The maritime shipping sector

facing the challenges of decarbonization and digitalization

Atos | WWF

Advancing together to harness technology for biodiversity conservation

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List of abbreviations

Acronym	Signification
ABS	American Bureau of Shipping
AER	Annual Efficiency Ratio
B2DS	Beyond 2 Degrees Scenario
CFD	Computational Fluid Dynamics
CII	Carbon Intensity Indicator
CMA-CGM	Compagnie Maritime d'Affrètement – Compagnie Générale Maritime
CMF	Cluster Maritime Français
DGAMPA	Direction générale des affaires maritimes, de la Pêche et de l'aquaculture
DWT	Deadweight tonnes (how much wight a ship in designed to carry)
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
EEPI	Energy Efficiency Performance Indicator
EETS	Energy Efficiency Technologies for Ships
EEXI	Energy Efficiency Existing Ship Index
EMS	Energy Management System
EMSA	European Maritime Safety Agency
ESD	Energy Saving Devices
ETP	Energy Technology Perspective
ETS	Emissions Trading System
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GLEC	Global Logistics Emissions Council
GloMEEP	Global maritime energy efficiency partnerships
GMF	Global Maritime Forum
HPC	High performance computing
IEA	International Energy Agency
IMO	International Maritime Organization
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IWSA	International Windship Association
JIT	Just in time
LSFO	Low Sulfur Fuel Oil
MARPOL	International Convention for the Prevention of Pollution from Ships : main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes.

MEPC	Marine Environment Protection Committee
MRV	Monitoring, Reporting and Verification
MSC	Mediterranean Shipping Company
NZE	Net Zero Emissions
PID	Propulsion Improving Devices
RTS	Reference Technology Scenario
SBTi	Science-Based Target initiative
SDS	Sustainable Development Scenario
SPS	Stated Policies Scenario
SEEMP	Ship Energy Efficiency Management Plan
SFC	Smart Freight Center
SZEF	Scalable Zero Emission Fuels
TEU	Twenty-foot Equivalent Unit
TTW	Tank-To-Wake
UMAS	University Maritime Advisory Services
UMS	Universal Measurement System
WEO	World Energy Outlook
WTW	Well-To-Wake
ZEMBA	Zero Emission Maritime Buyers Alliance

Executive Summary

The aim of this white paper is to identify the state of the art, challenges, trends, and levers of the decarbonization of the shipping sector, notably by exploring the contribution of digital technologies.

Maritime shipping, the maritime transport of freights and goods, has been growing for several years, and accounts for most of the world's freight transport. Although it is one of the least carbon- intensive modes of transport, the sheer volume of goods transported (around 80% of the volume of world merchandise trade), and the fact that fossil fuels are still overwhelmingly used, mean that the sector accounts for a significant share of global GHG emissions (2,9%). It is projected to represent between 90 to 130% of 2008 emissions by 2050 (under a business-as-usual scenario [1]) .

What's more, the sector is highly concentrated, with a few players controlling most of the volumes transported. Although these players' climate commitments are currently limited and heterogeneous, it is possible to drastically reduce emissions by getting these core organizations to commit. Their commitment should rely on the quantification of the shipping sectors' well-known decarbonization levers.

To identify the decarbonization trajectories to be followed by these industry players, numerous scenarios have been published. This study aims to understand the differences between these different scenarios:

- First, the scenarios do not use the same emissions accounting perimeters: some scenarios do not consider emissions from the entire fuel life cycle (Tank-To-Wake instead of Well-to- Wake); scenarios published before 2020 do not take into account the effects of the COVID health crisis; and lastly, the baseline years against which the reduction ambitions targets are estimated are not the same.
- Secondly, the share of global emissions allocated to the shipping sector (carbon budget allocation) is not systematically the same: in some scenarios, the sector's share must remain the same, while in others, its shipping emissions may increase relative to other sectors.
- Furthermore, the ambitions of the scenarios studied vary: some aim for net zero, others for variable percentage reductions, some set intermediate targets, while some others don't.
- Finally, the decarbonization levers explored and their contribution varies from scenario to scenario.

In a second part, the study details the various decarbonization levers available to the shipping sector, based on the Kaya equation which expresses GHG emissions as the product of demand, modal shift, capacity utilization, energy efficiency and carbon intensity of energy. The introduction of low-carbon alternative fuels is the lever most explored in prospective studies, as it is the most critical lever to align shipping with climate goals. However, they are not expected to deliver significant emission reductions in the short to medium term, as their deployment is slow and faces many constraints. Demand, modal shift and capacity utilization are also not expected to deliver significant emissions reductions. Therefore, energy efficiency improvements will be crucial for the shipping sector to keep pace with 1.5°C scenarios: it will need to improve by up to 40% by 2030 according to a UMAS study [1].

Operational optimization levers are a sub-category of energy efficiency levers that could deliver rapid and substantial emissions reductions. However, the extent of their contribution to the decarbonization of shipping is rarely assessed in-depth and they are rarely considered as major decarbonization levers. Their deployment also faces challenging constraints, related to contractual or financial incentives and the sector's inertia. Certain constraints to the use of operational and energy efficiency levers are identified: contractual constraints, financial constraints and constraints related to sector's inertia.

Following the identification of these different levers, the study focuses on the role of digital technologies in supporting the implementation of these operational optimization levers, in the short and medium term. The focus is on the extent of which digitalization can optimize the three groups of operational decarbonization levers, namely onboard energy consumption, routing decisions and terminal operations. The analysis highlights the most relevant use cases related to these groups of levers and the main technologies associated with them, such as predictive maintenance, smart routing and cargo tracking. It also provides a qualitative assessment of each technology's potential contribution to operational optimization. Sensors and Internet of Thing (IoT) systems, edge computing, satellites, artificial intelligence and automation could have a decarbonization potential. Beyond their contribution to some specific decarbonization levers, digital technologies can also contribute more transversely to the decarbonization of the shipping industry. Digital solutions facilitate collaboration between stakeholders and enable more accurate emissions reporting.

However, digital technologies also have environmental impacts: carbon emissions, resource depletion, pollution, or rebound effects. Lifecycle analysis is therefore essential for designing sustainable digital decarbonization strategies that manage environmental risk through monitoring and mitigating against potential rebound effects.

As a conclusion, this study outlines five key messages for the shipping sector:

- Currently, there is insufficient commitment from the sector's stakeholders to ensure the achievement of global targets to contain climate change to 1.5°C. In 2023 SBTi and IMO have updated their strategies and target setting to reduce GHG emissions for the maritime shipping sector. Stakeholders need to be encouraged, set ambitious targets, quantified reduction pathways and intermediate milestones.
- In the shipping studies, the sobriety lever (moderation of transport demand) is hardly analyzed: the demand trajectory is usually studied as an input parameter and not a lever that can be lowered. It should be studied in the same way as other levers, but this requires adopting a systemic approach that includes the entire freight value chain. What's more, the greater the market size, the greater the effort required to decarbonize the sector.
- Energy efficiency and operational levers could substantially contribute to shipping decarbonization in the short and medium term. Many of these improvements could be implemented rather quickly compared to alternative fuels (long term lever) despite challenges to the implementation such as interconnected cooperation between stakeholders, technical issues and financial barriers. Therefore, they should be promoted and developed rapidly.
- Digital technologies can contribute to the deployment of short and medium term operational decarbonization levers, such as onboard energy consumption, routing and terminals' operations and are an enabler technology that boosts data sharing harmonization, standardization, and transparency among participants to foster integration across the maritime supply chain.
- Attention must be paid to risks of negative externalities or rebound effects (biodiversity, wildlife corridors impact).

Introduction

The freight and logistics sector has grown rapidly in the 21st century and is now a key element of globalization and of our global economy. Freight refers to all the stages and means involved in the transport of goods. This includes, all the logistics involved, as well as the means used to reach the point of delivery, and the entire infrastructure such as airports, ports, rails, roads etc. Shipping refers specifically to all the stages and means involved in the transport of goods by sea.

As a global leader in digital transformation and a pioneer in decarbonization services for its clients, Atos commits to helping the acceleration of the decarbonization of all sectors including freight transportation, aligned with the SBTi Net-Zero framework and the SBTi maritime guidance published in May 2023. Atos seeks to put digital technology at the service of sustainable transformation by supporting public services and companies on the path to decarbonization through data and innovation. This study identifies the main levers that could play a role in the decarbonization pathway and discusses the extent to which digitalization can be useful.

Among all means of transport, maritime shipping is the one with the lowest emission intensity in terms of CO2eq/ton.km. However, because of the volumes transported, maritime shipping is responsible for around 2.9% of the global greenhouse gas emissions. Furthermore, this share of emissions could increase as the demand for shipping is expected to grow in the coming years. This makes it a priority sector to focus.

This white paper is based on the study of a hundred different sources from approximately fifty different actors, including institution reports as well as sectorial bibliography, and recent scientific articles. The subject of shipping decarbonization is particularly topical with new reports published on a regular basis. There is therefore a need for constant monitoring of this issue to keep it up to date. In parallel, some interviews were also conducted to include the perspective of different stakeholders.

The interviews were used as a support to complement, analyze, and interpret the information gathered through the bibliographic review.

This document focuses on the potential means to decarbonize the shipping sector. Although other environmental impacts are essential for mitigating shipping's environmental impact (eg. water quality, impact on biodiversity), they are excluded from the perimeter of this study. This paper solely deals with the greenhouse gases (GHG) emissions from the shipping sector. Hereafter, the term "emissions" will refer to all GHG emissions (not only CO2) which will be measured in CO2 equivalent.

Solutions involving carbon offsets are not considered because they are not yet proven to be efficient, with WWF France and institutions like SBTi not believing that these solutions should be considered to validate the GHG emission reduction of an institution or an activity. Finally, cost considerations, such as those related to the implementation of various solutions to decarbonize the shipping sector, are not the primary concern in this study.

The place of shipping in the freight sector and gap analysis between decarbonization scenarios

10.1. The freight sector: a growing sector with different means of transportation

The freight sector became one of the largest economic sectors globally through the 21st century. Between 1950 and 2020, the volume of global trade has grown 4,100% with the value of trade increased by almost 300 times. The freight and logistics sector was reputedly worth $8.6 trillion in 2020. [2]

The global freight sector is dominated by shipping as transportation mode.

In 2022 globally, 80% of global trade by volume is transported by sea. [3]

Maritime shipping is also an essential part of Europe's freight system, although slightly less important than the world average, representing 75% of extra-EU imports in 2021, with an upward trend since the early 2000s as shown in Figure 1. The second largest mode of transport is road, representing almost 20% of exports. However, it represents a larger part of Europe's internal trade at 31% [4]

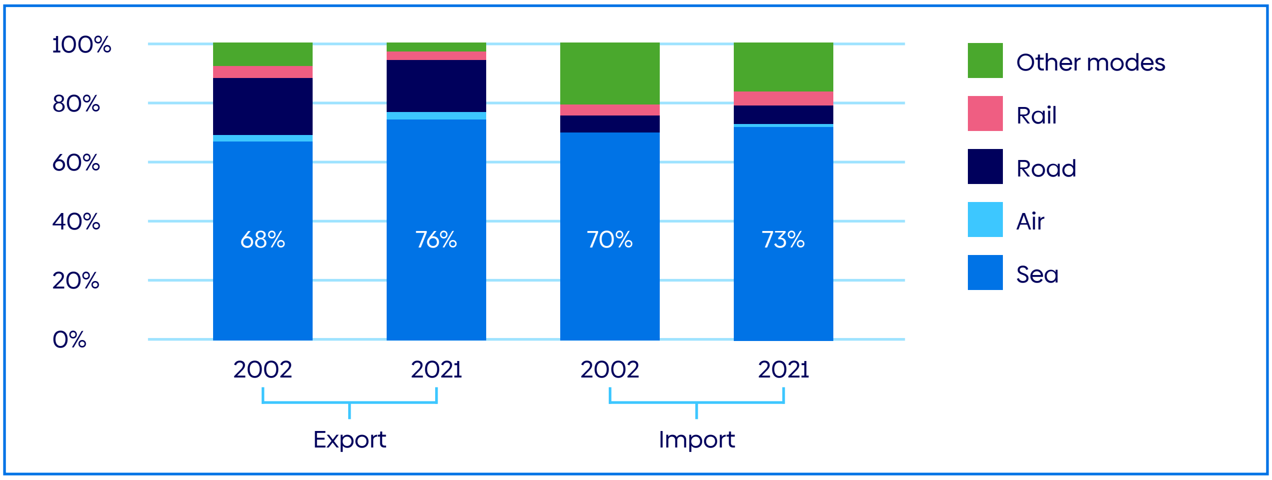


Figure 1: Quantity of extra-EU trade in goods, by mode of transport 2002 and 2021 (% of total, based on tons).
Source: [5]

The special status of air freight must be highlighted: although it represents a small share of the total volume of goods transported, it has other specific advantages that makes it a key element of the freight system. As demonstrated during the COVID 19 pandemic, air freight is a means of transporting both high-value and time-critical goods (e.g.: pharmaceuticals, advance industrial manufacturing) with lighter infrastructure requirements. It also tends to use passenger transport to carry freight: passenger and freight transport are more linked in air transport than in other modes.

The different means of transportation require different amounts of energy to transport the same weight which implies a different impact on climate change.

The different modes of transport (air, road, fluvial, rail, maritime) require different energy input for the same amount of freight transported (in KJ/t.km[1]), depending on their own physical constraints. Shipping is by far the most energy-efficient mode of transport per t.km: 20 times more efficient than road, and 100 times more efficient than air [6][2].

The energy required to transport goods is an essential element in understanding the contribution of the different modes of transport in relation to climate change, although it is not the only parameter (see Kaya equation in Part 2). Figure 2 compares the climate impact of the freight transport modes in terms of intensity, i.e in kilogram of CO2 equivalent emissions per t.km of good transported. The classification is the same as for energy demand previously mentioned.

1 The ton.kilometer (t.km) is the unit used to measure the quantity of goods transported, it corresponds to the transportation of a ton over one kilometer

2 Shipping: 90 to 160kJ/t.km, rail: 205 to 330 kJ/t.km, road: 1210 to 2426 kJ/t.km and air: 6900 to 9770 kJ.t.km

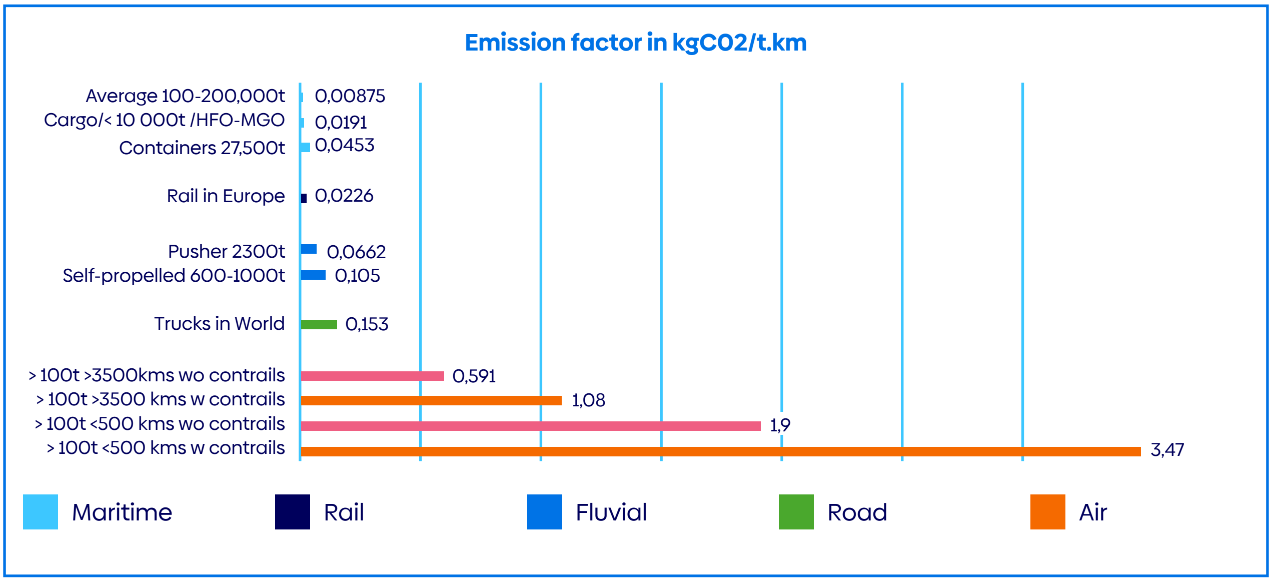


Figure 2: Comparison of the climate impact of different modes of transport for freight.
Source: I Care from the Base Empreinte ADEME [7]

Comparing the contribution of each mode of transport to global freight emissions in terms of the volume of goods transported in t.km, the difference in carbon intensity of the different modes of transport becomes very salient. In 2022, 80% of the freight volume is transported by sea [3]. As the following analysis is not realized for 2022 data, 2021 data is analyzed to show the contribution of each mode of transport to global freight emissions in relation to the amount of goods transported in t.km. Figure 3 shows the statistics for 2021 according to the International Transport Forum.

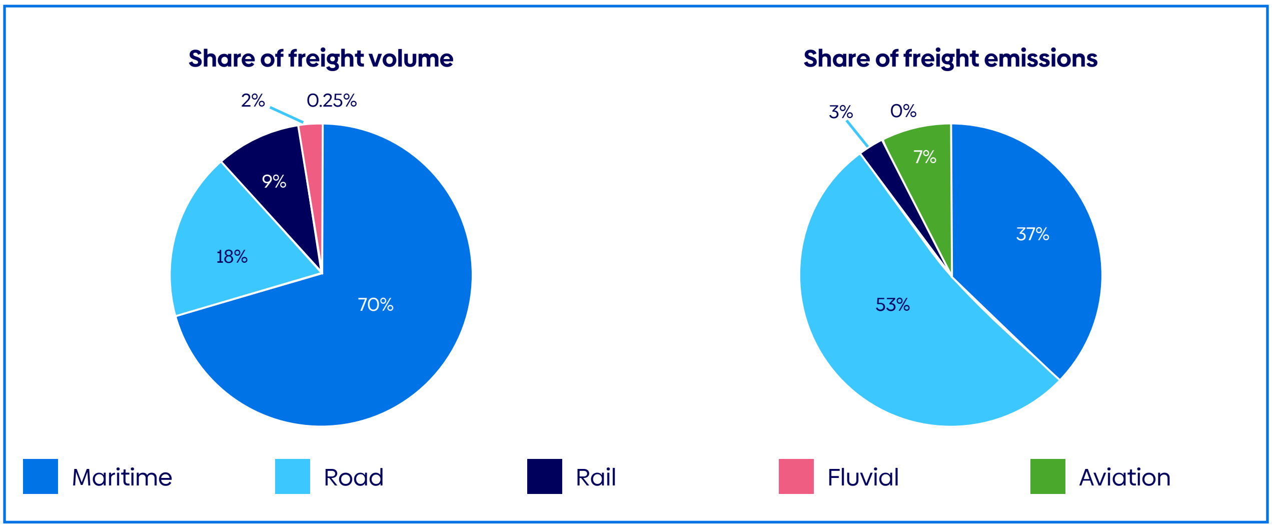


Figure 3: Share of freight volumes (in t.km) and GHG emissions by mode of transport.
Source: [8]

In 2021, shipping accounted for 70% of the freight volume but only 37% of freight emissions, while air transport accounted for 7% of global freight emissions but just 0.25% of the volume in t.km [8]. However, these transportation modes are not designed to carry the same volumes: for instance, long-haul aircrafts are designed to carry lower volumes than ships.

10.2. Maritime shipping: the most important means of transportation in total volume and emissions

Given that maritime shipping constitutes the principal freight transport mode and accounts for an important share of global emissions (2.9% of the world GHG emissions), this study specifically addresses this sub-sector.

The Science-Based Target initiative (SBTi) has created various sub-sector decarbonization pathways. Specifically for transport, the SBTi has developed guidelines for maritime and aviation, which have been accessible since early 2023 and 2021 respectively. [9], [10] On the other hand, road and rail guidance is still not published at the date of publication of this report.

Overview of the relevant actors of the shipping value chain.

Shipping's value chain can be broken down into four important types of participants as illustrated in Figure 4:

- **Shipbuilding:** composed of the shipbuilders, the marine equipment manufacturers and all the support companies such as engineering offices;
- **Ship operations:** including the ports, the ports operators, the shipping companies, shipowners, freight forwarders etc.;
- **Maritime fuel:** including the energy suppliers, the tankers, traders, refineries etc.;
- **Cross-functional players** working on this subject including international organizations, regulators, think tanks....

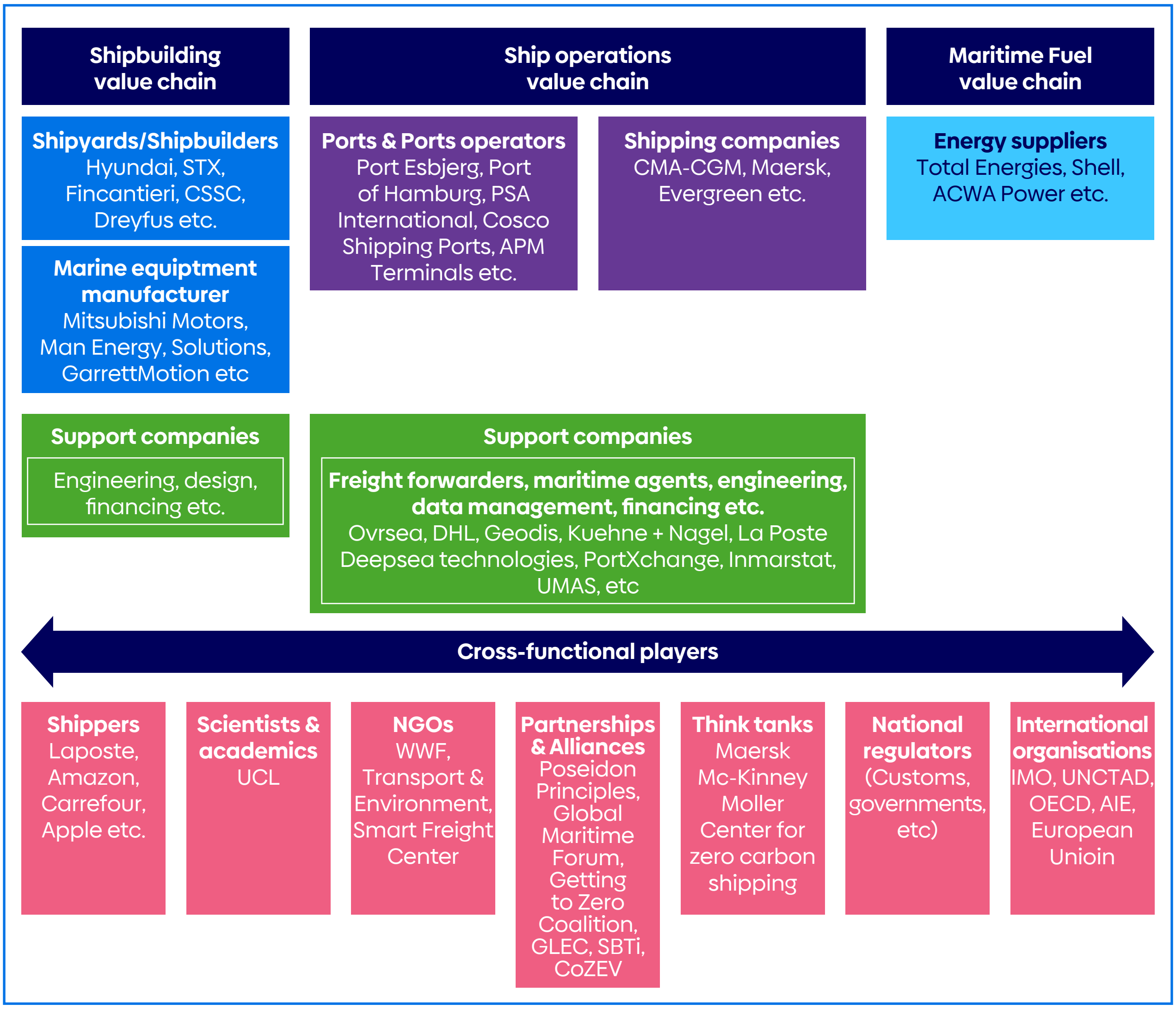


Figure 4: Cartography of the actors of the shipping sector. In white are examples of these actors.
Source: I Care

The **International Maritime Organization (IMO)** is the United Nations specialized agency responsible for the safety and security of shipping and prevention of marine and atmospheric pollution from ships. It covers all aspects of international shipping including vessel design, construction, equipment, manning operation and disposal. Since 1997, the IMO has addressed the issue of CO2 emissions through the publication of resolutions and strategies. The previous and first strategy concerning GHG emissions published in 2018 was revoked by the 2023 strategy published in July. This strategy will remain in place until a revised IMO GHG Strategy is published in 2028 as it is reviewed every five years.

