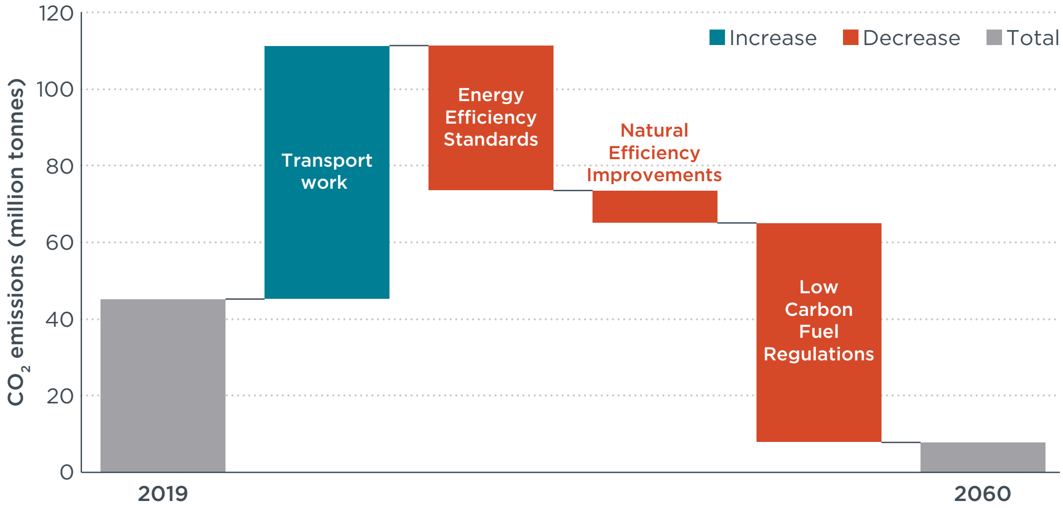

Figure 5. CO_2 addition/reduction potential by impact factor for cumulative CO_2 emission changes between 2019 and 2060 under the 1.5°C-aligned scenario

4. What if the low-carbon fuel regulations were delayed?

To this point we have considered a phased-in low-carbon fuel regulation for China's coastal fleet similar in timeline and stringency to the FuelEU Maritime Initiative (see details in Appendix D). However, even this arguably conservative policy proposal could be considered too ambitious by Chinese policymakers. The 2021 action plan for capping CO_2 emissions before 2030 does not adopt or even propose such measures. In order to demonstrate the impact of delayed implementation of low-carbon fuel regulations, we performed sensitivity analyses on 2°C-aligned and 1.5°C-aligned scenarios, with the regulations being introduced after the energy efficiency standards expire in 2045.

In Figure 6, we show that for the 2°C-delayed scenario, with energy efficiency standards as the only additional policy intervention before 2045, CO_2 emissions for China's coastal shipping sector would not peak until the introduction of low-carbon fuel regulations. The same is observed for the 1.5°C-delayed scenario.

Table 3 shows the annual and cumulative reduction of shipping fuel carbon intensity of each scenario. In order to reach the 2°C-delayed 2060 CO_2 emission reduction target with delayed introduction of low-carbon fuel regulations, the carbon intensity of shipping fuel would need to decline at 8% annually, or 71% cumulatively (relative to 2019), over the 15-year (2045-2060) delayed implementation period. Compare this effort to our original 2°C-aligned scenario, in which the cumulative reduction required was just 13% for the initial 15 years of implementation. And for the 1.5°C-delayed scenario 2060 target, the cumulative reduction required is 88%, an annual reduction of 13% for each of the 15 years. These results are presented as dotted lines in Figure 6. In sum, emission cuts needed in a scenario of delayed implementation of low-carbon fuel regulations are dauntingly high and would pose a major challenge to industry.

