ECONOMIST IMPACT

Global Maritime Trends 2050

Commissioned by

Contents

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About the research

Global Maritime Trends 2050 is a report by Economist Impact, commissioned by Lloyd's Register Foundation and Lloyd's Register. Economist Impact's research is based on a pragmatic literature review (see Appendix for a detailed methodology) and 16 in-depth, qualitative interviews with maritime policy and industry professionals.

Findings from the literature review were used to inform the global trends overview and formed the basis of our four futures. We then conducted 16 interviews with experts to better understand the implications of these futures, and what these mean for our four "what if" scenarios (more details on these are available in the introduction). The full list of interviewees, in alphabetical order, are:

- **Andrew Stephens**, executive director, Sustainable Shipping Initiative
- **Basil Germond**, chair in international security, Lancaster University
- **Ben Abraham**, CEO, Global Marine, Willis Tower Watson
- **Domenic Di Francesco**, Turing research fellow, Alan Turing Institute and data-centric engineer, AQ
- **Elizabeth Petit González**, head of communications and partnerships, Sustainable Shipping Initiative
- **Hing Chao**, executive chairman, Wah Kwong Maritime Transport Holdings
- **Hyun-ho Lee**, executive vice president, HD Hyundai Heavy Industries; managing director, Maritime Research Institute
- **JB-Rae Smith**, vice president, UK Chamber of Shipping; director, Private Group Companies, John Swire & Sons
- **Jesper Kristensen**, group chief operating officer, marine services, DP World
- **Johannah Christensen**, managing director, Global Maritime Forum
- **Katie Higginbottom**, head, ITF Seafarers' Trust
- **Kevin Forshaw**, director of industrial and strategic partnerships, University of Plymouth
- **Mark Bryan**, senior foresight manager, Future Today Institute
- **Nick Bartlett**, director and lead for financial services, insurance, transportation and manufacturing, Future Today Institute
- **Peter Thomson**, UN secretary-general's special envoy for the ocean, UN
- **Stavros Karamperides**, head, Maritime Transport Research Group, University of Plymouth
- **Stephen Cotton**, general secretary, International Transport Workers' Federation

Our thanks and gratitude go to these individuals for their time and insights.[1]

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The report was produced by a team of Economist Impact researchers, writers, editors and graphic designers, including:

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Foreword by Lloyd's Register

Over the past decade, the maritime industry has made significant strides in its decarbonisation journey. The introduction of EEDI in 2013 and subsequently EEXI and CII in 2022 have significantly increased the efficiency of both newly delivered and existing ships since 2013. The recently revised IMO greenhouse gas strategy has now set revised targets to further increase efficiency and move the industry to net zero emissions, by or close to 2050.

However, more can still be achieved through market-based measures, continued government support and international alignment to ensure a commercially viable and global level playing field for the industry and future fuel producers, enabling them to make immediate and medium-term investment plans.

Let's also not forget that over the past few years we have had a global pandemic and seen war break out in Europe. These have led to spikes in transport needs, periods of high inflation and an uncertain geopolitical landscape.

So, as we continue the journey towards a more sustainable future, it is not a question of when, but rather how we will achieve the required transition. That is why the future landscapes and thought-provoking 'What If' scenarios created and explored in this *Global Maritime Trends 2050* report are so vital.

They help lay the foundation to measure the success and speed of the transition, as well as its impact on the entire maritime ecosystem, including, most importantly, the skills and education of its people.

Plenty of research has been carried out into what an energy system could look like in the years to come, but this work purposely looks at the wider implications on trade, vessels, energy, ports and people, providing maritime stakeholders with the insights to enable decision-making.

In envisioning this path ahead and the rapid changes we have experienced over the past few years, digitalisation is also inseparable from decarbonisation in the maritime industry.

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By leveraging digital technologies and transformation, we can optimise vessel speeds, reduce fuel consumption, and enhance connectivity between land-based and maritime logistics. This integration holds the potential to not only make our global supply chains more efficient, but also significantly reduce emissions.

By delving into the potential future landscapes in this report, we can see the advantages of a collaborative, tech-driven, leaner and more visible industry. However, it also worryingly highlights the dangers of a lack of global co-operation and a slow and fragmented technology uptake.

Shipping, often invisible to the public, needs greater recognition for its vital role in delivering 90% of our goods to eight billion people.

However, the wellbeing of the two million seafarers who labour diligently to maintain our global supply chains cannot be overstated. They are the lifeline of our industry, and their efforts are indispensable. We must prioritise their needs in the march to 2050, offering fair wages, appropriate work and rest hours, and ensuring their health and safety. Moreover, we must attract, educate and nurture new and diverse talent, empowering them with the knowledge and skills required to navigate the challenges and opportunities of the future.

As we stand at the precipice of transformation, this report and the framework of the four maritime future landscapes serve as a compass—guiding us through these uncharted waters. It offers insights into the complexities of our changing world, from geopolitical shifts to emerging economies, and highlights the challenges and solutions that will shape the maritime industry.

We hope this report proves to be a valuable resource, enlightening and inspiring readers as they grapple with the realities and possibilities of the future.

Nick Brown
Chief Executive Officer, Lloyd's Register

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Foreword by Lloyd's Register Foundation

The future is full of uncertainty. The world faces some incredibly tough challenges both now and in the decades to come, which are putting human lives and the health of the planet at risk. These same challenges come with opportunities for change. As a starting point, this report explores what the future may look like, allowing us collectively to prepare for what lies ahead.

Global Maritime Trends 2050 shines a light on many of these challenges, including anticipated global population growth from seven to nine billion people, with the biggest increases expected in Africa and Asia. While many countries will have an ageing demographic with potential labour shortages in the future, others will have much younger populations who need safe jobs and the chance to earn a decent living. Providing opportunities for these young people to gain education and skills should be a priority for all industries in the coming years.

As well as labour challenges, these shifts in our global society will put increasing demand on urban development. We need reliable and resilient infrastructure in the right places that is fit for purpose now and in an ever-changing climate, both on land and at sea. People need water, food, accommodation, communication and transport networks in order to stay safe—and these are often the very things at risk in a disruptive event. The pandemic showed us that supply chains can easily be interrupted if resilience is not built in at the outset, putting human lives in danger. Large-scale infrastructure must be resilient, future-proof and based on safe engineering practices.

The future maritime system must keep goods moving in a safe and more sustainable way to meet society's needs while reducing the impact on the planet. This means an energy transition to alternative fuels, changes to port infrastructure around the world to accommodate vessels of different sizes and fuel types, and new shipping routes.

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Rising sea levels and urban development, both on land and as countries build out into the ocean, affect coastal communities. With 40% of the population living near the coast, how do we ensure that people are kept safe and have access to new employment opportunities while these changes occur? This report gives a picture of what this transition could look like and highlights what is needed right now for the transition to be effective, reliable and safe.

New technologies can help reduce the fragility of our existing maritime ecosystem, which is not just about shipping but includes industries that operate at sea or rely on the ocean, such as offshore energy, underwater cabling, aquaculture and blue food. These industries all rely on vessels that need operating, fuelling and maintenance. However, these technologies, which may develop quickly, must be safe and based on standards that protect workers and communities, and be accessible to all to avoid driving further inequalities.

The overarching message in the report is that shipping, as the heartbeat of global trade, has an incredible opportunity to be at the forefront of change. As we move towards a decarbonised world, shipping could be a shining example to other industries, with a genuine commitment to a fair and equitable transition for the benefit of all.

Ruth Boumphrey
Chief Executive, Lloyd's Register Foundation

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Executive summary

The global maritime industry is responsible for facilitating over 80% of the world's trade, but it also generates 3% of greenhouse gas emissions. The future of this industry will be shaped by critical forces, including the extent of global co-operation on climate change and the pace of technological uptake, against a backdrop of intensifying geopolitical and macroeconomic shifts.

In this programme, Economist Impact imagines four possible futures and scenarios for the maritime sector in 2050, exploring the impact on key components of the maritime economy including trade, vessels, energy, ports and people. This will enable industry players and policymakers to make vital decisions today to ensure that the desired outcomes can be achieved and the worst scenarios avoided.

The research led us to four insightful futures that depict what the maritime industry could look like in 2050:

- **Just, gradual transition**: characterised by high global co-operation on climate change combined with a gradual uptake of novel and/or advanced technology. This slower shift reflects some of the difficulties associated with reaching consensus and distributing the costs and benefits equitably. This future is only possible if countries take action to reduce emissions in the early to mid-2020s, which enables them to integrate technology early and scale gradually.
- **Rapid tech-driven transition**: characterised by high global co-operation on climate change combined with a rapid uptake of novel and/or advanced technology. In this future, global co-operation on decarbonisation will mandate a rapid roll-out of novel technologies through high investments, economic incentives and favourable policies. This future would see automated solutions, smart technologies, fuel and system efficiencies, and higher levels of data sharing adopted at scale.
- **Regionalised and fragmented transition**: characterised by high global fragmentation on climate change combined with a rapid uptake of novel and/or advanced technology. In this future, countries are unable to co-operate on decarbonisation—due to geopolitical or economic priority differences. In parallel, countries are experiencing rapid but unco-ordinated integration of technology to unilaterally meet national climate objectives and adapt quickly to growing climate challenges.
- **Delayed transition**: characterised by high global fragmentation on climate change combined with a slow uptake of novel and/or advanced technology. This combination results in the world reaching irreversible climate tipping points and what the IPCC projections deem as a worst-case scenario. This future is an unequal one—although the impacts of these tipping points are felt ubiquitously, the poorest economies and communities will do so most acutely. The implications of these extend across the maritime sector, forcing adaptation-led efforts across national jurisdictions.

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Economist Impact formulated a specific "what if" scenario to bring each future to life through **qualitative, fictional storytelling**. Though fictional, the insights from these scenarios are grounded in extensive desk research and insights from the expert interviews. These offer a window into a future that may manifest for the sector and the efforts needed today by industry stakeholders to prepare.

Scenario 1: What if nations embrace widespread adoption of green hydrogen?

This describes a brighter future. In this scenario, the maritime industry could become a decarbonisation enabler, linking key future producers of green energy such as China, Saudi Arabia, South Africa and the US. With further development, ammonia is likely to become the safest and most efficient way to transport hydrogen, creating many new jobs and upskilling opportunities.

Wider uptake of technologies in this scenario will reduce the number of physical tasks required on board, creating more opportunities for women in what is a male-dominated industry. The need for more tech-savvy ship managers would enable more women to take on management positions on land and at sea. In 2021, just 1.2% of the global seafarer workforce were women.

How we get here: to realise this scenario, there will be a need for global co-operation on climate change with clear targets and political support through investments and incentives. Ports will need to be redesigned for supply and storage of new fuels, and ships will need to experience a rapid uptake of new fuel technologies. In this context, training will be key to ensure a just and safe transition for workers.

Scenario 2: What if automated technology solutions became widely adopted?

This scenario explores the rapid rollout of novel technologies, driven by global co-operation on decarbonisation. This includes globally aligned protocols for managing cybersecurity and undersea infrastructure. More broadly, remote control, automation and Internet of Things (IoT) technologies could greatly enhance the efficiency of ships and ports, creating opportunities to increase maritime trade. An estimated 30.6 billion IoT units are expected to be in operation by 2025.

Human supervision by skilled employees will be critical, with assistants powered by artificial intelligence and immersive technologies such as the metaverse helping to simplify and enhance tasks.

How we get here: achieving this scenario requires strong industry-wide technology investment and a co-ordinated approach to decarbonisation. Global harmonisation of technology protocols and the rollout of industry training to match emerging innovation could help deliver the outcomes described in this scenario.

Scenario 3: What if regionalisation and population expansion lead to fragmented maritime trade?

The future in which countries are unable to co-operate on decarbonisation and trade is fragmented and regionalised—whether due to geopolitical differences or varying economic priorities. Localised systems of trade lead to smaller ships making shorter journeys, with escalating costs due to varied technology adoption across different regions. A lack of global co-operation on governance and trade increases the risk of 'dark fleets' operating under the radar.

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Countries pursue rapid but unco-ordinated integration of technology in order to unilaterally meet national climate objectives and adapt quickly to growing climate challenges. Limited co-operation, opaque data sharing and high intergovernmental tensions may leave room for more bad actors to operate with limited oversight.

How we get here: shifting population dynamics create new centres of demand in Asian and African economies, transforming maritime routes. Geopolitical and supply chain challenges lead to regionalisation. Low co-operation on innovation, data sharing and decarbonisation as well as disparate technology uptake causes port incompatibility. Combined, these lead to an undesirable outcome for the maritime industry.

Scenario 4: What if average global sea levels rise by at least 40 cm?

In this scenario, unpredictable storms and natural disasters make being at sea riskier than ever. This will be driven by fragmented global co-operation and slow technology uptake, resulting in irreversible climate tipping points. Unchecked, climate change destabilises many traditional shipping routes, prompting increased traffic in the unpredictable Arctic Ocean as ice retreats. Here, ice-free Septembers are predicted from 2030.

Extreme weather and natural disasters will increase the costs and requirements for shipping insurance, while rising sea levels could submerge many vital economic ports. Coastal communities are displaced, either gradually through government relocation programmes, or immediately in response to extreme events. According to current projections, 800 million people are already vulnerable to a 50 cm sea-level rise.

How we get here: this scenario may materialise as a result of low co-operation and action on climate change and slow and fragmented technology uptake. Rising water levels and soil salinity also disrupt food supply chains. Rising sea levels increase coastal inundation, forcing ports to close in low-lying areas in Shanghai and Houston.

As the maritime sector prepares to **decarbonise its activities and supply chains**, while navigating an increasingly **uncertain geopolitical, economic and social landscape**, it is important for industry and policymakers to start envisaging what possible futures could look like. We need **creativity and courage to imagine what futures** are available to us and how we need to act to address these. Global co-operation and the integration of technology, be it rapid or gradual, will be **crucial preconditions** to secure futures that are conducive to a thriving maritime economy, and life on this planet more broadly. Our hope is that t**his exercise allows industry leaders and local and national policymakers** to start planning for these plausible—albeit currently fictional—scenarios.