The IMO launched various projects in order to decrease the shipping GHG emissions. Among them:

- **The GloMEEP** (Global Maritime Energy Efficiency Partnership) Project which aimed at supporting the uptake and implementation of energy efficiency measures for shipping and ended in December 2019.[11]
- **The GreenVoyage2050 Project** (as a partnership with the Government of Norway) launched in 2019 to support the implementation of the GHG Strategy, particularly for developing countries and ports. It aims at developing global tools, training packages and guidance documents, partnerships with the industry and assistance to access funding for project implementation among others. [12]
- **The Future Fuels and Technology for low and zero carbon shipping project** - FFT project - is a partnership project between the Government of the Republic of Korea and IMO promoting the uptake of future fuels and technology.

Shipping companies: a highly concentrated number of players

Big international actors have emerged concentrating the biggest part of the market for some segments of shipping (eg tankers, containers). In 2022 the shipping sector counted around 103,000 vessels representing a great variety of size, usage and distance travelled [13]. Among these, three segments—bulk, tanker, and container—account for approximately 90% of global volumes, and 65% of emissions in the shipping industry as shown in Figure 5 [13]. However, they constitute only 27% of the global fleet in terms of the number of vessels, highlighting their significance as key areas of focus for future emission reduction pathways [14].

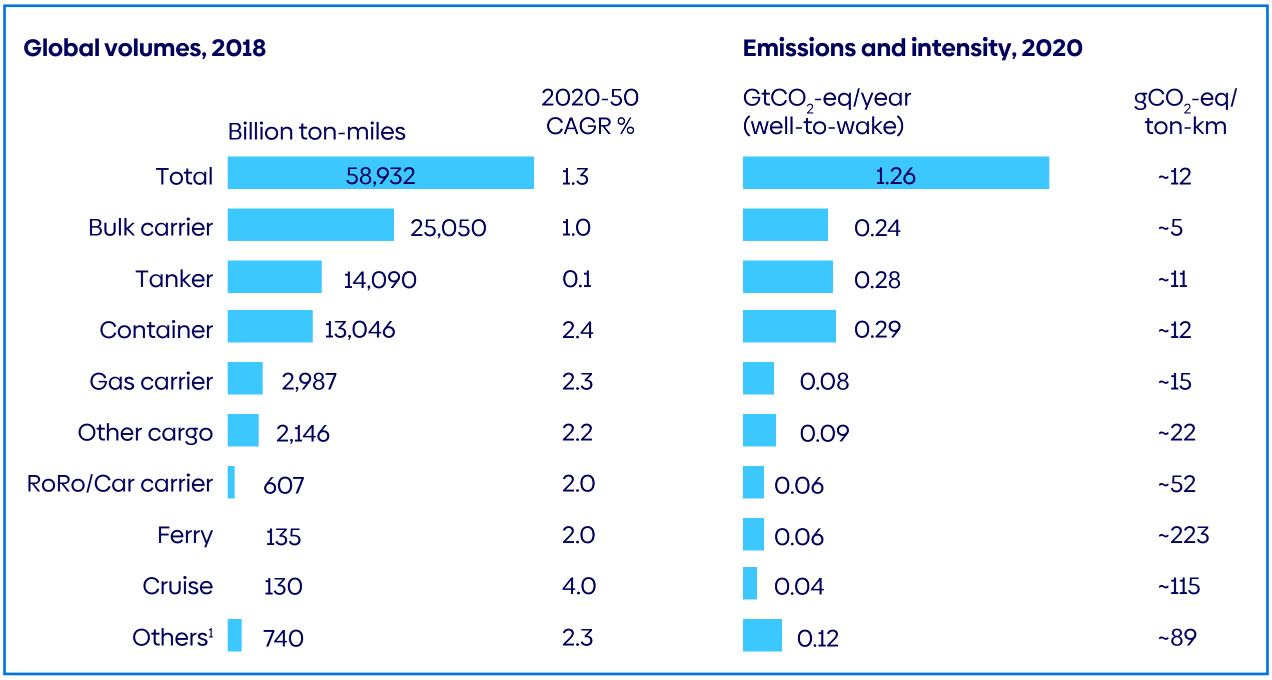


Figure 5: Contribution of different vessel types to maritime volumes and emissions.
Source: [13]

Regarding the **maritime container transport segment,** whereas there are more than 500 shipping companies in the world, almost 60% of the transport capacity is controlled today by only four of them: MSC, Maersk, CMA-CGM and COSCO. And the top 10 companies control 84% of the total capacity. As a comparison, the top 10 controlled 28% of the total capacity in the late 1970s. [15] This share has increased progressively thanks to the process of containerization that facilitated the globalization of shipping.

To increase their market share, the different shipowners used Mergers & Acquisitions strategies (as CMA acquired CGM in 1996) and industry alliances. The main alliances are the following ones:

- 2M: MSC and Maersk
- Ocean Alliance: CMA CGM, COSCO and Evergreen Line
- The Alliance: Hapag-Lloyd, ONE, HMM and Yang Ming.

Table 1 summarizes the data for the top 9 biggest container shipping companies, representing more than 80% of the container market share.

Shipping company	Transport capacity (in TEU[4])	Market share	Alliance
MSC	4 983 756	18,6%	2M
MAERSK	4 128 071	15,4%	2M
CMA CGM	3 463 971	12,9%	Oceam Alliance
COSCO	2 890 490	10,8%	Oceam Alliance
Hapag-Lloyd	1 797 027	6,7%	The Alliance
Evergreen Line	1 664 330	6,2%	Oceam Alliance
ONE	1 576 641	5,9%	The Alliance
HMM	807 677	3,0%	The Alliance
Yang Ming	705 614	2,6%	The Alliance

Table 1: Top 9 of the biggest container shipping companies and their alliances [3]
Source: [15]

Some actors have recently decided to diversify to control a larger share of the value chain.

Some actors have recently conducted financial operations to increase their integration in the sector.

Container lines (carriers) have recently established themselves as one of the biggest terminal operators, increasing their global market share from 18% in 2001 to 38% in 2017 [16]. Carriers have also diversified from terminal operators into towage, rail, barge, trucks etc. to become fully-integrated service providers in the shipping ecosystem.

The bulk and tanker segments are also relatively concentrated, with the top 30 largest companies controlling respectively 32% and 41% of the capacity expressed in deadweight tonnage in 2021[17].

The degree of concentration of the shipping sector is such that there are three segments generating most of the trade and the emissions, and within these three segments only a small number of companies are responsible for a significant part of trade and emissions.

3 TEU : Twenty-foot Equivalent Unit is the unit of measurement for a container : 8.5 feet high, 8 feet wide and 20 feet long.

Vessels' dependence on fossil fuel in the shipping industry

Vessels still mainly use fossil fuels, and the current replacement trajectory won't be enough to reach 2050 climate targets

The primary contributor to the climate impact of shipping is the combustion of fossil fuels, which account for approximately 99.9% of the fuel used in existing ships of 5,000 gross tonnage or more in international trade [18]. This fuel consumption encompasses heavy fuel oil (HFO), light fuel oil (LFO), marine gas oil (MGO) and liquified natural gas (LNG). A significant partis Heavy Fuel Oil (HFO), which accounts for 79% of the overall consumption. In recent years, reliance on HFO has gradually decreased, with a 7% reduction between 2012 and 2018. In replacement, a shift towards Marine Diesel Oil (MDO) and Liquefied Natural Gas (LNG) took place [14]. However, MDO and LNG are other types of fossil fuel with a significant climate impact.

This fuel replacement trend constated in fuel volumes is also confirmed by the trend observed in new vessel orders, as illustrated in Figure 6: 48.7% of new ships ordered will still be powered by conventional fuel. The average lifetime of a vessel is approximately 25 years, consequently vessels built in 2025 will have to be compatible with 2050 targets. However, only 51.3% of ships in the orderbook will be compatible with the alternative fuels that are expected to enable the shipping energy transition, including LNG whose positive impact on the climate is being debated. Excluding LNG, the figure drops to 11% of ships on order that are compatible with non- fossil alternative fuels. However, a vessel that is compatible with alternative fuels does not mean that it will use them exclusively: most motors are "dual fuel" meaning they can also use HFO fuel depending on the context (cost-efficiency, lack of alternative fuels supply etc.). The issues linked to the implementation of alternative fuels is developed in part 2.3.

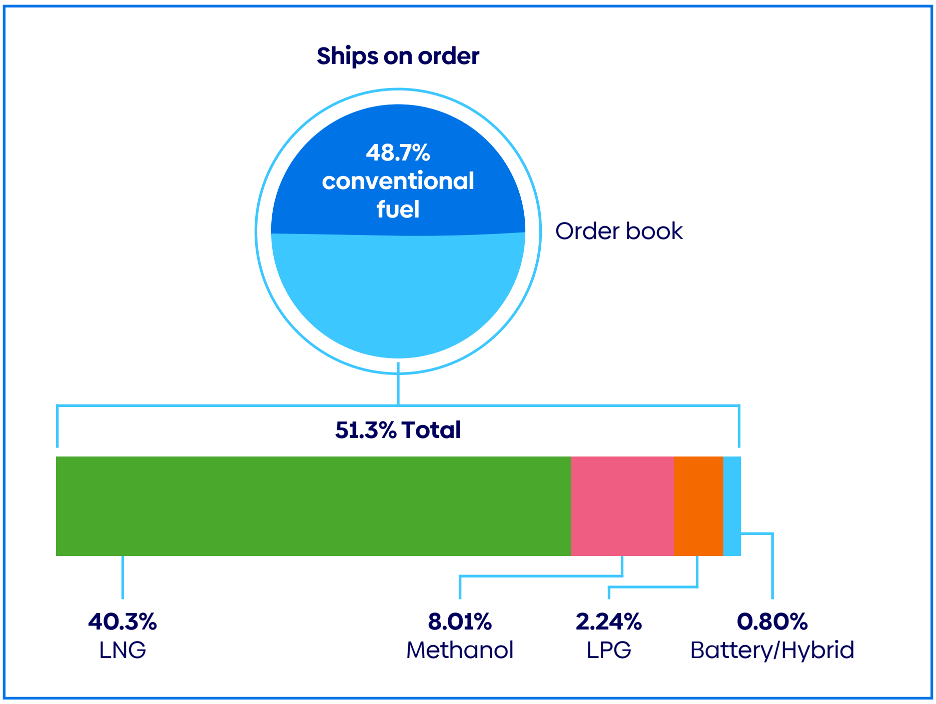


Figure 6: Ship orders and their fuel used.
Source: [18]

Ships mainly consume fuel to power their main engine, generating the propulsion, but some fuel is used for other purposes: in the auxiliary engine, to generate electricity, and in the boiler for heat generation. The auxiliary engines usually consume fossil fuel, independent of the fuel used by the main engine. This can represent up to 50% of the vessel's fuel consumption for refrigerated bulks [14].

Climate impact of shipping: GHG emission evolution

Shipping emissions represented 2.9% of global emissions in 2018.

In 2020, shipping accounted for 1.26 million tons CO2eq (in WTW[4]) [19] in the world. In the EU, shipping accounts for 3 to 4% of total EU CO2 emissions [4].

Historical evolution of the emissions: shipping efficiency has improved steadily in recent years.

Significant improvements have been achieved in the emissions intensity of the maritime sector in recent years, although emissions have risen in absolute value due to an ever- increasing demand.

Overall carbon intensity has improved, with a 20-30% reduction in emissions in 2018 compared with 2008 in gCO2/t/nm[5] [14].

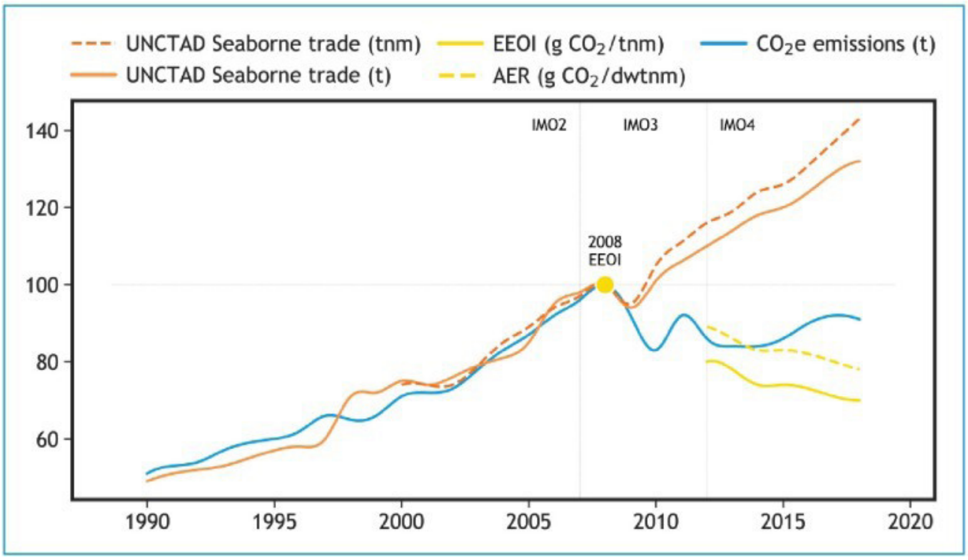


Figure 7: Inventory of GHG Emissions from International Shipping for the period 1990-2018, indexed in 2008.
Source: [14]

Figure 7 illustrates this historical evolution of emissions, carbon intensity and trade demand. Despite increasing demand (orange line), the total emissions (blue line) have not grown as fast as the demand and various intensity indicators have decreased since their introduction by the IMO (yellow line). It is then possible to identify three discrete periods for international shipping's emissions:

- **1st period 1990 – 2008:** continuous emission growth coupled to demand growth in seaborne trade (in t.nm);
- **2nd period 2008 – 2014:** relative decoupling of emissions from growth in transport demand. notably thanks to carbon intensity reduction. Apart from the 2008 crisis which affected global trade, the reduction in carbon intensity over this period was linked to decarbonization levers described in part 2 :
  - **The average vessel size increased** and was an initial trend leading to rapid emission reductions for the period 2008-2014 [20];
  - **Overall design efficiency** of new vessels was also a key element for most segments, especially for oil tankers, bulk carriers and chemical tankers;
  - **Speed reduction,** also referred to as slow-steaming, especially for bulk carriers, chemical tankers, container ships and oil tankers between 2008 and 2015, after which date most ships stopped slowing down due to other contextual elements (improving market situation, decreasing oil prices, end of the global financial crisis);
  - **Capacity utilization** was also a lever with great improvement between 2008 and 2012 but did not follow its optimization since 2012 for other contextual elements related to the global financial crisis.
- **3rd period 2014 – 2018:** continued but moderate improvement in carbon intensity, but slower than demand growth, resulting in an increase in total emissions.
- **The 2018-2022 period** is not represented in this graph and is also more turbulent and difficult to analyze with COVID-19 and supply chain disruption. In some cases, the speed has increased, which has reversed the reduction in GHG intensity. [20]

4 WTW (Well-to-Wake) : All emissions of shipping are accounted for, from the feedstock production to the fuel consumption.

5 Following the EEOI indicator

Difficulties to measure (and then report) emissions:

Although essential in understanding the sector's impact on the climate, accurately tracking emissions from the sector is difficult due to a number of factors:

- **The scope of the emissions considered.** Emissions occur throughout the whole life cycle of the fuel used. The most visible emissions occur during fuel combustion (the so-called "tank-to-wake" phase), but they also occur in the upstream phase, also known as "Well- to-Tank" phase which includes emissions associated with the extraction, refining, transport and distribution of fuels. Although the emissions associated with this upstream phase are significant (about 17% of combustion emissions), they are not always included in the sector's carbon accounting. When they are, the total emissions thus accounted for are referred to as "Well-to-Wake".

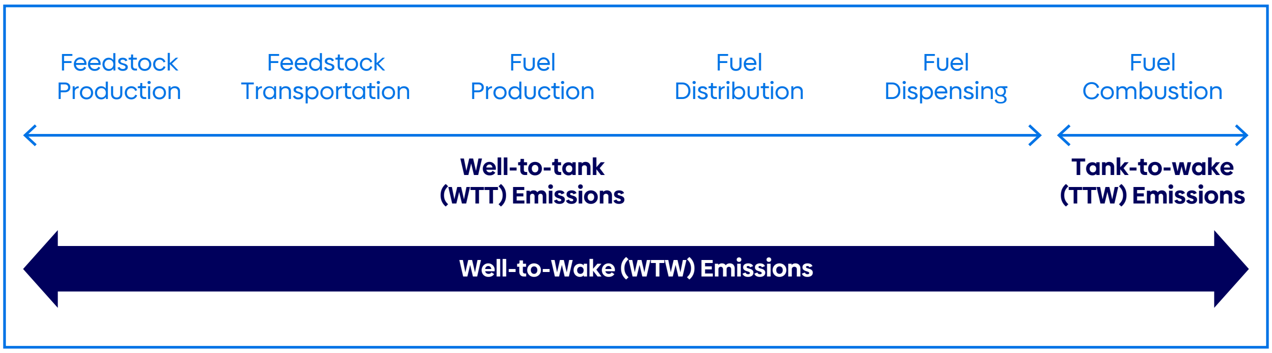


Figure 8: Description of WTT, TTW and WTW emissions.
Source: I Care

- Considering the whole life cycle of the vessels, although the main emission phase is the utilization phase, emissions linked to the construction, dismantling or recycling of the vessel can also have significant impact, as illustrated in Table 2. Yet, these emissions are rarely accounted for in studies.

Ship type	Construction-deconstruction foot-print/total emissions
Cargo ship	3 to 5%
Liner	10 to 20%
Mega-yacht and pleasure boat	15 to 20%

Table 2: Building and deconstruction footprint as a proportion of total emissions by vessel type.
Source: [6]

- In addition, some estimates are difficult to make because the data is not reported or is of poor quality. This can be improved using digital solutions, as developed in Part 3.3.1.

Shipping regulations: current reporting obligations will be reinforced by the introduction of new European carbon regulation

Institutions and public authorities have gradually introduced measures to monitor and mitigate the GHG emissions from the shipping sector.

The IMO has introduced a number of mandatory indicators to be respected by vessels in order to force the sector to meet its carbon targets [6] and [1]:

1. Since 2015: the **Energy Efficiency Design Index** (EEDI). It requires new ships of 400 gross tonnage or more (in UMS[6]) to meet a certain minimum energy efficiency level depending on their design, which will be tightened up in five-year stages. Additionally, starting 2018, the 30,000 vessels of 5000 UMS tonnage or more have had to declare their fuel consumption data annually.

- Since 2021, the **Energy Efficiency Existing ship Index** (EEXI) extend the EEDI to existing ship of 400 UMS tonnage or more. The reduction factor compared to the reference value (the nominal energy efficiency in 2000-2009) can be up to 50%. Compliance must be demonstrated by the 31st December 2023.

6 Universal Measurement System

Both EEDI and EEXI are technical indices of the theoretical energy efficiency of the ship.

- Since 2021, the **Carbon Intensity Indicator** (CII) is an operational index of the real carbon intensity based on the transportation capacity and sailed distance. Each ship of a tonnage equal to or greater than 5,000 UMS must reduce its actual carbon intensity in relation to a benchmark calculated on the basis of its category's carbon intensity in 2019: -5% in 2023, -7% in 2024, -9% in 2025 and -11% in 2026. Targets for the period 2027-2030 will have to be adopted by 2026 at the latest. The difference between the CII calculated and planned will be the basis for a note, from which incentives or corrections can be made.
- The ships must plan their energy efficiency improvement measures through the **Ship Energy Efficiency Management Plan** (SEEMP).

The principle of **Monitoring, Reporting and Verification** (MRV) has been introduced in **European regulation** starting with a first reporting period in 2018 to collect and analyze shipping emissions data. It concerns ships above 5000 GT on EU related voyages. This scope will be extended in 2024 to include new greenhouse gases (N2O, CH4) and new types of vessels from 2025: General Cargo and Offshore vessels above 400 GT. All reporting obligations are described in Regulation (EU) 2015/757 [21].

In Europe, the legislative package "Fit for 55" aiming at reducing emissions in Europe of 55% in 2030 compared to 1990 concerns the sector for 2 elements:

- The **revision of the Emissions Trading System** to include maritime transport in it. From 2024 and with a progressive inclusion of vessels depending on their ULS, 100% of the emissions in EU ports and intra-European travels will be included in the scope of the EU ETS. No free quota will be given, with a diminution of the quota ceiling of 4.2% per year.
- The r**egulation FuelEU Maritime** that will come into effect in January 2025 increases the share of renewable and low-carbon fuels in the fuel mix of international maritime transport in the European Union (EU). This regulation sets well-to-wake greenhouse gas (GHG) emission intensity requirements on energy used on board ships trading in the EU compared to 2020 (-2% in 2025, -6% in 2030, -14.5% in 2035, -31% in 2040, -62% in 2045 and -80% in 2050). Furthermore, from 2030, container ships and passenger ships must use shore power for container and cruise in certain EU ports (requirement extended to all ports where shore power is available from 2035) according to [22] and [23]

Maturity and climate ambition of the shipping companies

Segmentation overview: a sector not yet fully mature lacking meaningful climate ambition

Few sector participants are concentrating their large share of the global fleet. Their commitment to align their emissions with Paris Agreement targets would have a massive impact on the total emission of the sector. Indeed, as is illustrated on Figure 9, even if only a third of the container shipping companies had set ambitious targets, this could lead to 64% of container trade volume powered by clean fuels.

