MIT Technology Review Insights

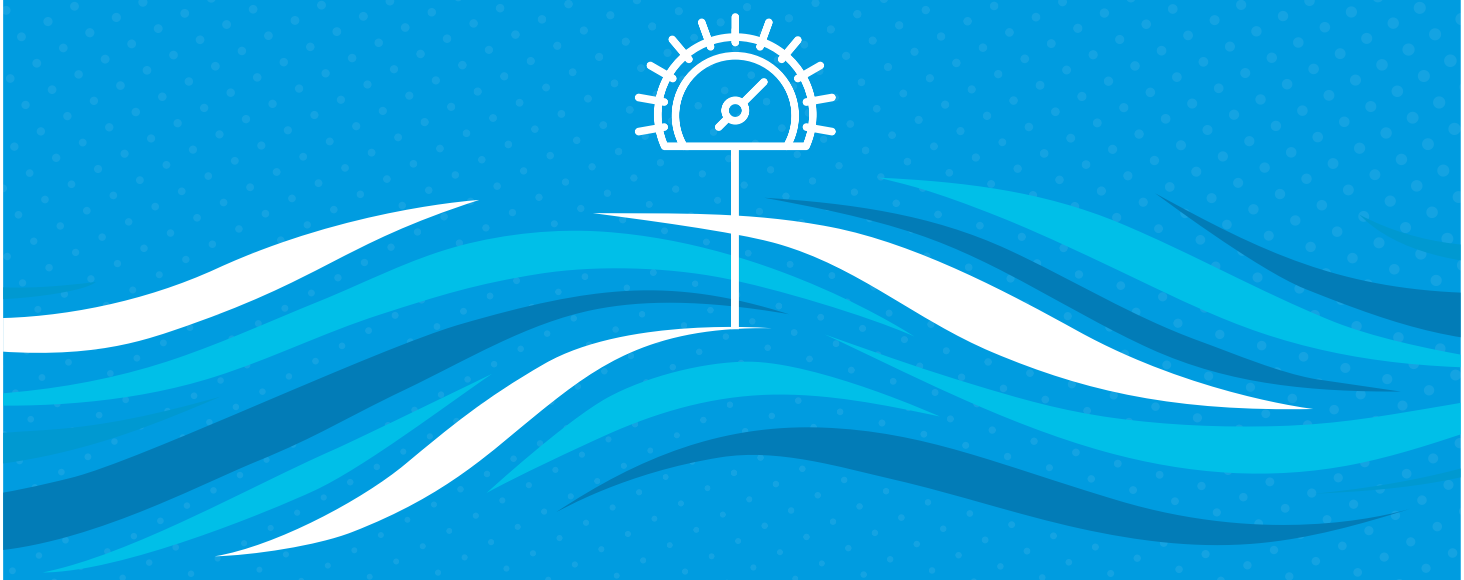
PARTNERS

Premier
Infosys

Platinum
Morgan Stanley

Gold
Canada's Ocean Supercluster

The Blue Technology Barometer



Ranking the economies that promote future ocean sustainability through new technology

Preface

MIT Technology Review Insights conducted a global research initiative to examine where and how "blue technologies" are being engaged to further efforts to clean up the oceans, reduce sea-related carbon emissions, and make maritime economic activities more economically and environmentally viable. These activities and assets have been quantified and ranked for 66 countries and territories with large or economically significant ocean coastlines. Ross O'Brien was the lead writer of the report, Jason Sparapani, Francesca Fanshawe, and Laurel Ruma were the editors, and Nicola Crepaldi was the producer.

MIT Technology Review Insights would like to thank the following individuals for their time, perspective, and insights:

Brad Ack, Executive Director and Chief Innovation Officer, Ocean Visions

Britta Bienen, Professor, Oceans Graduate School and Centre for Offshore Foundation Systems, University of Western Australia

Martin Cresswell, Technical Director, Hong Kong Shipowners Association

Sidhant Gupta, Founder and CEO, Clearbot

Andrew Hudson, Head, Water and Ocean Governance Programme, United Nations Development Programme

Pierre Lermusiaux, Associate Department Head for Operations, Department of Mechanical Engineering, MIT

Ghislaine Llewellyn, Deputy Oceans Leader, WWF International

Ronán Long, Director, WMU-Sasakawa Global Ocean Institute, World Maritime University

Tony Long, CEO, Global Fishing Watch

Bev Mackenzie, Manager of Marine Environment, BIMCO

Peter Neill, Founder and Director, World Ocean Observatory

Millicent Pitts, CEO, Ocean Exchange

Thierry Senechal, Managing Director, Finance for Impact

Boyan Slat, Founder and CEO, The Ocean Cleanup

Daniel Vermeer, Executive Director, Center for Energy, Development, and the Global Environment, Duke University

Daniel Watson, Co-founder and CEO, SafetyNet Technologies

Doug Woodring, Founder and Managing Director, Ocean Recovery Alliance

Contents

Executive summary

On the first day of the 2021 United Nations Climate Change Conference of the Parties (COP26), Prince Albert II of Monaco launched the third "Because the Ocean" declaration, noting the critical role the world's oceans play in the fight against climate change, such as absorbing over a quarter of the world's carbon dioxide emissions and most of its excess heat. But the fact that a separate pronouncement about the oceans needs to be made at the world's largest and most influential climate event also points to a lack of coordination between efforts to enhance marine sustainability and broader efforts to reduce carbon emissions.

A growing number of technologies and tech-enabled processes—known collectively as blue technology, or blue tech—are becoming important in several contexts that can help mitigate the effects of climate change or restore health to marine ecosystems. Science- and nature-based approaches are addressing environmental degradation and increasing decarbonization, either through directly removing carbon dioxide from the ocean or by using the ocean as a "platform" for renewable energy. Blue technologies are also creating and managing information and insight into maritime commercial activities through sensors and artificial intelligence-enabled analytics. Better and more complete data on the ocean and maritime industrial activities will help accelerate blue innovation and, over time, break down silos between conservation and decarbonization efforts to address climate change on land, in the atmosphere, and at sea.

The Blue Technology Barometer is a ranking of 66 countries and territories with large or economically significant ocean coastlines on their progress and commitment toward protecting ocean sustainability. The index consolidates scores given to each country or territory across four pillars: ocean environment, marine activity, technology innovation, and policy and regulation. The key findings are as follows:

- The top 10 scorers in the barometer—the "blue technology leaders"—are all advanced economies and, with the important exception of South Korea, are all Western economies. At 7.83, the United Kingdom ranks first, in large part because of its blue technology ecosystem and its leadership position in offshore renewable energy facilities, which includes the world's largest offshore wind farm. Germany follows closely, at 7.54; the German government has been a strong advocate and investor in coastal marine conservation at home and abroad. The United States (7.23) ranks fourth, propelled by the strength of its blue technology innovation sector. Four Nordic countries, which have collaborative solutions-minded governments and deep digital technology innovation ecosystems with numerous links to their maritime economies, are in the top 10: Denmark (7.37), Finland (6.93), Norway (6.92), and Sweden (6.71) rank third, fifth, sixth, and eighth, respectively.

There are many fronts on the raging war on the health of the world's oceans. Climate change is leading to warming water temperatures, rising sea levels, and disturbances in ocean salinity. Increased protein consumption is driving fishing to unsustainable levels, and systemic failures to manage waste have led to 150 million tons of plastic in our oceans today.

- After the top 10 leaders, the next 20 countries form the "blue technology challengers," with median scores in a gentle slope from Japan (11th, at 6.37) to India (30th, 4.67). While their overall scores show that challengers are making broad overall progress toward ocean sustainability, many countries reveal large divergences in the scores of two or more pillars. This uneven performance in countries' overall scores in most cases points to misalignments between the efforts of their maritime industries, governments, and conservation communities. Many countries in the bottom 60%, which we refer to as the "blue technology strivers," often struggle with the challenge of balancing the cultivation of economically viable maritime industries with ocean conservation efforts and usually lack the investment and scientific resources to build technology to compensate.
- Every economy in the world, and particularly ones with maritime industries and communities dependent on ocean coastal ecosystems, needs to do more to mitigate the effects of their activities on the ocean and life in the cryosphere, or frozen areas of the planet. This requires a mixture of actions and an accelerated use of new technologies. It also requires a willingness to coordinate various ocean sustainability research and conservation efforts. It's in these efforts to align scientific discovery and empirical observations on a global scale, in a way that connects the efforts of climate activists—on land and on the ocean—that blue technology will succeed in accelerating global sustainability efforts.