Table 3. Annual and cumulative reduction of shipping fuel carbon intensity for aligned and delayed scenarios

Scenario	Annual and cumulative reduction of shipping fuel carbon intensity					
	2025-2030		2030-2045		2045-2060	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
2°C-aligned	0%	0%	-0.9%	-13%	-7%	-58%
1.5°C-aligned	-0.4%	-2%	-1.9%	-24%	-11%	-62%
2°C-delayed	0%	0%	0%	0%	-8%	-71%
1.5°C-delayed	0%	0%	0%	0%	-13%	-88%

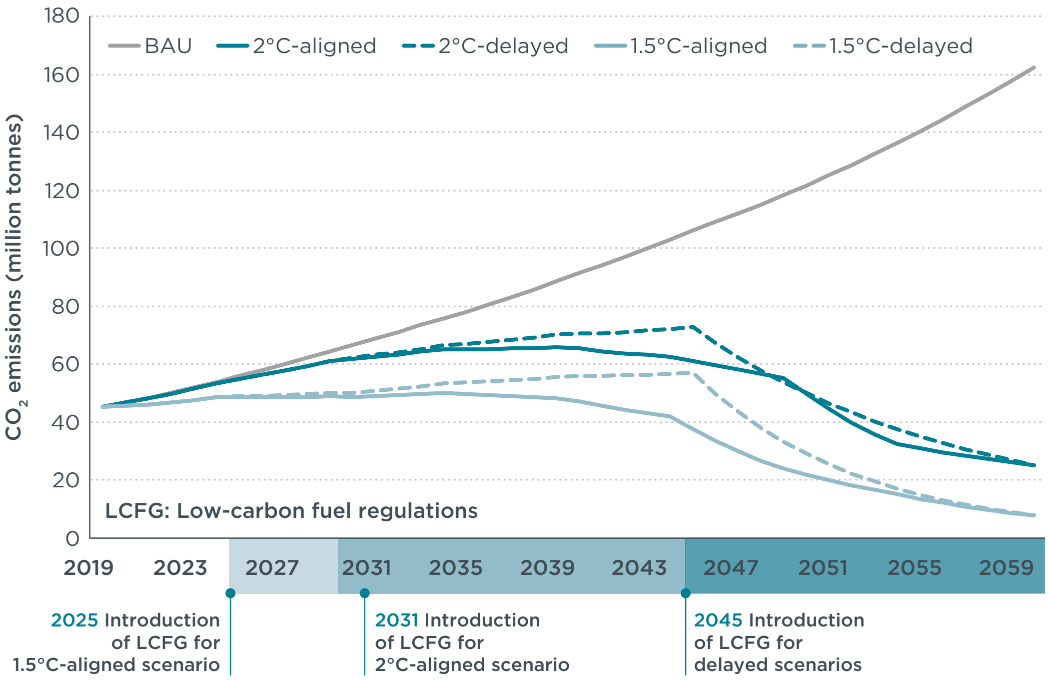

Figure 6. Impact of delayed implementation of low-carbon fuel regulations for 2°C-aligned and 1.5°C-aligned scenarios

Conclusions and future work

As the world's largest GHG emitter and second largest economy, China faces a tremendous challenge to decarbonize consistent with the Paris Agreement. As the world awaits the unveiling of the details of the recently announced carbon peaking and neutrality goals, this study took a deep dive into the country's coastal shipping sector and analyzed the decarbonization opportunities and challenges facing this sector over the next 40 years.

We estimate that a total of 45 million tonnes of CO_2 was emitted by the coastal shipping sector in China in 2019. This accounts for roughly 4.5% of the total CO_2 emissions contributed by the country's entire transportation sector. If no additional decarbonization policies are implemented, emissions are expected to more than triple by 2060 relative to the 2019 baseline, driven by increasing demand for transport work.

A phased-in low-carbon fuel regulation is essential, preparing the sector for a true decarbonization future, although mandatory energy efficiency standards and natural efficiency improvements will also drive down average carbon intensity of the coastal fleet. For the 2°C-aligned scenario, which aligns with the 2°C-target set in the ICCSD report (2021), overall CO_2 emissions would drop by 44% by 2060 relative to the 2019 baseline, with an overall carbon intensity decline of about 79%. For the 1.5°C-aligned scenario, which aligns with the 1.5°C-target set in the ICCSD report (2021), overall CO_2 emissions would drop by 83% by 2060 relative to the 2019 baseline, with an overall carbon intensity drop of about 92%.