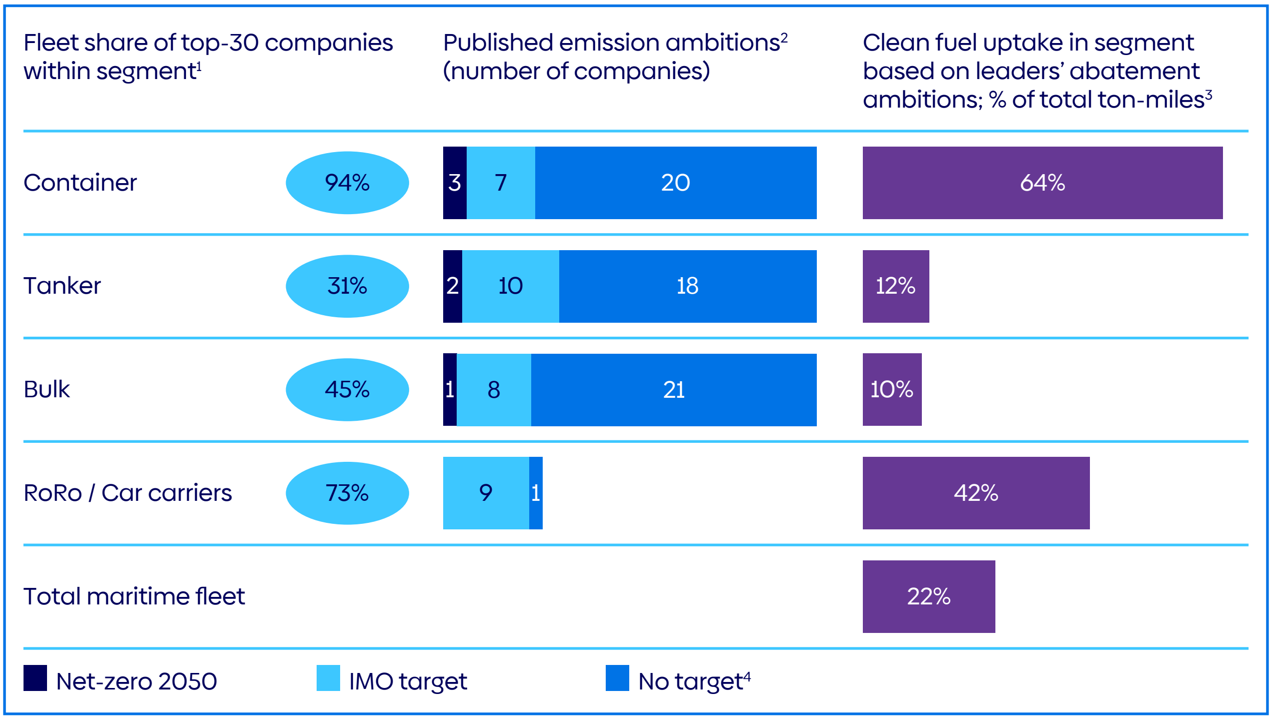


Figure 9: Shipping industry leader's published ambitions.
Source: [19]

The current decarbonization efforts are insufficient to bring the maritime industry to what is needed to meet the Paris Agreement targets according to Climate Action Tracker [24]. More is needed faster as Figure 9 illustrates that only a minority of companies have already set a target.

It is nevertheless encouraging to see that some of them have already chosen to set stronger targets than those recommended by the IMO. In it's most recent report the IMO called for 50% of the fleet to be net zero by 2050. Moreover, IMO published in July 2023 a revised strategy to reduce greenhouse gas emissions, the stated ambition is a raise from 50 to 100% of the fleet that should be net zero in 2050 involves the whole sector in this reflection. This should encourage all companies to set net-zero emission targets.

Overview on the top shipping lines commitments: heterogeneous commitments

Shipping line	Shipping Segment	Current major investment / investment focus areas	Target reduction in carbon / Green-House Gases (GHG) by year*			
			Base year	2030	2040	2050
Maersk	Carrier	12 x 16000 TEU methanol fuelled vessels	2020	50% reduction in fleet carbon intensity 70% absolute reduction (scope 1 and 2) for Terminal	100% Net zero GHG emissions accross all scopes	
MSC	Carrier	1st LNG Capable ship 2022 1st net zero carbon emissions capable ship in service by 2030	2008	40% reduction in fleet carbon intensity		100%
CMA-CGM	Carrier	1st 20000 LNG ship 2020 10% Alternative Fuels 2023	2008	40% reduction in fleet carbon intensity		100%
COSCO Shipping	Carrier		2019	12% reduction in fleet carbon intensity 15-20% for Terminal		Reach 100% by 2060
Hapag Lloyd	Carrier	12xLNG newbuild ships	2019	30% reduction in fleet carbon intensity	100% by 2045	
ONE	Carrier	1st Alternative Fuel Ship 2030	2008	70% (scope 1) reduction in fleet carbon intensity		100%
Evergreen	Carrier		2008	50%		100%
Star Bulk	Bulk	Improving the effciency of the fleet Participating in R&D new technologies and alternative fuels	2019	12% reduction in fleet carbon intensity by 2026		
Golden Ocean Group	Bulk	Technical and operational efficiency Assisted propultion Assisted fuels	2019	30% reduction in fleet carbon intensity		100%
Teekay Corp	Tanker	Auto-pilot system to reduce fuel consumption Testing plateform for improved voyage, vessel and weather optimization	2008	40% reduction in fleet carbon intensity		50% reduction in total fleet GHG emissions
Euronav NV	Tanker	2021: first bio-blend fuel pilot voyage 2022: bio fuel tested at pilot level during passage or at berth	2008	40% reduction in fleet carbon intensity	Net zero scope 1 and 2 latest by 2050 with an ambition to achieve it in 2040	

*Base years vary by shipping line, making comparisons before 100% achieved indicative only.
Targets are typically for "intensity" (g per TEU-km) rather than aggregate figures

Figure 10: Level of investment and speed of carbon reduction for the main shipping lines.
Source: [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37]

Figure 10 is a summary of the different commitments published by the main carrier companies. Maersk has some of the most ambitious targets, followed by Hapag Lloyd. According to their publications they should be the first to achieve net-zero emission in 2040 with a decrease of emissions of 60% in scopes 1 and 2 by 2030.

The following improvements can be identified:

- Even if ambitious targets are set, the scope 3 of emissions are excluded [38];
- Objectives are expressed in intensity and not in absolute;
- There are big differences between the targets set by the companies;
- There is a lack of consistency between methodologies used to set targets and base year that make it difficult to have a global overview on the sector future carbon emissions.

These points of improvement are linked to the fact that the sector is in its infancy when it comes to greenhouse gas emissions reduction. However, Figure 10 points out that things have been moving recently as some of the biggest companies have already made strong commitments.

SBTi engagements: a step forward for more ambitious targets

As the Maritime Guidance was published in 2023 still few shipping actors are engaged with SBTi on the Sectoral Decarbonization Approach, most are using the Absolute Contraction Approach. Nevertheless, Figure 11 provides an overview of the status of validation of the science-based targets for the companies identified in the SBTi segmentation “water transportation”.

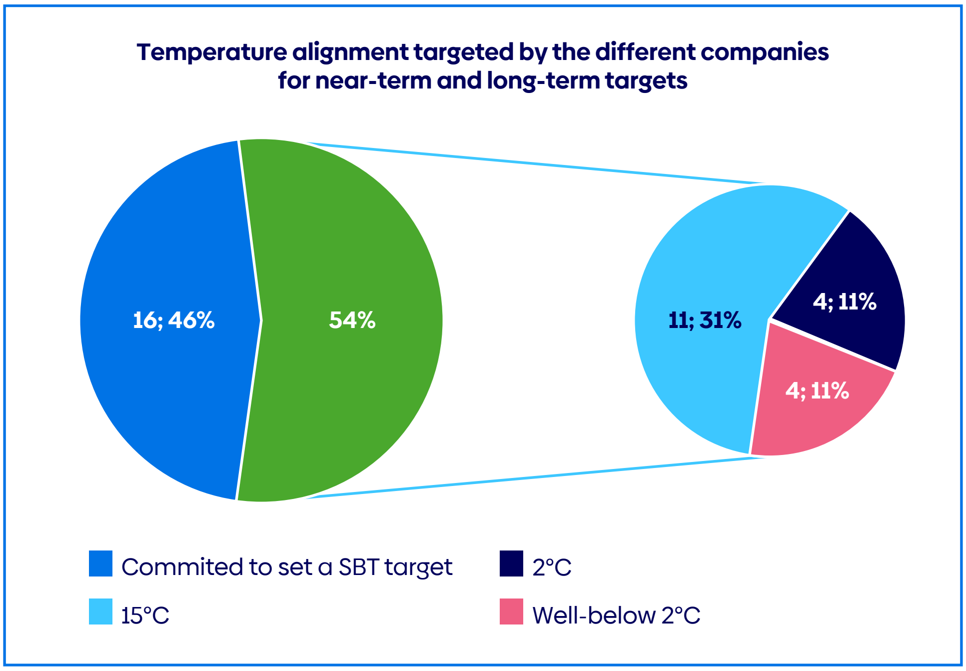


Figure 11: Percentage and number of SBTi targets set for shipping companies for each temperature alignment.
Source: I Care from the SBTi target dashboard [39]

54% of the commitments referenced in SBTi concerns targets that have already been validated, the other 46% are companies which committed to set a science-based target that has not yet been validated (companies that started the process less than two years ago). In total, 35 engagements taken by 24 companies belonging to the water transportation sector are referenced in SBTi. This illustrates that a lot of companies in the shipping sector are just starting their carbon emissions reduction journey .

Among the compagnies referenced in SBTi, some belong to the Top 9 of the biggest shipowners including COSCO (target set), Maersk (target set) and Evergreen (committed). These three companies alone account for 32.4% of the container market share. COSCO is aiming to reach net zero GHG emissions by 2050.

31% of the companies having a validated target are willing to achieve the 1.5°C temperature alignment. For this temperature alignment 2030 is the targeted year of 82% of companies.

Key message n °1

Currently, there is insufficient commitment from the sector's stakeholders to ensure the achievement of global targets to contain climate change to 1.5°C. In 2023 SBTi and IMO have updated their strategies and target setting to reduce GHG emissions for the maritime shipping sector. Stakeholders need to be encouraged, set ambitious targets, quantified reduction pathways and intermediate milestones.

Conclusion about the maturity and ambition of the shipping stakeholders

- There is currently a lack of consistency between the commitment of the different companies, their targets and the way they set them[7].
- As a few numbers of actors are controlling a huge part of the market, leadership could lead to a very significant reduction of the sector's carbon emissions.

7 SBTi targets should help to harmonize shipping companies' targets with the SDA maritime guidance if all decide to commit to SBTi.

10.3. Comparison of the different existing trajectories of the shipping sector

In order to plan the decarbonization of the shipping sector and to help companies to set ambitious targets, different scenarios exist in the literature and present some differences. This part presents the different scenarios that exist and the main discrepancies analyzed.

Different existing models of global shipping decarbonization scenarios

Building a decarbonization scenario for a sector requires calculating numerous parameters and making several assumptions.

Description of the main sources studied.

In this study, a focus is made on three different institutions and on the decarbonization scenarios they published.

- **IEA,** the International Energy Agency, is an international organization affiliated to the OECD[8], producing scenarios for global emissions. Those scenarios are developed based on the emission reduction that is targeted, but also on the different levers activated in order to achieve the reduction goals. The IEA also produces scenarios for the emissions of each specific sector. Hypothesis on the future share of the sector emissions in the global anthropogenic emissions are thus very important when it comes to producing sectorial scenarios. Three scenarios are studied : the **Sustainable Development Scenario** (SDS) published in 2020 from Energy Technology Perspective (ETP) [40]; **the Net Zero Emission scenario** published in 2021 and the **World Energy Outlook** (WEO) published in 2022.
- **IMO,** the International Maritime Organization is one of the main actors of the maritime sector (cf part 1.2.1). In 2018 IMO published a first strategy with goals for the reduction of carbon emission of the maritime sector. This strategy was updated in 2023 when they published a revised strategy to reduce carbon emissions from international shipping. This strategy was built on a more detailed trajectory for shipping emissions coming from the Fourth IMO GHG study 2020.
- **SBTi,** Science Based Target Initiative, is a partnership between the Carbon Disclosure Project (CDP), the United Nations Global Compact, the World Resources Institute (WRI) and the World Wide Fund for Nature (WWF) and is one of the We Mean Business Coalition (WMB) commitments. The SBTi helps compagnies to set emissions reduction targets consistent with limiting the temperature increase to 1,5°C and well-below 2°C compared to preindustrial levels. They published a special guidance for the Maritime sector in November 2022, updated in May 2023, in which they also provided decarbonization trajectories based on IPCC and IEA scenarios for global emissions.

Description of the other sources studied:

- **CE Delft** is an independent research and consultancy organization on climate and environmental policy for ocean shipping. To prepare the IMO 2023 new strategy, CE Delft was asked by Transport & Environment, Seas at Risk, Ocean Conservancy and Pacific Environment to quantify shipping GHG emission trajectories with the maximum technical abatement potential in 2030 “Shipping GHG emissions 2030 – Analysis of the maximum technical abatement potential”. The study explores 8 scenarios, where varying parameters are the demand growth, the share of alternative fuels available in 2030 and the speed reduction relative to 2018[41].
- **IRENA,** the International Renewable Energy Agency, is an intergovernmental organization supporting countries in their transition and promotes the adoption of sustainable use of renewable energies. It published a study in 2021 “A pathway to decarbonize the shipping sector by 2050” which explores 3 scenarios, including one which is compatible with a 1.5°C global warming. [42]
- **UMAS,** the University Maritime Advisory Services, is a commercial maritime advisory service, a partnership between UMAS International Ltd and the UCL Energy Institute. Working for public and private clients, it uses big data to understand drivers of shipping emissions, using models to explore shipping’s transition to a zero emissions future and providing interpretation to key decision makers. In 2023 a study “How can international shipping align with 1.5°C?” was published exploring 4 scenarios of alternative fuels mixes in 2030 and the required energy efficiency gains to comply with a 1.5°C scenario[20].
- **Concawe,** established by a small group of leading oil companies to carry out research on environmental issues and **OGCI** (Oil and Gas Climate Initiative, an international organization with twelve of the largest oil and gas companies). They ordered a study realized by Ricardo Energy & Environment in 2022 “Technological, Operational and Energy Pathways for Maritime Transport to Reduce Emissions Towards 2050”. The study explores 3 scenarios of decarbonization [43].
- **DNV,** Det Norske Veritas, is an international accredited registrar and classification society which provides services for industries including maritime. It published in 2022 the 6th version of its “Maritime Forecast to 2050” in which it describes some of the results of the 24 decarbonization scenarios they designed. The scenarios 7 and 19 were especially useful for this study because they were the most extensively described [18].

8 Organisation for Economic Co-operation and Development

Report publication dates must be considered to understand some gaps.

Among the represented scenarios, three of them are now considered obsolete.

- The Energy Technology Perspective (ETP), published in 2017 by the International Energy Agency [44], was updated in 2020 [40], and the Sustainable Development Scenario (SDS) has replaced the former Beyond 2 Degrees Scenario (B2DS). Only SDS is studied in this study. Both scenarios model a "well below 2°C" pathway in alignment with the Paris Agreement, relying on an accelerated and aggressive technology push.
- Furthermore, an updated version of the Science-Based Target Setting Guidance on Transport, initially published in 2017, is expected to be released in the coming years, along with the ETP 2023 and IPCC AR6 reports.
- Finally, the IMO 2018 has been updated to a 2023 version.

The timeline of publication of these scenarios is illustrated in Figure 12. As illustrated, some scenarios published before the COVID crisis could not plan the demand decrease linked to the crisis: this explains some of the gaps observed.

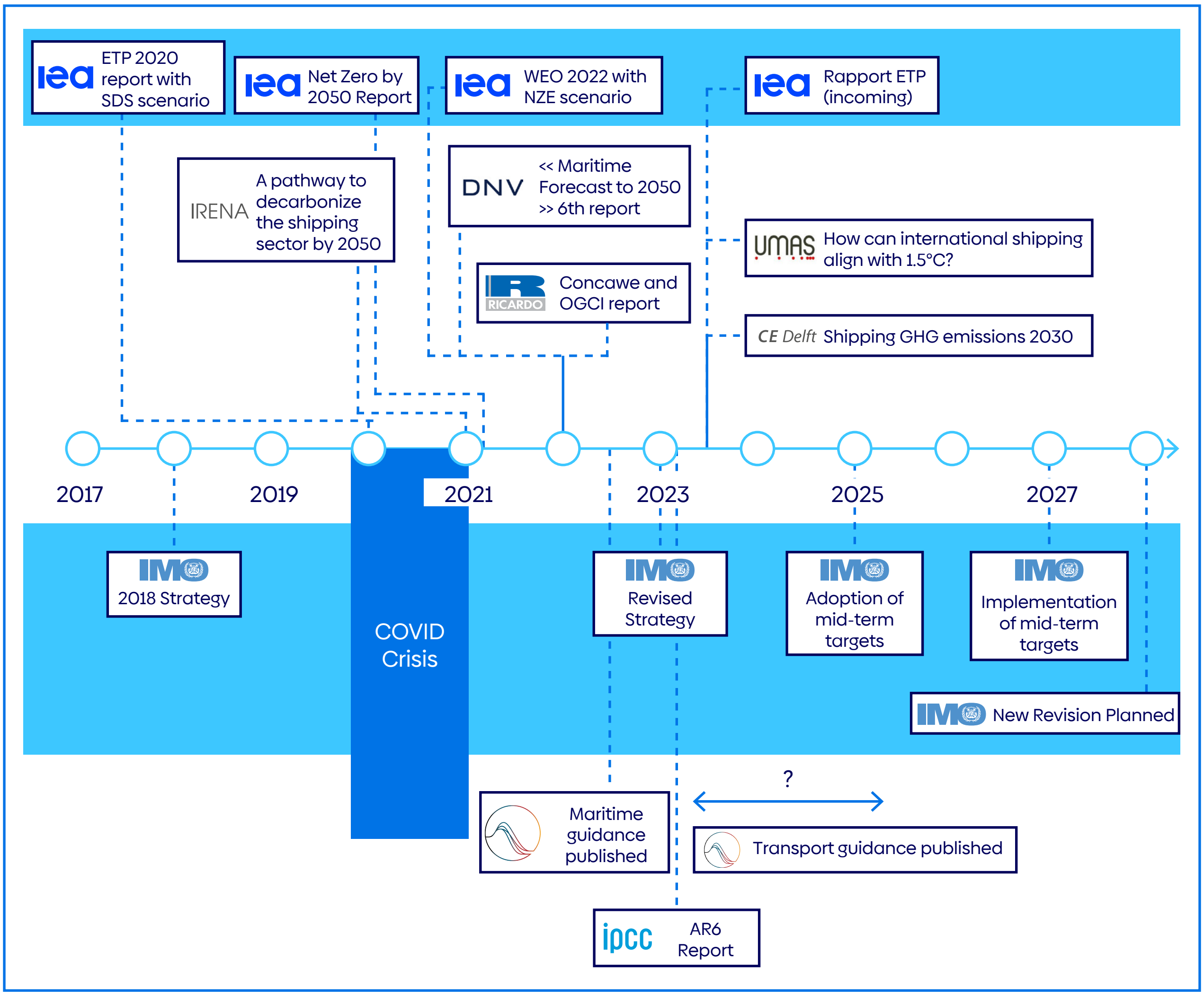


Figure 12: Planning of the publication of different reports and measures.
Source: I Care

Comparison of scenarios and ambitions

Global visualization of the different trajectories studied

The different main trajectories have been compiled in the same Figure 13 and 14 underneath to visually compare some gaps and differences identified. Initially, only the main sources (IEA, IMO, SBTi) are summarized in these figures.

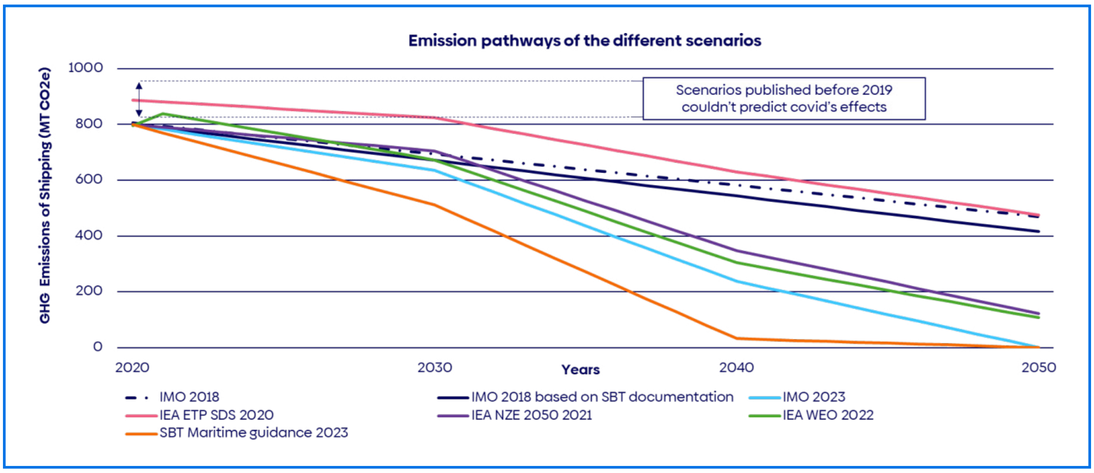


Figure 13: Emission pathways in absolute of the different scenarios
Source: I Care

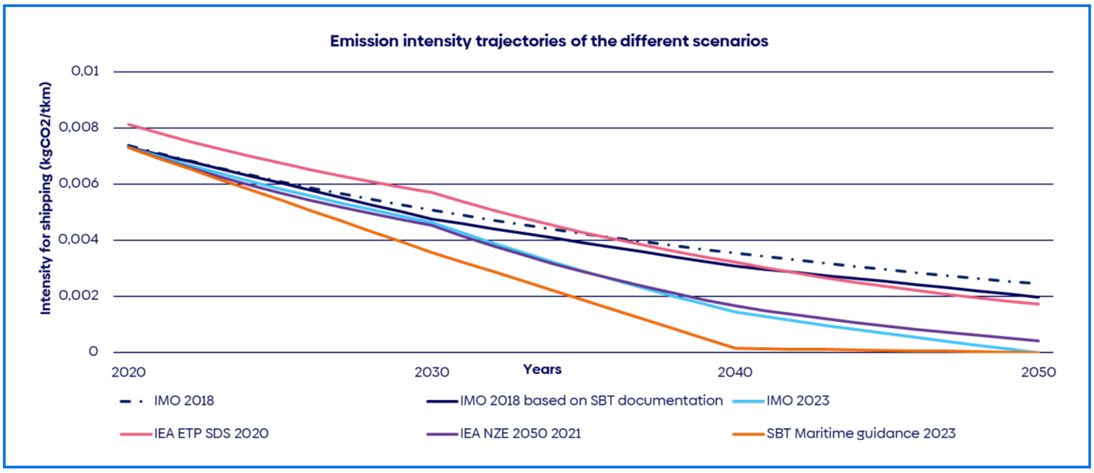


Figure 14: Emission intensity trajectories of the different scenarios
Source: I Care

Caveat on the construction of these scenarios/trajectory/pathway:

The IMO 2018 trajectory is represented twice with an adaptation based on the SBTi documentation for two reasons:

- The pathway linked to the International Maritime Organization publication in 2018 concerns Tank to Wake emissions. This pathway was updated in 2023 when the organization published a revised strategy to reduce greenhouse gas emissions. In this new report they used a Well to Wake perimeter to calculate the emissions.
- The base year from the scenario produced by the International Maritime Organization is 2008. In all the other scenarios the base year is 2020.

In the guidance published for the maritime sector, the Science Based Target Initiative added the Well to Tank emissions to the scenario proposed by the International Maritime Organization and they also adapted it to have a 2020 base year [10].

The original curve is represented as a dotted blue line and must not be considered. The "corrected" scenario is represented in gray as a continuous line and is the one that must be used to compare this scenario.

Five main gaps identified between the studies

The important gaps identified are detailed below. The Figure 15 and 16 underneath summarize these differences.