Methodology

The Blue Technology Barometer was developed on the analysis of select datasets and primary research interviews with global blue technology innovators, policymakers, and international ocean sustainability organizations. It quantifies the economies of 66 countries and territories with large or economically significant ocean coastlines along four separate pillars: ocean environment, marine activity, technology innovation, and policy and regulation. Within each pillar, a series of indicators—a list of qualitative and quantitative factors—were then selected and populated. Through trend analysis, research, and a consultative peer-review process with several of the subject matter experts interviewed for this report, weighting assumptions were assigned to determine the relative importance with which each indicator and pillar influenced a country's blue technology leadership.

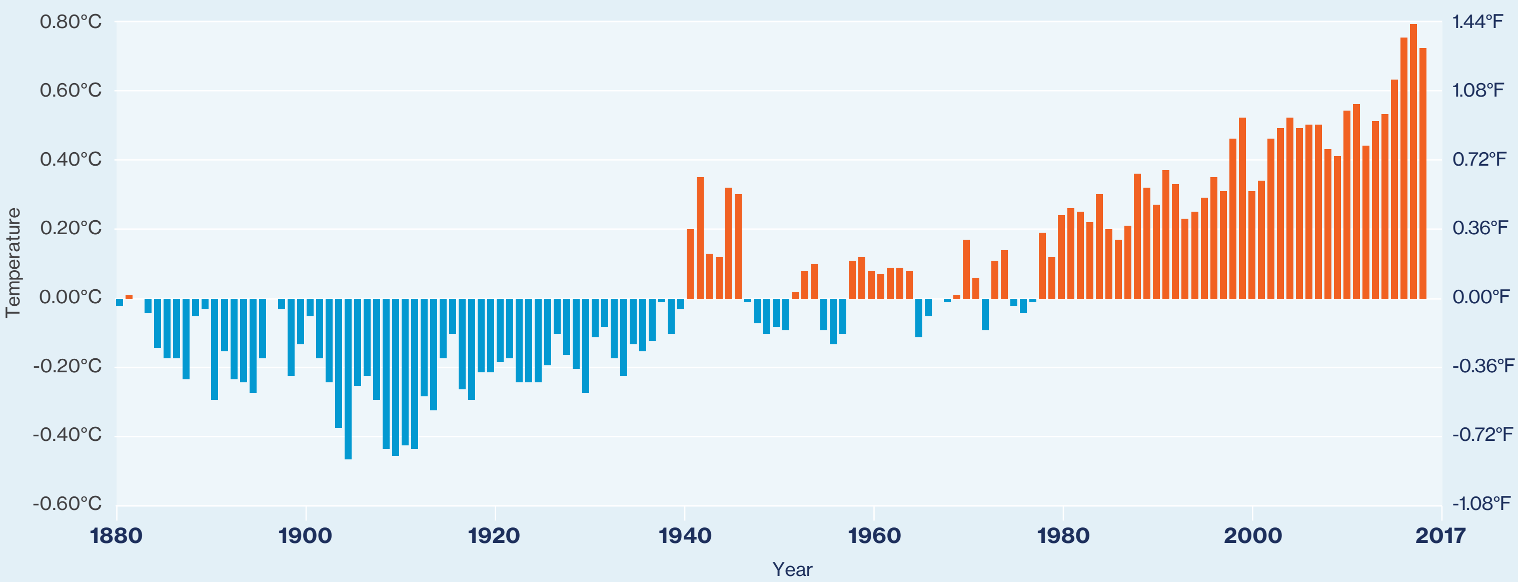
01 Introduction

Deep and wide: The world needs more blue technology

There are many fronts in the raging war on the health of the world's oceans. Climate change is steadily warming air and water temperatures, which will accelerate the melting of polar ice sheets—so much so that NASA recently forecast it will add 38 centimeters to global sea levels by the year 2100, or roughly half a centimeter annually for the rest of the century.[1] Warming, rising seas will not only create further disturbances in ocean salinity and pollution levels—they will force massive shifts in the livelihoods of the nearly 30% of the world's population that lives along its coasts (see Figure 1). Fast-growing economies have radically increased global trade and protein consumption, which is driving ocean-going transportation and commercial fishing to increasingly unsustainable levels. Systemic failures to recycle and manage solid waste have added 8 million tons of plastics to the 150 million tons in our oceans today, according to the nonprofit Ocean Conservancy.

Although nation-states and global corporations are stepping up efforts to promote cleaner oceans and more sustainable marine activity, the scope of the challenge is

Figure 1: Average change in global sea surface temperature, 1880-2017



Source: Compiled by MIT Technology Review Insights using data from NOAA, 2021[2]

Blue technology is being looked to as a means to boost efforts to combat climate change and restore marine health.

daunting. The European Investment Bank launched its Blue Sustainable Ocean Strategy in October 2019 to increase sustainable ocean-related economic activities, and is committing some €5 billion for blue economy projects. But that amount seems minuscule given the size of the problem.

Thus, technology and innovation are being looked at as levers to give ocean sustainability efforts scale. A growing number of technologies and tech-enabled processes—known collectively as blue technology, or blue tech—are becoming important in several contexts that can help mitigate the effects of climate change or restore health to marine ecosystems. One context includes science- and nature-based approaches to reduce pollution and address environmental degradation, such as microbial biotechnology approaches or "carbon-negative" polymers to take on the challenge of accumulating ocean plastics. Another context is the collection of attempts to increase decarbonization, either through directly removing carbon dioxide from the ocean or using the ocean as a "platform" for renewable energy. A third context is one that will arguably be the most impactful for global marine sustainability efforts: the creation and management of information and insight into maritime commercial activities, through sensors and AI-enabled analytics. Better, and more complete, data on the ocean and maritime industrial activities will accelerate blue innovation cycles, help the carbon- and resource-intensive shipping and fishing sectors operate more sustainably and, ideally over time, break down silos between conservation and decarbonization efforts to address climate change on land, in the atmosphere, and at sea.

Introducing the Blue Technology Barometer

The Blue Technology Barometer aims to assess the extent to which the world's maritime economies promote and develop blue technologies that help reverse the impact of climate change on ocean sustainability and integrate them into the larger fight to radically reduce, and ultimately remove, carbon from the atmosphere. MIT Technology Review Insights has compiled 20 separate quantitative and qualitative data and indicator sets for 66 countries and territories with coastlines and maritime economies. These indicators combine measures on how each country or territory's economic and maritime industries have affected its marine environment and how quickly it has developed and deployed technologies that help improve ocean health outcomes. Policy and regulatory adherence factors were also taken into consideration, particularly a country's observance of international treaties on fishing and marine protection. Cross-border cooperation is not only essential to making progress on environmental action in international waters—it underpins efforts to gather and process data about ocean health indicators such as temperature, acidity, and fish stock levels—so scientists, activists, corporations, and consumers can work together to craft more sustainable approaches.

These indicators have been organized into four pillars, each of which evaluates a set of metrics around a key driving theme: ocean environment, marine activity, technology innovation, and policy and regulation.

- **Ocean environment:** Carbon emission levels, and relative growth, that result from maritime activities. This pillar also contains metrics that assess a country's efforts to mitigate ocean pollution and enhance ocean ecosystem health.
- **Marine activity:** Efforts to promote sustainable fishing activities and increase and maintain marine protected areas.
- **Technology innovation:** Progress in fostering the development of sustainable ocean technologies across several relevant fields:
  - The "clean innovation" scores from MIT Technology Review Insights' Green Future Index 2021;
  - A tally of "maritime-relevant" patents and technology startups; and
  - An assessment of each economy's use of technologies and tech-enabled processes that facilitate ocean sustainability.
- **Policy and regulation:** Level of commitment to signing and enforcing international treaties to promote ocean sustainability and enforce sustainable fishing.