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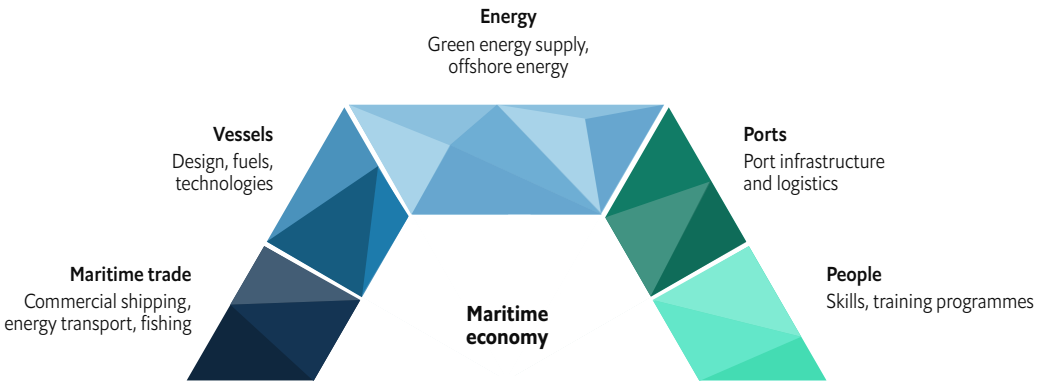
Introduction

For the maritime sector, as with every other sector globally, the triple planetary crisis—characterised by climate change, nature and biodiversity loss, and pollution[2]—will be the defining challenge that shapes the decades ahead. Global shipping accounts for 3% of global greenhouse gas (GHG) emissions, and the sector is far from achieving the necessary emission cuts needed to hit the Paris Agreement by 2050.[3] Yet this sector, more so than others, is deeply intertwined with the nature of global geopolitical and macroeconomic challenges. Ships deliver 80% of the world's trade,[4] so any disruptions, as demonstrated by the blockage of the Suez Canal in 2021,[5] are felt acutely across the globe. Amid global supply chain uncertainties, the urgent need to decarbonise, the integration of new technologies, concerns about human rights and safety at sea, and the future of labour supplies, what does the future of the maritime sector look like?

The aim of this study was to explore potential futures for the maritime sector in 2050, understand how these would manifest in hypothetical and specific scenarios, and how this would impact key components of the maritime sector (see Figure 1).

In order to do this, Economist Impact conducted an extensive literature review based on grey literature—for example from the International Energy Agency (IEA), the UN Conference on Trade and Development (UNCTAD) and

Figure 1: Key components of the maritime economy



Source: Economist Impact

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the International Monetary Fund (IMF)—as well as academic journals. The literature review identified a long list of trends that are expected to characterise the world through to 2050 across five key areas: geopolitics and macroeconomics; the environment; natural resources; technology; and social.

In assessing these global trends for 2050, the literature review also aimed to explore how these might manifest in the near term (2030) and medium term (2040). The findings of the literature review were then discussed, scrutinised and validated by a team of internal sectoral and methodological experts at Economist Impact and The Economist Intelligence Unit. The first section of this report outlines these trends in more detail.

The trends identified by the literature review formed the basis of the four maritime futures, discussed in the second section of this report. These are as follows:

1. **Just, gradual transition**: high global co-operation combined with a gradual uptake of novel and/or advanced technology.
2. **Rapid, tech-driven transition**: high global co-operation combined with a rapid uptake of novel and/or advanced technology.
3. **Regionalised and fragmented transition**: high global fragmentation combined with a rapid uptake of novel and/or advanced technology.
4. **Delayed transition**: high global fragmentation combined with a slow uptake of novel and/or advanced technology.

Finally, Economist Impact identified four specific "what if" scenarios to bring each of these futures to life through qualitative, fictional storytelling, which are discussed in the report's penultimate section. As such, the four scenarios are not predictions for 2050 based on quantitative modelling or forecasting. Though fictional, the insights from these scenarios are grounded in the findings of our literature review, extensive desk research and the 16 expert interviews (see About the research for more detail on these). The aim of these scenarios was to understand the trends that would affect the maritime sector more broadly, as well as the specific implications for people, ports, trade, vessels and fuels. These offer a window into a future that may manifest for the sector and the efforts needed today by industry stakeholders to prepare. The four scenarios we explore are as follows:

1. What if nations embrace widespread adoption of green hydrogen by 2050?
2. What if automated technology solutions became widely adopted in the maritime industry by 2050?
3. What if regionalisation and population expansion lead to deglobalisation and fragmented global maritime trade by 2050?
4. What if average global sea levels rise by at least 40 cm by 2050?

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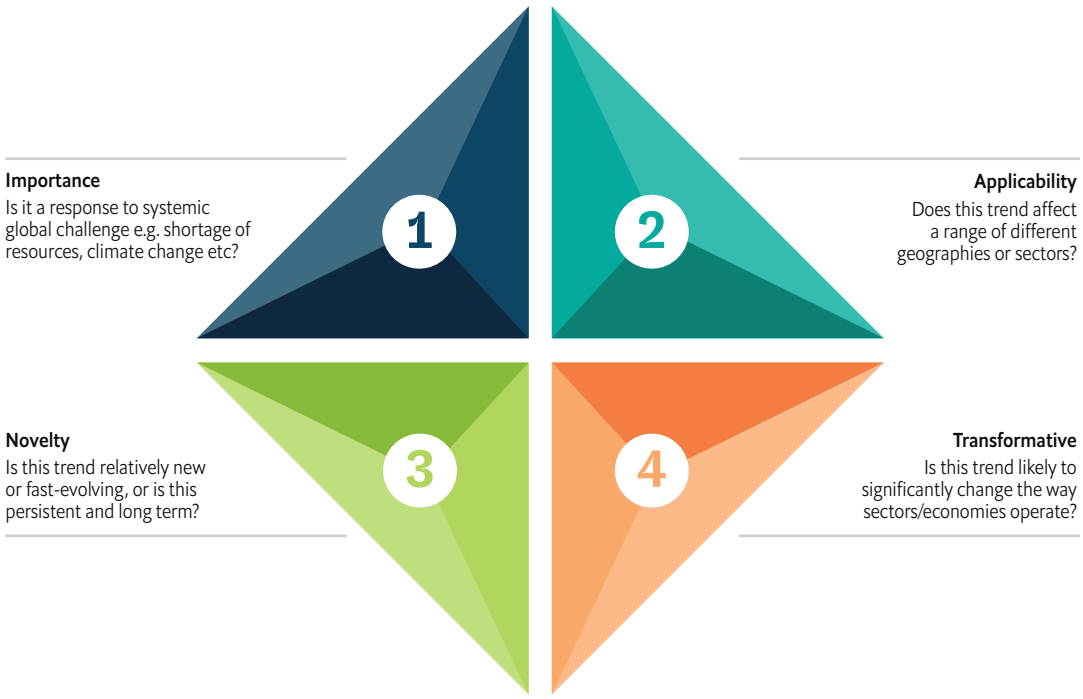
Global trends overview

Most of the trends that will shape the global economy in 2050 are extensions of the current status quo, albeit some new influences are emerging. This chapter presents a selection of the trends that are most likely to materialise and transform how sectors and economies function (see Figure 2). The trends have been categorised under five key areas—geopolitical and macroeconomic, social, environmental, natural resources, and technology. The following descriptions also focus on how some of them are expected to evolve in the near term (2030) and medium term (2040).

Figure 2: Guiding principles for trends selection



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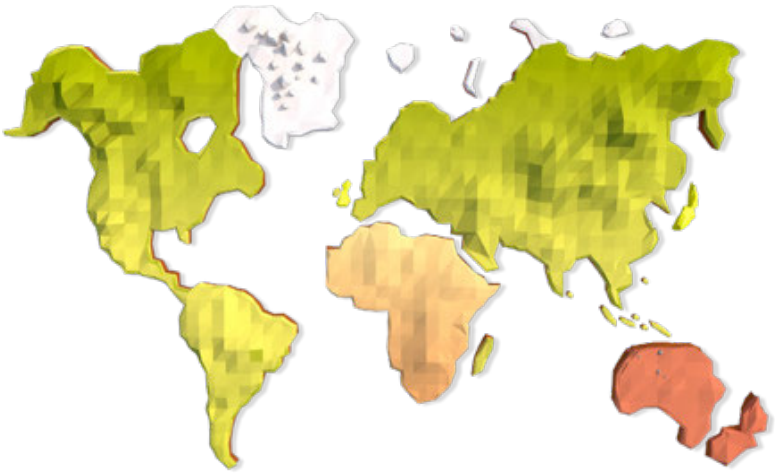
Geopolitical and macroeconomic trends

1. Growing populations across Asia and Africa

More than half of the projected increases in global population numbers up to 2050 will be concentrated in Asia and Africa across eight countries, according to the UN. These include the Democratic Republic of the Congo, Egypt, Ethiopia, India, Nigeria, Pakistan, the Philippines and Tanzania.[6] The population in Europe will continue to get older, and the region is projected to face the highest dependency ratio[7] by 2050, at 75%. By contrast, Asia and Latin America and the Caribbean are expected to have the lowest dependency ratio, at 56%, in 2050. Africa will have the youngest median age, at 25 by 2050,[8] by which time it is set to account for 25% of the world's population.[9] A number of macro- and micro-economic dynamics will be affected by population growth, including international migration, economic inequality and a country's workforce, but any resulting economic growth depends on age structure.[10]

More than half of the projected increases in global population numbers up to 2050 will be concentrated in Asia and Africa.



As such, in the context of growing populations, African and Asian economies can develop in myriad ways: larger working age populations can speed up innovation and growth, but they can also add to existing challenges relating to poverty alleviation, conflict and inequality.[11] Regardless, changing demographic trends will have an important impact on the maritime sector. According to International Transport Forum research, consumption patterns in regions with ageing populations will shift towards services and away from goods. And, in tandem, the process of globalisation based on labour-cost differentials and outsourcing production, which has driven maritime trade until now, will reach its limits, leading to a decline in cargo volumes.[12] In regions with growing populations, the consumption of manufactured goods will grow. By 2030 McKinsey estimates that the developing world (excluding China) may account for 35% of global consumption, led by countries such as India, Indonesia, Thailand, Malaysia and the Philippines.[13] Moreover, household consumption in Africa is expected to reach US$2.5trn in 2030, up from US$1.1trn in 2015. Nearly half of that will be spent in three countries: Nigeria (20%), Egypt (17%) and South Africa (11%).[14]

In this context, countries will need to invest in increasing the efficiency and resilience of their ports and logistics infrastructure to keep up with growing demand for imports and consumption. Population changes may also affect production dynamics and see the rise of domestic supply chains across industries.[15] Maritime trade routes and logistics will need to account for these changes.

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2. Deglobalisation and fragmentation become more entrenched

As trends emerging today become more entrenched, 2050 will be characterised by deglobalisation and fragmentation, which place greater emphasis on regional links, near- and friend-shoring, economic blocs for regional free trade, and protectionist policies to protect some sensitive and/or strategically important sectors.[16] Supply chains, trade and strategic alliances have also long been shaped by oil industry interests. Increasing renewable energy adoption and more decentralised energy systems (see below) will result in trade disruptions (as countries reduce their reliance on oil imports), and in the long term, more regionalised alliances.[17,18] Trade routes will shift in response to this transition, and networks will be regionalised as increasingly wealthy developing countries use their improved economic position to respond to ongoing frustrations with the World Trade Organization's dispute settlement process.[19]

Estimates suggest that, in 2050, Asian countries, namely China, India, Indonesia, South Korea and Japan, will make up half of the world's top ten economies.

3. The dominance of Asian economies

The coming decades will see the dominance of Asian economies, driven by shifting population dynamics, new resource demands and technological innovations.[20,21,22] The Economist Intelligence Unit expects China to overtake the US to become the largest global economy by 2050, with a nominal GDP of more than US$80trn, compared with around US$17trn in 2022.[23] The same estimates suggest that, in 2050, Asian countries, namely India, Indonesia, South Korea and Japan, will make up half of the world's top ten economies. In 2022 they accounted for three of the ten. This trend will be accompanied by **de-dollarisation**; while the dollar is expected to remain strong, its gap with other currencies is set to narrow.[24] A possible new BRICS[25] currency will only strengthen the dominance of these emerging economies further.[26] Currently, the dollar is used in 84.3% of cross-border trade, compared with just 4.5% for the Chinese yuan. A BRICS currency has the potential to destabilise this dollar dominant regime, meaning that these countries could fund their entire import bills by themselves. In 2022, as a whole, the BRICS countries ran a trade surplus of US$387bn, mostly thanks to China. Moreover, their economic influence is only set to rise in the coming years—and, as such, countries around the world are likely to be more willing to do business in the BRICS currency.[27] As the economic and political influence of Asian economies increases, **maritime trade** in the region will continue to expand. Already, as of 2021, Asian economies accounted for 43% of maritime exports and 64% of imports, and four of the top five countries supplying seafarers were in Asia, with the Philippines holding the top spot.[28,29]

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4. The regionalisation and/or localisation of conflicts

Remaining conflicts are likely to be concentrated within regions as global wars become more costly. According to a 2012 statistical model developed by the University of Oslo,[30] the proportion of countries facing internal armed conflicts will decline from around 15% in 2009 to an estimated 7% in 2050. The model expects that the few remaining conflicts will be concentrated in East, Central and Southern Africa and in East and South Asia.[31] As we are seeing with the war in Ukraine, regional and/or global wars will have consequences for the maritime sector, in particular trade and logistics. The need to source commodities from different parts of the world puts new pressures on marine transport infrastructure and services; fuel prices increase, thereby raising shipping costs, and in some instances regular trade routes are disrupted.[32] That said, Russia's invasion of Ukraine and enduring tensions between the US and China—to name a couple of examples—may escalate into a global war. These wars will be global, as in likely involving a number of actors (including NATO members). However, they are unlikely to be global in theatre, as global conflicts are fought through new and/or different means (see below).