	ETP 2020: SDS	NZE 2021: NZE	Maritime sector	IMO[1] 2018	IMO 2023	Concawe & OGCI 2022	UMAS 2023	DNV 2022	CE Delft 2023	IRENA 2021
1- Base year	2020	2020	2020	2008	2008	2020	2018	2022	2008	2020
2- Perimeter of emissions	WTW	WTW	WTW	TTW	WTW	WTW	WTW	TTW	WTW	?
Covid effect	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
3- Carbon budget dispatch[2]	12% ↑ 3%	↑	→	→	→	?	?	?	?	?
4 – Ambition[4] (in absolute)	NZ[3]	NZ	NZ	-50%	NZ	-70% to -103%	NZ	NZ and -50%	-28/47%	+10% to -80%
Target year	2070	2050	2050	2050	2050	2050	2050 With 2030 and 2040	2050	2030	2050

Outdated reports

(1) IMO 2018 has been replaced by IMO 2023

(2) Carbon budget dispatch: is the share of shipping emission in the global anthropogenic GHG emission supposed to increase (↑) or remain stable (→)?

(3) NZ = Net Zero

(4) The ambition level is given for absolute emissions. When there are different scenarios for a source, the range of ambition between the most and least ambitious scenarios is given

Figure 15: Comparison of the different scenarios on selected criteria.
Source: I Care from the reports mentioned before

Scenario		IEA SDS	IEA NDE	Science Based Targets	IMO	Ricardo	UMAS	DNV	CE Delft	IRENA
Demand		/	NA	NA	NA	/	/	/	+	+
Decarbonization levers	Operational efficiency	+				/	+	++	++	++
	Energy efficiency	++				++	+++	+	+	
	Alternative fuels	+++				+++	++	+++	+	+++
Carbon capture		/	/	/	/	+	/	/	/	/

Caption: degree of activation of levers in scenario

+++ Strong ++ Medium + Weak

/: not mentioned in the study

Figure 16: : Comparison of the 5th gap : levers considered and their contribution to the targets achievement by each scenario studied.
Source: I Care

a) Base year selected

Not all scenarios select the same base year for the reduction of GHG emissions. All the targets announced by IMO are based on the GHG emissions from 2008, whilst IEA and SBTi choose 2020 as a reference year.

First gap: the base year of the scenarios

- All the targets announced by IMO are based on the GHG emissions from 2008. Therefore, CE Delft also uses the same base year.
- The IEA and SBTi use 2020 as the base year.
- Some other sources use other base years for various reasons (more recent or more representative years)

b) COVID interference, perimeter of emissions accounted for

The scenarios IEA ETP SDS 2020 and IMO 2018 were published before 2019 with no consideration of the effect of Covid in their predictions. For the IEA ETP SDS 2020 which uses 2020 as the base year, this explains why there is a difference in value of emissions in 2020. However, IMO 2018 uses 2008 as the base year, so the emissions targeted for 2020 were lower than they were (COVID interference helped to achieve this target). Furthermore, IMO 2018 only calculates Tank to Wake emissions which are then lower than Well to Wake emissions.

Second gap: the inclusion of the covid effects on the trajectories and the perimeter of emissions accounted for

- Scenarios published before 2020 have incorrect estimated emissions for 2020 than published after the covid crisis;
- IMO 2018 only calculated the Tank to Wake emissions when all the other scenarios calculated the Well to Wake emissions.

c) Differences in the accounting for the carbon budget allocation

As developed in Annex 1, a key parameter to understand the construction of a scenario is the evolution of the **carbon budget allocation of the sector** considered. The carbon budget allocation is the share of the sector emissions in the global anthropogenic emissions that can decrease, increase, or stay the same compared to the reference year. The share of shipping in the **global carbon budget allocation** remains stable in IMO and SBTi scenarios, while it shows an increase in the future in scenarios derived by the IEA, as shown in Figure 17. This is explained notably by the assumption of an increase of shipping of the global freight transportation linked with modal shift.

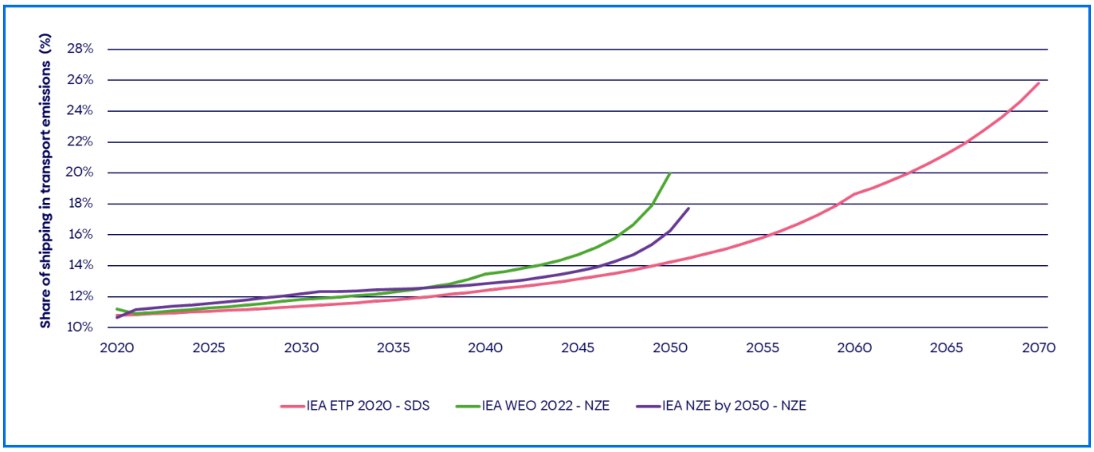


Figure 17: Share of emissions attributed to the shipping sector within the transport sector in IEA scenarios

This can be explained by the fact that both the SBTi and IMO use socio-economic scenarios from the IPCC for the projection of global emissions while IEA uses its own projections.

Third gap: the carbon allocation budget for the sector

- SBTi and IMO have a carbon budget that remains stable through years.
- IEA increases the carbon budget allocated to shipping in the following years.

d) SBTi's scenario is the most ambitious in terms of target and pattern of decarbonization.

A first gap between these scenarios is the level of ambition in term of absolute values of each scenario. The Figure 18 summarizes the different ambitions for some major studies.

- The IMO 2023 and the SBTi scenarios are the most ambitious in term of absolute target in 2050;
- The SBTi scenario is the one with the fastest decarbonizing pathway with regular milestones;
- The older scenarios (IMO 2018, IEA 2020) are less ambitious.

Scenario	Reference year	CO_2 emissions in reference year ($MtCO_2$)	2030	2040	2050
IMO 2018	2008	1157	-	-	-50%
IMO 2023	2008	*1173*(1)	-20% to -30%	-70% to -80%	Net Zero
IEA ETP SDS 2020	2020	*887*(2)	-7%	-29%	-46%
IEA NZE 2050 2021	2020	800	-12%	-56%	-85%
IEA WEO 2022	2020	1796	-15%	-62%	-87%
SBT Maritime Guidance 2023	2020	*799*(3)	-36%	-96%	Net Zero

(1)Only the value of the emission for year 2018 was given in the IMO 2023 documentation, recalculation from the estmation of it representing 90% of the emission in 2008 (IMO)

(2)Estimation from a linear regression with the values of ETP 2020 SDS

(3)Values from "Review of maritime transport 2022" published by UNCTAD

Figure 18: Comparison of the GHG emission ambition of the different scenarios in absolute
Source: I Care

Furthermore, comparing the ambition in intensity (cf Figure 14) the following elements can be noted:

- SBTi and IMO 2023 are still the most ambitious;
- IEA NZE 2050 is very close to the IMO 2023 scenario (closer than the absolute comparison curves in Figure 13): the shipping demand of IEA NZE 2050 is then much higher than the one considered in IMO 2023.

Fourth gap: the level of ambition of the trajectories studied

- SBTi maritime is the most ambitious scenario.
- The new IMO has a more ambitious objective in terms of absolute emissions reduction for 2050 than IEA NZE (that has a further deadline for net zero – 2070).
- IEA WEO is the most ambitious scenario of IEA scenarios for absolute values, not far from the IEA NZE 2050.
- The intensity ambitions of the IEA NZE 2050 and the IMO 2023 are similar though IMO 2023 has more ambitious targets in absolute emissions reduction: the shipping demand of IEA NZE 2050 is much higher than the one considered in IMO 2023

e) The levers activated to build the trajectories

An important gap between the studies is the different decarbonization levers considered and their estimates. Indeed, as mentioned in the Figure 16, different studies don't consider all levers. This section looks at the other scenarios (DNV, IRENA, Concawe, UMAS, CE Delft) to understand how the different levers are expected to contribute to the achievement of each target. If there are different scenarios for a source, the levers studied are the same and the trend of the global contribution is the same of all scenarios.

As the IMO and SBTi approach is to set targets and objectives to be achieved, they don't measure the decarbonization potential of each lever. This is a "top-down approach" which explains why there are no elements corresponding to these sources in Figure 16. Alternatively, the other scenarios calculate the cumulative potential of the levers activated to achieve their ambition (a "bottom-up approach").

The demand moderation lever has a special status among the levers considered.

Indeed, in most scenarios, transport demand is **considered as an input parameter** that is projected to continue to grow, with an annual growth of 2.1% in world maritime trade over the next five years [2]. The demand growth scenario studied is based on the IPCC RCP 2.6 (SSP2) scenario for IEA, SBTi and IMO scenarios (see Annex 2).

However, **demand is not only an input parameter but also a lever.** There are two ways to act on demand moderation (expressed in t.km): either reduce the amount of goods transported (in tons) or reduce the distance over which they are transported (in km). To implement demand moderation in the shipping sector, the effort would have to come from companies and regulators. Companies of all economic sectors (and not only shipping) that generate the trade demand have an important role to play by rationalizing their supply chains to limit unnecessary and emissive-intensive transport in terms of weight or distance. Strategic relocation or regionalization could be an option to reduce distance, while ecological design could be an important lever to reduce weight. All companies are encouraged to do so, as these transport emissions are also included in their carbon footprint as scope 3 emissions.

Only two studies analyze demand as modifiable "moderation of the demand" lever with a small contribution to the global decarbonization of shipping:

- CE Delft mentions a « change in demand growth » lever with a range from +2 to -9%
- IRENA's study mentions "reduced demand"

Demand moderation as a lever (and not as a parameter) is **hardly analyzed and the demand trajectory studied is systematically increasing for all the scenarios examined. Some scenarios examine the possibility of a slowdown in demand growth (increase of +73% instead of +100% for one of IRENA's scenario for example) and its impact on GHG emissions.**

Operational levers are not systematically studied or do not always represent an important lever in decarbonization scenarios despite their great potential in the short and medium term.

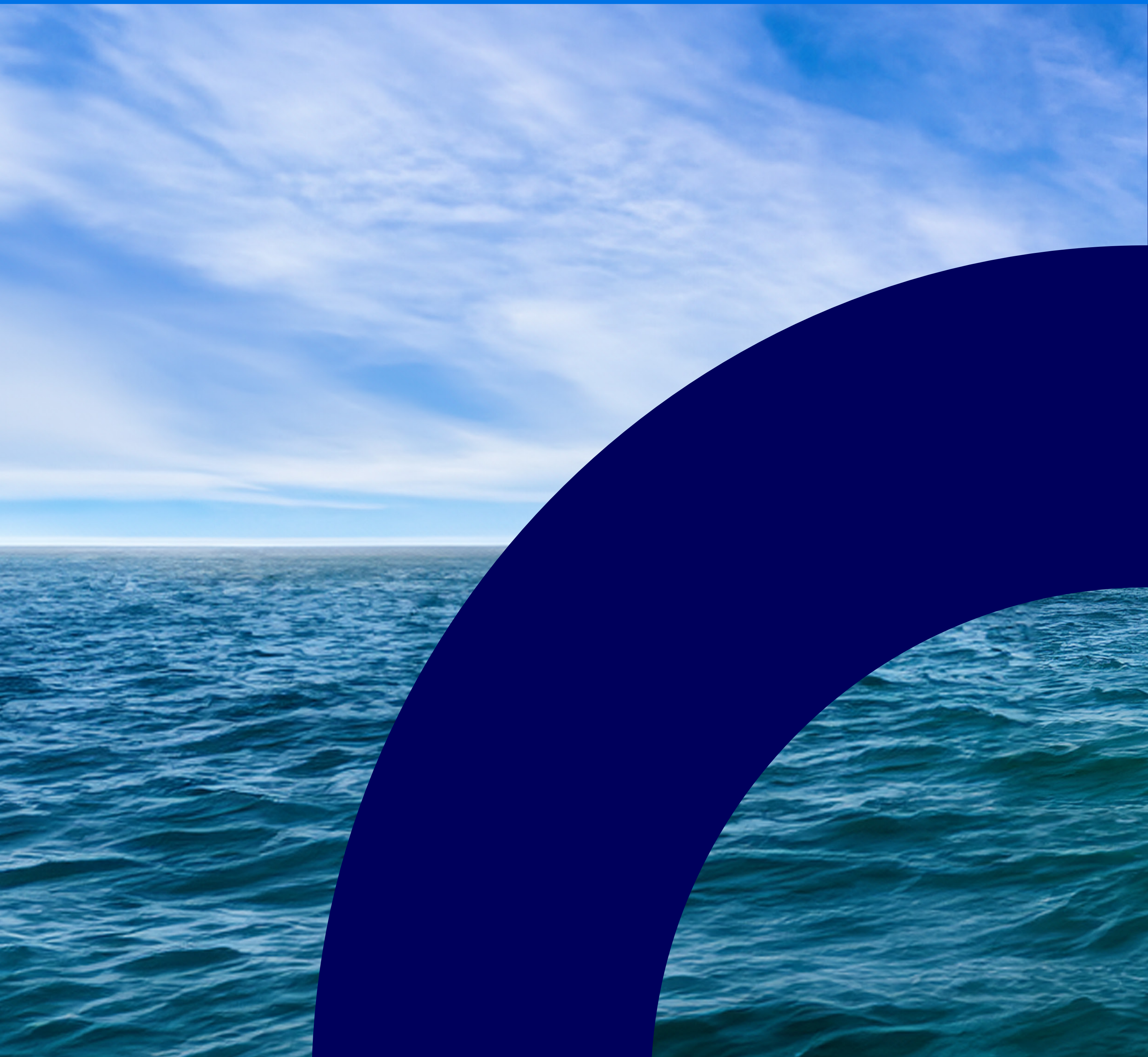
Most scenarios mainly utilize the fuel decarbonization lever to achieve long-term decarbonization. However, scenarios exploring short or medium-term targets (CE Delft and UMAS) tend to indicate that this lever will not contribute to shipping decarbonization fast and wide enough. Indeed, the implementation of this lever requires production capacities and specific infrastructures that are part of a long-term vision.

Fifth gap: the activation of the levers are very different for each scenario

- The lever of moderation of the demand is hardly analyzed: the demand trajectory is usually considered as a parameter and not a lever. No study considers that a significative decrease in demand is a credible (and examined) lever
- The operational levers are not systematically studied or do not always constitute a major lever for decarbonization scenarios despite their great potential.
- Concawe scenario considers carbon capture levers

Key message n °2

In the shipping studies, the sobriety lever (moderation of transport demand) is hardly analyzed: the demand trajectory is usually studied as an input parameter and not a lever that can be lowered. It should be studied in the same way as other levers but this requires adopting a systemic approach that includes the entire freight value chain. What's more, the greater the market size, the greater the effort required to decarbonize the sector.



The levers for decarbonizing maritime shipping are well known, with some specific constraints and opportunities

To achieve the decarbonization targets of the maritime shipping sector, different levers can be activated. This section describes these levers, their potential, and their limitations. To have a global picture of all existing levers, they are classified according to the Kaya equation adapted for the transport sector (as detailed in Figure 19), which is frequently used in decarbonization studies.

This equation allows identifying levers of action to reduce the shipping sector emissions:

- Lever (1): **Total transport demand** corresponds to shipping demand per kilometer, expressed in tonne.km.
- Lever (2): The share of demand for the transport mode (maritime shipping sector) in total transport demand is measured as a percentage. This lever corresponds to the notion of **"modal shift":** total transport demand can remain constant while observing the decline of one transport mode in favor of another, eg a decline of shipping transport in favor of rail transport. As this study focuses on the decarbonization of the shipping sector, the modal shift lever is not studied because the emission studied are of shipping only..
- Lever (3): The ratio between the number of vessels (in vessel.kilometer) and the quantity of goods (tonne. kilometer) of this mode of transport. This ratio, expressed as vessel/good, represents the opposite of a vessel's **"capacity utilization",** which is quantity of goods per vehicle.
- Lever (4): **Energy efficiency** corresponds to the amount of energy required by a vehicle to cover one kilometer. This value varies for each type of vessel. It is measured in toe[9]/vessel.kilometer
- Lever (5): The **carbon intensity of the energy used** represents the quantity of CO2 emissions per unit of energy consumed. This value varies according to the energy source considered. It is expressed in tCO2/toe. TOE corresponds to Tonne of Oil Equivalent (TOE) it is a unit of measurement for energy.

Levers are identified for reducing CO2 emissions, not for offsetting or carbon capture. Therefore, solutions involving carbon offsets are not addressed in this study.

Figure 19: The five levers for decarbonizing shipping, used in the Kaya equation emissions breakdown
Source: I Care

Figure 20 presents an overview of the levers and their potential to decarbonize the shipping sector.

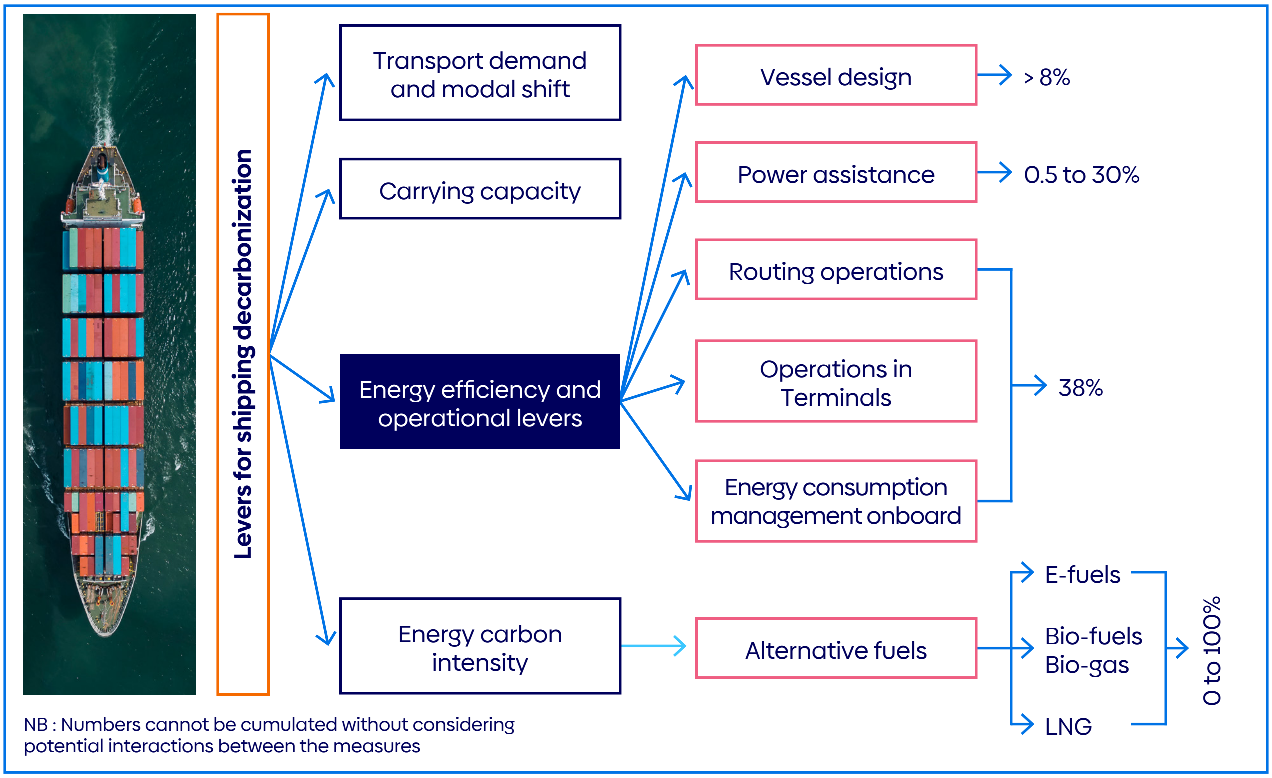


Figure 20: The main levers and their potential to decarbonize the shipping sector
Source: I Care

9 Tone of Oil Equivalent : unit of energy defined as the amount of energy released by burning one tonne of crude oil.

This study is especially focused on energy efficiency and operational levers. This is partly because these levers **can and must be addressed in priority** to achieve decarbonization targets as developed below. In comparison, alternative fuels are expected to bring emissions reductions later.

The data and justifications for the fuel consumption or emissions reductions associated with the various decarbonization levers cited in this section were mainly obtained from four studies and projects, namely the Glomeep [11] and Fuel Future and Technology projects in collaboration with the IMO [46], a study by Ricardo Energy & Environment for Concawe[10] [43] and the IEA ETP Clean Energy Technology Guide [40]. Where not stated otherwise, the information presented in this section has been taken from these studies.

2.1. Improving the energy efficiency and operational levers in the short and medium term is essential

Energy efficiency is the process of reducing the amount of energy required to perform a task, provide a product or a service. A clear definition of the task, product or service is therefore fundamental to measure the evolution of energy efficiency.

Operational levers relate to the way ships, ports and more broadly freight are operated. They do not necessarily include developments in technology but can indirectly benefit from it.

The two concepts are different; nevertheless, in the literature they are not systematically studied separately. In fact, both types of lever lead to reductions in ship's energy consumption (which corresponds to the "energy efficiency" lever in the Kaya equation), even if the means employed are different. Consequently, both types of levers are studied in this section.

Energy efficiency and operational levers can substantially contribute to shipping decarbonization in the short and medium term.

In a recent study, UMAS highlighted via a scenario analysis of low-carbon alternative fuel uptake by 2030 that each scenario required a continuous, significant and similar energy efficiency increase additional effort to comply with a 1.5°C global warming scenario: between 34% and 40% improvements compared to 2018 levels [20][11].

Other studies and sector initiatives tend to corroborate this analysis and try to quantify the decarbonization potential of short-term efficiency measures. For instance, the Getting to Zero Coalition[12] acknowledged in late 2022 that short term technical and operational efficiencies could unlock up to 25% emissions savings [47].

The crucial role of energy efficiency levers of decarbonization is also acknowledged by the IMO climate strategies which introduced **objectives in term of carbon intensity of the shipping sector,** both in 2018 and 2023. Also, the reporting obligations it introduced for the sector (see Part 1.2.4) have a strong focus on vessels and fleets energy efficiency improvements.[1]

As detailed in this section, energy efficiency levers are **rather mature,** and most could be implemented rather quickly, compared to alternative fuels.

10 Concawe is a research and lobbying organization on environmental issues relevant to the oil and gas industry. Its members are oil&gas industry companies operating in Europe.

11 In this study, shipping demand is an entry parameter and is not studied as a decarbonization lever as such.

12 This coalition gathers around 200 organizations in the maritime industry, including 160 private companies of the maritime, energy, infrastructure and finance sectors. The coalition goal is to promote deep sea shipping decarbonization.