Figure 2: The Blue Technology Barometer country rankings

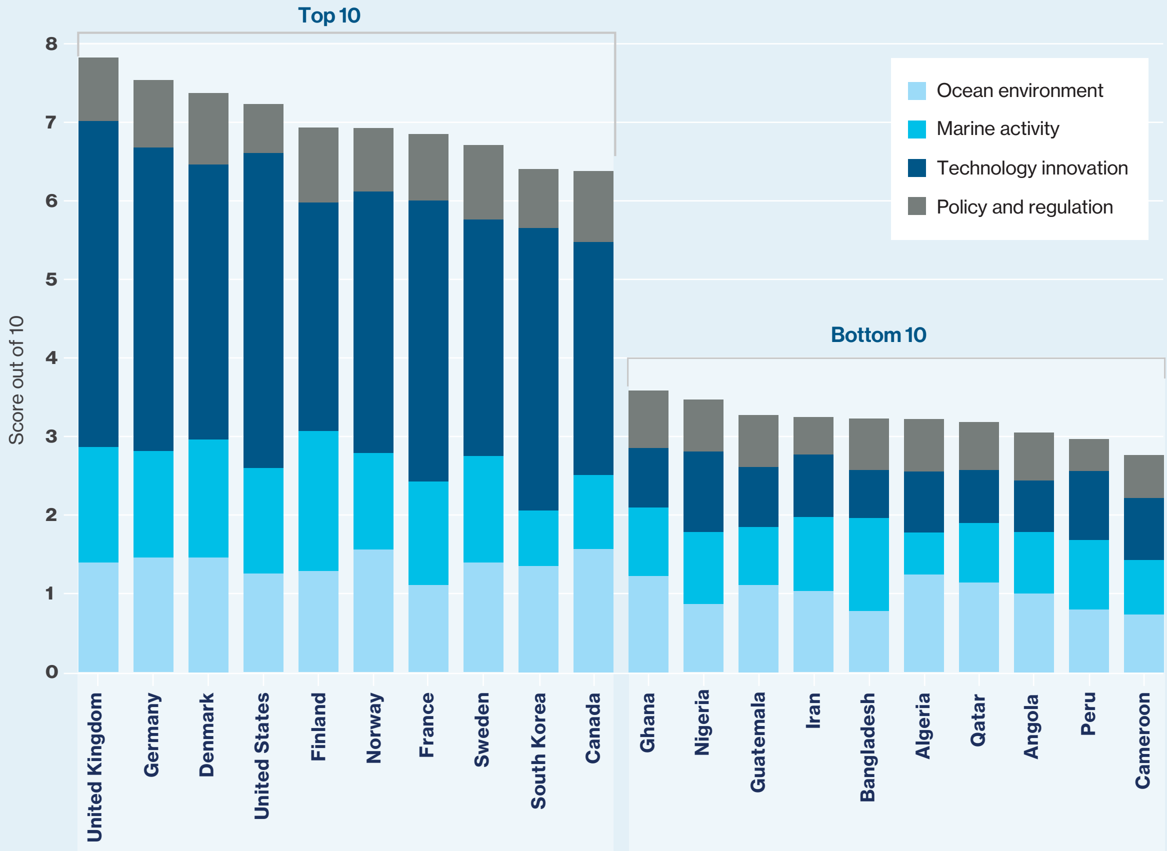
Leaders	The 10 countries making the greatest progress and commitment toward protecting ocean sustainability.	1	United Kingdom	7.83	6	Norway	6.92			
		2	Germany	7.54	7	France	6.85			
		3	Denmark	7.37	8	Sweden	6.71			
		4	United States	7.23	9	South Korea	6.40			
		5	Finland	6.93	10	Canada	6.38			
Challengers	The 20 countries that are making progress or commitment toward protecting ocean sustainability.	11	Japan	6.37	18	Taiwan	5.59	25	Arab Emirates	5.09
		12	Belgium	6.28	19	Brazil	5.49	26	Portugal	4.94
		13	Netherlands	6.13	20	Poland	5.40	27	Iceland	4.83
		14	Spain	6.04	21	Italy	5.38	28	New Zealand	4.77
		15	Australia	5.97	22	Chile	5.32	29	Philippines	4.69
		16	Ireland	5.81	23	Singapore	5.28	30	India	4.67
		17	China	5.70	24	Greece	5.26			
Strivers	The 36 countries that are making slow and uneven progress or commitment toward protecting ocean sustainability.	31	Russia	4.65	36	Dominican Republic	4.38	41	Ukraine	4.17
		32	Colombia	4.55	37	Egypt	4.37	42	Saudi Arabia	4.16
		33	Romania	4.54	38	Thailand	4.3	43	Indonesia	4.13
		34	Mexico	4.49	39	Ecuador	4.29	44	Malaysia	4.08
		35	South Africa	4.48	40	Costa Rica	4.18	45	Hong Kong, China	4.08
		46	Bulgaria	4.01	51	Argentina	3.94	56	Pakistan	3.61
		47	Vietnam	3.99	52	Tanzania	3.89	57	Ghana	3.58
		48	Uruguay	3.97	53	Kenya	3.87	58	Nigeria	3.47
		49	Israel	3.96	54	Morocco	3.65	59	Guatemala	3.27
		50	Turkey	3.94	55	Kuwait	3.64	60	Iran	3.24
		61	Bangladesh	3.23						
		62	Algeria	3.22						
		63	Qatar	3.19						
		64	Angola	3.05						
		65	Peru	2.97						
		66	Cameroon	2.76						

Source: MIT Technology Review Insights, 2021

Each indicator is scored from one to 10 (10 being the best performance in each) and is weighted in its contribution to its respective pillar. Each pillar is then given a weight to determine its importance in the overall score of the country. As our research efforts center on which countries are developing blue technology to promote ocean health, the technology pillar is ranked highest, at 50% of the overall score.

The top 10 scorers—blue technology leaders—are all advanced economies and, with the important exception of South Korea, are all Western economies (see Figure 3). At 7.83, the United Kingdom ranks first, in large part because of its blue technology ecosystem: the country has robust research and development in maritime and sustainability technologies, a number of blue tech startups, and is one of the most committed developers of offshore renewable energy, operating the world's largest operational offshore wind farm, a 50-megawatt facility off the coast of Aberdeenshire, Scotland. The UK is also committed to fishing and marine conservation activities and has made modest but significant progress on reducing carbon dioxide from marine activities. Germany follows closely, at 7.54: it is also a maritime technology leader, and the German government has been a strong advocate and investor in coastal marine conservation at home and abroad. Much of

Figure 3: Pillar-to-pillar comparison: Top 10 versus bottom 10



Source: MIT Technology Review Insights, 2021

Germany's domestic coastal sensitivity has a pragmatic focus on combating the effects of extreme flooding and rising sea levels (Hamburg is undergoing a 30-year, half-billion-dollar effort to refurbish its 100 kilometer network of seawalls and dikes),[3] which was again brought into sharp relief after the devasting floods of summer 2020. The United States (7.23) is ranked fourth, also propelled by the strength of its blue technology innovation sector.

Nordic countries, which combine pro-technology approaches to fight climate change with mature shipping and fishing industrial clusters and collaborative, solutions-minded governments, take up four of the top 10 slots: Denmark (7.37), Finland (6.93), Norway (6.92), and Sweden (6.71) rank third, fifth, sixth, and eighth, respectively. All these countries have deep digital technology innovation ecosystems with numerous links to their maritime economies; Sweden's Ericsson announced plans in 2020 to develop a 5G-based cellular mesh network running between ships and shore-based infrastructure.[4] And Nordic countries are staunchly globally minded in their efforts to promote ocean sustainability: Finland's government in May adopted a resolution to pressure international agencies to reduce greenhouse gas emissions from maritime and inland waterway transport.[5]

South Korea (6.4) and Canada (6.38) close out the leaders in ninth and 10th places. South Korea is the world's powerhouse in blue technology intellectual property, with three times as many patents in maritime sustainability technology filed over the last decade as the US has. Tidal wave energy is a particular area of competence; South Korea has several companies developing onshore and offshore wave conversion approaches, notably Ingine, which has been developing wave energy projects across the Pacific, including a recent clean energy collaboration project with an indigenous community in British Columbia.[6]

The United Kingdom ranks first, in large part because of its blue technology ecosystem.