5. Security-first spending, strategies and policies

Persistent geopolitical tensions and new technologies will heighten the importance of energy security, defence and maritime security, health and food security, and cybersecurity. The renewed focus on energy security, particularly in light of conflicts such as the Ukraine war, is accelerating the global energy transition (see below).[33] Energy trade will continue to be a central issue, particularly in the transition period, as countries look to decarbonise while guaranteeing more traditional energy supplies.[34,35,36] More localised or decentralised renewable energy systems could also stabilise geopolitics and security more broadly, as energy sources would be less concentrated.[37]

For the maritime industry, it could mean bringing a greater focus to securing new energy sources, such as offshore wind, tidal and wave, among others, as well as new food sources, like aquaculture (see below). Beyond this, **maritime defence spending has been increasing as maritime trade routes become more strategic and contested, and critical sea-based infrastructure expands and becomes more vulnerable** (to cyber attacks in particular).[38,39] Finally, with the rapid integration of advanced technology that is set to characterise the years ahead (see below), **cybersecurity** will become an increasingly important concern. Hackers have the potential to take control of critical infrastructure and sensitive consumer and government data.[40,41] These concerns spill into the maritime sector, jeopardising the safety of the crew, vessel, cargo and even ports, causing delays in voyage, or the loss or manipulation of external sensor data.[42]

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Environmental trends

1. Mainstream use of climate technology, including carbon removal solutions

Climate technologies, including carbon removal solutions, will become a mainstream and necessary component in net zero scenarios for 2050.[43] Even if all mitigation targets are met, the Intergovernmental Panel on Climate Change (IPCC) expects that carbon capture, utilisation and storage (CCUS) and other carbon removal technologies will still be required.[44] By 2030 the IEA's net-zero scenario will require 1,286 $MTCO_2$ to be captured yearly.[45] Current development trajectories are not set to meet these requirements, but momentum is growing.[46] By 2050, then, it is likely that CCUS technologies will become mainstream. The maritime sector will increasingly see the use of nature-based solutions including blue carbon sources such as mangroves, tidal marshes and seagrass meadows—all of which have the capacity to capture and store CO_2 from the atmosphere at a rate of two to four times faster than terrestrial ecosystems.[47]

2. A chronic shortfall in environmental financing

Debates on environmental finance (green and climate finance) will continue to take place through 2050, as it is unlikely that discussions on the volume, direction and pace of finance will be resolved in the short to medium term. Estimates suggest that developed economies must invest at least US$1trn in energy infrastructure by 2030 and US$3trn to US$6trn annually across all sectors by 2050 to reduce GHG emissions and mitigate climate change.[48] As countries deal with the effects of climate change directly (see below), adaptation finance in particular should increase in response. Negotiations between international governments and businesses around the world on how best to accelerate this are likely to persist. For the maritime sector, this will mean more attention on decarbonising shipping and possibly more taxes on industry players to fund climate adaptation and mitigation initiatives. The Poseidon Principles, launched in 2019 and developed by global banks and shipping industry players, is one example of this. The principles provide a framework to integrate climate considerations into lending decisions for the maritime industry.[49]

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3. Standardised environmental reporting and disclosure norms

Environmental reporting will become standardised. It will become a requirement for businesses and governments to monitor, collect, assess and disclose regular, comparable data on a number of environmental challenges across sectors. Over the past few years, numerous environmental standards have emerged. Efforts are ongoing to harmonise these and agree on a set of globally accepted standards that governments and businesses can adhere to. The creation of the International Sustainability Standards Board is a huge step towards this.[50] The coming years will solidify these trends towards regulation and standardisation.

4. Adapting to the impacts of climate change and biodiversity loss

Societies will ramp up efforts to adapt to and manage the real impacts of climate change and biodiversity loss through increased investments, the development of new technologies, and migration of people and economic activities. Even if the limit of 1.5 degrees of warming is adhered to and 30% of degraded ecosystems are restored by 2030, communities will face the tangible impacts of climate change through rising sea levels, more frequent natural disasters, extreme weather and biodiversity loss (which can affect human health).[51] In particular, the IPCC estimates that sea levels are expected to rise by 0.29m to 0.51m by 2100 in a business-as-usual scenario.[52] Globally, an estimated 800 million people, living in 570 coastal cities, are already vulnerable to a sea-level rise of 0.5 metres by 2050.[53] In response, governments and businesses will need to invest in a combination of physical infrastructure and nature-based solutions that enable them to adapt.[54] The risks to port infrastructure are especially high in this context, and key ports such as those in Shanghai and Rotterdam are already under pressure. The impacts of climate change and biodiversity loss will result in a new wave of climate migrants fleeing increasingly uninhabitable areas: the World Bank estimates that 216 million people across six world regions will have to move within their countries by 2050.[55] This will have implications for social and political cohesion (see below).

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Natural resource trends

1. The widespread deployment of food technology and the primacy of alternative proteins

Food technology will come in different forms, and will be deployed as more resource-efficient solutions are required to meet demand for nutritious and sustainable food.[56,57] According to the USDA, the number of food-insecure people in 2022 was estimated at 1.3 billion, an increase of 118.7 million people, or 10%, from 2021.[58] Animal proteins currently account for 40% of the world's protein intake,[59,60] and demand for aquatic foods in particular is set to rise from 20.5kg per head in 2019 to 21.4kg per head in 2030.[61] Current agricultural systems account for 30% of global emissions,[62] and take up 70% of the world's arable land.[63,64] At sea, around 85% of global fish stocks are already over-exploited, depleted, fully exploited or in recovery from exploitation.[65] Food technologies such as precision fermentation, cultured meat, lab-grown seafood and vertical farms can be deployed across regions, but particularly in land-scarce areas, to make food production more efficient and sustainable.[66,67] Aquaculture will also need to expand and increase efficiently and sustainably in order to meet demands. This will entail the use of software, artificial intelligence (AI), satellite technologies and other technologies to improve resource efficiency and protect fish health, as well as investments in innovative feeds (such as insects) to reduce reliance on soya and wild fish.[68,69]

2. Dominance of renewable energy

Renewable energy will become the dominant source of energy as pressures to decarbonise mount, investments continue to increase and technologies advance. Globally, renewable energy sources are on track to account for over 90% of global electricity capacity expansion between 2022 and 2027,[70] surpassing coal to become the largest source of electricity generation by 2025.[71] In particular, between now and 2050 the IEA expects wind and solar capacity to grow four to five times faster than any other source of energy.[72] Offshore wind is now one of the fastest growing energy technologies, and floating wind power could soon follow suit. Last year saw 50 floating offshore wind turbines commissioned, and global stock is set to exceed 5 GW by 2030 and 25 GW by 2035.[73] Beyond this, the coming decades will see the growth of other sources of ocean-based renewable energy, such as wave and tidal, both of which are in relatively mature phases of development.[74,75] Maritime trade routes in international trade will change as the practicalities of exporting energy and the more widespread availability of renewable energy may encourage more regionalised energy trade routes.[76]

Between now and 2050 the IEA expects wind and solar capacity to grow four to five times faster than any other source of energy.

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Figure 3: Renewable energy projections by country / region.
Top producers expected to be China, followed by EU, US, India, Brazil (TWh)

	Historical			Stated policies		Announced pledges	
	2010	2020	2021	2030	2050	2030	2050
World	4,234	7,539	8,060	15,073	32,452	7,575	8,873
North America	**860**	**1,334**	**1,385**	**2,668**	**5,858**	**3,361**	**7,895**
US	445	833	874	2,034	4,849	2,620	6,573
Central and South America	**743**	**888**	**910**	**1,287**	**2,287**	**1,501**	**3,365**
Brazil	437	525	509	700	1,099	761	1,329
Europe	**963**	**1,596**	**1,631**	**2,836**	**4,249**	**3,491**	**6,422**
European Union	660	1,069	1,112	1,971	2,854	2,470	4,318
Africa	**115**	**184**	**197**	**440**	**1,429**	**665**	**3,234**
Middle East	**18**	**35**	**48**	**166**	**966**	**234**	**2,227**
Eurasia	**229**	**279**	**285**	**340**	**545**	**384**	**786**
Russia	170	219	222	249	399	252	416
Asia Pacific	**1,306**	**3,223**	**3,604**	**7,334**	**17,117**	**7,938**	**4,944**
China	791	2,192	2,466	4,901	9,658	5,056	12,704
India	162	325	337	956	3,866	990	5,745
Japan	115	216	232	356	586	391	768
Southeast Asia	105	266	296	506	1,463	668	2,802

Source: IEA World Energy Outlook 2022[77]

Renewables generation in terawatt-hours. The Stated Policies Scenario shows the trajectory implied by today's policy settings. The Announced Pledges Scenario assumes that all aspirational targets announced by governments are met on time and in full, including their long-term net zero and energy access goals.

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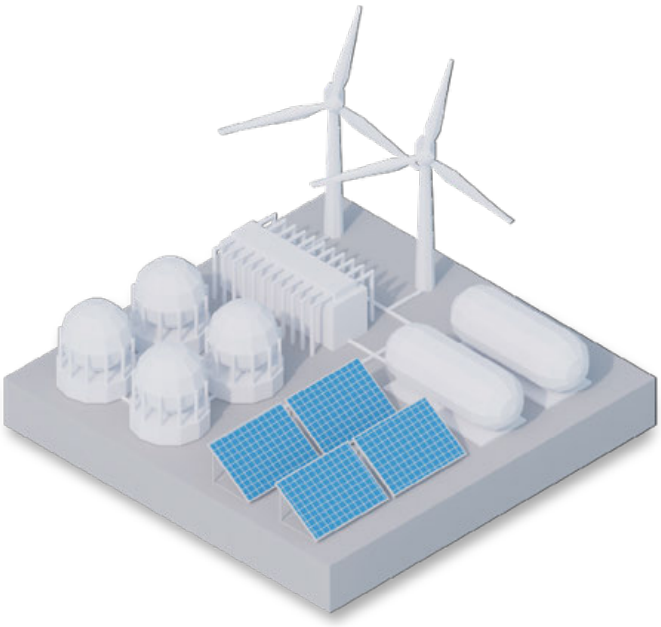
3. The use of novel and/or unconventional fuel sources gains momentum

Outside of renewables, growing demand for cleaner and more sustainable energy sources will lead to the discovery and use of novel forms of energy such as hydrogen, methanol, biomass, nuclear fusion or waste. In the coming decades, the adoption of these unconventional sources is set to increase as decarbonisation efforts become a priority.[78] International shipping enables 80-90% of global trade but also comprises about 70% of global shipping energy emissions, while national or domestic shipping accounts for the remaining 30%. Methanol- and ammonia-derived fuels are already promising in their ability to cut emissions, and, as a result, large shipping companies are investing in these resources.[79,80] The further use of alternative fuel sources could substantially reduce emissions. Green ammonia and methanol are already in the development phase, with around 80 pilot technology projects currently underway.[81] Maersk, a shipping and logistics company, has plans to develop Europe's first green ammonia facility by 2026.[82] They expect the first large methanol-powered ships to be ready by 2024, and small ammonia vessels by 2026.[83] The widespread use of hydrogen fuel and hydrogen carriers could follow on from these early contenders, although this may still be decades away. Currently, biofuels are a viable short-term option for the industry, and the direct use of green hydrogen is possible for short sailings, though not yet at scale. Although the technology is not yet ready for widespread commercialisation, some countries are already laying the foundations for hydrogen as a potential transport fuel.[84]



4. The battle for critical minerals and resources

Growing demand for renewable energy (see above) and new sensor- or chip-based technologies (see below) will increase the economic and geopolitical influence of countries that house minerals, rare earths and large sources of renewable energy.[85] The growth of renewable energy will also see critical minerals—such as lithium, nickel, cobalt, manganese and graphite—become the basis of economic growth, geopolitical competition and strategic trade alliances. For instance, to achieve its net zero targets, Europe will require up to 26 times the amount of rare earth metals in 2050 compared with today.[86] As such, by 2040 the IEA expects revenue from energy transition minerals to surpass coal by almost US$100bn.[87] The production of these minerals, however, will be geographically concentrated: in 2019 the Democratic Republic of the Congo and China alone were responsible for 70% and 60% of global cobalt and rare earth mineral production, respectively.[88] Similarly, for electric vehicles (EVs) and their supporting infrastructure (see below), exporters of batteries and critical minerals will experience growing economic activity and influence. That being said, other environmental alternatives may also provide viable and competitive solutions to clean energy requirements, for instance, silicon-based batteries for EVs.[89,90]

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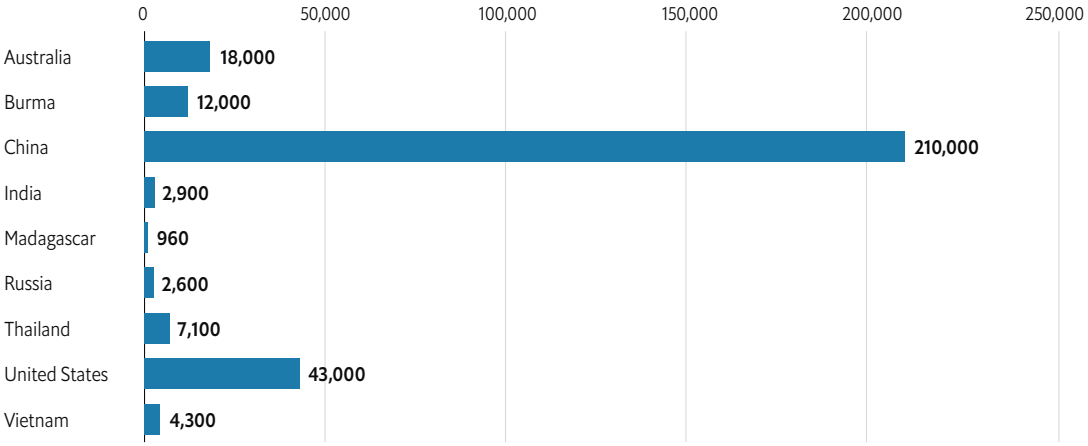
Figure 4: Rare earth minerals mine production by country, 2022
(Tons)



Source: USGS[91]

Additionally, **deep sea mining is likely to gain prominence as an important source of critical minerals.** This will generate new opportunities for the maritime economy, but the associated environmental concerns will need to be properly accounted for. Mining the deep sea can cause the extinction of species that live on the ocean floor, destroy deepwater ecosystems, disturb water columns, and generate sediment plumes and toxins that could impact marine life far beyond the mine site.[92] A WWF study highlights that demand for critical minerals can be reduced substantially—between 20% and 58% from now to 2050—with new technology, **circular economy models and recycling**. Particularly, it highlights that, in 2050, all new mineral demand can likely be met through a circular economy.[93]

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Technological trends

1. Enhanced efficiencies with the mainstream use of AI

AI adoption is gaining momentum across sectors and is set to become a mainstream technology in the coming decades. There are multiple applications, ranging from improved healthcare, safer and more efficient transport, personalised education, improved software for everyday tasks, and increased agricultural crop yields. **It is predicted that, by 2040, AI applications will affect almost every aspect of life.**[94] Aside from profit—one study finds that early adopters of AI in the transport and logistics sector enjoyed profit margins higher than 5%—its potential in driving efficiency and achieving sustainability goals will be a key driver of AI adoption in the future.[95] A Microsoft and PwC report highlights the fact that AI used in sustainability-related contexts could add up to US$5.2trn to the global economy by 2030.[96]

Like others, the maritime sector stands to benefit. Commercial ships will increasingly rely on machine learning, AI and satellite technology to improve shipping safety and efficiency. Today's empirical models process only about 10% of vessel data, compared with 90% for AI models, which can then generate accurate performance insights. In this way, AI-driven models can optimise decision-making, and even address safety issues that may arise due to lack of situational awareness or data.[97,98] By 2050 there is the possibility that remotely controlled or even fully autonomous small commercial ships could operate near coastal areas with absolutely no crew onboard.[99]

Generative AI also has applications. SeaGPT, an AI chatbot tool to simplify communication between crew managers and port agents, automates processes such as drafting emails and extracting essential information from communications with the port agency for crew members, who highlight email overload as a concern.[100,101] SeaGPT is expected to eventually become an executive assistant to the crew—running in the background and retrieving relevant data to handle communication that does not require direct human involvement.[102] For widespread AI use, however, it is important to note that interoperability issues, regulation and policy bottlenecks will need to be addressed.[103]

Today's empirical models process only about 10% of vessel data, compared with 90% for AI models, which can then generate accurate performance insights.