Energy efficiency and operational levers of decarbonization can be divided in 5 categories:

- The first one revolves around all the aspects of **vessel design,** ranging from hull form to engine and propulsion technologies, for new-build or existing vessels. This lever is an energy efficiency lever as defined above.
- The second category is **power assistance** levers, which refers to decarbonization levers that rely on alternative power generation technologies for the ship operations (to navigate and/or produce electricity onboard). Power assistance levers could be considered both an energy efficiency lever (for instance, using wind power to navigate increases the energy efficiency of a ship) and a carbon intensity lever (for instance, by replacing some of the fossil fuels consumed by low carbon electricity). In this study, power assistance levers are considered as an energy efficiency lever.
- Third are **routing operations levers** that can be undertaken while ships are at sea, notably slow-steaming, weather routing and speed optimization. This lever is an operational lever.
- Fourth are **energy consumption management onboard** levers, that enable to optimize the energy consumption of ships according to various parameters. This lever is an operational lever.
- Fifth are the **operations in Terminal.** This lever is an operational lever.

A summary and comparison of main energy efficiency and operational levers is shown in Figure 21, based on various sources, according to the following criteria:

- The GHG emissions reduction potential;
- The stakeholders that are involved in the implementation of this category of levers;
- The maturity of this lever. In order to evaluate the maturity, the indicator of Technology Readiness Level (TRL) is used: for a TRL from 1 to 3, the technology is at basic stage of research, from 4 to 6 the technology is in development, from 7 to 8 it is tested through pilots and demonstrations and at 9 the technology has proven efficient;
- Other externalities linked to the lever (costs, other environmental impacts as noise, pollution)

		GHG Reduction Potential	Involved Stakeholders	Maturity	Other Externalities
Energy Efficiency Levers	Vessel and Motor Designs	0.5 - 8%	Shipbuilder, Ship Operator, Institutional Actors		- Stability + NoxSox reduction - Noise
	Power Assistance	0.5 - 30%	Shipbuilder, Ship Operator, Institutional Actors, Port, Energy Supplier		
Operational Levers	Routing	0 - 38%	Shipbuilder, Ship Operator, Institutional Actors, Port, Energy Supplier		Slower Voyage
	Onboard Energy Consumption Management		Ship Operator, Institutional Actors		
	Operations in Terminal		Port, Ship Operator, Institutional Actors		

Shipbuilder Port Ship Operator Energy Supplier Institutional Actors

*Refer to the range of possible emission reductions for different technologies within each group of measures. Source: Concawe

NB: Numbers cannot be cumulated without considering potential interactions between the measures. Therefore the amount of GHG reduction potential written corresponds to reduction of group with the maximum potential

**NA: Every operational sub-lever can be quantified as to its GHG reduction potential but it cannot be easily aggregated. No macro quantification found in literature.

Figure 21: Comparison of existing energy efficiency levers.
Source: [11], [43]

2.1.1. Vessel design levers: the technology gains for new designs, retrofitting and improving engines

One of the key levers for increasing the energy efficiency is vessel design, which encompasses new vessel designs, retrofitting, and the integration of advanced engine technologies to align the design with the actual operational profiles of the vessel.

Levers for the design of a new generation of ships

Some solutions need to be implemented during the initial design and construction phases, and are exclusively applicable to the new generation of ships. Indeed, the shape, weight, and size dimensions of a vessel play a significant role determining its performance, speed, and water resistance. Therefore, one of the key aspects of new vessel design is to r**educe the hull resistance through lightweight construction and optimal hull dimensions,** which directly translates to fuel savings and GHG emissions reduction. As a result, new ships are designed to be lighter and larger, and their hull is optimized through a comprehensive series of model tests and computational fluid dynamics (CFD) assessments.

This lever is **mature and applicable to all types of vessels and fleet segments for new constructions.** In addition, it has an immediate return on investment and results in **4 to 8% reduction in main engine fuel consumption and GHG emissions.** However, obtaining reliable and precise data on the actual operational profiles of vessels is a crucial challenge for optimization studies. Furthermore, achieving overly specific optimizations can be challenging due to the limited time allocated to the vessel design phase and the need to preserve versatility for any potential resale of the vessel.

Some innovative techniques also contribute to **reducing friction,** such as air-cavity lubrication systems. In addition to installing extra pumps and piping, this system requires changes in the hull shape, making it exclusively suitable for new vessel construction. However, **the effectiveness of this technology is affected by the operational profile of the vessel and by wave and weather conditions,** which currently restrict its widespread adoption. Its potential for GHG emissions reduction reaches **7% for candidate vessels.**

Levers for retrofitting existing vessels

To address the decarbonization challenge raised by the long lifespan of existing vessels (around twenty to thirty years on average), retrofits are among the key levers in vessel design. For existing vessels, hull form optimization is limited, but **retrofitting the bulbous bow, improving the bilge keel's position, or adjusting the shape of bow thruster tunnels** can lead to significant savings when ships operate for a large part of the sailing time at conditions other than the design draft and contract speed. The GHG reduction potential of bulbous bow retrofit ranges from **3 to 5%. Advanced hull coatings** can also help reduce surface friction by mitigating corrosion and damage and preventing organic growth. This innovative and well-established technique contributes to **0.5 to 5% of reduction in GHG emissions.**

Alongside hull considerations, **propulsion technologies** can be optimized for both new vessel designs and retrofitting efforts. In fact, replacing the propeller with an upgraded design, determined through comprehensive CFD analysis for maximum efficiency, can significantly **reduce overall fuel consumption, up to 5%.** However, the most efficient propulsion systems come with high costs, ranging from 5% to 25% of the vessel's total cost, depending on the type.

Improving the engines

While the two preceding levers focused on hydrodynamic optimization either for new vessels or retrofits, one final lever is to improve the efficiency of engines, or the overall energy use of vessel with advanced engine technologies. While auxiliary systems are primarily designed to generate electricity for engines and other primary systems under extreme conditions or full load, they often operate at reduced loads (below 80% and even 50% in the era of slow steaming), causing accelerated wear. **Optimizing auxiliary systems based on actual vessel operational profiles, rather than design conditions,** can unlock significant energy and fuel savings potential through several methods, including speed control of pumps and fans, control strategies for cooling water systems, room ventilation, etc. This measure is **in development but can result in an up to 5% reduction in total fuel consumption.** Additionally, low-grade waste heat energy from the engine exhaust or cooling systems can be recovered to provide useful electricity or shaft power, thus reducing the fuel consumed to power the vessel, as well as the **overall emissions produced by 3 to 8%.** An exhaust gas boiler is part of these waste heat recovery systems and recovers excessive heat from the exhaust gas of auxiliary diesel engines to produce steam, hot water, or useful heat.

2.1.2. Power assistance levers

Power assistance levers refer to the **use of alternative energy sources to reduce the power demand of main and auxiliary engines, which results in lower fossil fuel consumption.** There are four main levers: wind power used as propulsion power, onboard electricity generation from renewable energy, shore power supply while at berth and use of electricity as alternative power source for main engine propulsion.

Wind power as a propulsion power

Wind power assistance levers are considered to have the most potential within this group of levers because they are technologically mature and could significantly reduce fuel consumption. They r**ely on wind power to replace some of the propulsion power needed to move the ship.** Implementation options vary: fixed sail, flettner rotors or kites. The advantage of such solutions is to mobilize energy that is abundant, generate zero emissions, is free at consumption, without conflict of use and with reduced infrastructure requirements. These solutions can be implemented on most ships, even though flettner rotors or fixed sails are less easy to integrate on existing vessels, notably containerships. It is important to highlight that the expected fuel consumption potential vary greatly depending on the solutions, the type of ship or the route, but estimations state GHG reduction potential ranging from a **few percents to 30%.** These technologies are rather mature and commercial developments have already started. Nonetheless, the extent of their future adoption by ship owners is still unclear.

Generation of electricity from renewable sources onboard

Another explored lever is power generation from renewable sources onboard, instead of using fossil fuel powered auxiliary engines. Some ships are already equipped with **solar panels,** notably bulk carriers. Main obstacles remain issues associated with the space required to install the panels, the resistance to difficult sailing conditions and the contribution it can bring to meeting the power demand on board. It is expected that solar panels could reduce auxiliary engines fuel consumption by a **few percents,** which should not result in substantial emission reductions. **Wind power generation** is also considered as a potential option but is still under R&D. For the same reason, it should not result in substantial GHG reductions.

Shore power while at berth

Shore power is also a significant power assistance lever. It refers to ships consuming electricity provided by the port's infrastructure for their needs while at berth, instead of using their own generators. Therefore, the emission gains of this lever depend on the carbon intensity of electricity in the country from which the boat is sourced. A maximum threshold value can be computed to determine whether the carbon intensity of the electricity from the country in which the boat is sourced is sufficiently low to be a more sustainable solution than the electricity provided by a ship's auxiliary engines powered by marine diesel oil. The value of 784 gCO2e/kWh can be found in the literature [48]. This threshold is high enough so that shore-power is more sustainable in most cases [49]. Indeed Figure 22 illustrates that in a representative sample of countries, only China and Morocco are close to that limit.

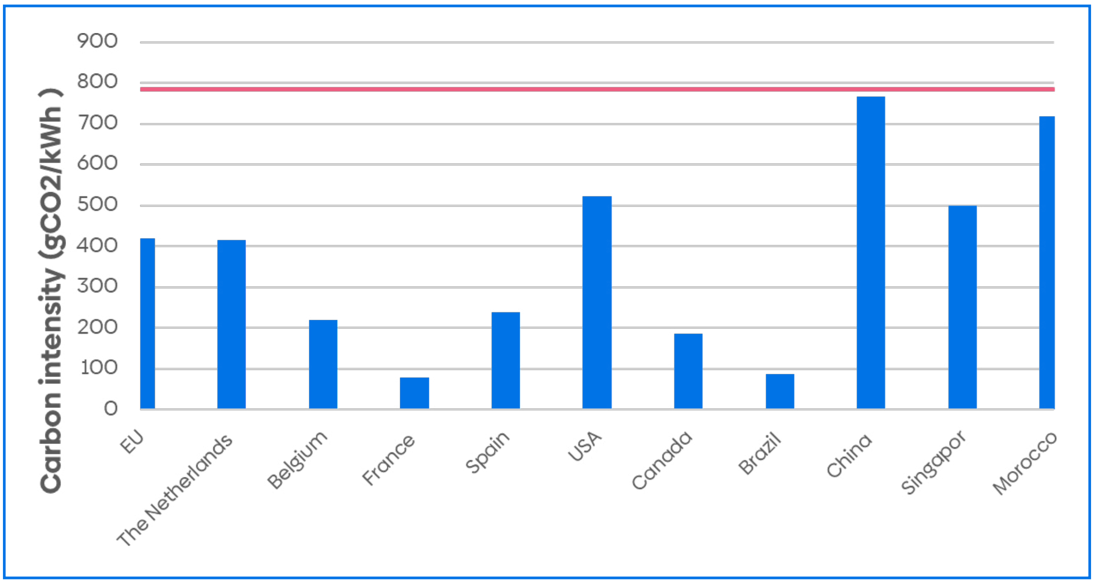


Figure 22: Comparison between the threshold of the electricity generated by auxiliary engines with some carbon intensity of electricity generation in countries hosting major ports worldwide.
Source: I Care from the Base Empreinte ADEME [7] and [49]

The **obstacles** associated with shore power development are twofold. The first is technical and is associated with the **infrastructure development** in ports to address the power demand of larger vessels, which requires significant electrical network upgrades. For vessel owners, it requires retrofit works to implement a shore power connection or implementation directly in new-build vessels. The second main obstacle is **economical** since the return on investment for both ports and vessel owners is dependent on fuel and electricity price evolution. Ports might face inconsistent demand from vessels and vessel owners might be reluctant to make an investment without some certainty around costs evolutions and shore power availability worldwide.

The emissions reductions that can be expected from shore power development vary depending on both fuel consumption for power generation and the carbon intensity of the electricity mix where the electricity supply happens, but could **represent 50 to 100% fuel consumption** reduction at port. A notable positive externality of shore power, and a critical reason for its recent development pushed by new regulations is that it also allows air quality improvement in port areas.

Use of electricity as an alternative power source for main engine propulsion

Finally, the last set of power assistance decarbonization levers available relate **to the use of electricity as an alternative power source for main engine propulsion. This can be in the form of a fully electric, battery-powered main engine or hybrid motorization.** In both cases, advantages include:

- The increased energy efficiency of electric propulsion systems compared to conventional propulsion (around 90% instead of 40%).
- The potential lower tailpipe emissions, notably in terms of GHG if the carbon intensity of the electricity is low enough (the rationale is the same as for shore power), but also in terms of NOx or SOx emissions.

Even though battery or hybrid electric vessels are already feasible, the issue is that with current and anticipated technology, the size and weight of batteries that would be required for battery-powered transoceanic voyages are not compatible with viable operations. Another issue is that this lever requires adequate port infrastructure, just as described previously for the shore power lever. **Therefore, this lever main decarbonization potential is limited to short distance and/or small vessels.**

2.1.3. Routing operation lever

Modifying routing parameters such as speed (slow steaming or speed optimization management) and sailing route (adapted to external parameters such as weather or currents) can lead to significant emissions reductions.

Reducing ship's speed, also known as slow-steaming, is a natural decarbonization lever, since fuel consumption is a cubic function of speed. One advantage of this lever is that it leads to direct cost reduction since fuel consumption decreases. If slow steaming has already proven to be very efficient in the past to reduce fuel consumption as mentioned in Part 1.2.3, its implementation often requires some adjustments and optimization. Indeed, vessels and their machinery are often designed for a specific speed optimum, which in turn affects the emission reduction potential of slow steaming [50]. There are other barriers limiting the potential of adoption of slow-steaming, notably **contractual** ones (see Part 2.2 and 3.3.2). Industry stakeholders argue that another limitation is the **potential rebound effect** speed reduction could induce: if the voyage takes longer, it might create a need for more ships to sail to transport the same amount of goods. [50]. There are other barriers limiting the potential of adoption of slow-steaming, notably contractual ones (see Part 2.2 and 3.3.2). At the scale of a vessel though, slow steaming adoption can result in significant GHG reductions, ranging from a few percents to around 30% depending on the level of the speed reduction.

Optimizing the route according to the evolution of weather conditions is another lever for routing optimization. Often offered by digital providers, weather routing involves being able to collect and analyze the vast amount of weather and currents data to propose alternative, fuel-efficient routing options. This lever requires rather low investment and hardly any major changes on the vessel, but it supposes that the captain and management of the ship devolve part of their responsibilities to another party. The gains associated with this lever can vary a lot depending on the routes, the weather conditions or the type of vessel, but literature and service providers estimate it could go as far as 5-10% fuel consumption reduction [51] (see part 3.2.1 for more details about this lever).

2.1.4. Onboard energy consumption levers

Onboard energy consumption management and optimization is another lever that can be activated to reduce emissions. It involves monitoring and managing energy consumption, principally electricity, associated with lighting, air conditioning, heating, ventilation but also all the other energy consuming equipment aboard. For this lever, like the other one previously quoted, the extent of the emissions reduction that can be obtained depend heavily on the operational conditions of the vessels and the equipment already installed. Nonetheless, literature suggests that this could add up to several percents of auxiliary engines fuel consumption.

2.1.5. Terminal operations levers

Optimizing terminal operations also constitutes a lever for increased energy efficiency in the shipping industry.

More efficient **port logistics** can reduce the time ships spend at port, either waiting outside the port or at berth to discharge and charge cargoes, thus reducing energy consumption. Ports are at the center of the logistics system, involving many stakeholders. Ensuring better collaboration, communication and data sharing between these participants paves the way for more optimized port operations. Initiatives encouraging such collaboration and communication like Port Collaborative Decision Making systems (see part 3.3.2) are a step in that direction. However, actual GHG emissions reduction that could be attained is difficult to measure.

Ports are also at the center of a new paradigm regarding ship's speed management, that could generate significative emissions reduction: Just-in-Time arrival (see case study below).

Just-in-time arrival as an opportunity to improve energy efficiency.

Inspired by the concept of Just-in-Time (JIT) developed in the manufacturing industry, Just-in-Time arrival refers to the optimization of ship's speed to arrive at the port when berth, fairway and nautical services are available, in order to limit inefficient fuel consumption during the voyage and too much anchorage time outside the port, waiting to discharge the cargo. Figure 23 illustrates how JIT arrival impacts vessels speed.

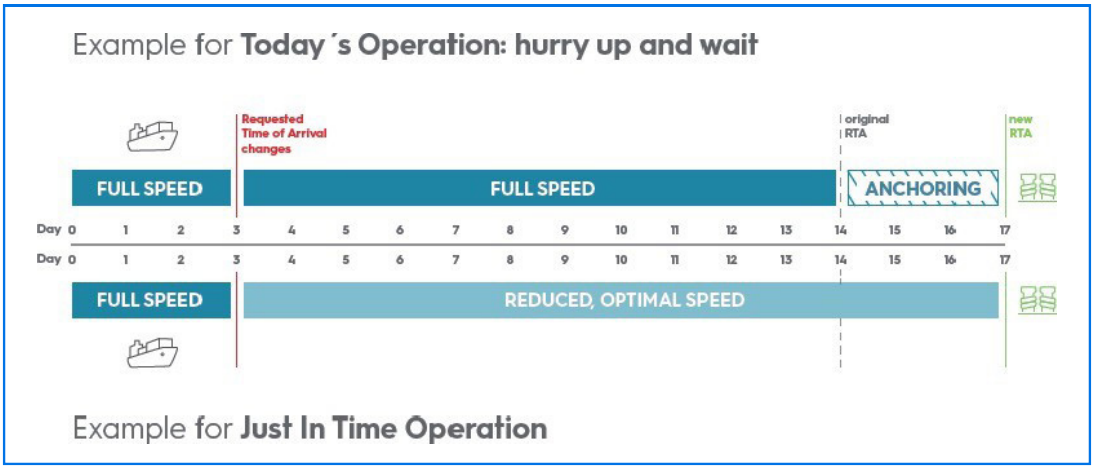


Figure 23: Illustration of JIT arrival in the shipping industry.
Source: [52]

JIT arrival development would require multiple organizational, contractual and technical changes in the shipping industry, notably to share the appropriate data and ensure its trustworthiness, or to share the benefits of a reduced fuel consumption with all the stakeholders in order to align their incentives to implement it [53]. But the results in terms of reduced emissions could be significative: a simple scenario analysis presented by BIMCO and Nautilius Labs shows that current contractual restrictions bring about more emissions-intensive speed, as illustrated in Figure 24. In the case study presented, the speed efficiency unlocks around 20% CO2 emissions reduction.

Case Example

This is a typical speed inefficiency that ofteh results from contractual restrictions. Depending on the specific segment, the underlying reasons may vary. It could bedue to the desire to maximize demurrage, the need to maintain a single warranted TC speed for claims purposes, or the result of sales terms of the transported goods. The outcome is a voyage with a less profitable and more emissions-intensive speed. In this scenario, a VLCC was compelled to maintain its warranted TC speed rather than adopting the most optimal speed.

	Optimal for Best TCE	Actual Voyage	Difference
Freight	$4,666,000	$4,666,000	
Non-Fuel Voyage Days	$116,650	$116,650	
Sailing Days	99.95	92.5	-7.45
Speed *kts*	10.95	12.53	1.58
ME Consumption *mt/day*	36.29	51.96	15.67
Aux Consumption *mt/day*	6.3	6.3	
Total Fuel Consumption *mt*	4,450	5,583	1,132
Total Fuel Cost	$1,736,914	$2,142,305	$405,391
TCE Per Day	$22,654	$20,626	$2,028
Voyage Result	$2,812,436	$2,407,045	$405,391
Co_2 Emissions *mt*	13,935	17,456	3,521

Figure 24: Illustration of JIT arrival impact on various voyage parameters, notably profitability and CO2 emissions.
Source: [54]

2.1.6. Optimization of capacity utilization lever

Optimizing capacity utilization is a lever of the Kaya equation as defined in Figure 18, when considered for one vessel. However, when considering a whole fleet, optimizing capacity utilization allows to reduce the amount of energy required for transport, and therefore corresponds to an energy efficiency lever.

Indeed, by optimizing the utilization rate of the vessel on each voyage, the number of voyages the vessel must make to transport the same volume of goods can be reduced. This is a well-known operational efficiency lever in the shipping industry to balance supply and demand. Optimizing capacity utilization also has the advantage of reducing the cost per unit transported for cargo owners, while increasing revenues for shipping companies. For this reason it is already a fairly common practice in the industry, although various factors, particularly economic, can explain under-utilization. Some studies suggest that it could lead to significant GHG reductions, ranging from 0 to 30%.

An obstacle to be considered is not to overload ships, so that they operate in appropriate conditions, remain energy efficient and do not deteriorate faster than expected.

2.2. Challenges to the implementation of energy efficiency and operational decarbonization levers

The adoption of energy efficiency and operational measures in the shipping sector encounters significant challenges, stemming from contractual arrangements and financial incentives, as well as industry dynamics.

The first one originates from complex **contractual agreements between stakeholders.** Charterparty contracts, for instance, specify which party bears specific costs related to a voyage. Charterparty contracts cover a significant part of worldwide shipping: in container shipping, about half of the leading companies ships (in terms of number of ships) are [55]. Figure 25 represents the cost allocations for voyage and time charterparty contracts.

Cost element	Voyage Charter ($/tonne)	Time Charter ($/day)
Cargo handling	Charterer	Charter
Voyage Expenses	Ship Owner	Charter
Operating Expenses	Ship Owner	Ship Owner
Capital Costs	Ship Owner	Ship Owner

Figure 25: Cost allocation associated with charterparty contracts.
Source:

This cost allocation results in split incentives between stakeholders, regarding **investments in energy efficiency improvements.** For instance, if the shipowner, who would be responsible for investing in a ship's retrofit, is not bearing the cost of fuel consumption, it has little incentive to engage in that process.

Another example of split incentive related to charter contracts is the case of **demurrage.** Demurrage is a charge to be paid to the owner of a chartered ship on failure to load or discharge the ship within the time agreed. It refers to the time that a shipowner has lost because the charterer could not complete required cargo operations within an agreed time frame [53].. It encourages ships to reach their destination as quickly as possible, even if it means waiting at anchorage [51].This practice, referred to as "Sail Fast Then Wait" in the industry, results in unnecessary emissions because of inefficient speed management.

Moreover, International maritime trade operates on a network of **bilateral agreements,** heavily relying on the principle of **privity of contract.** While this legal framework has served the industry well, it poses a significant obstacle to decarbonization efforts. In fact, privity of contract promotes individualism and fails to support multi-party solutions, which are essential for addressing the environmental challenges facing the industry. Consequently, to facilitate the adoption of energy- efficient practices and foster essential collaboration, a **new contractual framework is needed.** [56], [53].

However, the main challenges in reshaping the contractual landscape lie in the **large number of stakeholders** that must be convened to reach consensus, the **resistance to change** inherent in the traditional industry, and the global scope of maritime trade necessitating worldwide agreements.

Shipping stakeholders increasingly recognize that overcoming these barriers necessitates **sharing of knowledge and collaboration** among diverse stakeholders [47].

In conclusion, overcoming these obstacles will require a collective effort involving all relevant stakeholders and a shift towards a more collaborative and sustainable contractual framework. Digital technologies offer promising ways to address these challenges, as they can improve transparency, data sharing and real-time monitoring, providing the necessary tools to implement energy-efficient practices. The contribution of digital technologies will be further explored in part 3.

Key message n °3

Energy efficiency and operational levers could substantially contribute to shipping decarbonization in the short and medium term. Many of these improvements could be implemented rather quickly compared to alternative fuels (long term lever) despite challenges to the implementation such as interconnected cooperation between stakeholders, technical issues and financial barriers. Therefore, they should be promoted and developed rapidly.