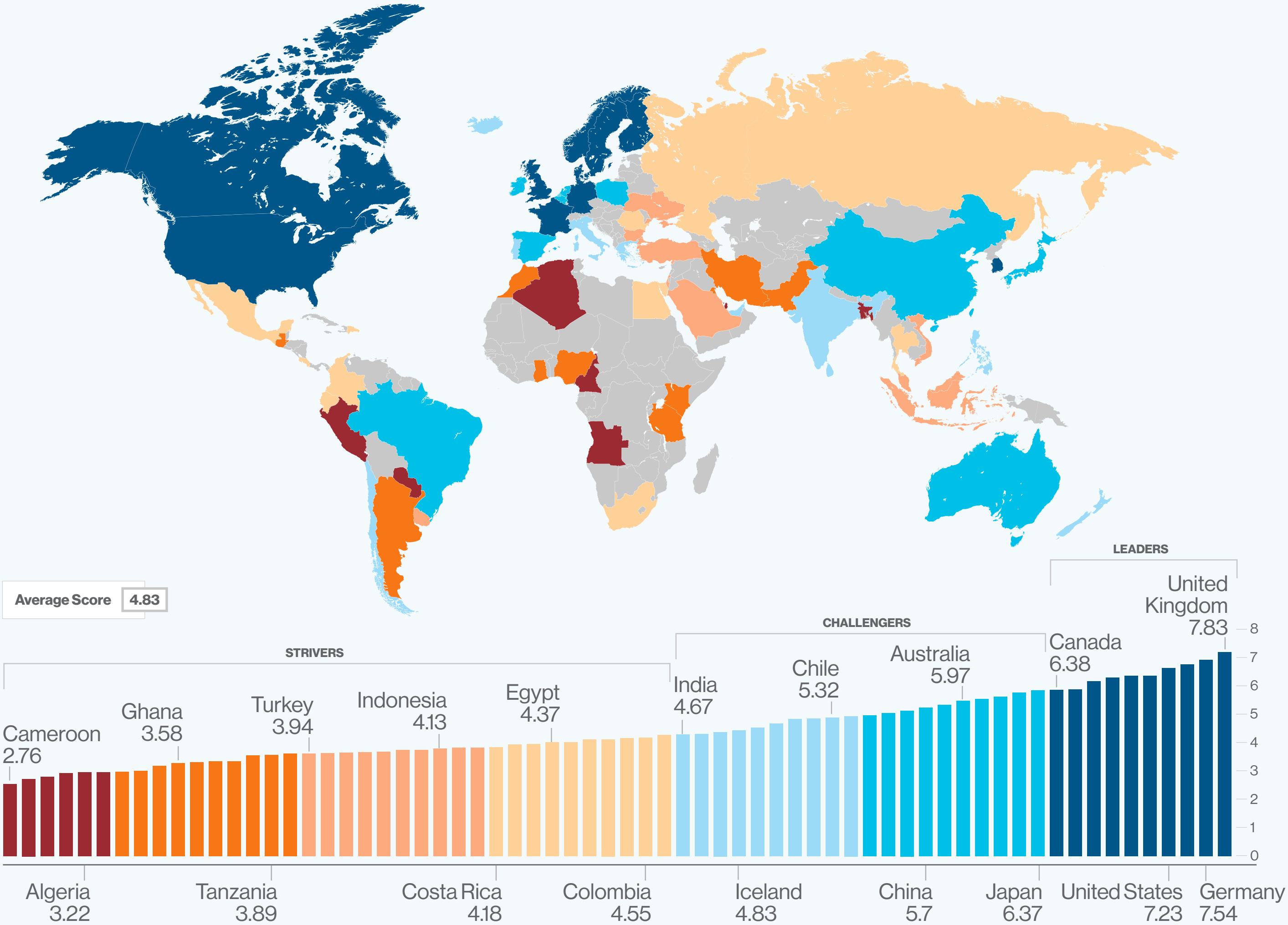
Unfortunately, there's often a lack of coordination between efforts to increase the health and resilience of the ocean and more terrestrial, or land-based, efforts to reduce carbon emissions, when in fact they're inexorably linked and success in one sphere depends on the other. After the top 10, 15 countries form the blue technology challengers, with median scores in a gentle slope from Japan (11th, at 6.37) to Australia (15th, at 5.97) to Poland (20th, 5.4) to India (30th, 4.67). While their overall scores show that challengers are making broad overall progress toward ocean sustainability, many countries reveal large divergences in the scores of two or more pillars.

This uneven performance in countries' overall scores in most cases points to misalignments between the efforts of their maritime industries, governments, and conservation communities. Japan, for one, fosters a highly R&D-driven industrial economy, and its high score in the technology pillar points to the government's intention to transform its maritime industries—its "Roadmap to Zero Emission from International Shipping" program aims to develop a carbon-neutral ocean vessel by 2028.[7] But Japan's blue innovation gains are weighed down by poor scores in carbon emissions reductions and slow progress on ocean health, which places its ocean environment score toward the bottom of the pack. Australia, thanks to a national commitment to ocean pollution management and marine conservation, is the leader in the ocean environment pillar, but has a middling technology innovation performance.

Diverging pillar scores become more pronounced the further down the "challenger" ranks, as the economic and maritime resource security pressures of more emerging economies come into conflict with broader attempts to use technology to fight climate change. This is particularly true for China (17th, 5.7), whose resolute focus on decarbonizing its economy has expanded to include R&D investment in blue technology, bolstering its renewable energy program with offshore power, and enhancing efficiency in its maritime industries with robust satellite infrastructure. Yet China's high ranking (fourth) in the technology innovation pillar is countered by its less-than-average scores in every other pillar. The country's expansive deep-water fishing industry is particularly problematic and emblematic of its poor efforts to contribute to international marine conservation, as its fleets put pressure on efforts to combat illegal, unreported, and unregulated fishing. The Environmental Justice Foundation estimates that poor regulation of international trawlers by Ghana (57th, 3.58) costs the nation's fishing industry—which provides livelihoods for 10% of the country—tens of millions of dollars in lost revenue annually.[8]

Seafood is not the only contentious resource-access issue complicating the ability of nations to commit to sustainability. The world's oceans are also increasingly seen as a collection of natural resources that can be exploited to develop low-carbon technology and processes. Deep sea miners have their sights set on areas such as the Clarion-Clipperton Zone, an expansive area of the North Pacific off Mexico that's believed to hold large deposits of polymetallic nodules; these iron and manganese oxide compounds have rich stores of the rare earth minerals used in lithium batteries and other low-carbon technologies. Ironically, many countries keen on such exploration include small island nations, which are bearing the brunt of the economic, social, and environmental degradation climate change is causing. The tiny Micronesian country of Nauru, through a joint venture with a Canadian mining company, has plans to mine the Clarion-Clipperton Zone and has given the United Nations' International Seabed Authority a two-year warning that it will do so unless deep sea mining laws are further clarified, exploiting a clause in the United Nations Convention on the Law of the Sea.[9] Formalized in March 2021, India's national Blue Economy Policy blends national and resource security strategies with marine sustainability efforts; the former includes an Arctic exploration program