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2. Increased integration of the metaverse and immersive technologies

Human avatars or simulated versions of places such as concerts or workplaces in the metaverse will become the norm in 2050.[104] The metaverse is a virtual, three-dimensional space where people can virtually interact with each other. It is described as an extension of the internet, providing a more immersive experience that is based on imitating the real world.[105] Visualisation technologies, such as augmented reality (AR), virtual reality (VR) and mixed reality (MR), together sometimes referred to as extended reality (XR), can enable a fully immersive experience for metaverse users.[106] According to research conducted by Pew, 54% of experts anticipate the metaverse becoming a more refined, fully immersive and well-functioning aspect of daily life for a half billion or more people globally by 2040.[107] By the 2030s, the expectation is that substantial parts of the world will be digitalised and explorable.[108]

As these technologies advance, they will increasingly have the potential to support training, maintenance and remote-control functions in the maritime sector. They offer new ways to visualise operational tasks either on-site or remotely. For example, a use case for MR training would be to pre-experience possible dangerous situations on-board an offshore asset or a vessel at sea, without impacting facility operations for training purposes. This is a cheaper and more accessible alternative.[109,110] Especially also in light of shutdowns, such as those seen during the covid-19 pandemic, XR-supported training can help continue education for seafarers.[111] Challenges to the adoption of these technologies include expensive and unreliable internet connectivity at sea coupled with the turbulence experienced by ships. These applications mainly rely on GPS sensors to align a virtual model with the real world, and the ship's motion adds extra components to this calculation.[112]

3. Better connectivity will further the use of the Internet of Things across sectors

The excitement over the Internet of Things (IoT) is driven by its ability to bring previously isolated objects, from fridges to Ferraris, online. Data collected from IoT sensors can be monitored, fed back to instigate an action, inform the design of an algorithm or trigger a response in another connected object, maybe hundreds of miles away.[113] The benefits of using IoT lie in the collection and analysis of the data generated through the technology, and then using this information to inform next steps.[114] Any industry reliant on making, moving or selling objects that were previously not connected to the internet stands to benefit. For example, sensors can be used to reduce waste by optimising lighting or heating based on occupancy levels or reduce in-transit product spoilage by monitoring temperatures.[115]

The maritime IoT market was forecasted to grow at a compound annual growth rate of 6.2% between 2020 and 2027. By this year, shipping organisations plan to invest US$2.5m on IoT-based solutions, achieving cost savings of about 14%.[116,117] This growth can be achieved on the back of improving connectivity at sea through the use of lower Earth orbit satellites and 5G capabilities to enable higher data rates and security. There will be an expected 30.9 billion IoT units in 2025, up from 13.8 billion in 2021.[118] Other IoT applications in the maritime sector include the use of radio frequency identification (RFID) to increase speed and safety in the movement of goods and better manage ports by addressing scaling and privacy issues.[119,120] IoT sensors ensure complete visibility of devices, which enable vessel operators to control and monitor remote maritime assets, and safeguard offshore assets from damage, theft and unauthorised movement.[121]

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4. Global consensus and collaboration to facilitate the adoption of block chain technology

The buzz around blockchain technology has grown since 2015, and representatives from many industries have joined an open, if unstructured, discussion on the potential disruptive capabilities of this emerging technology. By 2030 it is predicted that it will be easier and faster to exchange value and data among users, institutions and countries as the use of blockchain technology ensures instant, across-the-board transparency, allowing for improved traceability.[122,123,124] Blockchain technology could bring efficiencies into existing bureaucratic processes. Areas that could stand to benefit include reducing the likelihood of shipping delays, which are often caused by slow manual administrative processes. Another is in reducing processing and administration costs, which can comprise nearly a fifth of total transport costs. **According to an estimate from 2017, digitalising paperwork could save the sector a total of US$38m per year.**

Blockchain provides companies with the framework to speed up business operations, keep real-time track of cargo, improve visibility in the global supply chain, and reduce customs clearance time, costs and risks.[125,126] To unlock this potential, the industry is already piloting blockchain applications. The Norwegian Seafood Association, for instance, is using the technology to share supply-chain data throughout the industry.[127] Blockchain can also provide specific data about fish origin, including where they were produced, what they were fed, when they were harvested, and how they were processed and transported.[128] In 2018 an effort to digitalise the supply chain through a blockchain-enabled global trade platform was launched. Within this, port and terminal operators, shipping companies, customs authorities, freight forwarders, logistics companies and other players could exchange data securely and collaborate efficiently. However, completely embedding blockchain requires full industry buy-in.[129,130] A noteworthy example is the October 2022 partnership between the Australian Border Force with Singapore to complete a blockchain trial of international trade documents.[131]

Blockchain can provide specific data about fish origin, including where they were produced, what they were fed, when they were harvested, and how they were processed and transported.

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Social trends

1. The automation of the workplace

As advanced technologies become more accessible and cheaper, workplaces are seeing more automation. This will require workers to develop new skills, which could realise more value, but it also raises concerns over potential job losses. As many as 300 million full-time jobs around the world could be automated in some way by the newest wave of AI (including platforms such as ChatGPT).[132] As such, the ubiquity of AI, smart devices and the metaverse (see above) will require a newly trained workforce. These trends will extend to the maritime sector. Approximately 1.8 million people make up the maritime workforce—their roles and responsibilities are expected to change with time as advanced technologies are increasingly used in the industry. As such, future workers will require a new set of skills. According to a survey conducted by the Korean Ministry of Trade, Industry and Energy, for instance, the introduction of smart and eco-friendly ships in the industry will raise the required number of technical employees from 35,549 in 2018 to 49,000 in 2028.[133]

2. The advent of a knowledge-assisted economy

As society moves to embrace technology, data and a more "advanced practice of production",[134] **the knowledge economy will evolve into a knowledge-assisted economy where people are assisted by custom versions of AI and other digital tools to complement their existing skills.**[135,136] Intellectual capital will remain critical, but will be enhanced by the benefits of custom technologies.[137] As discussed above, the advent of this will come with important social implications for workers and skill demands. A study of the US workforce, for instance, estimates that around 19% of workers could see at least 50% of their tasks impacted by large language models such as generative pretrained transformers (GPT).[138] This could make the maritime industry more appealing to a newer generation of seafarers and also help alleviate some of the challenges that these workers face around health and wellbeing, connectivity between shore and sea, and system and process efficiencies.[139] In this context, it will be crucial for the industry to focus on skills centred around digital technologies and systems.[140]

According to a survey conducted by the Korean Ministry of Trade, Industry and Energy, the introduction of smart and eco-friendly ships in the industry will raise the required number of technical employees from 35,549 in 2018 to 49,000 in 2028.

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3. The movement of people for employment opportunities and climate repercussions

Migration will continue to shape economies and societies, but the decades ahead will see these driven by labour shortages in the West and the need to adapt to climate change. However, the majority of African and Middle Eastern countries, unlike their European and North American counterparts, are set to see a larger working-age population, and therefore a stronger labour force.[141,142] Population growth has the potential to boost innovation, particularly in Africa—where the digital economy is projected to reach US$180bn by 2025 and US$712bn by 2050.[143] Investing in digital skills and infrastructure will be key if these outcomes are to materialise.[144] For economies with ageing populations, governments will be implementing policies that encourage the immigration of skilled workers from countries with growing populations.[145] Migration will also take place in order to deal with the direct impacts of climate change (see above), which will be felt most intensely in countries across Africa.[146] The influx of migrants, however, may also contribute to social friction (see below) and give rise to maritime safety and security issues around the rights of incoming migrants and risks of human trafficking. For the maritime sector, shifting population dynamics will directly impact the overall global supply of labour to the industry as well as their demographics. That being said, the maritime sector already depends on a labour market based on the import of labour.[147] As such, rising populations in African nations may supplant dominant sources of labour supply to the industry, which are predominately Asian countries, particularly the Philippines.

4. Multiplied inequalities and social friction

The anticipated period of short-term economic slowdown and long-term climate impacts will worsen inequalities within and between countries in the medium to long term. The Economist Intelligence Unit expects stagnated growth in most of the developed world in 2023, with slow rebounds from 2024 onwards and persisting economic uncertainties.[148] **In the long term, the working class, youth and marginalised communities will face financial pressures and setbacks, particularly where social safety nets are lacking. As a result, this will multiply inequalities within countries and social frictions will emerge.** Already, top-down financial pressures have resulted in industrial action in the form of strikes across much of Europe, particularly the UK.[149,150] To add to this, the influx of migrants for economic and climate reasons (see above) will exacerbate tensions.[151] The just transition is gaining momentum in the context of climate change for similar reasons. The net zero transition will spawn new industries that require new skills.[152] This comes with risks for workers, including maritime workers and seafarers (see above). In the regions most immediately impacted by climate change, social friction may be driven by forced internal migration. For instance, the World Bank estimates that up to 86 million Africans, 40 million South Asians and 17 million Latin Americans will have to migrate within their own countries by 2050 as regions become unliveable.[153] This may exacerbate existing conflicts, especially in states that are already considered fragile.[154]

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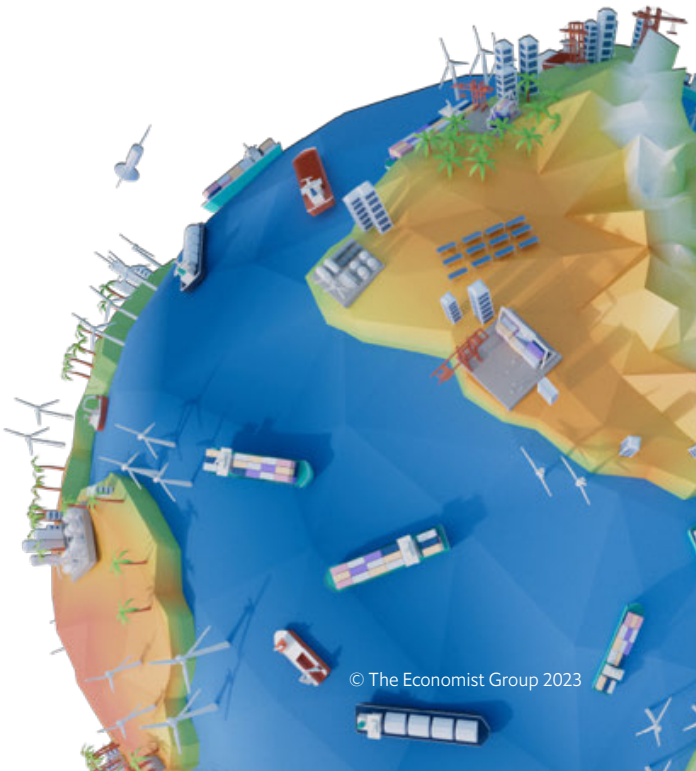
Four futures for the maritime sector in 2050

The trends outlined in the preceding section can be combined in varying ways to create very different futures for the maritime sector. To refine these possible outcomes, Economist Impact analysed the trends across two axes: the nature of global co-operation on the climate agenda and the speed of technology uptake. Climate change and decarbonisation are set to be defining challenges for the coming decades. "The whole question [of trends that will shape the world up to 2050] needs to be looked at in line with what the IPCC is predicting," says Peter Thomson, the UN secretary-general's special envoy for the ocean. "There are low confidence and high confidence scenarios that depend on the actions we take today. This is primarily what will dictate what the world will look like in 2050, and what will determine the reality of life on this planet in the 21st century." Similarly, technology is advancing rapidly and a crucial question will be the speed with which these are disseminated across the globe and how. "We need a radical new approach to innovation," argues Kevin Forshaw, director of industrial and strategic partnerships at the University of Plymouth. "It's not just the technology itself—that in many ways is already being done. To actually enable technology to flourish, developments in regulation have to take place at a global scale."

"The whole question [of trends that will shape the world up to 2050] needs to be looked at in line with what the IPCC is predicting. There are low confidence and high confidence scenarios that depend on the actions we take today. This is primarily what will dictate what the world will look like in 2050, and what will determine the reality of life on this planet in the 21st century."