Contribution of digital technologies to shipping decarbonization

3.1. Introducing the benefits of digitalization for decarbonization in the shipping industry

3.1.1. Digitalization and decarbonization are two interdependent shifts in the shipping industry

Decarbonization and digitalization represent two major shifts in the way the shipping business operates. On the one hand, digitalization empowers stakeholders to glean insights from intricate datasets, enabling process optimization, enhanced decision-making, and increased efficiency. On the other hand, decarbonization requires robust GHG emissions monitoring, vast operational and organizational changes, and renewed strategies from all stakeholders. **Digitalization enables new decarbonization solutions,** such as better emission tracking or operational efficiency gains, while decarbonization is a major challenge for the industry and constitutes a key **driver for increased digitalization.** Therefore, these two shifts have strong interdependences (Figure 27). In the EU, the interaction between both is referred to as a "twin transition" [57].

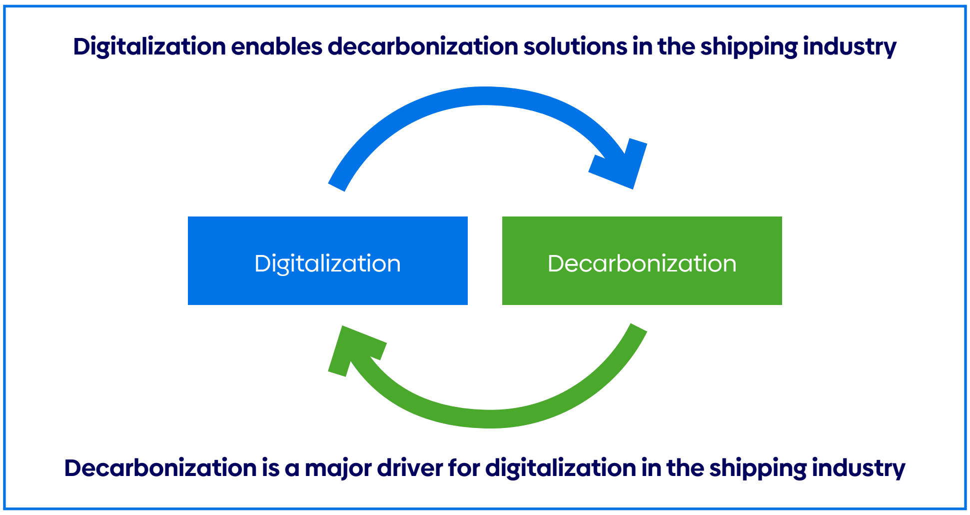


Figure 26: Digitalization and decarbonization are interdependent trends in the shipping industry.

Digitalization refers to the **process of enabling, improving and/or transforming operations, functions, processes and/or activities, by using digitized data to obtain actionable knowledge with a specific benefit in mind** [58].

It therefore **relies on a succession of steps which bring different value,** and each one leverages specific technologies to deliver the intended benefit in the end (Figure 27). The data needed is first identified and then collected via dedicated devices such as sensors, manual sources, etc. Second, data is transferred relying on communication technologies such as satellite, Wi-Fi, mobile networks like 5G, that enable connectivity and often machine to machine communication. Next, data needs to be stored in a repository or data lake, using technologies such as cloud computing or edge computing. Fourth, data processing and analysis employ algorithms to sort intelligence and insights from the data collected, increasingly by using artificial intelligence techniques. Lastly, comes the data use phase. It includes technologies of data visualization that create representations helping the interpretation of the information obtained and modelling future trends, ranging from charts, diagrams, maps, dashboards and more recently virtualization technologies such as Augmented Reality and Virtual Reality. It also includes the generation of data-driven decisions and actions, with different levels of automatization.

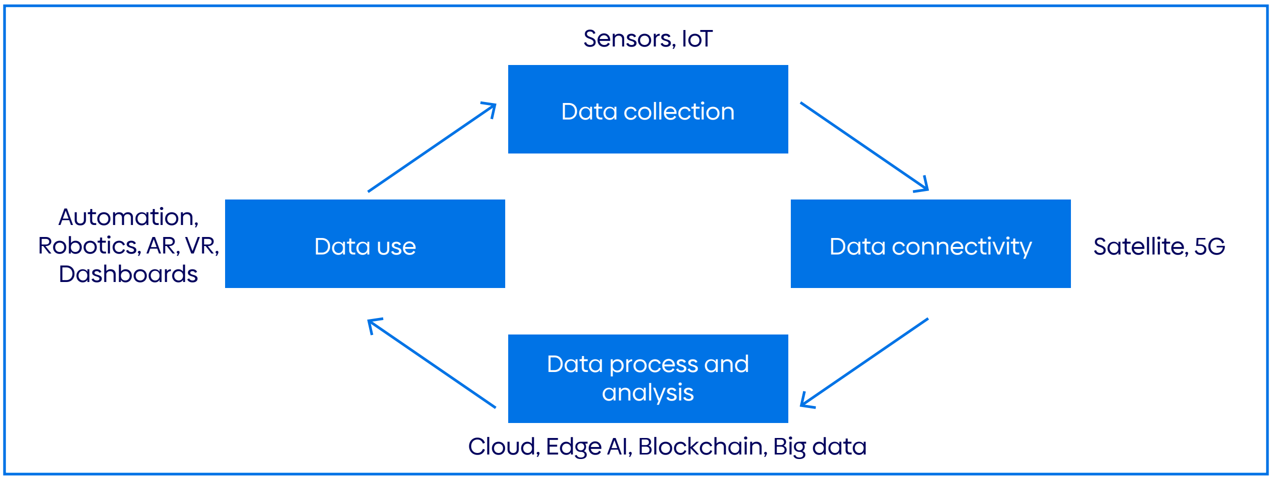


Figure 27: Data Value Chain. In grey, examples of technologies associated with the step of the digital value chain.
Source: I Care.

All steps contribute to designing a digital solution, but all are not equally critical depending on the use cases. As next parts of the study will demonstrate, at times there is more value added in the collection of the appropriate data, or in the ability to ensure that it is transferred and stored in the most efficient manner. In other occasions the hardest part is to extract actionable information out of data collected and to generate the appropriate action. In most cases, a combination of contribute to the digital solution impact.

3.1.2. Digital decarbonization use cases in other sectors

Literature about the benefits of digital solutions for decarbonization purposes is abundant and covers many economic sectors. For instance, the World Economic Forum estimated in 2022 that **up to 20% emissions reduction** could be obtained by 2050 via more than 30 digital use cases across the Energy, the Materials and the Mobility sectors [59]. It illustrates that there are many opportunities of digitally-enabled emission reductions. Some digital decarbonization solutions are sector specific, like the ones explored in the World Economic Forum study. But some are applicable to many industries, including shipping industry. Some of these more generic use cases are presented below.

- Digital solutions can help establish accurate diagnostics via **performance monitoring and analysis,** notably of carbon sensitive parameters such as energy consumption.
- Digital technologies have had a tremendous impact on the **design phase of products and services,** enabling rapid prototyping, iterative design, and real-time collaboration across various locations. Design software, 3D modelling, and augmented reality technologies also contribute to improving design phases.
- Digital solutions also enable new scales of **predictive analysis,** leveraging data analysis technologies and artificial intelligence solutions, with applications for maintenance purposes, to predict weather or for demand forecasting.
- **Traceability** can greatly benefit from digital solutions, notably via the creation of online collaborative platforms that centralize data from various stakeholders. Enthusiasm around blockchain technologies also demonstrate the relevance of digital technologies for traceability improvements. Digitally-driven traceability has applications for corporate sourcing purposes or for data monitoring, GHG emissions for instance.
- Different types of **optimizations** can be performed thanks to data analysis technologies and artificial intelligence algorithms. Organizations can use several data sources to identify patterns and make data-driven decisions. The outcome can take various forms but include cost reduction, reduced resources consumption or performance improvement.
- **Automation helps streamline economic activities** by reducing human intervention. Ranging from routine data entry and reporting to automated manufacturing using robotics, automation brings efficiency in many tasks. It also brings safety with increased accuracy, by performing hazardous or repetitive tasks and with instant reactivity.

These use cases illustrate how various technologies, corresponding to different steps or combination of steps of the digital value chain can contribute to decarbonization in different economic sectors. To further explore how digital technologies and shipping decarbonization levers interact, this study conducts an analysis based on a list of main technologies. It is voluntarily, non exhaustive and generic – meaning that the study does not explore technologies with a high granularity but rather focus on more established groups of technologies, like many other studies do.

The list was built based on the technologies mentioned in the literature and by the industry stakeholders, and is the following: sensors, Internet of Things (IoT), satellite, 5G, cloud computing, edge computing, blockchain, artificial intelligence, virtual and augmented reality, digital twins, and automation.

3.2. Digital technologies enable decarbonization of shipping operations

Regarding decarbonization levers, this study is focused on operational optimization levers as defined in Part 2.1. This encompasses the optimization of energy consumption onboard, routing (weather routing and slow-steaming) as well as terminal operations. To illustrate digital technologies contribution to these decarbonization levers, this part presents practical and real-life use cases.

An overview of the global decarbonization levers is reminded on Figure 28, also included in previous section.

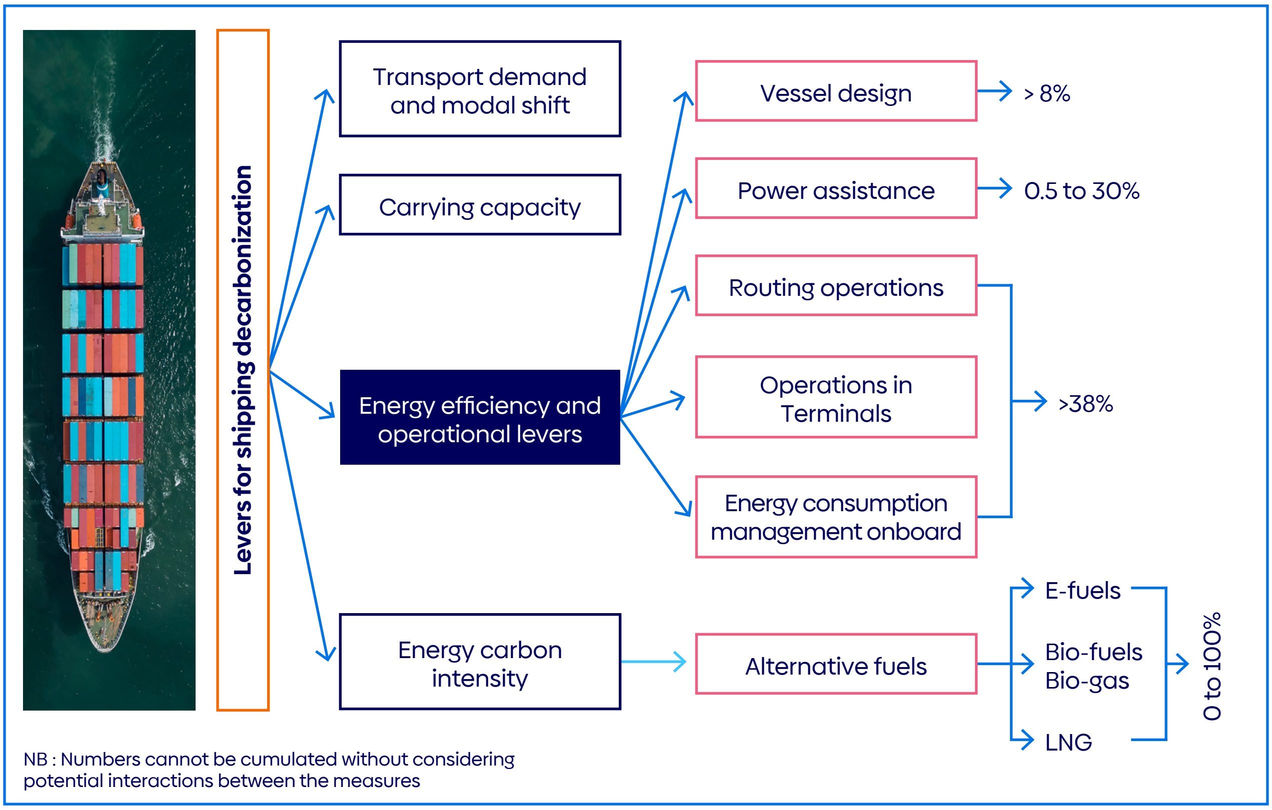


Figure 28: The main levers and their potential to decarbonize the shipping sector.
Source: I Care based on reports from IMO, IEA, Ricardo and Glomeep

3.2.1. Digital use cases that contribute to decarbonize shipping operations

a) Onboard energy consumption lever

Onboard energy consumption and operations refer to the optimization of energy consumption when the vessel is operating. This energy consumption includes power generation via auxiliary engines, electricity consumption for lights and equipment, heat and/or cold production, ventilation. It usually represents a significant part of the ship energy consumption and there is room for optimization. Such optimization can rely on digital technologies for the following use cases.

Predictive maintenance

Ships are equipped with many systems which performance can be enhanced with accurate monitoring, to detect adjustments, maintenance, and repair needs. Predictive maintenance offers a proactive approach to this issue. It leverages better data collection from systems and **data analytics** to improve systems performance, detect anomalies and expand their lifetime.

Sensors and notably IoT solutions enable better monitoring providing accurate and continuous data. This is especially true since the shipping industry still relies heavily on manually compiled reports such as Noon reports[13].

13 Noon reports are the most common tool for vessel performance reporting in the shipping industry. It consists in a daily data sheet prepared by the chief engineer daily, with data about vessel performance, position and weather conditions.

Predictive maintenance also relies on **data analytics** to identify performance gaps and indicate required actions to correct them. Data analytics enable vast amount of data processing to identify patterns and anomalies. It can be significantly improved by **Artificial Intelligence solutions** that can, additionally, continuously improve and adapt their predictive capabilities. That can have an improvement on performance, as parts are replaced before they fail.

Predictive maintenance can also benefit from **edge computing solutions** which allows for **data processing** closer to the sensors, reducing connectivity issues when the ship is at sea.

Ultimately predictive maintenance not only increases operational onboard performance but also limits time ships need to stay at shore for maintenance, repair or due to equipment breakdown.

Energy management systems

Energy management systems (EMS) are designed to manage and enhance energy performance, with a systematic approach to monitor, control and optimize energy consumption onboard vessels. They encompass all energy consuming devices on the ship, but notably auxiliary engines, heating, ventilation and air conditioning systems. EMS rely on **continuous and real-time monitoring and data collection** of various parameters like fuel consumption, engines performance, load factors etc. The data is **processed and analyzed with data analytics tools** and **Artificial Intelligence algorithms** that compare performance to baseline scenarios. It can notably help optimize engines load. Digital technologies associated with EMS also simplify emissions monitoring and reporting obligations with more automated reports, for compliance with regulations by the IMO or other regulatory frameworks.

b) Routing optimization

Routing optimization revolves around the idea that some routes are more energy efficient than other, depending on the dynamic variation of many parameters such as weather, currents, or traffic at choke points. Therefore, digital technologies offer perspectives as presented below.

Smart routing

Artificial Intelligence can be leveraged to optimize shipping routes, considering multiple factors such as weather, traffic, and fuel efficiency, ultimately reducing costs, improving delivery times and a ship's sustainable performance. Precise data about ship's position, sea condition, and weather can be leveraged to adopt the optimal route. Digital technologies enable the **gathering and processing of multiple dynamic data points** in real-time, to **identify optimization opportunities.**

The carbon footprint of a journey can be optimized keeping a constant speed and foreseeing optimum arrival time at the terminal (in agreement with the port) that can guarantee berth availability making it possible for a vessel to adapt its speed to arrive at port at the appointed date (see Part 2.1.5 about Just-in-Time arrival).

Autonomous ships

Ships' automatization can improve routing performance. **Autopilot solutions** help ensure that the optimal route is always followed by the ship. It can also contribute to control the ship's rudder in the most energy efficient manner with a steadier course resulting in less deviation from the course line.

Enhanced performance relies on **sensors and IoT technologies** that **provide for the needed data,** coupled with high-performance **AI tools** that facilitate data processing and decision making. **Edge computing** can contribute to autonomous ship's performance by resolving some of the connectivity issues ships can encounter while at sea. **New satellite technologies** like Low Earth Orbit satellites, which have lower latency, are other enablers of more autonomous ships because they improve connectivity in remote areas.

AI and Edge computing can enable autonomous ships to navigate on their own, reducing the need for manual intervention and improving safety.

Autonomous ships should analyze their own **operational performance** and make decisions based on that information to achieve more efficient navigation at sea and operations in harbor, making them more economical and reducing their carbon footprint.

c) Terminal operations optimization

Efficient terminal operations can have significant impact on the sustainability of the whole freight value chain. With fast and secure operations, combined with transparent data sharing and communication among participants, each stakeholder can better synchronize to optimize their operations in a sustainable manner, avoiding unnecessary emissions related to delays or other inefficiencies.

Smart ports

Ports are at the node of modern logistics, with multiple stakeholders involved in their efficient operations. They are also at the center of various and large information exchanges related to ships, cargoes, or inland transportation. Ports are increasingly relying on digital solutions to **optimize their operations** and avoid inefficiencies, that eventually result in costs, delays, and environmental degradation (notably GHG emissions, air pollution, water pollution or noise). Tremendous amounts of **operational data can be collected** about a terminal's infrastructure and equipment via **sensors and IoT technologies.** With the support of **data analytics** that processes data in real time, ports can progressively automatize decision making, leveraging **AI solutions. Cloud computing** can be used to centralize and optimize port operations. **Connectivity technologies** like 5G can also contribute to facilitate smart ports operations to **support the transmission and processing** of vast amounts of data.

Eventually, ports' capacity management and operational performance can be enhanced through **automated processes** and digital solutions. These solutions avoid handling and exchanging documents manually, or sharing information by phone, fax or email. **Software solutions** make on- line freight data available, reduce paperwork and human errors, whilst facilitating and streamlining intermodal transfer. It is the whole freight system and associated supply chains that can benefit from smarter ports operations.

Cargo tracking solutions

Better cargo tracking can enhance visibility of supply chains and allow for better coordination of stakeholders at port. **More reliant and real-time information** about the goods (location, condition, size etc.) can achieve more efficient handling of the cargoes, with the help of **IoT technologies.**

Blockchain technologies can also contribute to better **tracking** of goods and transactions with secure and decentralized recording of data about cargoes and transactions. The full logistic process can benefit from more consistent and reliable information of the goods with the possibility to track and record each process step during the transaction chain.

Cloud computing provides flexible and centralized **data storage and analysis** services for a more efficient and accessible cargo tracking system among stakeholders.

Edge computing provides lower latency for **data processing,** while **5G's** high speed and lower latency quickens **data transfer,** enabling more precise cargo tracking in ports equipped with this technology.

3.2.2. Exploring individual technologies contribution to operational decarbonization

The previous section presented the links between operational decarbonization levers and digital technology use cases. To better understand the nature and extent of the contribution of each technology identified, this section provides a summary of the benefits of these technologies and their relevance to the three groups of operational levers studied: onboard energy consumption, routing operations and terminal operations optimization. For each lever, the contribution of various technologies is considered at three different levels of contribution:

- **Major contribution:** there is clear evidence that potential GHG emissions reduction obtained by a lever is dependent on the adoption or development of digital technologies, or can be greatly enhanced by them. Evidence stems from scientific literature or case studies.
- **Contribution:** there is some evidence that GHG reduction depends partly on digital technologies or can be significantly improved by them. Nonetheless, their impact is lower because there are other brakes or opportunities associated to the lever, like policy development, business model evolution, or organizational changes, for instance.
- **Minor contribution:** unlocking the full potential of emissions reduction from a lever can be achieved with minor contribution of a digital technology.

A synthesis of the contribution of all these technologies to decarbonization levers is shown in Table 3. The table provides a rationale for the interest of each technology group for the deployment of these decarbonization levers. Green cells correspond to "Major contribution", blue ones correspond to "Contribution" and grey cells to "No or minor contribution".

Digital value chain step	Digital Technology	Rationale	Operational optimization at sea		Operational optimization in port
			Routing	Onboard energy consumption	
Data Collection	Sensors	Sensor technologies enable to collect real-time data.			
	Internet of Things	IoT technologies allow for more automatized data collection and transmission.			
Data connectivity	Satellite	Satellite technologies can improve ships connectivity to allow for data-driven optimization solutions.			
	5G	5G enables increased connectivity in port areas.			
Data processing	Cloud computing	Offering scalable data storage and computation power to support complex modelling and simulation.			
	Edge computing	Edge computing can resolve some connectivity issues and increase computation power.			
	Blockchain	Blockchain technologies can increase trust, traceability and transparency among actors to overcome organizational or business barriers.			
Data Analysis	Artificial intelligence (AI)	AI driven approaches can improve the capacity to generate knowledge and action out of complex datasets.			
Data Analysis	Virtual reality and Augmented reality	VR and AR are visualization tools that provide immersive experiences. They are a bridge between the virtual and real worlds.			
Data collection, data processing, and data use	Digital twins	Digital twins technologies enable real time monitoring and optimization of performance all along the ships life-cycle.			
Data use	Automation	Automation can contribute to minimize human errors or latency. It improves speed and accuracy of adjustments.			

Table 3: Contribution of digital technologies to energy efficiency decarbonization levers.
Source: I Care

Cloud Computing

Cloud computing is the model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (i.e., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. Cloud Computing concept has already transformed the traditional way that most of the computational tasks and digital services are developed, delivered, and managed.

In the digital environment, CSP (cloud service providers) are the most common third party that organizations seek help with their decarbonization.

Cloud technology is leveraging the decarbonization in enterprise with more efficient server population (higher server utilization), better PuE (Power Usage Efficiency), efficient and consolidated number of low-carbon Data Centers locations.

The adoption of cloud computing technology in the shipping industry can create a collaborative environment to enable the delivery of cross-border services to all the participants and their supported end users, providing reliable information and instant processing.

A migration strategy to the maritime cloud ecosystem requires to identify the emerging technologies that can facilitate the efficient delivery and deployment of a complete maritime cloud framework. On-demand self-services, ubiquitous network access and location-independent resource pooling address some of the shipping sector most pressing needs to harness the potential of digital technologies for more efficient operations.

The availability of a reliable internet connection when ships are in areas with poor coverage remains a major challenge for cloud computing's contribution to operational levers of decarbonization.

However, cloud computing provides scalable, flexible, and collaboration-friendly solutions to issues like data storage or access to computing power. Therefore, it supports data-intensive monitoring, simulations, and analytics that stakeholders can rely on to optimize their onboard energy consumption, routing decisions and terminal operations. As such, cloud computing can be considered a major contributor to all three groups of operational decarbonization levers.

Edge Computing

The rise of connected ecosystems and new experiences driven by technologies are putting pressure on the limited bandwidth of centralized infrastructures and cloud. Latency-sensitive applications, such as artificial intelligence and automatized operations, cannot be widely adopted if today's digital architecture does not support them, or is not able to guarantee real-time decision-making. Hence the need to bring computation closer to the point of data generation and consumption to reduce bandwidth pressure and power consumption, which have high bandwidth decision-making requirements.

In addition, even in areas covered by 5G technology, it may not deliver the real-time data and response times required by the new ship operation optimization solutions. As a result, more and more organizations are considering a hybrid model that includes edge computing to complement their existing wide cloud strategy.

This concept of moving storage, computation, and networking from centralized computing to the proximity of operations is called edge computing. It encompasses a set of technologies that enable distributed computing and bring real decision closer to the Ship Operations. Edge computing can enable faster, more efficient, and more secure data management for maritime shipping operations, such as navigation, cargo tracking, maintenance, and safety. It significantly improves data-driven operations optimization strategies across the shipping value chain, while vessels are at sea or in port areas.