Figure 4: The Blue Technology Barometer rankings world map



Source: MIT Technology Review Insights, 2021

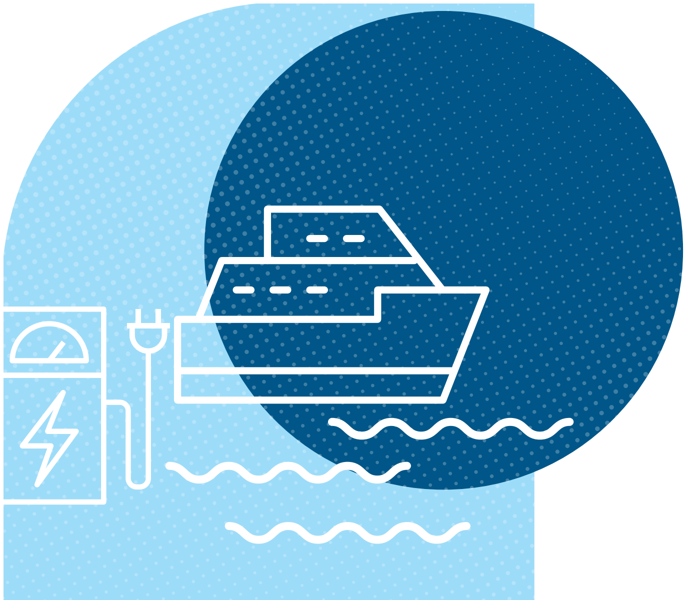
and a Deep Ocean Mission, which claims exclusive rights for deep sea mining of polymetallic nodules in 75,000 square kilometers of international waters.

Many countries in the bottom 60%, which we refer to as the blue technology strivers, often struggle with the challenge of balancing the cultivation of economically viable maritime industries with ocean conservation efforts and usually lack the investment and scientific resources to build technology to compensate.

Every economy in the world, and particularly ones with maritime industries and communities dependent on ocean coastal ecosystems, needs to do more to mitigate the effects of their activities on the ocean and life in the cryosphere, or frozen areas of the planet. This requires a mixture of actions and an accelerated use of new technologies. It also requires a willingness to coordinate various ocean sustainability research and conservation efforts. This includes combining or collocating multiple blue technology deployments—offshore wind platforms that host seaweed farms, for instance—as such initiatives are critical to efforts to increase ocean resilience at scale. Such thinking is most important in technology and policy framework developments that parlay ocean health action into more systemic efforts to decarbonize the planet. The Blue Technology Barometer provides a view of the steps leading nations are taking to combine and coordinate the applications, resources, and social will required to achieve this.

02

Ocean environment



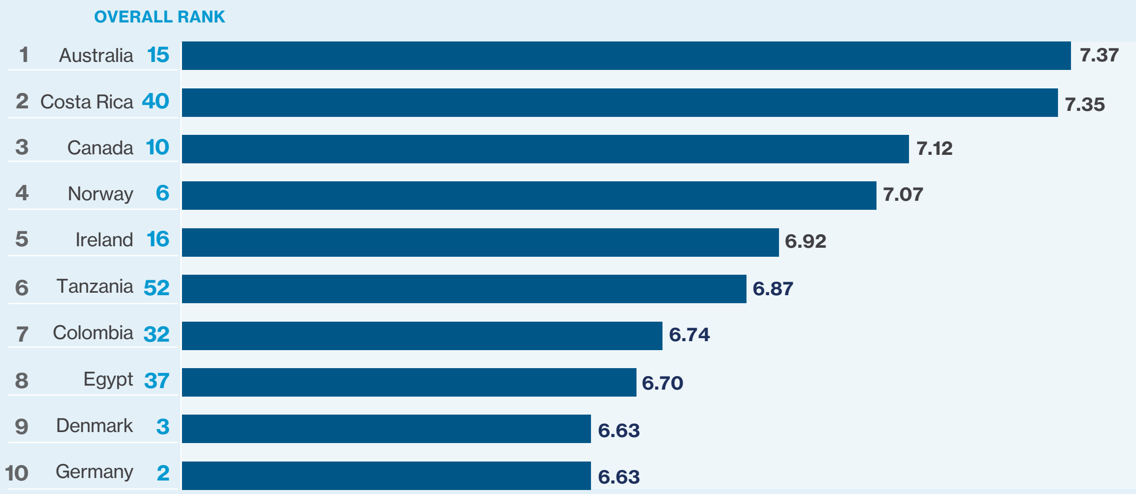
The Blue Technology Barometer measures each country's environmental impact on its maritime environment as well as the greenhouse gas emissions it produces through shipping, fishing, and other maritime activities. The indicators combine data on carbon emissions levels, and recent changes, with coastal pollution efforts and ocean health and recycling efforts. Blue technology leaders are active participants in efforts to reduce carbon emissions in maritime shipping and transport and are keen investors in technology aimed at mitigating coastal pollution. Tackling carbon emissions among oceangoing vessels is a challenge for even blue technology leaders, as the global shipping industry in many ways acts as a country unto itself, and it's largely outside the purview of national carbon emissions reduction plans.

But domestic maritime transportation figures into such plans. And the number of projects to introduce clean energy-powered ferries, barges, and other coastal boats into port and public transportation systems is growing (see Figure 5). Electric ferries launched in Kingston, Quebec, could lead to a broader transition toward electric marine transportation across Canada (10th overall, and third in the ocean environment pillar). Innovation-intensive decarbonization efforts in marine transport are even cropping up in blue technology challengers, particularly in island emerging economies: the Philippines, which already performs well on marine sector emissions reductions, has been developing a plan to electrify inter-island ferries nationwide as a key component of its overall Paris Agreement commitment to reducing carbon emissions. These efforts have even produced prototype ferries using wave energy.

> Reducing carbon emissions in oceangoing vessels is a challenge as the global shipping industry is largely outside the purview of national carbon reduction plans.

Blue technology strivers, by contrast, often mesh larger industrial and economic development strategies with ocean sustainability, and the former drivers outweigh the

Figure 5: Top 10 in the ocean environment pillar

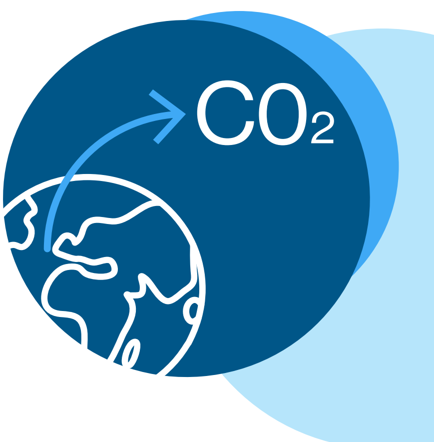


Source: MIT Technology Review Insights, 2021

latter. Vietnam (47th overall) has several blue economy development goals that include pollution management and promoting sustainable marine industries. But with the country in 58th place on the ocean environment pillar, it's likely that these goals have been overshadowed by government efforts to have Vietnam's 28 coastal cities and provinces account for at least two-thirds of its gross domestic product by 2030.