Peter Thomson, UN secretary-general's special envoy for the ocean, UN



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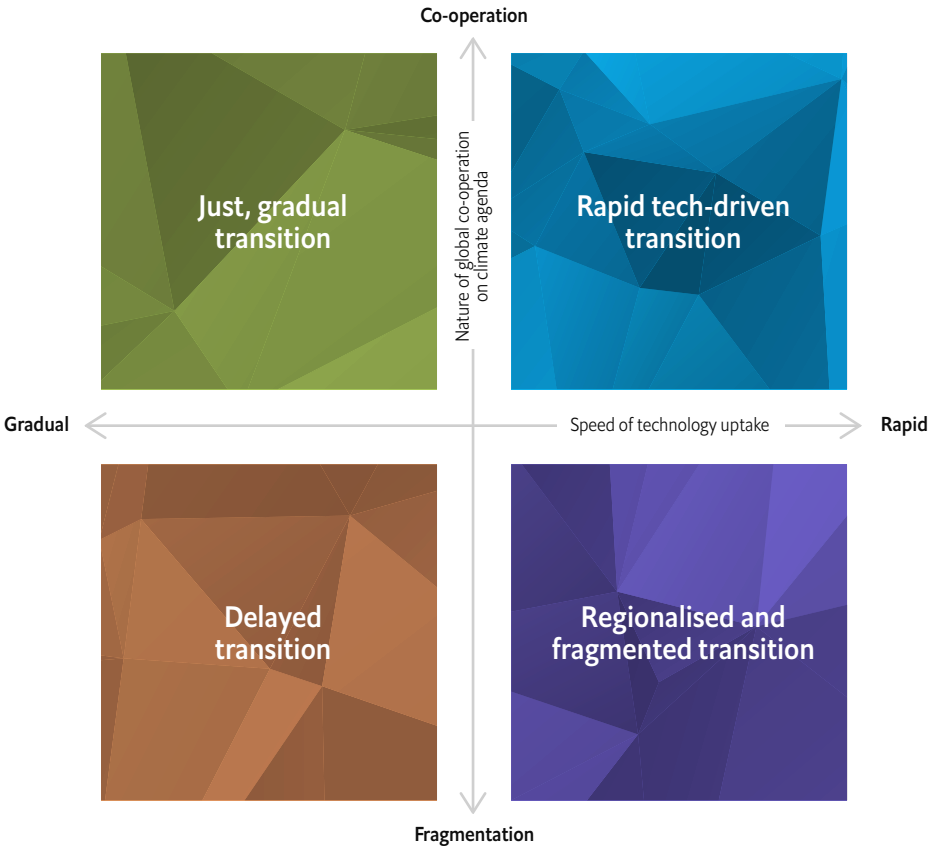
Across the two axes, the following four futures have been identified:

1. **Just, gradual transition**: high global co-operation combined with a gradual uptake of novel and/or advanced technology.
2. **Rapid, tech-driven transition**: high global co-operation combined with a rapid uptake of novel and/or advanced technology.
3. **Regionalised and fragmented transition**: high global fragmentation combined with a rapid uptake of novel and/or advanced technology.
4. **Delayed transition**: high global fragmentation combined with a slow uptake of novel and/or advanced technology.

Below, we outline some of the key assumptions of each of these futures in more detail. The assumptions of these futures are grounded in the trends identified by the literature review as well as the findings from our 16 expert interviews.

Figure 3: Futures matrix



Source: Economist Impact

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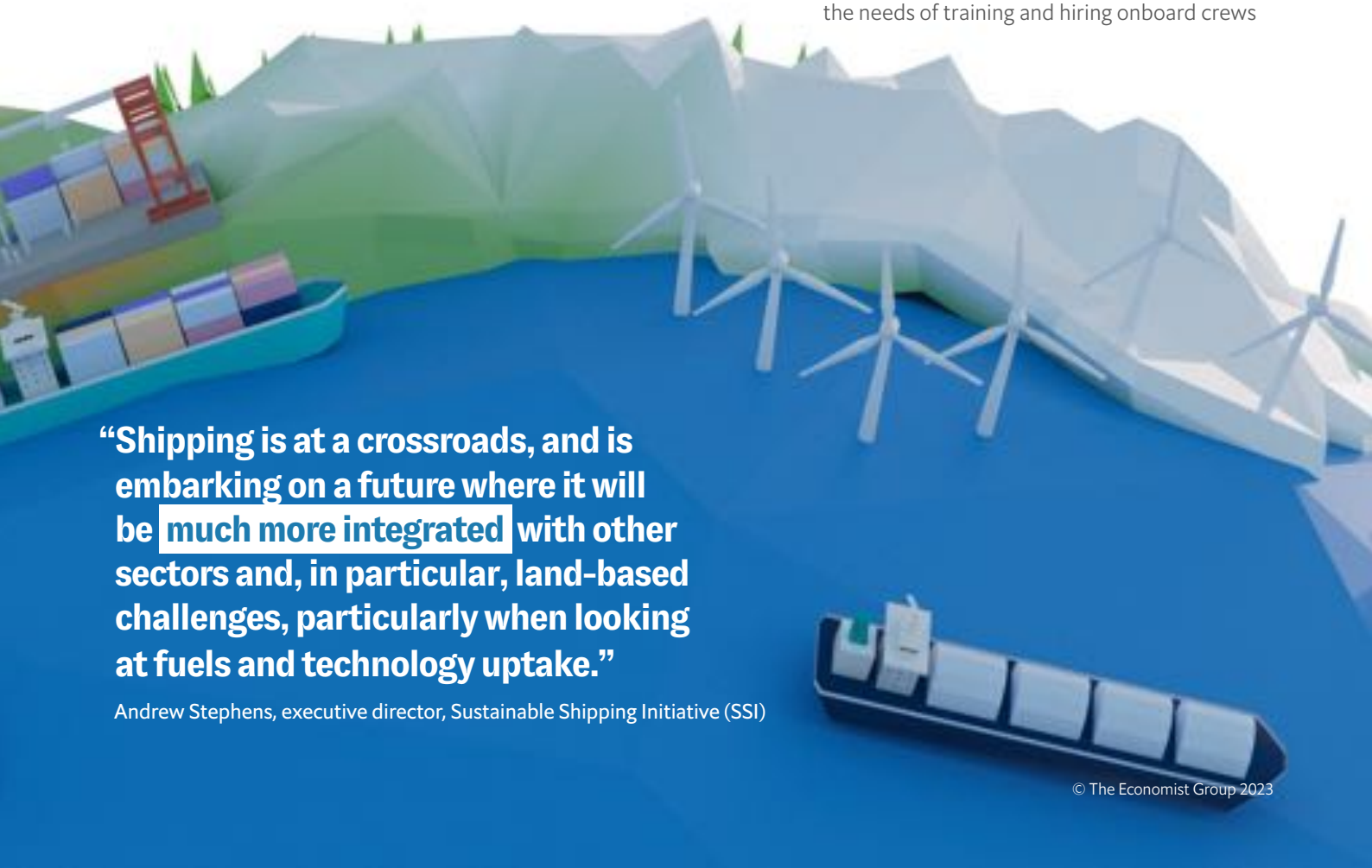
Just, gradual transition

A just, gradual transition sees high levels of global co-operation combined with the gradual but regulated integration of novel technologies. It encompasses broader discussions on what the maritime sector needs to do to decarbonise successfully and equitably. "Shipping is at a crossroads, and is embarking on a future where it will be much more integrated with other sectors and, in particular, land-based challenges, particularly when looking at fuels and technology uptake", says Andrew Stephens, executive director at the Sustainable Shipping Initiative (SSI). Elizabeth Petit González, head of communications and partnerships at SSI, is concerned about the just transition element of the transition, which if not taken into account early in the decision-making process may only benefit the global north: "countries of the global south and small island developing states – many of whom are very reliant on shipping for their survival and already face higher shipping costs – risk being left out and having to suffer the negative impacts of emissions and air and water pollution for longer. For this dynamic to shift we need to think not just about where power is concentrated but how it is distributed."

This transition in the maritime sector will be guided by an intergovernmental agreement that successfully limits global warming to 1.5 degrees by 2050 and paves the way for the integration of novel technologies. According to Hyun-ho Lee, vice president at HD Hyundai Heavy Industries and managing director of the Maritime Research Institute, "for shipping companies, the major issue is working toward carbon neutrality, and what the next fuel and energy sources will be. As such, there will be different sets of fuels used in 2050 that will require different systems such as engines, fuel supply systems, fuel tanks and bunkering infrastructures. Also, the needs of training and hiring onboard crews



"Shipping is at a crossroads, and is embarking on a future where it will be much more integrated with other sectors and, in particular, land-based challenges, particularly when looking at fuels and technology uptake."

Andrew Stephens, executive director, Sustainable Shipping Initiative (SSI)

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for operating new different systems will be increased". In addition to this, "ship owners will need to focus on retrofitting these alternative fuels. That will be the key task, as ship size and energy use are greatly interlinked," explains Hing Chao, executive chairman of Wah Kwong Maritime Transport Holdings, emphasising that retrofitting onboard carbon capture utilisation and storage systems could be an important part of the strategy as well. JB Rae-Smith, vice president at the UK Chamber of Shipping and director, Private Group Companies, John Swire & Sons, does not expect a silver bullet alternative fuel to emerge in the future, as "nothing that is going to run ships in a commercially viable manner is not in discussions already—including hydrogen or ammonia."

But in this future, technology integration will take place gradually: reflecting some of the difficulties associated with reaching global consensus, distributing the benefits, and ensuring that policy, investments, and health and safety standards progress at a steady pace. This is only possible under the assumption that countries took action to reduce emissions in the early to mid-2020s, which enabled them to integrate technology early, and scale these solutions gradually.[155] Additionally, alternative fuels (for instance, ammonia[156]) can be toxic. As a result, ship owners will need to thoroughly integrate seafarer safety precautions into how they design new vessels and retrofit existing vessels for the use and transport of these fuels. Beyond this, the use of new fuels will need reskilling and education for crew, so that workers feel empowered to safely handle them. In this context, safety and training will be key to ensure a just transition for the workers involved.[157]

Rapid, tech-driven transition

High levels of global co-operation may also be accompanied by rapid integration of novel technologies across the maritime sector. This future—a rapid, tech-driven transition—would see automated solutions, smart technologies, fuel and system efficiencies, and higher levels of data sharing.[158] "I believe industry will move faster than IMO [International Maritime Organization] targets, which is why I feel very confident about the future of fuels and technologies like green hydrogen," says Mr Thomson. As such, the assumption in this future is that global co-operation on decarbonisation will mandate the rapid roll-out of novel technologies through high investments, economic incentives and favourable policies that can keep up with the pace of industry innovations. "If the world globally gets on track for zero emissions, there will be economic incentives and the maritime industry will massively change," explains Katie Higginbottom, head of the ITF Seafarers Trust.

In this context, the technological trends identified can manifest in the maritime sector in a number of ways: affecting fuel sources, trade dynamics, vessel designs, port infrastructure and skill requirements. "[When] enabling some of these technologies in the open sea, you need good connectivity, and right now, there just isn't," says Nick Bartlett, who is the director and the lead for financial services, insurance, transportation and manufacturing at the Future Today Institute. "With the increase of satellite-based internet and satellite connection, that's going to become much easier: as the technology continues to scale and gets cheaper and more efficient, it'll be a lot easier for people to communicate back to the ship more in real time. This will help drive a lot of the developments." The rapid uptake of technology, if done collaboratively, could also mean that maritime jobs are better protected.

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"Even with automation, there will still need to be people on board ships to deal with the safety requirements. maritime industry will need to compete with other sectors for talent."

Katie Higginbottom, head, ITF Seafarers' Trust

"Even with automation, there will still need to be people on board ships to deal with the safety requirements. The maritime industry will need to compete with other sectors for talent", explains Ms Higginbottom. Mr Stephens echoes this sentiment: "Recent history has seen cost as the primary focus when it comes to seafarers, but new skills associated with rapid technological uptake may change this."

But this future is not without its risks, the main one being cybersecurity. "At the moment, cyber risks are not so big for ships, as they are not as connected [in] real time as other sectors," explains Ben Abraham, CEO of Global Marine at Willis Towers Watson. "However, autonomous ships that are more connected open up a whole new can of worms in terms of potential cyber exposure."

Echoing this, Mr Forshaw adds: "Increasing the autonomy of vessels opens up massive risks around cybersecurity and the potential to cause very serious disruption. Not only in vessels, but also port operations. So, although it's a good thing [in terms of efficiency], we need to be adopting very different risk assessment processes [to deal with this]." Basil Germond, chair in international security at Lancaster University, warns that another security risk is undersea infrastructure: "It is evident that the security of undersea infrastructure will be key. Not just the energy infrastructure and pipelines, but also the communication infrastructure [which is also vulnerable to cyberattacks]. Developing security mechanisms to address future threats will be important."

"Increasing the autonomy of vessels opens up massive risks around cybersecurity and the potential to cause very serious disruption. Not only in vessels, but also port operations. So, although it's a good thing [in terms of efficiency], we need to be adopting very different risk assessment processes [to deal with this]."

Kevin Forshaw, director of industrial and strategic partnerships, University of Plymouth

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"The developing countries of today will move from playing only an exporting role towards also being end-users of products, becoming important participants in the global supply chain."

Hing Chao, executive chairman,
Wah Kwong Maritime Transport Holdings

Regionalised and fragmented transition

At the other end of the matrix, a regionalised and fragmented transition would combine low levels of co-operation with the rapid integration of technology. Stephen Cotton, general secretary of the International Transport Workers' Federation, believes we are already seeing hints of this: "In the supply chain, we are already observing concepts like nearshoring [and] offshoring." According to Johannah Christensen, managing director at the Global Maritime Forum, frustration with intergovernmental processes may be the source of this: "It's not fragmentation that is leading to IMO breakdown in negotiations, it's lack of progress in the IMO that may lead to greater fragmentation." Significant geopolitical changes will also underpin this. Mr Germond explains that the current power dynamics may change with the rise of China: "Western countries have benefited from enduring control of global oceans. This allowed them to grow their economies, control supply chains and project military power globally. What happens next depends on China, and the nature of their leadership contest. This will have an important maritime dimension both in terms of naval and economic power." Finally, population dynamics will play a role, as they will be a source of consumer demand and economic growth in other Asian and African economies. "Indonesia will be one of the most important economies in 2050 and is located on important shipping lanes and choke points," explains Mr Germond. "From the point of view of any state, it will be strategically wise to build this relationship. India too is poised to have more room for manoeuvre, especially in the face of China." Mr Chao similarly argues, saying that "the developing countries of today will move from playing only an exporting role towards also being end-users of products, becoming important participants in the global supply chain."