Different insights estimate that edge computing can reduce GHG emissions, providing relevant benefits as:

- Improved fuel efficiency: it can optimize the route planning and speed control of ships, based on real-time data from sensors, weather forecasts, and traffic information. This can reduce fuel consumption and emissions, as well as save time and costs.
- Reduced idle time: it can facilitate the coordination and synchronization of port operations, such as loading and unloading, customs clearance, and inspections. This can reduce the idle time of ships at ports, which is a major source of GHG emissions.
- Enhanced sustainability: it can enable the monitoring and reporting of GHG emissions from ships, using standardized and verifiable methods. This can support the compliance with environmental regulations, as well as the adoption of voluntary initiatives and incentives for emission reduction.

- Real-time data analysis: it can enable the collection and processing of large amounts of data from various sensors and devices on board ships or at ports, to provide real-time insights and feedback for decision making. This can help improve the operational efficiency, safety and environmental performance of ships and ports. For example, real-time data analysis can enable dynamic route optimization, which can reduce fuel consumption and emissions by avoiding congestion, weather hazards or other factors that affect sailing conditions.
- Remote monitoring and control: it can enable the remote access and control of various systems and equipment on board ships or at ports, using wireless communication networks and edge devices. This can help reduce maintenance costs, downtime, and human errors, as well as enhance safety and security. For example, remote monitoring and control can enable condition-based maintenance, which can reduce fuel consumption and emissions by avoiding unnecessary or excessive maintenance activities that affect engine performance.
- Predictive maintenance: it can facilitate the prediction of failures or malfunctions of systems and equipment on board ships or at ports.

But Edge computing has also relevant challenges in the current moment in the maritime shipping industry, such as:

- The need for reliable and secure connectivity, especially in remote areas and harsh environments.
- The need for interoperability and integration of different data sources and platforms, across different stakeholders and jurisdictions.
- The need for scalability and flexibility, to cope with the increasing volume and variety of data generated by ships and ports.
- The need for innovation and collaboration, to develop and deploy edge computing solutions that meet the specific needs and challenges of the maritime shipping industry.

Sensors & Internet of Things

Sensors collect digitized data and are used for monitoring and decision-making purposes. IoT refers to a network of interconnected physical objects, including sensors but also other devices like machinery or computers. These devices collect and exchange data autonomously among each other through machine-to-machine communication. Sensors and IoT technologies enable more responsive monitoring, controlling and optimization of processes in many sectors. These technologies are gaining traction across various sectors seeking to optimize and automatize their operations. Notably, they are part of the key technologies enabling industry 4.0, which is expected to bring more efficiency, flexibility, and sustainability to many industries.

In the shipping industry, sensors and IoT technologies are increasingly used to enhance real-time decision-making and facilitate the information flow between various stakeholders. Hence their major contributions to the three groups of operational decarbonization levers: these technologies can support optimization of onboard energy consumption, routing and terminal operations. The extent of their contribution to shipping decarbonization will heavily depend on companies' ability to deploy these technologies, along with the digital environment required to support and take advantage of their operation. Integrating them on a significant part of the operating ships could take several years [60].

One of the main challenges with sensors & IoT technologies is being able to manage the flow of incoming data to extract insights out of it. Sensors and IoT systems also require maintenance, notably to make sure that the sensors are properly calibrated to properly collect data.

Automation

Automation refers to the application of advanced control systems, artificial intelligence, and robotics to perform tasks with minimal human intervention. Automation's primary objective is to enhance operational efficiency and safety, by automating tasks that were traditionally labor- intensive or prone to human error.

In the shipping industry, automation is under much scrutiny by stakeholders that seek to optimize their operations and decision making. It englobes operations while the ship is at sea, related to routing decisions and autopilot implementation, but also automated energy consumption management systems. In terminals, automation is leveraged to streamline processes, increase cargo handling efficiency as well as facilitate communication and data sharing among the many stakeholders.

Blockchain

Traceability, transparency, and trust are key issues in the shipping industry and the global freight ecosystem more with many stakeholders involved in this fragmented and international value chain. Growing concerns about sustainability have only increased the need to develop solutions to these issues.

By creating an immutable ledger of transactions shared across multiple stakeholders, blockchain technologies ensures data integrity, reducing the risk of disputes among companies. Transparency of blockchain records allows for the tracking of sensitive data that can contribute to foster more collaboration in the shipping industry. Thus, it could have a significant impact on routing optimization strategies and terminal operations optimization. Blockchain contribution to other decarbonization levers such as alternative fuels is also explored by some industry actors.

Artificial Intelligence

Artificial Intelligence (AI)has different challenges in the short and medium future and should be tailored to different stakeholders to ensure Data quality standard, client centric approach, security standard, skilled workforce, regulatory compliance, and a trusted partnerships ecosystem to support decarbonization in the maritime transport sector. AI needs certain time to develop and implement AI customized use cases and it may vary depending on use cases' complexity and previous AI experiences.

Further, Artificial Intelligence technologies allow machines to perform tasks typically requiring human intelligence, such as analyzing data to recognize patterns and generate actions. The main applications of AI are machine sensing/vision, prediction, automatization, and natural language processing. AI technologies enable faster, more accurate and self-reinforcing data processing and action generation. Therefore, the use cases for AI are countless depending on the activities they are applied to.

Currently, the maritime industry relies heavily on human interaction for its complex operation, notably onboard the ships or at port. AI can contribute to optimize these operations with decision- making support and process automation. Application to shipping could foster greater optimization by using the data available regarding ships performance, weather conditions, port congestion and operations, about cargo or hinterland transportation. These technologies help organizations harness the vast amounts of data generated by their activities and gain useful insights allowing optimizations of various parameters like fuel consumption or routing and enable predictive analytics that can be applied to ship maintenance requirements or demand forecasting in terminals for instance. AI also makes it possible for monotonous, repetitive yet sensitive tasks to be automated, allowing for increased accuracy.

There is clearly a growing momentum around AI in the maritime industry, with markets growing rapidly in recent years and expected to continue in the next 5 years too. [61] Because it has different use cases regarding data processing, prediction and automation, AI contributes, and will increasingly contribute, to the optimization of all three groups of operational decarbonization levers studied. Therefore, AI is a major contributor to onboard energy consumption, routing and terminal operations decarbonization levers.

Connectivity - Satellite technologies

Satellite technologies are critical to ship navigation as well as deep-sea internet and communications connectivity. Satellite technologies already enable seamless communication and data transfer, supporting various aspects of shipping operations. For instance, satellites are key data sources for parameters such as weather or currents. Another use case is ship location and identification, with systems such as Automatic Identification System (AIS), helping prevent accidents and ensuring compliance with international regulations. Satellite technologies are also the main source for meteorological data, which can be used for weather routing optimization for instance.

Satellite technologies have therefore been used in shipping for many years. But their contribution to decarbonizing the sector could be significant in the coming years, particularly to support the growing need for connectivity while ships are at sea. New technology such as Low-Earth Orbit connectivity, which provides low-latency data exchange and greater bandwidth, is expected to support digitally driven operational optimization while at sea (onboard energy consumption and routing operations).

Digital Twins

With increasing use of data and digital technologies in their process, some companies in the shipping industry explore the possibility to rely on digital twins to reach new levels of physical and virtual world integration. A digital twin is a highly detailed data-driven model that mirrors the structure, performance, and operational aspects of a physical object and interacts with it. This enables comprehensive monitoring, analysis and optimization of various parameters and processes. Digital twins offer a useful interface for data integration and as such enable new collaboration schemes, like the examples of Port Collaborative

Decision Making systems and green charterparties detailed in part 3.3.2. Therefore, applications of digital twins technologies to ships and ports are gaining traction in the shipping industry. Many uses cases are also related to vessel design levers of decarbonization, since digital twin offer a powerful interface to perform complex simulations of new design or retrofit strategies.

Digital twins require a combination of many other digital technologies to be efficient, ranging from sensors and IoT devices to data storage and management solutions, artificial intelligence, or advanced visualization technologies. This means that digital twins are a technology that is more useful to stakeholders that already have a high level of digitalization. Digital twins' adoption in the shipping industry is emerging but not mainstream yet. However, because it holds such potential in terms of optimization and digital integration for various players in the shipping industry, we consider that digital twins can have a contribution to operational decarbonization levers.

Virtual reality (VR), Augmented reality (AR) and 5G were the other technologies in the list of main technologies studied to assess their potential contribution to operational decarbonization levers. Since 5G technology is dependent on infrastructure availability, its potential applications in the shipping industry are restricted to certain areas like ports terminals. Therefore, its contribution is considered rather minor compared to other technologies studied. with no or minor contribution to Routing Optimization or Onboard energy efficiency. VR and AR are not yet widely adopted in the shipping industry. For now, it appears that the main uses cases revolve around training and simulation use cases. Their contribution to operational optimization and energy efficiency is therefore rather indirect compared to other technologies studied. Therefore, they are also considered to have only minor contribution to these decarbonization levers.

This technology-centric approach illustrates that there are many ways digital technology could contribute to operational decarbonization levers. It also highlights the major contribution potential held by the following technologies: sensors & IOT, satellite, cloud computing, Artificial Intelligence and Automation.

This does not mean that other technologies should not be considered by stakeholders when designing their digital decarbonization strategy, but that they added value is less directly linked to operational optimization, subject to further technological development or larger commercial uptake.

3.3. Transversal contribution of digital technologies to decarbonization

Apart from its contribution to some specific decarbonization levers, digital technologies can also contribute more transversally to the decarbonization of the shipping industry, notably by fostering collaboration and enabling more accurate emissions reporting.

3.3.1. Digital solutions facilitate emissions data collection, integration, reporting and strategical use.

It is important to emphasize that tracking and reporting ship's emissions is the first step in any decarbonization strategy. Knowing the starting point of emissions and having measurable performance indicators is essential for cargo owners, shipping companies and port operators.

Shipping transport stakeholders are under **increasing pressure to measure and report the GHG emissions** (and other pollutants such as sulfur oxides) associated with their activities, whether from the IMO, governments, other institutions, or business partners (see corresponding reporting requirements in part 1.2.4). A lot of participants still rely on approximate measurement of emissions due to outdated fuel consumption monitoring. Experts pointed to Noon reports[14] as an outdated reporting method for ship performance indicators. Noon reports still rely heavily on human input, do not provide accurate and continuous performance monitoring, and data points and formats are not always standardized.

Data management is also a cross-cutting enabler for the design of digital decarbonization strategies. Ensuring that the **right data is collected, aggregated and quality controlled** is essential. Stakeholders should have the right data management processes and infrastructure in place to gain efficiency and clarity from large, complex data sets.

The multiplication of communication funnels and data sharing among various stakeholders will require coordination between actors, notably to establish the required data standards that enable interoperable communication among actors [62]. As an example, stakeholders are currently exploring how to standardize message formats and processes to enable just-in-time arrivals [63]

However, as the implementation of such monitoring solutions could take some time and pose some challenges (such as sensor calibration over time), some stakeholders are pushing for an interim "reform" of noon reports and the creation of a "vessel report" standard for the years to come [60]. There are several objectives behind this proposition but the main are:

- Adapt ship performance data collection to the emerging trend of decarbonization and digitalization that require and enable greater optimization;
- Provide more data (e.g. Noon reports, bunker, port or cargo data) and ensure its quality.
- Standardize the data collected to respond to new reporting requirements (IMO data collection system, EU MRV, CII, EEXI or initiatives such as the Poseidon principles[15]).

Robust monitoring and measurement of emissions and other performance parameters is essential to adopt a decarbonization strategy, to establish a baseline, to track trends and report on developments. Digital solutions providing emissions monitoring and reporting services are gaining ground in the industry and appear technologically and commercially mature.

14 See definition in part 3.2.1.a)

15 The Poseidon principles are a set of voluntary guidelines for financial institutions active in the shipping industry. It provides a framework for assessing and disclosing carbon intensity of portfolios and encourage underlying companies to reduce their emissions.

3.3.2. Digitalization fosters carbon data emission collaboration and emission data transparency amongst stakeholders

Collaboration among actors of the freights and goods value chain will be necessary to achieve decarbonization targets and help operational decarbonization strategies. Digitalization has the potential to boost such collaboration and play a pivotal role in facilitating decarbonization efforts.

This potential is rooted in the capacity of digitalization to encourage trusted and transparent data sharing between stakeholders who historically considered such information as sensitive or difficult to share in real time. Digital solutions enable accurate and continuous data collection, efficient monitoring, complex optimization and provide the communication platform for enhanced collaboration.

One of the ways in which digital technologies foster collaboration is by mitigating the concerns related to **data confidentiality.** Traditionally, companies in the shipping sector were often reluctant to disclose operational details, viewing them as proprietary and sensitive information. However, digitalization offers a means to securely share data while retaining control over access. By implementing blockchain technology, for instance, data can be encrypted and securely stored, ensuring that only authorized parties have access. This safeguards sensitive information, reassuring stakeholders that their data remains confidential.

In parallel, robust cybersecurity management is critical to ensure the integrity, availability, and confidentiality of shared information. Protecting digital infrastructure from cyber threats and vulnerabilities not only mitigates operational risks but also builds trust in the adoption of sustainable technologies. A proper digital risk management strategy should cover all relevant areas, include response plans and training in the management and detection of digital and operational technology risks.

Transparency benefits from the data sharing opportunities provided by digital technologies such as cloud computing. Vessel performance, cargo tracking, emissions data or sea traffic are just examples of data streams that can be shared among stakeholders to gain a comprehensive understanding of shipping operations, as a basis for collaborative decarbonization efforts. For instance, digitally driven transparency and trust can enable ports to incentivize ships to adopt the most energy efficient routing options: some ports are already trying this measure.

Furthermore, digital solutions offer the capability for more **synchronization and planning** via real- time data collection, aggregation, and processing from various sources and stakeholders. Port operations optimization, which require numerous stakeholders to collaborate, exchange information and synchronize their decisions is just one example of this. Sharing data about vessel arrival, cargo, port handling capacity or other nautical services helps streamline port operations.

Another example of the benefits of digital technologies for planning purposes related to emission reduction solutions is the carbon management system implemented by Port Esbjerg. This software, co-created with Honeywell, aims at optimizing the port's shore power supply to incoming ships. In addition to supplying renewable electricity to ships, the system monitors energy consumption and emissions, and pinpoints potential improvements opportunities. The solutions is cloud-based, relies on many sensors for data collection and uses Artificial Intelligence algorithms to process the data. [64]

Example of collaborative initiative using digital technologies: Port Collaborative Decision Making

Port Collaborative Decision Making is an organizational concept developed with the ambition to increase efficiency of the overall maritime transport operation. The concept was inspired by the aviation sector. **It focuses on the port as a nodal point of the transport system, which requires both internal coordination among the many agents involved at in the port, and external synchronization with the other actors of the transport process** (ships, other ports, hinterland transportation etc.). The goal is to avoid sub-optimizations that are detrimental to the system as a whole by facilitating greater integration, better situational awareness and planning. The concept relies on increased data sharing, standardization, and transparency among actors to foster integration[65], [66]. Valencia, the biggest port in the Mediterranean Sea in terms of container shipping, is equipped with a Port CDM system. Coupled with a digital twin solution, the ports expects to achieve 10% reduction in ship's call time [67].

Key message n °4

Digital technologies can contribute to the deployment of short and medium term operational decarbonization levers, such as onboard energy consumption, routing and terminals' operations and are an enabler technology that boosts data sharing harmonization, standardization, and transparency among participants to foster integration across the maritime supply chain.

3.4. Digitalization levers must be used with care to avoid or limit side impacts

The development and use of digital technologies also comes with a significant impact on the environment. The digital sector is estimated to represent 4% of global GHG emissions [68], with projections pointing towards an increasing trend in the future [69]. Digital technologies rely on hardware (including infrastructures) and software which generate GHG emissions for their construction, operation and disposal. Emissions breakdown between the different equipment is the following: devices have the most impact on GHG emissions, followed by data centers and networks. Breakdown between the different steps of the life cycle of digital industry shows that the production phase has the most impact on climate change, followed by the use phase and marginally the distribution phase [68][16]. An example of use phase carbon impact that should be carefully monitored by stakeholders is that of model training in artificial intelligence applications. This is an essential part of AI solutions development but it is a very energy intensive process [70].

The development of the digital sector and its value chain also comes with other significant environmental impacts such as abiotic resources depletion (mineral, metal and fossil), tensions on freshwater resources or biodiversity loss. Regarding these other environmental impacts, user equipment are again responsible for the majority of the impacts.

	Energy	GHG	Water	Electricity consumption	Abiotic resource depletion
User equiptment	60%	63%	83%	44%	75%
Network	23%	22%	9%	32%	16%
Data centers	17%	15%	7%	24%	8%

Figure 29: Breakdown of impact of the digital world in 2019, by environmental indicator.
Source: [68]

For these environmental impacts, the manufacturing phase is also usually more impactful than the use phase[68].

Considering these other environmental impacts is critical to ensure that digital solutions to decarbonization issues do not result in shifting the impact from one parameter to the other. To this end, the framework established by the EU taxonomy for sustainable activities offers an interesting guideline. For an activity to bring substantial contribution to an environmental objective (i.e. be taxonomy aligned), it has to verify the Do Not Significantly Harm (DNSH) principle: being sustainable regarding one objective implies not impacting negatively the others.

The issue of digital solutions' impact on resource consumption is amplified by the fact that many decarbonization solutions (such as electrification of passenger vehicles, wind power or photovoltaic electricity generation) also rely on critical resources: as illustrated by a foresight study conducted by the European commission in 2020 [71] many resources are critical for both decarbonization technologies and digital technologies. This means that on some occasions, digitalization and decarbonization solutions could eventually compete for the same resources, resulting in tensions on supply chains.

A potential downside of using digital technologies as sustainability catalysts is also the **increased pace of equipment renewal.** Technology development and fast-paced innovation of digital technologies may result in the obsolescence of some devices and equipment which then need to be replaced, sometimes more rapidly than expected. This is a critical issue since the fabrication phase accounts for so much in the impact of digital solutions, as highlighted above. Some studies show that the environmental gains expected from digital solutions can be very sensitive to this parameter [72].

16 This study does not include the end-of-life phase of digital devices as there is not enough reliable data to estimate its overall environmental impact.

Rebound effects are another source of potential concern when exploring the decarbonization potential of digital solutions. They occur when an innovation supposed to produce gains in resource use efficiency does not deliver the expected gains because of behavioral or systemic responses that increase consumption. Rebound effects can be **direct,** which means that the good or service consumption will increase because of the higher efficiency; a good example of that is how more efficient mobile connectivity technologies, like the switch from 3G to 4G, led to increased data consumption. Rebound effects can also be **indirect,** when the gains from efficiency on one matter is reinvested in another product or service, that overturns the overall expected gains.

Finally, rebound effects can be structural when the **decrease in price prompts structural changes in the way people produce and consume.** For instance, rapidly decreasing costs of digital devices resulted in consumers increasing the number of devices they own.

Investigating whether digitalization has a positive or negative effect on energy consumption, and on decarbonization, is therefore a difficult task. The interactions of digital technologies and energy consumption are complicated [73]:

- There are direct effects from the production, usage and disposal of information and communication technologies (ICT) on energy consumptions;
- Digitalization creates economic growth which is still closely linked to energy consumption, essentially consisting of fossil fuels (around 80% of primary energy consumption worldwide);
- Digital solutions enable energy efficiency;
- Digitalization fuels tertiarization of the economy with the rise of ICT services share of GDP, which are usually less energy intensive activities.

While the last two interactions tend to reduce energy consumption, the first two interactions tend to increase it. Thus, it is important to explore the effect of digital solutions on all these parameters to understand how it can contribute to decarbonization.

An identified gap in the literature is **the absence or small number of studies that take into account the potential rebound effects associated with digital technologies** [74]. Companies that disclose use cases about the benefits of their solutions also hardly ever take into consideration net GHG impact, rebound effects or shifted impacts.

In conclusion, it is very complicated to anticipate and measure the overall impact of digitalization on sustainability. Leveraging digital solutions to increase energy and operational efficiency, resulting in GHG emissions reductions or other environmental gains, should therefore be investigated with caution. **Life-cycle analyses and multi-impact studies should be carried out by every digital technology developer** to identify potential risks of rebound effects or shifted environmental impact. It is critical to make sure that the expected environmental gains are significant enough given the effort and that the impact is not just displaced to another sector, use phase or environmental issue. Sensitivity analysis are useful tools to test the outcomes associated with various hypothesis and scenarios, to steer the environmental performance associated with a digital solution. Finally, evaluating the environmental benefits in hindsight is very useful to confirm the relevance of decarbonization levers and strategies.

Key message n °5

Attention must be paid to risks of negative externalities or rebound effects (biodiversity, wildlife corridors impact).

Conclusions

This study has provided an overview of the maritime sector, its place within the freight sector, the climate challenges it faces and how the main players in the sector are addressing them. Overall, their commitments are heterogeneous in terms of ambition and scope of emissions, and few of the actors studied have analyzed the real possibility of achieving their targets by quantifying the potential of each decarbonization lever. Finally, where targets exist, they tend to be long-term, with no intermediate milestones.

With a small number of players controlling a large share of the market, first movers' leadership could lead to a significant reduction in the sector's GHG emissions, which can be followed by industry- wide disruption. The current commitments are insufficient to ensure an increase of global temperature below 1.5°C, however, building a bottom-up trajectory of decarbonization levers can help set the right priorities for the decarbonization pathway.

This paper also aimed at comparing the different existing decarbonization scenarios for the sector. Beyond the differences in ambition, scope and activation of the levers, the lever of sobriety is rarely analyzed in maritime transport studies: the evolution of demand is often studied as an input parameter and needs to be analyzed in depth, requiring a systemic approach that includes the entire freight value chain.

The various levers for decarbonizing the sector were listed, with a particular emphasis on energy efficiency and operational levers that can be activated in the short and medium term. Slow and weather routing, onboard energy consumption optimization and terminal operations optimization including just-in-time arrival are detailed. The study highlights the importance of activating these measures to meet the 1.5°C target. Certain contractual, economic, and technological brakes limit or prevent their implementation. It is important to stress that the emissions gains must not be achieved at the expense of other externalities. Particular attention should be paid to marine protected areas, wildlife corridors or areas of particular importance for biodiversity. Just as green corridors are being discussed to reduce carbon emissions, blue corridors to reduce noise and ship strikes on whales and dolphins, for example, should be defined as parameters when optimizing shipping routes.

Finally, we have included information on use cases of how digital technologies can contribute to the decarbonization of the sector in the short and medium term, as well as identifying several challenges, such as the fact that some companies lack comprehensive data collection, while others are at an early stage of analysis and decision-making. Digital technologies can be a trigger for comprehensive and accurate data collection, modelling and harmonization in a transparent way for greater collaboration between maritime supply chain stakeholders.

The real potential of digital technologies to reduce GHG emissions must consider the risks associated with the deployment of digital solutions, such as:

- Rebound effects: what increase in transport and energy demand - and therefore emissions- can be expected because of the use of these technologies?
- Other environmental impacts: do these reductions in GHG emissions lead to an increase in the impact of other parameters (resource depletion, impact on biodiversity, etc.)?

This study therefore encourages initiatives to identify use cases and pilot projects whilst systematically applying life-cycle analysis to decarbonization-related technology solutions and digitalization services, to limit the risks listed above.