Removing carbon

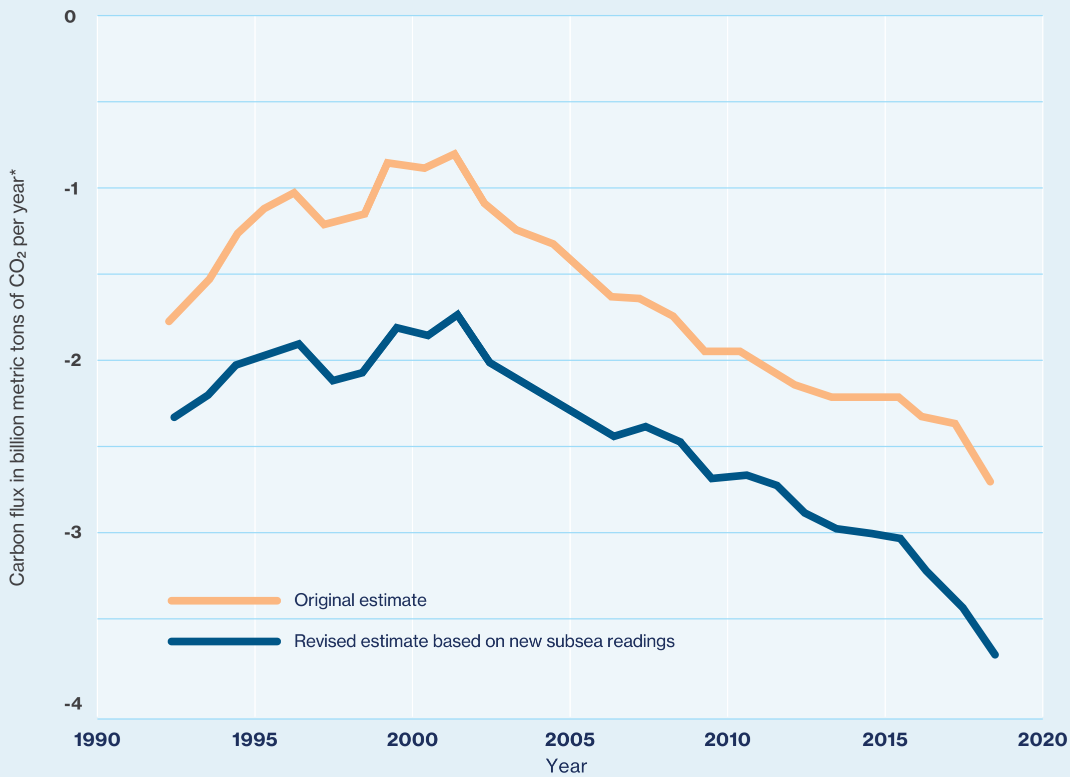
Ocean ecosystems bear the brunt of global warming. It has been estimated that the world's oceans capture and store between roughly a third of the world's greenhouse gas emissions and most of the excess heat created by human activity. But research in 2020 from Nature Communications, using corrected data for temperature gradients between the surface and a few meters' depth, suggests that the oceans have likely absorbed 67 billion tons of carbon dioxide between 1992 and 2018—nearly 50% higher than previous estimates (see Figure 6).[10] Higher carbon capture puts more pressure on ocean acidity and temperature levels, contributing to ecosystem degradation and extreme weather events. If these carbon dioxide volumes go unchecked, the ocean's role as a global carbon sink will be unsustainable. Luckily, many blue technology responses are emerging to extract carbon dioxide from the ocean, which will restore and reinforce its role as a system for carbon sequestration, or removing carbon dioxide from the atmosphere. These include cultivating macroalgae and sinking large amounts



Ocean ecosystems bear the brunt of global warming. The world's oceans capture and store about a third of greenhouse gas emissions and most of the excess heat created by human activity.

Figure 6: Effect of near-surface temperature corrections on ocean CO_2 levels

Research using corrected data for temperature gradients between the surface and a few meters' depth, suggests that the oceans have likely absorbed nearly 50% more carbon dioxide than previous estimates.



*Carbon flux is the amount of carbon exchanged between the earth's atmosphere and the ocean. The carbon flux is negative because the ocean absorbs more CO_2 than the air in the annual exchange.

Source: Compiled by MIT Technology Review Insights using data from Nature Communications, 2020[11]

of seaweed to capture and sequester carbon, or using ocean-based carbon dioxide removal (CDR) technology to manipulate seawater through physical, chemical, or electrical means.

Brad Ack is executive director and chief innovation officer at Ocean Visions, a US-based coalition of oceanographic research institutions, conservation groups, and corporations that helps develop new climate and ocean sustainability technologies. Ocean Visions has drafted three technology roadmaps for CDR technologies "that use the power of the ocean to remove carbon dioxide and permanently store it." The first involves macroalgae and cultivating seaweed to capture and sequester carbon, in the deep sea as well as in coastal waters. The second approach centers on alkalinity enhancement: alkaline materials mixed with seawater creates a chemical reaction that takes carbon dioxide out of the water, and turns it into bicarbonate, which is a safe form of carbon storage, and then allows the ocean to take up more carbon. The third pathway focuses on several electrochemical processes that separate carbon dioxide from seawater and turns it into separate streams for easy carbon dioxide extraction.

Any of these tech-enabled innovations eventually could handle fundamental carbon removal issues at scale. But efforts to enhance the ocean's carbon sequestration utility "can't just be a technological fix," says Doug Woodring, founder and managing director at Hong Kong-based Ocean Recovery Alliance, which develops entrepreneurial programs to reduce plastic pollution. Achieving the requisite scale will take time and tremendous cost, Woodring says, and there are many ways more localized efforts can be ramped up quicker. "Planting mangrove forests and regrowing seaweed beds are great ways to engage communities, create relevant jobs, and quickly

> "Planting mangrove forests and regrowing seaweed beds are great ways to engage communities, create relevant jobs, and quickly boost tourism and aquaculture through fast-reviving food and fish stocks."
>
> Doug Woodring, Founder and Managing Director, Ocean Recovery Alliance

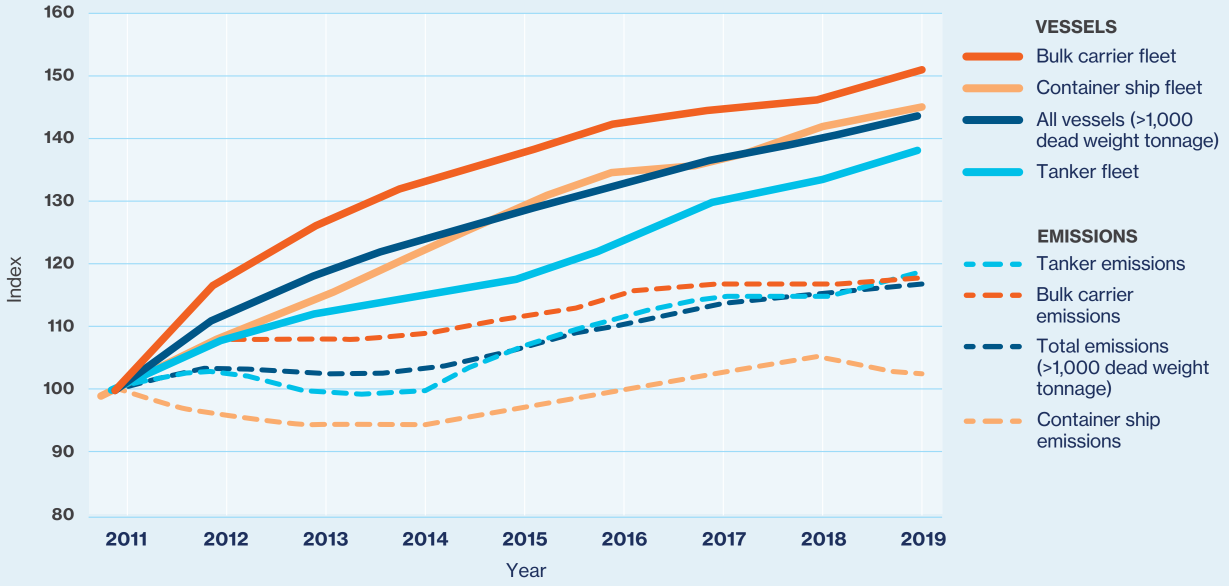
boost tourism and aquaculture through fast-reviving food and fish stocks," says Woodring. Nature-based sequestration takes advantage of a global coastline ecosystem and produces multiple sustainability benefits simultaneously, such as improving animal ecosystems and reducing toxicity levels. Such efforts are not completely without blue technology; Woodring points to conservation efforts to reverse mangrove depletion in Myanmar using satellite-gathered visual and environmental data.

Global shipping: Quest for low-carbon fuels

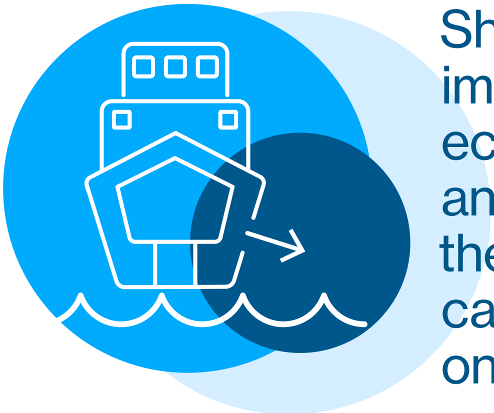
The shipping industry is a significant contributor to global carbon emissions, but its participants collectively form a complex web of interdependent networks and ecosystems (see Figure 7). Shipping companies have a unique appreciation of their role in climate change, says Bev Mackenzie, manager of marine environment at BIMCO, a membership organization for the international shipping industry. "Everybody in this industry knows our carbon footprint is as large as Germany's," she says, referring to an oft-used comparison climate change watchers make between the two, "and that we must do something about it. At the same time, we have to transport most of the things that keep us warm and stop us from starving–and if we transported them by another mode, the carbon impact would probably be a lot worse," Mackenzie adds.