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"The combined trend of deglobalisation and automation will have a significant impact on what will be moved by sea," mentions Mr Rae-Smith. Deglobalisation may lead to a downscaling of assets, from ports to vessels. "Those who have invested in mega transhipment hubs will suddenly have to rethink, as de-globalisation and regionalisation will mean that scale from transhipment is no longer your competitive advantage. The importance of a port won't necessarily be based only on its size, but increasingly its strategic ability to hold on to a specific type of trade. I think this will open up new areas and regions to trade," says Jesper Kristensen, group chief operating officer for marine services at DP World. Mr Chao adds to this: "The fragmentation of global trade will lead to smaller ships being in greater demand, as they will have more flexibility and ability to trade across territorial borders."

"Once you have that [fragmentation], you move away from systems that aim to ease trade to something that almost stops trade. The maritime sector is driven by derived demand, so if we do not have ease of trade, we are going to see the trade volumes drop."

Stavros Karamperides, head, Maritime Transport Research Group, University of Plymouth

The assumption here is that countries may be unable to co-operate on decarbonisation—whether due to geopolitical or economic priority differences—and, in turn, will rely on the rapid integration of technology to unilaterally meet national climate objectives and adapt quickly to growing climate challenges. As such, the rates of technological integration will vary by country, as the absence of co-operation will mean that technological adoption depends on financial and technical capacity. The risk here is that poorer economies will be left behind, exacerbating economic inequalities. Another is that technologies are deployed without careful consideration and preparation. Given the latter, the risks of cyber attacks in this future are particularly high. Limited co-operation, restricted data sharing and high intergovernmental tensions may leave room for more bad actors to operate with limited oversight. "A big concern is the potential for bad actors—organisations or even nation states—that want to disrupt commerce and shut things down. There will be a lot more opportunities for this in that future," says Mr Bartlett. Maritime trade will also be severely impacted. According to Stavros Karamperidis, head of Maritime Transport Research Group at the University of Plymouth, "Once you have that [fragmentation], you move away from systems that aim to ease trade to something that almost stops trade. The maritime sector is driven by derived demand, so if we do not have ease of trade, we are going to see the trade volumes drop," he says.

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Delayed transition

A delayed transition describes a future where global co-operation is fragmented and technology uptake is slow, resulting in irreversible climate tipping points and what the IPCC projections deem as a worst-case scenario of a more than two degrees Celsius of warming by 2100.[159] The impact of this global temperature increase across regions is likely to be uneven. According to the extreme sea level projections, the North Sea, the Atlantic coasts and the Black Sea will see the largest increases in terms of mean sea level, while the Baltic Sea will see the smallest.[160] In the coming three decades, low lying countries in Asia like Vietnam, Indonesia, the Philippines and Thailand will also be severely impacted, putting an estimated 300 million people at risk of floods in 2050.[161] Humanity is forced to adapt to this planetary and climate crisis. As above, this future is an unequal one—although the impacts of these tipping points are felt ubiquitously, the poorest economies and communities will do so most acutely. The implications of these extend across the maritime sector, forcing adaptation-led efforts across national jurisdictions. "The worsening of climate change will mean some vessels and goods will become uninsurable, due to inevitable increases in natural disasters and tougher conditions at sea that increase the risks of things going overboard," warns Mark Bryan, senior foresight manager at the Future Today Institute. "As such, what gets shipped comes down to what companies are willing to pay for and what they are willing to take risks on." And, as Mr Thomson explains, "exclusive economic zone boundaries may become more contentious because of rising sea levels … And large numbers of coastal communities will inevitably be forced to relocate as their lands become uninhabitable."

In the coming three decades, low lying countries in Asia like Vietnam, Indonesia, the Philippines and Thailand will also be severely impacted, putting an estimated 300 million people at risk of floods in 2050.

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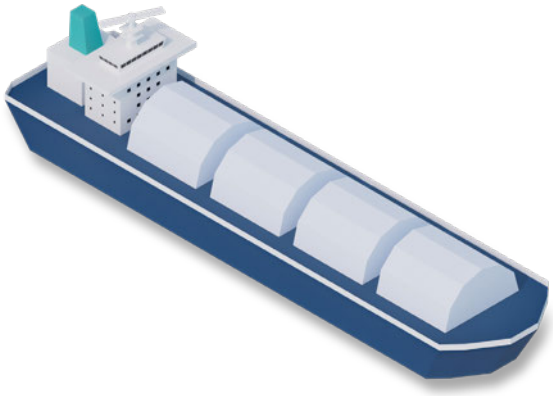


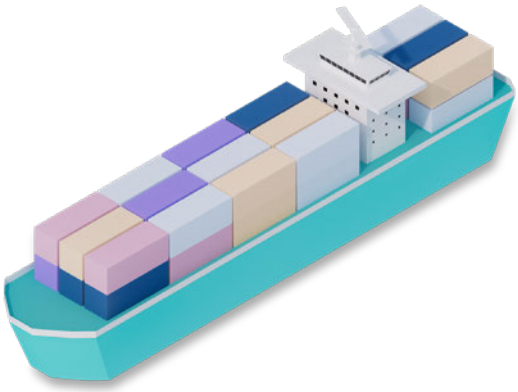
"The worsening of climate change will mean some vessels and goods will become uninsurable, due to inevitable increases in natural disasters and tougher conditions at sea that increase the risks of things going overboard."

Mark Bryan, senior foresight manager, Future Today Institute

These shifts will not only alter the composition of maritime cargo, infrastructure and communities, but maritime trade routes as well. The Arctic, for instance, is rapidly becoming a new conflict centre as ice melting has created new shipping lanes, opened existing seasonal lanes for longer periods of the year, and made natural resource extraction more viable.[162,163,164] According to Mr Chao, these new shipping lanes will have an impact on ship design, with ice-breaking capacity becoming more relevant.

A study published in *Nature Communications* in June 2023 estimates that the Arctic Ocean will experience sea-ice free Septembers as early as the 2030s.[165] Although there is no clear consensus on when some Arctic routes, particularly the Northwest Passage, will become suitable for regular commercial traffic, some experts predict ice-free passage through the Northern Sea Route for three to six months of the year and the Northwest Passage for two to four months of the year by 2100.[166]

The IPCC warns that technology development will play a crucial role in mitigating and adapting to climate change.[167] However, this future assumes a gradual integration of technology. Contrary to the first future, where the gradual uptake of technology is accompanied by co-ordinated efforts to limit warming to 1.5 degrees, the gradual integration of technology in this context means that sufficient emissions reduction is not achieved, exacerbating the existing challenges of adapting to an increasingly uninhabitable world.



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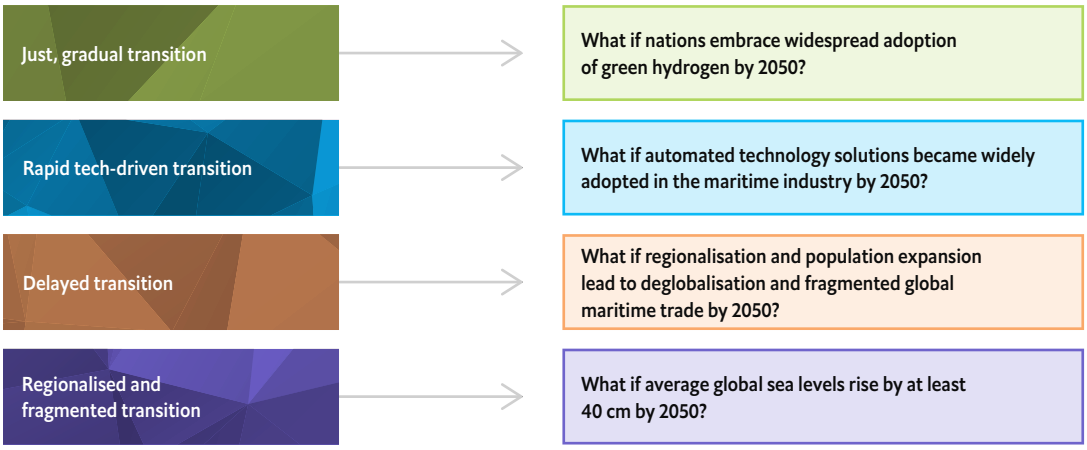
What if scenarios

To understand how various components of the maritime sector may transform in each of the futures discussed in the preceding section, Economist Impact developed four scenarios. They are purely fictional, but are based on the assumptions outlined above and the findings of our literature review. The first two scenarios, on green hydrogen and automated technology solutions, depict optimistic visions for the future of the maritime sector. Conversely, the latter two scenarios, on fragmentation and sea-level rise, present two bleaker possibilities for the sector (and our planet).

The purpose of this exercise is to offer industry leaders and policymakers a snapshot into what the global maritime sector could look like should we either succeed or fail to act on the shrinking window of opportunity to prevent the worst effects of climate change. The hope is that this will empower these individuals to act now, strategically and intentionally, for the safe and sustainable future that they would like to see for themselves and their business, and position the maritime sector as an enabler of change rather than a reactor.

Figure 4: Four what if scenarios for the maritime sector



Source: Economist Impact

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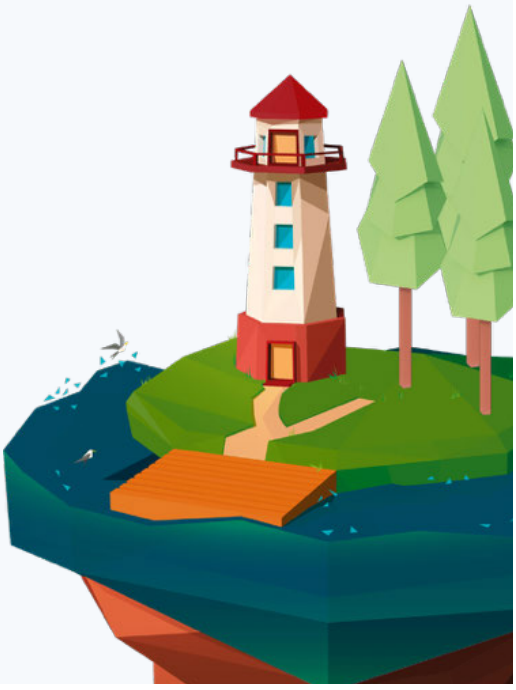
WHAT IF METHODOLOGY

Each of the what if scenarios discussed below are situated within the assumptions that have been laid out above for their respective futures. Economist Impact recognises that, in each of the futures, a variety of other scenarios could have been explored. For instance, within the just, gradual transition future, we could have zoomed into another fuel (for instance, methanol) or centred the discussion on themes like the successful deployment of climate adaptation finance or widespread uptake of alternative seafood protein sources. Our choices for the what if scenarios are not meant to reflect Economist Impact's predictions of what is more important and/or more likely. The decision on each of the four instead came out of discussions with internal and external experts to determine what elements would be the most interesting to explore for the maritime sector.

Once the themes were identified, Economist Impact sought to explore how developments in each of the four scenarios would impact the five components of the maritime sector: trade, energy, vessels, ports and people. To this end, Economist Impact conducted additional desk research of grey literature and structured our expert interviews to understand, more broadly, what would be required for each of the four scenarios to become a reality. More specifically, however, we researched and inquired about what studies exist to measure or estimate the impacts of each scenario on the five components, what specific changes would be required in the maritime sector to adapt to this, and how the industry has been preparing or intends to prepare for these specific changes.

We relied on the findings of these exercises to develop these scenarios, and ensured that despite being fictional and hypothetical, they remain grounded in reality and consensus regarding what would be required of the sector, and what the key implications are.

Some impacts were more obvious than others. We incorporated these regardless. But to ensure that each scenario presents a fresh take on the topic, we sought to centre the narrative of each scenario on a slightly less prominent, albeit, possible, repercussion. For instance, the possible (and existing) impacts of sea level rises on ports are well covered in existing literature. So this is featured in our scenario, but it was not the focus. Instead, the opening of the Arctic passage—and therefore, the relationship between sea level rises and maritime trade—is a possibility being discussed by researchers and industry experts globally but is less frequently focused on in discussions. As such, our scenarios are by no means exhaustive or entirely representative of all the ways these changes will affect the sector, whether it is green hydrogen adoption or trade fragmentation.



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What if... nations embrace widespread adoption of green hydrogen by 2050?

Note: each of these scenarios is fiction, but grounded in historical fact, current speculation and real science. They are set in the different possible futures identified in the preceding section.

SCENARIO:

It has been 25 years since the historic agreement of 2025, which saw over 194 heads of state agree to ban any new national oil and gas developments, mandate the complete phase out of fossil fuels across sectors by 2050, and distribute energy transition benefits equally through loss and damage funds.[168] In response, the IMO revised its decarbonisation targets of reducing CO_2 emissions by 40% by 2030 and 70% by 2050[169] to a 90% reduction by 2040 and complete eradication by 2050.[170] These targets gave industry the impetus it needed to develop zero-carbon fuels at the level that was required, which was a challenge initially, but which ultimately spurred a green hydrogen revolution. In 2021 fossil-based fuels accounted for 99% of energy consumption in international shipping.[171] Transitioning away from this required different tanks, vessels and skills, at the same time as undoing old habits and ways of working.