Annexes

5.1. ANNEX 1: Some examples of organizations and frameworks for shipping

Some international non-profit organizations have created frameworks to help calculating these emissions and created organizations on this subject:

- The Smart Freight Center has created the program Global Logistics Emissions Council (GLEC) as a framework for multinationals and their suppliers to help them with a harmonized, efficient, and transparent way to calculate and report logistics emissions [75].
- The Aspen Institute with Amazon, Patagonia and Tchibo formed the Zero Emission Maritime Buyers Alliance (ZEMBA) as a non-profit organization and initiative of Cargo Owners for Zero Emissions Vessels (coZEV) in order to enable companies to access zero-emission shipping solutions.[14]
- The Maersk Mc-Kinney Moller Center for Zero Carbon Shipping is an independent, non-profit research and development center working in the energy and shipping sectors with industry, universities and authorities. Founded in 2020 by the American Bureau of Shipping, A.P. Møller - Mærsk, Cargill, MAN Energy Solutions, Mitsubishi Heavy Industries, NYK Line and Siemens Energy, the center aims at accelerating the transition of these industries. It proposes decarbonization pathway and investment/regulatory advisory and helps the development and implementation of new energy technologies, providing overviews of systemic changes. [15]
- The University Maritime Advisory Services (UMAS) is maritime advisory service working with UCL Shipping Team for public and private clients. It uses big data to understand drivers of shipping emissions, using models to explore shipping's transition to a zero emissions future and providing interpretation to key decision makers. [9]
- The Global Maritime Forum (GMF) is an international not-for-profit organization "committed to shaping the future of global seaborne trade to increase sustainable long-term economic development and human wellbeing". To do so the forum develops and shares insights and participates to working groups on these issues.

5.2. ANNEX 2: Different scenarios in IMO, IEA and SBTi

To assess the impact of different technology choices and policy targets on global emissions, the International Energy Agency, the Science-Based Target Initiative (SBTi) and the International Maritime Organization have formulated the aforementioned decarbonization scenarios, with a focus on the maritime shipping sector. The corresponding reports encompass assessments of emissions both in absolute value and carbon intensity of the shipping activity, as well as major levers to meet climate objectives and sector-specific goals.

These different scenarios and their connections are represented in Figure 30. A description of each scenario is given below.

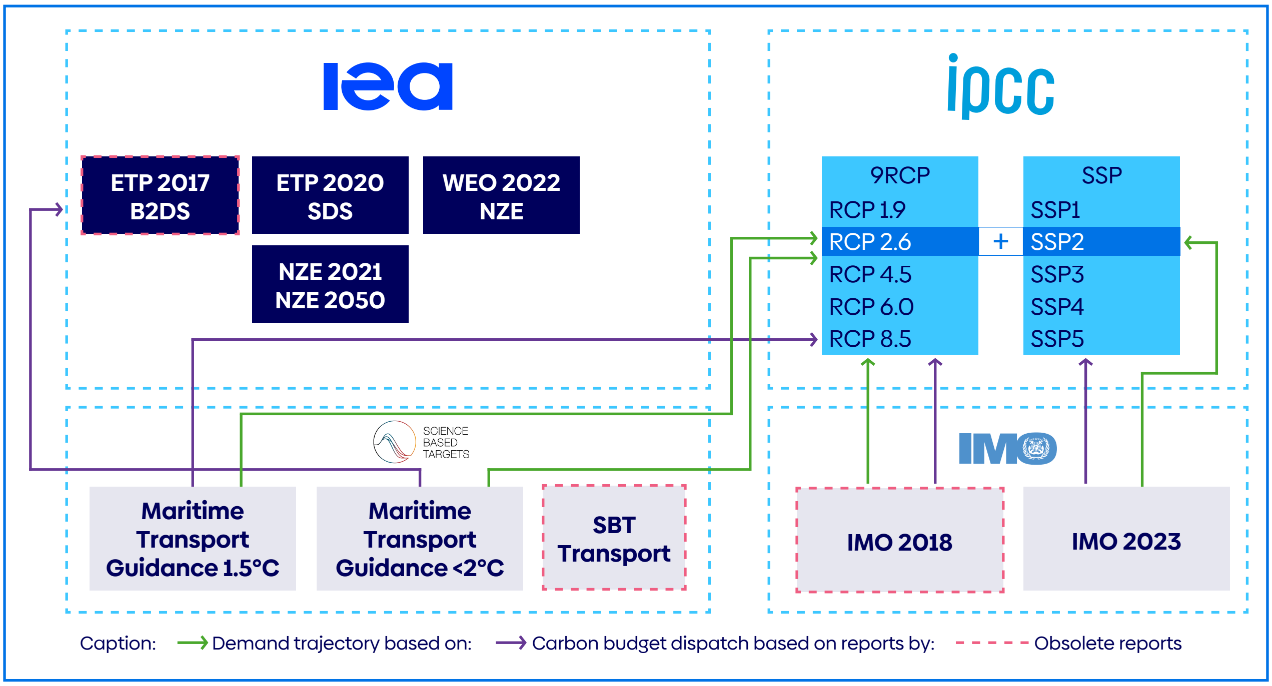


Figure 30: : Interconnections between decarbonization scenarios tackling the maritime shipping sector, predominantly grounded in IPCC reports for sectoral pathways.
Source: I Care from the IEA [36]–[39], IPCC , SBTi [9] and IMO reports [20], [23], [40]

IEA but mostly IPCC reports are taken as references to build the demand trajectories and carbon budget dispatch of the maritime shipping sector in IMO and SBTi scenarios. IPCC, the intergovernmental panel on climate change, is an intergovernmental organization which goal is to evaluate the causes and consequences of climate change. To do this, they produce socio- economic pathways (SSP) which then define the possible global emission trajectory. The scenario SSP2 allows to limit global warming under 1.5°C compared to preindustrial levels. For example, the Science Based Target Initiative has developed its demand trajectory in the Maritime Transport Guidance [9] based on the Shared Socio-economic Pathway SSP2 and the Representative Concentration Pathway RCP 2.6, as designed by the IPCC. In addition, the carbon budget was derived from the Beyond 2 Degrees Scenario by the IEA [36].

More detailed description of the studied scenarios: IEA, IMO and SBTi

IEA: Four scenarios including shipping with differing ambitions depending on the models used

The Figure 31 and Figure 32 illustrate the evolution of the decarbonization of shipping in the four IEA scenarios respectively in absolute and intensity emissions.

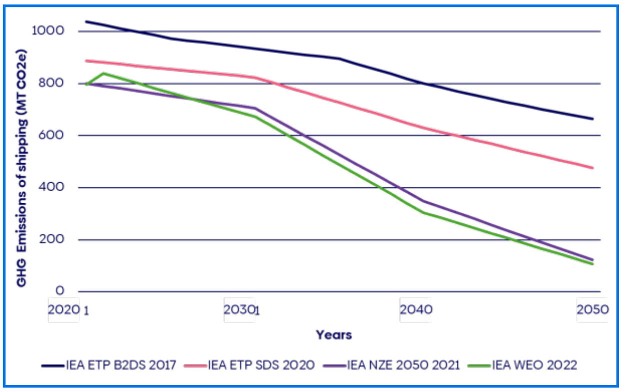


Figure 31: Absolute emissions of shipping in the different IEA scenarios.
Source: I Care

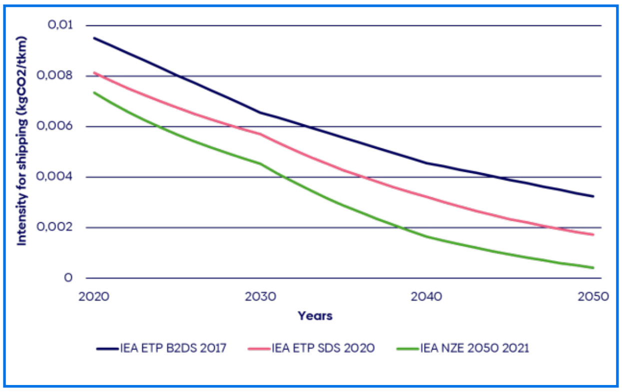


Figure 32: Emissions in intensity of shipping in the different IEA scenarios
Source: I Care

Among the various decarbonization scenarios developed by the International Energy Agency, four are of interest in the bibliography and were published in four distinct reports. Firstly, **the Energy Technology Perspective (ETP) reports** primarily emphasize energy innovation, focusing on technologies that are either available or in development.

- The **Beyond 2 Degrees Scenario** (B2DS) was outlined in the ETP 2017 report. In this scenario, all available policy levers are actively employed across all sectors, including global shipping, throughout the forecast period. In response to the outcomes of the Reference Technology Scenario (RTS), the objective is to push clean energy technologies to their maximum potential in an aggressive and accelerated manner, aligning with the more ambitious goals of the Paris Agreement. The overarching aim is to achieve carbon neutrality by 2060 in order to limit the future temperature increase to 1.75°C. One of the key inputs for this scenario is the demand trajectory, which expects annual maritime freight activity to grow from 99 trillion ton-kilometers in 2015 to 349 trillion ton-kilometers in 2060 [36].
- In the updated 2020 version, this scenario was replaced by the **Sustainable Development Scenario** (SDS). Compared to the Stated Policies Scenario (SPS), the SDS outlines the significant changes required to achieve key energy-related goals of the United Nations Sustainable Development Agenda, including those set forth in the Paris Agreement. Similar to the B2DS, it models a 'well below 2°C' pathway, with a specific target of limiting future temperature increase to 1.65°C by 2070 while achieving net-zero emissions in the same year. Meanwhile, the shipping sector is projected to experience an annual average increase of 2.4%, amounting to a 230% increase over the period leading up to 2070 [37].

Following the context of COP21, the **Net-Zero Emissions by 2050 (NZE) scenario** sets more ambitious objectives. It aims to achieve net-zero CO2 emissions by 2050, emphasizing technical feasibility, cost-effectiveness, social acceptance, and the continued growth of the economy and secure energy supplies. In this scenario, the marine shipping sector is projected to experience a 171% increase in activity by 2050 [38].

Finally, the World Energy Outlook (WEO) 2022 retained the same scenario storylines as NZE but adapted the inputs to incorporate the latest information on energy markets and technologies, considering the context of the energy crisis and COVID-19 recovery. However, the report does not provide projections for shipping activity growth [39].

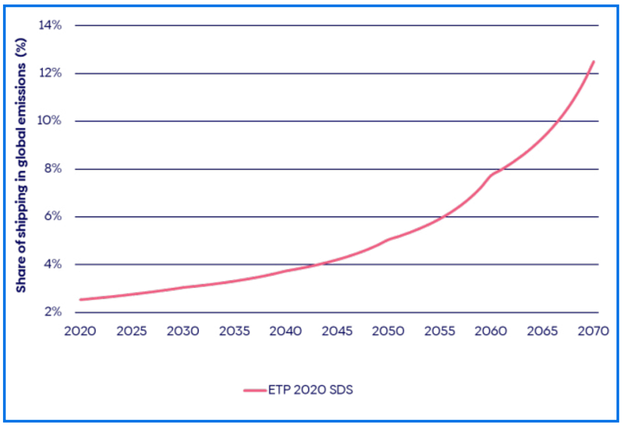


Figure 33: Share of the shipping sector in global emissions in the Sustainable Development Scenario presented in ETP

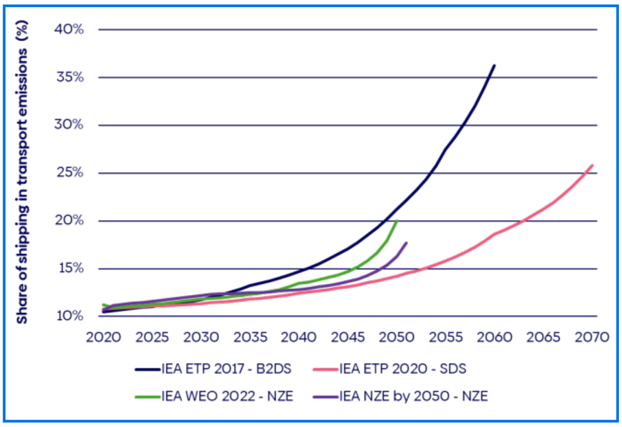


Figure 34: Share of the shipping sector in transport sector emissions in the different IEA scenarios.
Source: I Care

In all these IEA scenarios, the share of emissions allocated to shipping increases in the upcoming years, as depicted in Figure 33 for the SDS scenario in ETP 2020 [37]. Additionally, Figure 34 demonstrates that the proportion of shipping emissions within the transport sector also increases across all IEA scenarios. Moreover, these scenarios do not aim to define a specific emission reduction target for shipping. Instead, they map out a path to achieve global climate targets through various levers that aim to offset emissions resulting from the growth of the shipping sector. All four scenarios rely on the same primary levers of action. In the short term, the sector can curb fuel consumption through strong efficiency improvements for new vessel designs and retrofits for existing ships (hybridization with electricity, wind assistance, slow steaming, improved hull coating, more efficient operational practices, etc.) and fuel switching to biofuel. In the long term, the primary levers involve switching to emissions-free hydrogen-based fuels (hydrogen and ammonia) and adopting new marine propulsion technologies. The contribution of the various measures in ETP 2017 and the updated version in 2020 are given in Figure 35 and Figure 36.

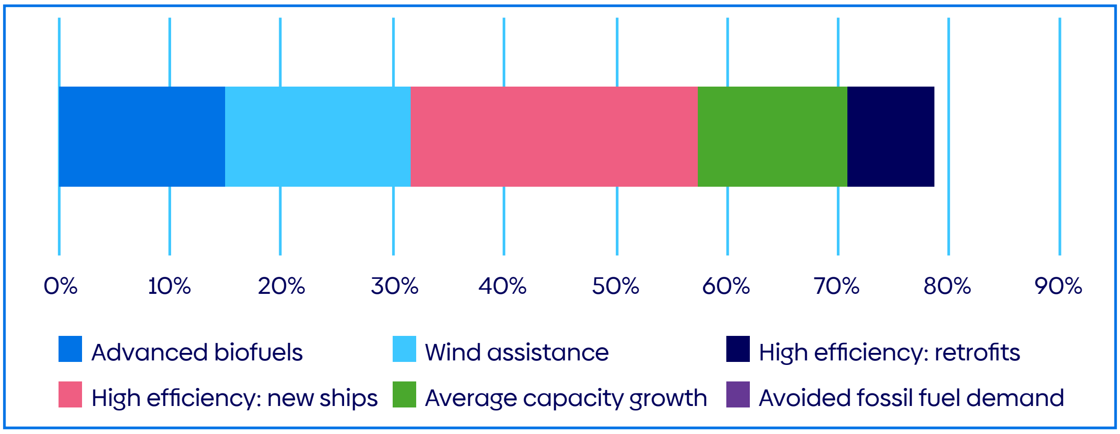


Figure 35: Global CO2 emissions reductions in international shipping by mitigation category in the Beyond 2 Degrees scenario relative to the Reference Scenario, 2060.
Source: [36]

According to Figure 35, the most significant measures in ETP 2017 are strong efficiency improvements, primarily focused on improving fuel efficiency for new vessel designs and incorporating wind assistance. Additionally, half of the marine fuel mix is transitioned to advanced biofuels, with a smaller portion allocated to other low-carbon energy carriers.

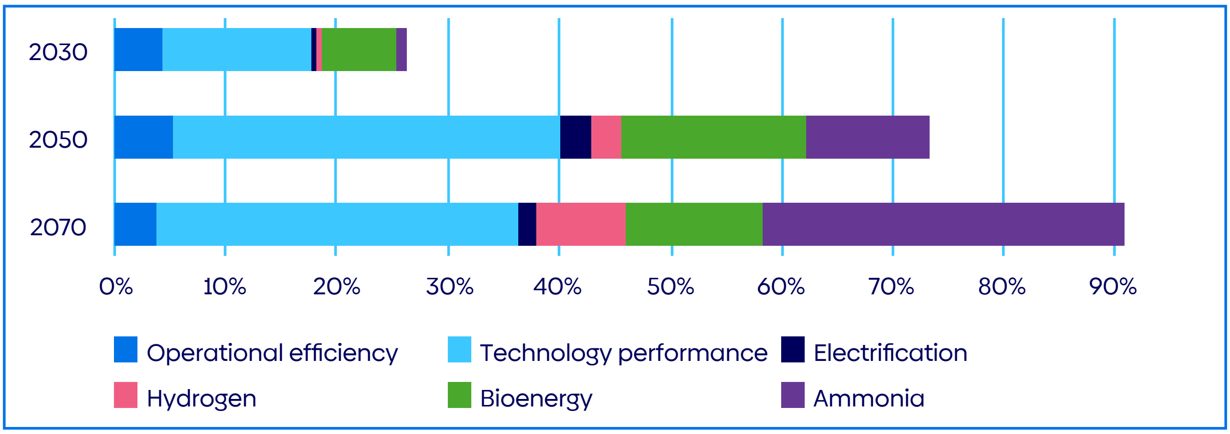


Figure 36: : Global CO2 emissions reductions in shipping by mitigation category in the Sustainable Development Scenario relative to the Stated Policies Scenario.
Source: [37]

In the updated version ETP 2020, long-term measures primarily focus on fuel switching to low- carbon fuels like biofuels and emissions-free hydrogen-based fuels such as hydrogen and ammonia, as well as the adoption of new marine propulsion technologies. Conversely, in the short term, the priority lies with biofuels and energy efficiency measures like hybridization with electricity, the use of kites, implementing slow steaming, adopting contra-rotating propellers, enhancing hull coatings, and implementing waste heat recovery. These differing contributions are represented in Figure 37.

IMO : the initial strategy to reduce GHG emissions and its updated version.

The Figure 37 and 38 illustrate the evolution of the decarbonization of shipping in the two IMO scenarios respectively in absolute and intensity emissions, including the reconstitution of IMO 2018 scenario based on SBTi documentation.

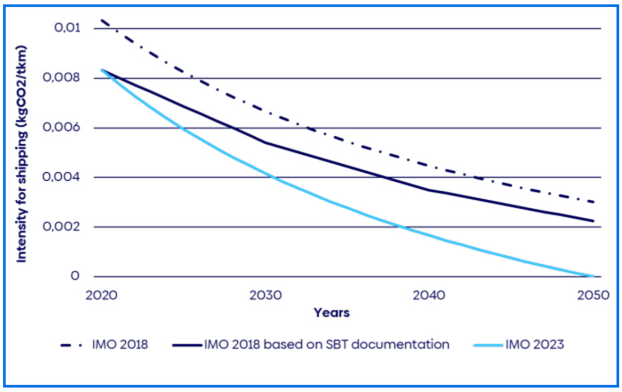


Figure 37: Absolute emissions for shipping for the different IMO scenarios.
Source: I Care

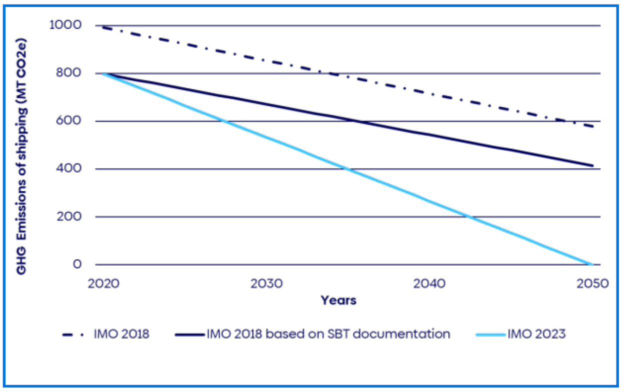


Figure 38: Emissions in intensity for shipping for the different IMO scenarios
Source: I Care

Two scenarios published are from the International Maritime Organization. Those two scenarios are not independent as the one published in 2023 is the revised version from the one published in 2018.

In 2018 an initial strategy was adopted to reduce GHG emissions from international shipping. At this time, it was already announced that this strategy was to be revised every 5 years. This publication was preceded by the publication of the Third IMO GHG Study in 2014 which estimated that the emission form international shipping in 2012 represented 2.8% of the Global emissions. The first announced goal was to reduce the total GHG emissions by at least 50% by 2050 compared to 2050. The final objective was to develop a pathway consistent with the goals set by the Paris Agreement. In this publication 3 main levers of action were identified: energy efficiency of the ships, carbon intensity of international shipping and greenhouse gas emissions from international shipping [40].

In 2023 the published revised strategy was more ambitious as the main goal announced was to reach net zero emissions close to 2050 and the emissions were no longer concerning the Tank to Wake perimeter, but they were extended to the Well to Wake perimeter. The pathways developed in this publication were mainly Two scenarios published are from the International Maritime Organization. Those two scenarios are not independent as the one published in 2023 is the revised version from the one published in 2018.

According to the saying of an expert, this revision is a good advance since it implies that 100% of the fleet will need to be compatible with green fuel in 2050 (compared to 50% of the fleet in the last version which let the opportunity to vessel owners to build new vessel not compatible with green fuel – 90% of owners considered this option). As the vessels have a lifetime of 25 years this has an immediate consequence for the construction of vessels.

SBTi: The guidance for the maritime sector

The Figure 39 represents the evolution of the SBTi shipping scenario in intensity.

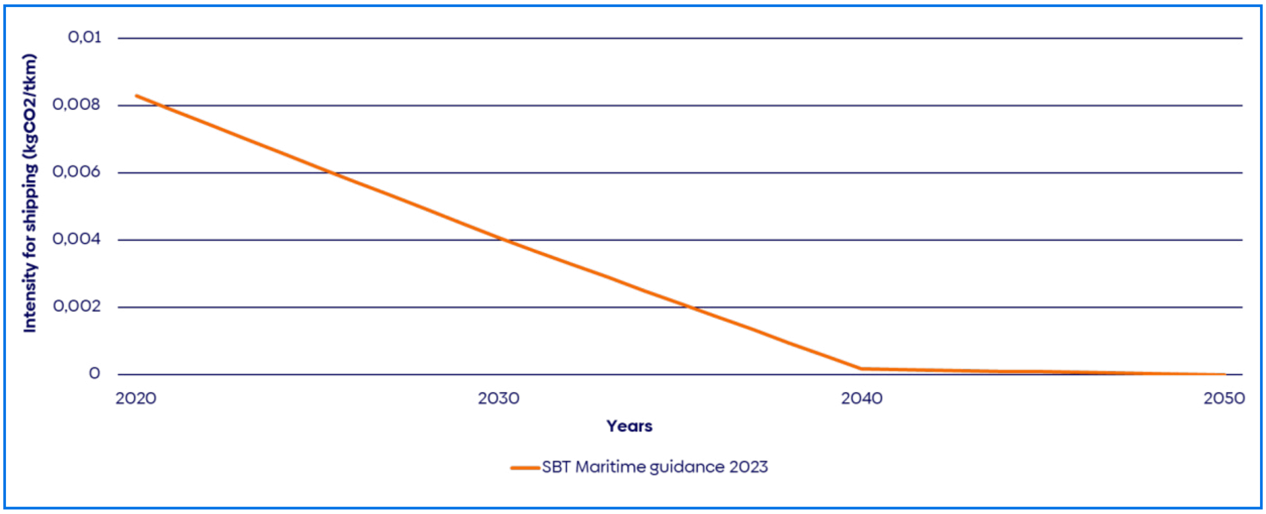


Figure 39: Emissions intensity pathways of SBTi scenario.
Source: [9]

Finally, the last scenario that was studied is the one extracted from the SBTi Guidance for the Maritime sector published in May 2023. This "1.5°C aligned carbon budget scenario" bases its sectoral carbon budget allocation on the one which was developed in the 2018 IPCC Special Report. One of the main messages of this report is the urgency to set near term ambitious targets for the emissions reduction. One of the main assumptions of this scenario is the equal probability to the uptake biogenic fuels, fuels based on renewable electricity and fossil fuels with carbon capture and storage [9].

In the SBTi Maritime Guidance a second scenario "Well below 2°C aligned carbon budget" is developed. It is based on the B2DS scenario from ETP 2017. However, according to SBTi, this scenario will only be accepted for the scope 3 of the companies that want to set a target [9] so this scenario is not studied in detail.

5.3. ANNEX 3: Bibliographical review

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