Figure 7: Comparison of fleet tonnage and CO_2 emissions in the shipping industry, 2011–2019

The shift toward larger tankers, bulk carriers, and container vessels combined with efficiency gains and the scrapping of less efficient vessels, has meant that CO_2 emissions growth has trailed behind the increase in fleet deadweight.



Source: Compiled by MIT Technology Review Insights using UNCTAD calculations, based on data provided by Marine Benchmark, 2020[12]



Shipping has unique environmental impacts, including the shock to ecological systems that hull cleaning and ballast water discharge brings, and the emissions from burning fuel, "black carbon," which contributes more than one-fifth of all shipping emissions.

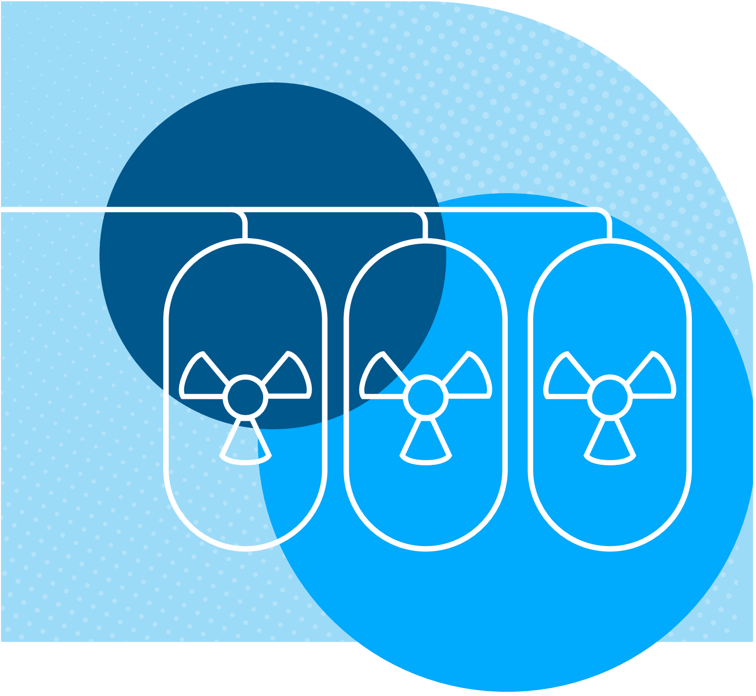
National governments are becoming conscious of the industry's impact, and many blue technology leaders are looking at integrating shipping into their Paris Agreement and national transportation carbon emissions targets. The UK will reduce shipping emissions—which account for 3% of the country's total greenhouse gases—for the first time in its sixth national Carbon Budget, which aims to reduce national emissions by 78% (compared to 1990 levels) by 2035.[13] Greece, which controls nearly 60% of Europe's shipping tonnage, is leading an effort to include the shipping industry into the European Emissions Trading System of the European Green Deal, by creating an industry fund based on the "polluters pay" principle.[14]

Shipping also has unique environmental impacts. One is the shock to ecological systems that hull cleaning and ballast water discharge brings. Another is black carbon, or emissions from burning fuel, which contributes more than one-fifth of all shipping industry emissions and, as Mackenzie explains, darkens polar ice sheets, reducing their "albedo effect," which reflects heat.[15] Darker ice absorbs more heat; therefore, black carbon adds to the impact of carbon emissions on increasing ocean temperatures, explains Mackenzie, and has become "one of the industry's biggest and most difficult problems to solve, as it is still dependent on high-sulfur fuels," she adds.

The industry has made some improvements, however. It has been building more efficient ships, with better hull designs and better engines. And since the 2008 financial crisis, ships have been running more slowly, which adds to their efficiency, says Martin Cresswell, technical director of the Hong Kong Shipowners Association. But for all that, it will still be challenging for global shipping to achieve the International Maritime Organization's target of a 40% reduction in carbon intensity by 2030 and a potential 70% reduction by 2050 (relative to 2008 levels), as progress has been slow.

"New International Maritime Organization regulations require ships to meet a 1% annual carbon intensity index reduction target from 2020 to 2022, and a 2% yearly reduction from 2023 to 2026," Cresswell says. That leaves a large gap, he notes, adding that the industry has not yet tackled how shipping will meet its 2030 40% carbon intensity reduction target, which will require annual reduction levels to be stepped up to 5% or 6% after 2026. "This will most likely force many older ships to be recycled. The chief problem for the industry is in finding effective low-emission fuels to burn," says Cresswell. The industry is now testing how engines that run on diesel perform when they burn methanol, ammonia, and even hydrogen, he adds.

Liquified natural gas (LNG) is currently the only lower carbon emission fuel widely available, but it is not a likely long-term solution, as it only reduces CO2 emissions by around 20% compared to an engine burning diesel fuel. Cresswell cautions that there is also the danger of methane slip, which occurs when methane created by unburned LNG fuel gets ejected by ships. "LNG lowers the carbon footprint of ships, but if an engine doesn't burn LNG properly, it will increase its slip" and wipe out its emission reduction gains, says Cresswell.



Lower-carbon fuels are being trialed by the shipping industry, but real progress could come from more radical alternatives like wind or nuclear power.

Other zero-carbon fuel alternatives also present challenges, observes Cresswell. "Hydrogen has potential for powering ships using fuel cells or even in converted diesel engines." Some blue economies, particularly Japan, are developing maritime hydrogen capabilities for short sea shipping. But hydrogen production, even "green hydrogen," created from clean sources, is incredibly energy intensive, and its storage and transport are costly. "A car, truck, or small ship on coastal voyages can carry hydrogen in a pressurized cylinder, but deep sea ships on long voyages need too much fuel," says Cresswell. "Liquid hydrogen has to be carried at minus 262 degrees Celsius–a hundred degrees colder than LNG." That makes building and maintaining hydrogen fuel tanks and fuel transfer system prohibitively expensive and dangerous, because any leaking liquid hydrogen is highly flammable. A global system of bunker tanks for hydrogen also needs to be built, meaning that economies of scale for liquid hydrogen as a clean fuel for ships is realistically a long way off.

Ammonia is a more attractive zero-carbon emission fuel for shipping but also has a number of limitations for large oceangoing vessels. It already has worldwide supply and storage infrastructure, particularly in the United States, thanks to its use in industrial agriculture, and it is relatively easier to store, requiring temperatures of only minus 33 °C. "But it takes up more than four times the space that equivalent energy fossil fuel requires and is highly poisonous in small amounts," says Cresswell. And it wouldn't be that green when produced at the scale required: "Currently 1.8% of the world's CO2 is created to produce some 176 million tons of ammonia, but international shipping uses 300 million tons of fossil fuel a year, equivalent to needing about 480 million tons of ammonia."

Real step-change progress in the near term will likely come because of more out-of-the-box approaches. Wind is being considered, and there's a growing innovation movement in reimagining the ancient technology of sailing ships. Swedish shipbuilder Wallenius Marine's 200-meter Oceanbird cargo vessel uses 105-meter-tall sails and emits only 10% of a traditional vessel's greenhouse gases. And in 2022, France's TransOceanic Wind Transport plans to launch four regional and transatlantic cargo routes plied by a fleet of sail-powered vessels, each capable of transporting more than 1,000 tons. Cresswell also sees potential in nuclear power: "Small-scale molten salt reactors the size of a big refrigerator could produce 10 megawatts of energy." He notes this technology is being explored for maritime applications in the US, UK, Japan, South Korea, and China in particular, where molten salt technology is gaining traction as a clean energy approach for the country's pressing rural electrification requirements. While the potential is exciting, Cresswell concedes that nuclear-powered ships will present an acceptance challenge. "You will need to get the general public well on your side before you have lots of commercial ships traveling around the world, going in and out of lots of different ports."