New centres of energy power

In the early 2020s and 2030s a handful of countries were at the forefront of green hydrogen. Japan was one of these: in 2023 it announced plans to promote a "hydrogen society", in turn providing support for the production of hydrogen and ammonia supply chains and infrastructure, and laying the groundwork for becoming one of the biggest importers.[172,173] Other first movers in this space included South Korea, the US, the EU and China, all of which continue to lead this space today.[174] Additionally, due to its dependence on solar energy, green hydrogen also gave some former oil producers the opportunity to reinvent themselves. Saudi Arabia was once a dominant oil exporter, but the 2025 mandate to phase out fossil fuels meant that the country had just ten years to significantly restructure its economy and raise its national decarbonisation ambitions. In 2023, it announced plans to develop a single-site solar power plan with a generation capacity of 2,060 MW.[175] This paved the way for its new role as a leader in solar energy and green hydrogen exports.[176]

The increased importance of solar also empowered Africa to become a key energy exporting region. In 2022, despite being home to 60% of the world's solar resources, the region produced just 1% of global solar capacity. Yet, in 2022, the region already produced 40% of global minerals, critical components for hydrogen technologies. Egypt, Mauritania, Morocco, Namibia and South Africa already announced plans in the early 2020s to develop low carbon hydrogen projects. By 2030 the region was producing 5,000 megatons of hydrogen per year and was able to export a portion of this to Northern Europe at competitive prices.[177]

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Ammonia as a carrier

The debate waged in the 2020s on the most suitable mode for transporting hydrogen proved decisive. At the time, the shipping industry already had experience carrying ammonia as cargo, and therefore developed a strong sense of the safety considerations associated with this. Conversely, there was much less experience transporting liquid hydrogen and while toxicity is not a concern, hydrogen can be flammable.[178] In comparison, ammonia presents little risk of combustion and has lower storage requirements due to its higher density.[179] Liquid hydrogen also needs to be stored at a far colder temperature than ammonia (minus 253°C vs minus 33°C).[180] Further refinement of conversion technologies in the 2030s, which led to more efficient conversion of ammonia to hydrogen, cemented ammonia's position as a carrier.

Hello to new strategic ports

The widespread use of green hydrogen prompted city planners and industry leaders to rethink port infrastructure and strategy. From the mid-2020s onwards, hubs for distribution of hydrogen and ammonia started popping up in various parts of the world. These entailed developing import and export storage and supply infrastructure. The Port of Hastings in Australia began positioning itself as a strategic export facility as early as 2020,[181,182] setting the foundation for a green hydrogen corridor from Australia to Japan.[183] Similarly, South Africa developed a new port of Boegoe Baai, which was focused on the production and export of hydrogen in the form of ammonia to the port of Rotterdam.[184]

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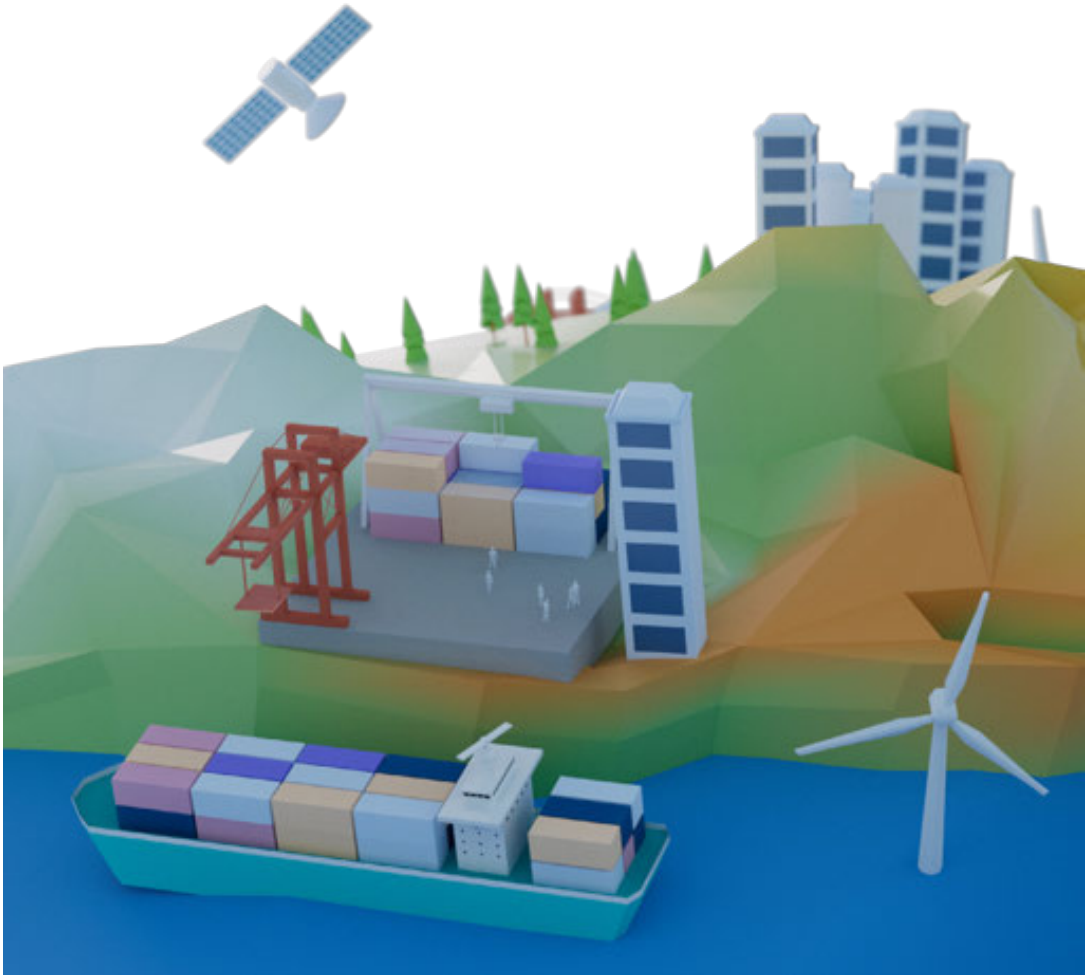
Investing in people

Over 750,000 seafarers required additional training between 2020 and 2050 as a result of the world's successful decarbonisation efforts.[185] Ships transporting ammonia are equipped with more advanced technologies and systems. This required extensive reskilling and training programmes and paved the way for women's inclusion. The need for more tech-savvy ship managers enabled more women to take on managing positions on land and at sea.[186] Additionally, the wider uptake of advanced automation technologies reduced the number of physical tasks required on board, gradually undoing the culture of masculinity associated with seafaring jobs.[187] In 2021 just 1.2% of the global seafarer workforce was women.[188] Last year, in 2049, the target set in 2020, for women to make up a quarter of all seafarers by 2040, was finally met.[189]

The widespread adoption of green hydrogen that we see today within the maritime sector owes its success to the political backing for decarbonisation across states. This spurred public investments, subsidies and incentives towards producing renewable energy and reduced some of the upfront costs associated with green hydrogen. Through effective global co-operation and incremental changes to technologies including a gradual shift in fuelling systems, a just energy transition could be achieved.



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What if... automated technology solutions became widely adopted in the maritime sector by 2050?

Note: each of these scenarios is fiction, but grounded in historical fact, current speculation and real science. They are set in the different possible futures identified in the preceding section.

SCENARIO:

Earlier this year, when hackers took control of a key port in Belgium, the maritime sector came face to face with the harsh realities of a highly interconnected world. But port operations only suffered short delays before operators were able to resolve the issues and regain control of their systems. Global co-operation and agreements on cybersecurity protocols put in place over the past two decades have made this possible. The attack on the Antwerp port is not the first of its kind, but just one example of how timely intervention, effective collaboration and pre-existing cybersecurity protocols can limit negative repercussions through enhanced resilience.

The 'new normal' of ships and vessels

The world's first autonomous cargo ship made its maiden voyage in 2022. The ship, Suzaka, completed a 500-mile journey from Tokyo Bay to Ise Bay navigated entirely by AI.[190,191] Today, remotely controlled and even fully autonomous commercial ships are the new normal. Indeed, as of 2040, about 11-17% of the global shipping fleet was autonomous.[192,193] These use companion drones to assist with situational awareness and have holographic displays of ship systems for shore-based operators or "digital captains".[194,195] But these ships manage a large number of tasks autonomously, including course corrections, docking and cargo handling through on-going data exchange with "smart" ports. Now, automation and advanced analytics help determine the best path by factoring in weather conditions, optimal fuel usage and unforeseen events relying on real-time forecasts.[196,197]

Contrary to the expectations and speculations that prevailed in the early 2020s, the importance of human supervision remains critical; albeit such workers exist in smaller numbers and have adopted vastly different roles and responsibilities, which require new skills. Seafarers are now controlling the system that steers the ships as opposed to steering the ship themselves. This was made possible through the use of IoT, robotics and predictive analytics. As such, industry roles have transformed from mostly ship-based to mostly shore-based roles.[198]

The emergence of autonomous ships was preceded by the 2018 IMO working group, the Correspondence Group on Autonomous Ships, that adopted guidelines for safely operating ships using remote and autonomous technologies.[199,200] The IMO's early efforts in

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2022-23 to regulate the operations of Maritime Autonomous Surface Ships (MASS) focused on balancing the benefits derived from new, advanced technologies with safety and security concerns, impacts on the environment, and international trade facilitation.[201] (MASS refers to a ship that can, to varying degrees, operate without human interaction. Degree four—adopted by the industry since 2040—refers to a completely autonomous ship)[202]

A knowledge-assisted economy

Fears of technology, specifically AI and automation, replacing the human workforce dominated discussions in the 2020s. These have since abated. While automation had the potential to reduce demand for seafarers by around 22% between 2020 and 2040, these impacts were offset by the uptick in global maritime trade, which saw demand for seafarers increase within that period.[203] The human workforce was not replaced by technology.

Instead, the knowledge economy was merely replaced by a knowledge-assisted economy. Technology-powered assistants, such as chatbots or voice assistants[204], have brought in more efficiencies and greater safety. In the maritime sector in particular, AI-powered assistants manage inventories and conduct incident investigations, speeding up the retrieval of relevant information and automating some routine tasks. Technology initially slowed the growth in the number of seafarers needed,[205] but global collaboration ensured that overall trade volumes increased sufficiently to prevent the loss of jobs. This allows the crew to spend more time maintaining the ship and applying themselves to their work with greater knowledge in the safest way possible.[206] The push for autonomy in the sector was driven by the need to make the environment safer for the seafarers, for example by protecting them from hazardous environments and reducing accidents.

The human workforce was not replaced by technology. Instead, the knowledge economy was merely replaced by a knowledge-assisted economy. Technology-powered assistants, such as chatbots or voice assistants, have brought in more efficiencies and greater safety.

What has changed since the 2020s, however, are the skills required: as the industry embraced more expensive and complex technologies across fuels, vessel design and port logistics, this also meant competition for skilled workers. Today—and in stark contrast to the early 2020s—the maritime sector has to compete with other sectors for talent and workers. As a result, the industry saw better paying, higher qualifying jobs that gave seafarers and land-crew more leverage than before.

Inspired by the uptick of industrial action that characterised the 2020s, the maritime workers of 2050 used this newly acquired leverage to successfully push for strict regulations on working hours, job security, working conditions, and operational safety and health.

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Customs clearance and ship repairs in the metaverse

Beyond fundamental automation of processes, the use of alternative reality and the metaverse sets the maritime sector apart from other industries. Back in 2021-22 the initial hype around the metaverse abated, stalling its application across industries, including the maritime sector. High costs associated with collecting, processing and storing the required high-resolution data was a major roadblock. However, as other technologies advanced, the metaverse and VR were inevitably integrated into maritime systems and processes.

Early use of the metaverse in the shipping industry was seen in services to assist decarbonisation efforts. Generative 3D design software enabled optimal retrofitting, speeding up the decarbonisation of existing fleets. Moreover, extended reality visualisation tools enabled remote operations by connecting ships with their 3D virtual models and data.[207] This facilitated surveyors to assess damage to ships and repair crew to fix systems remotely, using robots with ultrasonic probes on a ship to measure the extent of damage. Importantly, this allows the shipping industry to tap into the best and most cost-effective talent around the world. Today, ships rarely dock at ports for simple repairs as these are conducted at sea remotely through the metaverse.

Customs clearance has also been revolutionised in the metaverse. The creation of virtual customs windows has meant that ships can complete customs procedures long before reaching physical borders. A new generation of marine robots are deployed to ships for inspection, equipped with AI-driven cameras which generate navigable holograms for inspectors. This has dramatically reduced wait times and enhanced efficiency of border control operations.

Training institutes are also commonly using metaverse and immersive technology-driven alternative reality models that provide seafarers with a close to reality simulation of what their routine and tasks on ships would look like. This is a marked improvement from early 2025, where education held the smallest market share (2%) of AR and VR by use case globally.[208] In addition to its use in training, immersive technologies are helping design digital twin models that accurately predict the remaining service life of a ship, providing valuable insights for ship inspection, maintenance planning and operational decision-making.[209] Although the use of these technologies started with training modules, they are now also used across various phases of a ship's life cycle, ranging from design and manufacturing to operation and maintenance, as well as for sustainable end-of-life ship dismantling.

Immersive technologies are helping design digital twin models that accurately predict the remaining service life of a ship, providing valuable insights for ship inspection, maintenance planning and operational decision-making.

Harmonious regulation, as well as high levels of co-operation, are necessary for the maritime sector to reap the benefits of automation and virtual realities while managing the challenges. These high levels of collaboration that have characterised the past 30 years have enabled countries to mitigate the threats of cyber attacks and ensure that technological innovation in the sector fosters better paying, higher quality jobs, and more trade.

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What if... regionalisation and population expansion lead to deglobalisation and fragmented global maritime trade by 2050?

Note: each of these scenarios is fiction, but grounded in historical fact, current speculation and real science. They are set in the different possible futures identified in the preceding section.

SCENARIO:

Last week, a large ship travelling from the port of Shanghai was denied entry into Europe's largest port based on its failure to comply with specific technical standards. Voyages across the Asian-European shipping route, once among the busiest in the world, are no longer commonplace, and in a world of already-fragmented trade, this decision has proven both controversial and consequential. But for many experts who have been studying the fracturing of globalisation since the mid-2020s, this does not come as a surprise.

Technical barriers and smaller vessels

The main challenge associated with these new dynamics has been the wide variations in technical standards. Rather than standardising technologies, each country and region has pursued its own form of innovation. As a result, and in order to further incentivise regionalised trade, countries moved away from imposing sanctions, and towards enforcing strict technical standards. It is not uncommon now for different ports to have their own standards and requirements for ships entering and leaving. Ships are now smaller, as the regionalisation of trade has reduced the need for large-scale trade flows, as well as the distances travelled.