Low-carbon fuel regulation would hold the biggest decarbonization potential, compared to energy efficiency improvement. We decomposed the scale of impact of different factors for the 1.5°C-aligned scenario and found that by 2060, increases in transport work from the Chinese coastal shipping sector could add 66 million tonnes of CO_2 emissions to the 2019 level. The low-carbon fuel regulations would help to reduce CO_2 emissions by more than 57 million tonnes, tightened energy efficiency standards would cut another 38 million tonnes, and natural efficiency improvements would shed an additional 8 million tonnes.

Finally, we found that a delay in the low-carbon fuel regulations until 2046 would pose a major challenge to industry. We performed sensitivity analyses of 2°C-aligned and 1.5°C-aligned scenarios by modeling a delay in the low-carbon fuel regulations until 2046, essentially giving it 15 years to help the sector achieve its 2060 targets. We showed that for both scenarios, the sector's CO_2 emission peaking would thus be delayed to around 2045. In the 2°C-delayed scenario, the industry would need to cut the carbon intensity of shipping fuel by 71% cumulatively for 15 years relative to the 2019 baseline. For the 1.5°C-delayed scenario, industry would have to cut the carbon intensity of shipping fuel by 88% cumulatively over 15 years relative to 2019 baseline.

Once the official action plan to reach the sector's 2060 target is announced, our model will need to be recalibrated to see if the proposed measures will be sufficient to put industry on the track to true decarbonization. Although we highlighted the importance of low-carbon fuel regulations, we did not analyze the availability or cost of low carbon marine fuels in China. Future work will be needed to understand the marine fuel market in China, to develop certification standards for low-carbon marine fuels, to analyze the cost of developing a fuel supply chain for them, and to identify policy options to promote first movers.

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Appendices

A. Calculating factual transport work for China's coastal shipping sector

The quantity of cargo moved per cargo type was collected from China's Transportation Statistical Yearbook 2020. A corresponding relationship between ship type and associated cargo type was assumed and presented in Table A 1. Transport work was then calculated by multiplying the amount of cargo moved by the average voyage distance derived from the 507 sample ships using SAVE, as presented in Table A 2.

Table A 1. Cargo types and corresponding ship types and amount moved in 2019

Cargo type	Ship type	Amount moved in 2019 (million tonnes)
Coal	Bulk carrier	754
Iron ore		319
Grains		58
Containerized cargo	Container	986
Crude oil	Oil tanker	145
Petroleum products	Chemical tanker	32
LNG/LPG	Liquified gas carrier	4
Others	Other	461

Table A 2. Average voyage distance per ship type and total transport work in 2019

Ship type		Mean voyage length (nm)	Cargo moved in 2019 (million tonnes)	Transport work (billion tonne-nm)
Bulk carrier	**Coal**	743	754	560
	Non-coal bulk cargo		377	280
Container ship		573	986	565
Liquified gas carrier		935	4	4
Oil tanker		713	145	103
Other		675	461	311
Total		---	2727	1823

B. Estimating future transport work

For each year after 2019, transport work per ship type was estimated based on transport work of the previous year and an annual growth rate for the estimation year. For fossil-based energy products, assumptions for annual growth rate are presented in Table B 1; they are sourced from the ICCSD report (2021).

Table B 1. Annual growth rates for transport work of fossil-based energy products

Scenario	Annual growth rate in transport work					
	Coal		Oil		Gas	
	2020-2030	2030-2060	2020-2030	2030-2060	2020-2030	2030-2060
BAU	-0.3%	-2.2%	1.2%	-1.5%	6.1%	-0.5%
2°C-aligned	-1.5%	-5.3%	-0.2%	-1.7%	5.1%	-1.0%
1.5°C-aligned	-4.1%	-9.2%	-2.4%	-7.4%	4.4%	-4.2%

For other products, annual growth rates were the product of annual growth rates of GDP per capita (ICCSD, 2021) and elasticity between transport work growth and GDP per capita growth, all presented in Table B 2. The resulting annual growth rates for all other products were presented in Table B 3.

Table B 2. Assumptions for annual growth rates for GDP per capita and elasticity between transport work growth and GDP per capita

Scenario	GDP annual growth rate					
	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2060
All	5.0%	4.8%	4.4%	4%	3.6%	3.2%
	Elasticity between transport work growth and GDP per capita growth					
BAU	1	0.9		0.8		
2°C-aligned	1	0.8		0.7		
1.5°C-aligned	1	0.7		0.6		

Table B 3. Annual growth rates for transport work of all other products

Scenario	Annual growth rate in transport work						Average	
	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2060	2020-2030	2030-2060
BAU	5.0%	4.3%	4.0%	3.2%	2.9%	2.6%	4.7%	2.9%
2°C-aligned	5.0%	3.8%	3.5%	2.8%	2.5%	2.2%	4.4%	2.5%
1.5°C-aligned	5.0%	3.4%	3.1%	2.4%	2.2%	1.9%	4.2%	2.2%

C. Fleet turnover model

We collected number of ships of China's coastal shipping fleet in 2019 from China's Transport Statistical Yearbook 2020, which includes number of ships per ship type only for ships larger than a certain threshold and the total number of ships, presented in Table C 1.

Several assumptions were made to estimate fleet turnover between 2020 and 2060.

» Each year, a constant share of the fleet is newbuild ships. This share was assumed differently for different ship types, based on the historical newbuild ratio for the same ship type of China-flagged Type 1&2 vessels in the IHS ship database (Table C 2).

» Each year, average ship capacity increases. We assumed that for each ship type, the capacity growth limit is the largest ship capacity of the same type of China-flagged Type 1&2 vessels in the IHS ship database. The growth trend for ship capacity was assumed differently for each scenario (Table C 3).

» Each year, the growth rate for total ship capacity per ship type equals that year's transport work growth rate of the corresponding ship type.

With these assumptions, we were able to estimate the total number of ships needed for a future year (Figure C 1) for each ship type and the number of newbuild ships for that year. The remaining number of ships was the existing fleet of that year.

Table C 1. Number of ships per ship type in 2019

	Bulk carrier	Oil tanker	Liquified gas carrier	Container ship	Others[a]	Total
Number of ships	1752	1249	73	290	7000	10364

Note: The "Others" type includes smaller-sized bulk carriers, oil tankers, liquified gas carriers, container ships and all other ship types unidentified. The total fleet capacity of this category represented less than 10% of total capacity of China's coastal fleet.

Table C 2. Assumptions for share of newbuild ships per ship type, constant over years

Ship type	Share of newbuild ships for each year
Bulk carrier	4.8%
Oil tanker	5.6%
Liquified gas carrier	6.4%
Container ship	7.4%
Others	5.5%

Table C 3. Assumptions for capacity growth (annual growth of fleet average DWT) trend per ship type

Scenario[a]	Bulk carrier	Oil tanker	Gas tanker	Container ship	Chemical ship	Others
BAU	1.6%	2.0%	0.6%	0.6%	1.4%	3.0%
2°C-aligned	1.8%	3.2%	0.5%	1.4%	1.6%	3.5%
1.5°C-aligned	1.9%	3.6%	0.6%	1.6%	1.8%	4.2%

Note: [a]. For BAU scenario, we cap the capacity growth to 75% percentile of the existing oceangoing container fleet of the same ship type; except for liquified gas carriers, where the 85% percentile was used as the 75% percentile was lower than the current average capacity; For 2°C-aligned, we cap the capacity growth to 95% percentile of the existing oceangoing fleet of the same ship type; For 1.5°C-aligned, we cap the capacity growth to the largest size of the existing oceangoing fleet of the same ship type.