The geopolitical roots of fragmentation

Between 1950 and 2020 global trade volumes increased by an aggregate of 4,500%.[210] But the last decade has seen cross-continental trade over large distances become increasingly limited to high-value goods. Underpinning this has been the trade war between the US and China. Relations began unravelling in the early 2020s over tensions in the South China Sea and Taiwan;[211] concerns about China's naval forces and anti-access capabilities;[212] and competition around semiconductor and chip manufacturing.[213] To safeguard national production, countries began to shift away from the globalised production systems of the early 2000s to more localised systems that rely on regional and geopolitical links. Maritime routes are therefore shorter and are dominated by trade between neighbours. The regional trading blocs and agreements in the late 2010s and early 2020s—from the Regional Comprehensive Economic Partnership in Asia-Pacific to the US-Mexico-Canada agreement—were snapshots into more exclusive trade dynamics that persist today. Vessels are also increasingly being designed for short-haul trips. In addition, food has become increasingly localised, although this emerged largely out of climate necessity rather than as a reaction to global trade.

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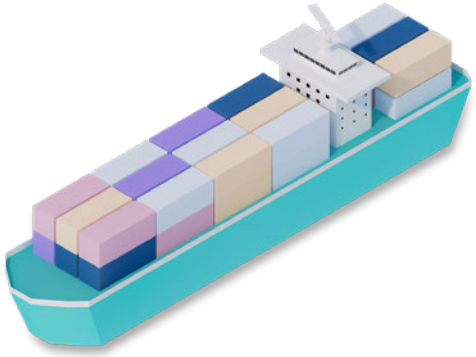


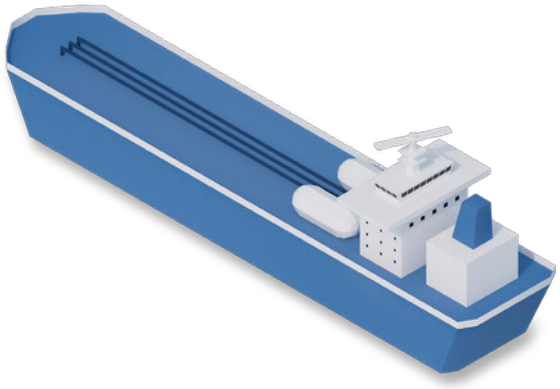
Power to the populous

The past two decades have also seen drastic population changes that have shifted how economies function. The Democratic Republic of the Congo, Egypt, Ethiopia, India, Nigeria, Pakistan, the Philippines and Tanzania were responsible for more than half of global population increases between 2022 and 2050,[214] making them home to the world's largest labour pools—and, in particular, the world's future seafarers. By the early 2040s, populous African nations became the primary source of seafarers for the industry, previously dominated by the Philippines and India. An important driver of this was the fragmentation and regionalisation of trade, which meant that shipowners turned to regional labour pools. But perhaps more importantly, the shipping industry in Asia continues facing stiff competition for labour from onshore activities, given the rise of manufacturing facilities to support localised supply chains, which created room for more African entrants.

Navigating in the dark

Global fragmentation on governance and trade has allowed dark fleets, particularly in the fishing industry, to operate under the radar. These first emerged in the 2020s, when the first global map of dark fleets was launched.[215] Between 2022 and 2030 global monitoring and tracking capabilities advanced, giving governments a better grasp of their main routes and activities. But the lack of global co-operation has undermined these efforts; although surveillance systems are more advanced, coordination and enforcement among national authorities is harder than it has ever been. As such, this has created a more conducive environment for them to operate freely.

The confluence of geopolitical challenges and new population dynamics have entrenched the fragmentation and regionalisation that took root in the early 2020s. Maritime trade has adapted, but the costs of this have not gone unnoticed. Due to today's entrenched regionalisation and fragmentation, international maritime trade is now increasingly costly due to lost economies of scale. Varying technical standards and the prevalence of dark fleets only complicate this further.



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What if... average global sea levels rise by at least 40 cm by 2050?

Note: each of these scenarios is fiction, but grounded in historical fact, current speculation and real science. They are set in the different possible futures identified in the preceding section.

SCENARIO:

Emil, who turns 60 this year, ends his career as a seafarer similar to how it began: along the Arctic shipping lane. His first job came in 2025: at the age of 35, he was asked to work on one of the few ships that crossed the Northwest Passage. Emil has worked on a range of different ships since, but today, in 2050, he returns from a final expedition on the same route as his maiden voyage.

Uncharted waters

It has been five years since Arctic Sea routes have become widely available.[216] This year, the Northern Sea Route and the Northwest Passage saw 20,000 ships transit through their shipping lanes, a record number that is comparable to the Suez Canal in 2022.[217] Just 20 years ago in 2030, this passage was limited to a handful of ships, due to geological limitations and insufficient port and logistics infrastructure. Climate change has made these routes accessible—albeit void of their previous biodiversity and climate benefits—and many others unreliable.

Unreliable conditions for workers and containers

The conditions on board are also tougher now than they have ever been. Unpredictable storms and natural disasters make being at sea riskier than ever. According to Emil, seafarers are now required to undergo training that equips them for harsh climatic conditions. "Despite all the preparations we receive, nothing prepares us for the realities on board, especially when working on routes as challenging as the Northwest Passage," he recounts.

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Safety and wellbeing have become an increasingly important concern for seafarers like Emil. The Polar Code (an international regulation for ships operating in polar waters) was adopted as early as 2015 to ensure that ships are designed to account for operational and safety considerations in polar waters, but seafarers remain worried about the environmental conditions and hazards at sea. Vessels must also follow strict protocols to align with increasingly specific insurance requirements. Climate conditions are tough as is, but travelling through Arctic passages comes with even larger risks that make insurance companies reluctant to insure certain goods. Likewise, shipowners are more nervous about how seafarers handle equipment.

Fragile ports and forgotten cities

The opening of the Arctic passage has resulted in a number of new ports in and around Canada and Greenland.[218,219] It also made existing ports more accessible and strategic. In 2020 there were 16 ports along the Northern Sea Route that were ice-covered but have since become essential.[220] Similarly, the ports of Kirkenes, Norway, and Vopnafjörður, Iceland, are now more important due to their location.[221] But these have come with high costs, not just in terms of development, but also in terms of the ports lost in the process. Once hubs for economic and social activities, the ports of Shanghai, Houston and Lázaro Cárdenas—all of which were identified as being most at risk from climate change in 2020[222]—are no longer in operation. Coastal communities were forced to relocate, either gradually through government programmes or immediately in response to extreme events.[223] In 2020 Indonesia's capital, Jakarta, was home to 30 million people.[224] Since then, 95% of its coastal areas have been entirely submerged,[225] forcing almost its entire population to relocate.[226] Tensions abound as these vast communities struggle to integrate and forget. The disappearance of ports and cities were a stark wake-up call.

New maritime ecosystems

This is just one of the ways in which the reality today differs from the norm in the 2020s. Melting sea ice has resulted in irreversible marine ecosystem changes within our oceans: what was once a tropical ecosystem is now an Arctic marine ecosystem. The repercussions of this are evident globally. Between 2020 and 2030, the four major sea regions of China, for instance, lost 15% of their economically important fish species.[227] Beyond this, some of the food baskets that once supplied the world with the vast majority of its nutrients, like the Mekong Basin, have largely dried up and lost their agricultural potential. Rising sea levels also contributed to higher rates of soil salinity,[228] while continued resource extraction depleted groundwater reserves.[229] This forced many countries to turn to aquaculture to meet growing demand for food and protein. Yet, despite technological progress, the limited availability of natural resources keeps prices high, making seafood a luxury that many cannot afford.

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Designing for uncertainty

In the context of these changes, for companies and individuals working to build ships of the future, the design process has proven to be the most challenging aspect. Back in 2020 ships used to be designed to fit the exact dimensions and requirements of various canals, say, for example, Panamax ships for the Panama canal[230] and Suezmax for the Suez Canal.[231] Rising sea levels and accompanying climate challenges have increased the frequency of coastal inundation and droughts, making it harder to rely on these dimensions. This uncertainty made it harder to design ships for 2050 and beyond, given the average lifespan of a ship is about 20 years, and comes with financial repercussions in the immediate term.

A majority of the ships used today were built between 2030 and 2040. But some of these are no longer fit for purpose to navigate today's routes. Indeed, recent negotiations between industry leaders and policymakers came to a halt when parties failed to reach consensus on new ship design standards. Additionally, existing ports have had to be redesigned to adapt to sea level rise: elevating port areas above current sea levels and building protection measures against inundation and extreme weather.[232,233] Although effective in reducing disruption to infrastructure, these have also restricted the movement of ships.[234] Overall, the number of new ports has almost doubled since 2020 to continue to meet growing trade demands, many of which were designed to be climate resilient at the outset.[235]

Following unsuccessful attempts to reduce emissions in the 2020s, the world is now having to cope with the impacts of climate change head on. The opening of the new Arctic trade route has been symbolic of so much that has been lost in the last few decades: from thriving ecosystems to human livelihoods and community histories. The world now operates in a state of heightened uncertainty that forces us to make rash decisions and accept what comes our way.

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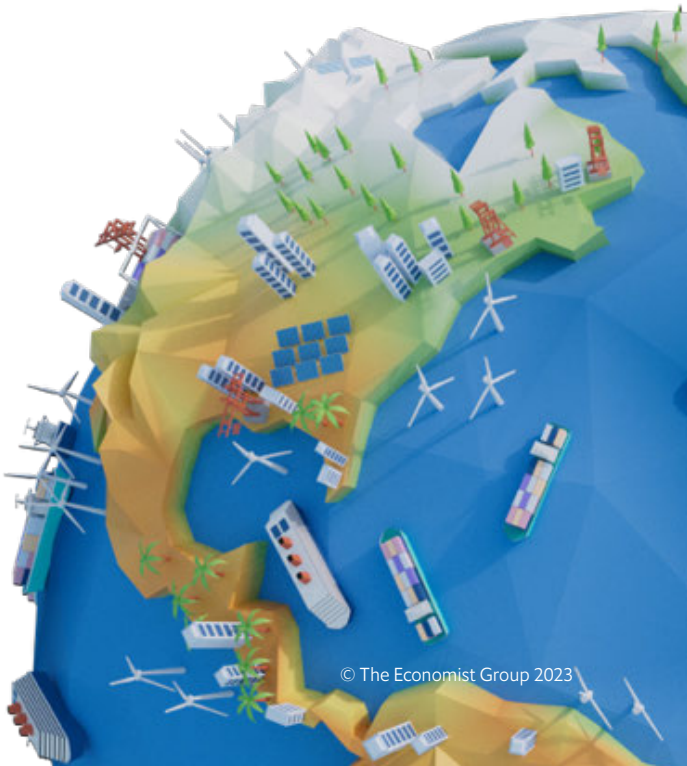
Conclusion

As the maritime sector prepares to decarbonise its activities and supply chains, while navigating an increasingly uncertain geopolitical, economic and social landscape, it is important for industry and policymakers to start envisaging what possible futures could look like. Global co-operation and the integration of technology—be it rapid or gradual—will be crucial preconditions to secure futures that are conducive to a thriving maritime economy, and life on this planet more broadly.

Our first two scenarios explore the widespread adoption of green hydrogen and the prevalence of automated solutions in the industry. They represent two positive visions for the industry, and shed light on what could get us there, the challenges and opportunities. Conversely, the scenarios on sea-level rise and fragmented global trade paint a bleaker picture of the future of the maritime industry. They both seek to imagine what the world could look like in the context of failed attempts at global co-operation, which prevents the integration of technology, however rapid or slow, to meaningfully benefit societies and economies.

To decarbonise at the scale and urgency needed, this report is a reminder that co-operation and innovation are not only necessary, but also need to go hand in hand to realise futures that are productive, fair and liveable. The tools and pathways are there, but to see how these can come to life, we need the creativity and courage to imagine what futures are available to us. Our hope is that this exercise allows industry leaders and local and national policymakers to start planning for these plausible—albeit currently fictional—scenarios.



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Appendix: detailed literature review methodology

The aim of the literature review was to provide a critical and objective review of the key geopolitical/macroeconomic, social, environmental, natural resources and technological trends shaping the global economy up to 2050 and their impact on the maritime sector. For this, Economist Impact was guided by the following research questions:

1. What are the key trends affecting the maritime sector by 2050? What does each decade (2030s/2040s/2050s) look like?
2. How can maritime stakeholders prepare for major risks arising from these trends?
3. To what extent can the maritime sector harness new opportunities?
4. How will people within maritime value chains be affected?
5. What if certain policy or technological breakthroughs (for example on alternative fuels or pollution regulation) were achieved by 2050? How could they come about?

Economist Impact conducted a pragmatic review based on grey literature. The types of sources consulted include the following, but the full and accurate list of references are included as footnotes:

- **Private-sector reports** (examples: Maersk; MSC; CMA CGM; DP World; APM Terminals; The Economist Intelligence Unit)
- **Academic journals/Google Scholar** (examples: *PNAS, Frontiers in Sustainable Food Systems, Journal of Maritime Economics and Logistics, Sensors*)
- **International organisations** (examples: IEA; UNCTAD; IMF; IMO; BIMCO; INTERCARGO; International Chamber of Shipping; Global Maritime Forum; World Shipping Council; Chatham House; the World Bank; IRENA; ADB)
- **News sources** (examples: *The Economist; Financial Times; Hydrogen Insight; BBC; Energy Live News*)

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The literature review was guided by, but not limited to, the following search terms with a focus on maritime trade (commercial shipping, fishing, naval, aquaculture), its vessels (design/propulsion/fuel/technology), energy (production/availability), ports, wider supply chains, regulations, investment gaps, people and skills:

- For the overall topic: maritime, shipping, ports, value chains, seafarers, shipbuilders, shipowners, cargo owners
- For geopolitical/macroeconomic trends: regional conflicts, trade wars, piracy
- For social trends: workers' rights, inclusivity and diversity
- For environmental trends: greenhouse-gas emissions, air pollution, noise pollution
- For technological trends: alternative fuels, AI, big data

The outcomes of our internal consultation with sectoral experts from Economist Impact and The Economist Intelligence Unit helped narrow our search terms further to look specifically at: deglobalisation; population growth; securitisation; climate technology; environmental finance; climate adaptation (finance and development); food technology; renewable energy sources, trade and production; the evolution of AI and the metaverse; automation; shareholder business models; social inequalities; climate migration; and economic migration.

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