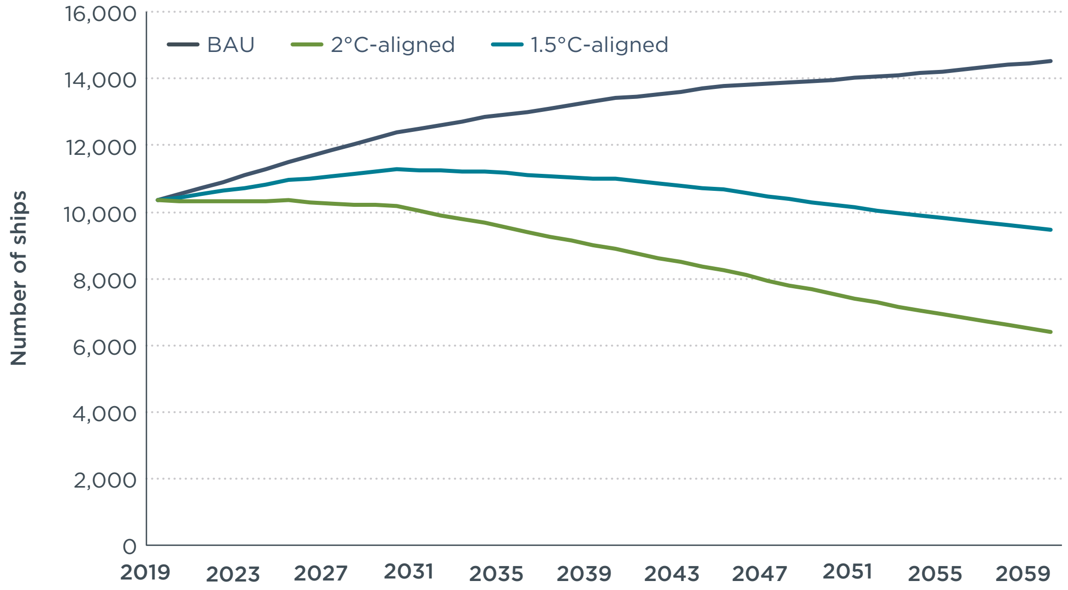

Figure C 1. Number of ships of China's coastal fleet between 2020 and 2060, three scenarios

D. Assumptions for policy-driven and natural fleet carbon intensity improvement

The mandatory energy efficiency standards are similar in design to IMO's EEDI. We assumed introduction of such a policy in 2025, phasing in progressively every five years with a total of four phases (Table D 1).

Table D 1. Requirements for mandatory energy efficiency standards, 2°C-aligned and 1.5°C-aligned scenarios

Phases	Scenario	Requirements	
		Container ships	All other ships
I: 2025-2030	2°C-aligned	-10% from 2019 level	
	1.5°C-aligned	-20% from 2019 level	
II: 2030-2035	2°C-aligned	-25% from 2019 level	-20% from 2019 level
	1.5°C-aligned	-35% from 2019 level	-30% from 2019 level
III: 2035-2040	2°C-aligned	-35% from 2019 level	-30% from 2019 level
	1.5°C-aligned	-45% from 2019 level	-40% from 2019 level
IV: 2040-2045	2°C-aligned	-40% from 2019 level	
	1.5°C-aligned	-50% from 2019 level	

Additionally, we introduced low-carbon fuel regulations starting in 2030 for a 2°C-aligned scenario and 2025 for a 1.5°C-aligned scenario. These regulations also phase in progressively every five years, with a similar stringency design as the FuelEU Maritime Initiative (Table D 2).

Table D 2. Fuel carbon intensity limits, relative to 2019 baseline, 2°C-aligned and 1.5°C-aligned scenarios

Year	2°C-aligned	1.5°C-aligned	FuelEU Maritime
2020-2025	—	—	98%
2025-2030	—	98%	94%
2030-2035	98%	94%	87%
2035-2040	94%	87%	74%
2040-2045	87%	74%	41%
2045-2050	74%	41%	25%
2050-2055	41%	25%	—
2055-2060[a]	29%	12%	—

Note: [a]. The final limits for 2°C-aligned and 1.5°C-aligned were calculated to ensure that the 2°C-target of 2°C-aligned and 1.5°C-target of 1.5°C-aligned can be reached.

Finally, natural efficiency improvements are adapted from the Fourth IMO GHG study (Faber et al., 2020). These improvements include energy-saving technologies on ship design, operational optimization measures, and using lower carbon shipping fuel. To avoid double-counting, we didn't take into account CO_2 reduction potential of lower carbon shipping fuel for calculating average annual CO_2 reduction potential for natural efficiency improvements. The final impact from natural efficiency improvements is presented in Table D 3 and applies to the entire fleet.

Table D 3. Annual carbon intensity reduction rate of natural efficiency improvements, three scenarios

Scenario	2020-2030	2030-2060
BAU	-0.8%	-0.6%
2°C-aligned	-0.8%	-0.6%
1.5°C-aligned	-2.5%	-0.4%