Partner perspective | By Kendra MacDonald, CEO Canada's Ocean Supercluster

Canada's Ocean Supercluster

Accelerating innovation to solve some of the world's biggest challenges in ocean

Our ocean is on the front line in the fight against climate change, absorbing more carbon than the rainforest. With pollution, overfishing, rising temperatures, and other risks, our ocean is under mounting pressure. Whether coastal or inland, this impacts everyone.

We rely on the ocean to help us feed the world, move people and goods, provide the energy we need, and help regulate the planet. While we recognize human activities will continue, it's the way in which we do them that must change.

The blue economy is increasingly a global conversation and a race against time to find solutions to reduce these pressures so we can continue to build our lives, communities, and economies around it as we have for generations. It's through forward-thinking policy, bringing together Indigenous knowledge and Western science, the commitment to working together, and accelerated innovation that we can solve these problems and create sustainable economic growth in the process.

The sustainable development of our ocean is one of the most important opportunities of our time.

In 2018, Canada put a bold new program into place that would see the establishment of Canada's Ocean Supercluster and four other national, industry-led clusters to advance Canada's global competitiveness. Since then, the Ocean Supercluster has been built from the ground up and grown to almost 450 members across the country, approving over 60 projects with a total value exceeding $300 million and delivering hundreds of new made-in-Canada ocean products, processes, and services to the world.

These projects are transformational and collaborative. They bring together startups, scaleups and mature companies, the research community, regional innovation hubs and incubators, investors, and government, all with a shared interest in accelerating the development and commercialization of ocean innovation in a way that's never been done before. They tackle shared challenges across the fishery, aquaculture, offshore energy, marine renewables, bioresources, marine transportation, defense, and ocean technology to build a digital, inclusive, and sustainable blue economy for everyone.

The Ocean Supercluster is advancing technologies that allow us to fish smarter, sustainably, and with greater transparency through monitoring fish movement and health; remote operations and real-time analytics for aquaculture; and artificial intelligence to track fish processing.

Reducing reliance on diesel is the focus of several projects, including smart ocean energy grids; vessel coatings that prevent leaching, increase fuel efficiency, and reduce underwater noise; green transitionary fuel; and battery storage for the electrification of large vessels.

The pan-Canadian supercluster is making these and many other projects possible, encouraging the perspectives and participation of Indigenous peoples, women, youth, and under-represented groups so that we benefit from all experiences as we work to create a healthier and more productive ocean.

Covering 70% of our planet, the role of our ocean to our collective future cannot be ignored. In the next decade, the global blue economy will outpace the growth of the broader economy. This is a tremendous economic opportunity, and as Canada's Ocean Supercluster engages with a growing number of international partners, addressing the ongoing impacts on climate and ocean health through innovation is a focal point. The actions of any one nation can affect us all. We have seen this through the pandemic and it is also true in our ocean journey, where we will need to work together to build a healthier planet and a brighter future.

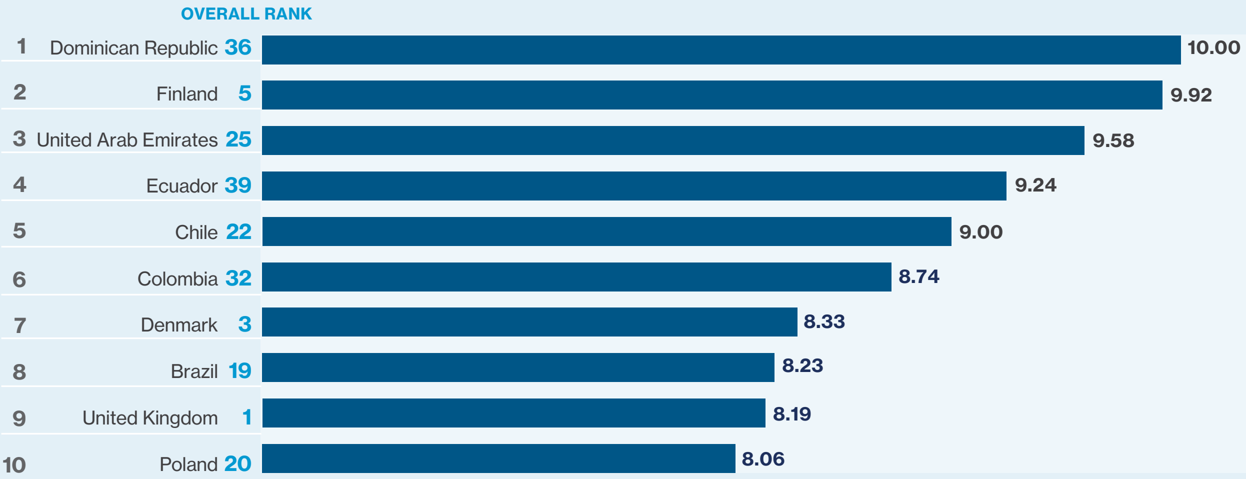
03

Sustainable marine activity

The marine activity pillar measures each country's level of commitment to preventing ecosystem degradation through two primary metrics: fishing sustainability, measured as a percentage of each country's total fish catch that comes from over-exploited or collapsed stock, and the percentage of a country's exclusive economic zone that's been established as protected marine areas. At the top of the sustainable marine activity ranking are mostly advanced economies, with large fishing or coastal tourism industries, that have invested in efforts to sustain such resources. On the other end of the scale are largely emerging economies that may have the need and desire to mitigate their impact on marine ecologies but either lack the resources to do so or are in highly degraded ocean environments. Five of the lowest scorers in this pillar—Greece, Turkey, Algeria, Morocco, and Israel—have their coastlines largely along the Mediterranean Sea, which the United Nations' Food and Agriculture Organization has deemed the world's most overfished, with more than three-quarters of its catch areas depleted.[16]

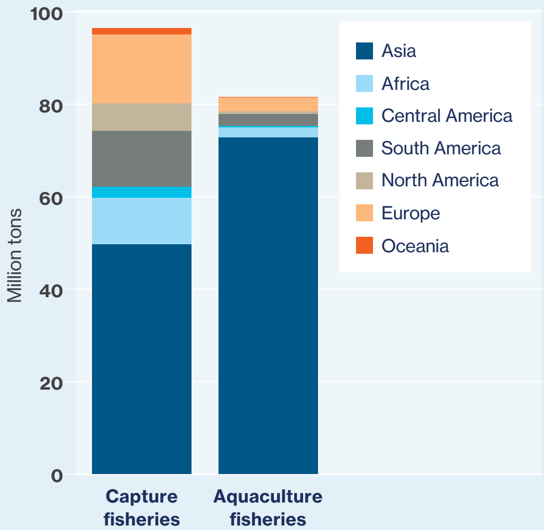
Not all blue technology strivers are uniformly poor stewards of their maritime ecosystems (see Figure 8). Costa Rica (40th, 4.18) is famously a world leader in

Figure 8: Top 10 in the marine activity pillar



Source: MIT Technology Review Insights, 2021

Figure 9: Captured versus aquaculture fisheries production, 2017-2018



Source: Compiled by MIT Technology Review Insights using data from the Food and Agriculture Organization of the United Nations, 2020[21]

Each year, between $10 billion and $23 billion worth of fish are taken by illegal, unreported, and unregulated means.

ecosystem preservation and has a government that's staunchly committed to making conservation and nature-based approaches part of its economic development. This extends to marine conservation: President Carlos Alvarado recently vetoed a law authorizing trawl fishing in the country's waters.[17] Such commitment has helped Costa Rica earn the second-highest ocean environment pillar score. Other emerging-economy strivers with concerted ocean sustainability efforts earning them high pillar scores include Tanzania (52nd overall), Colombia (32nd), and Egypt (37th).

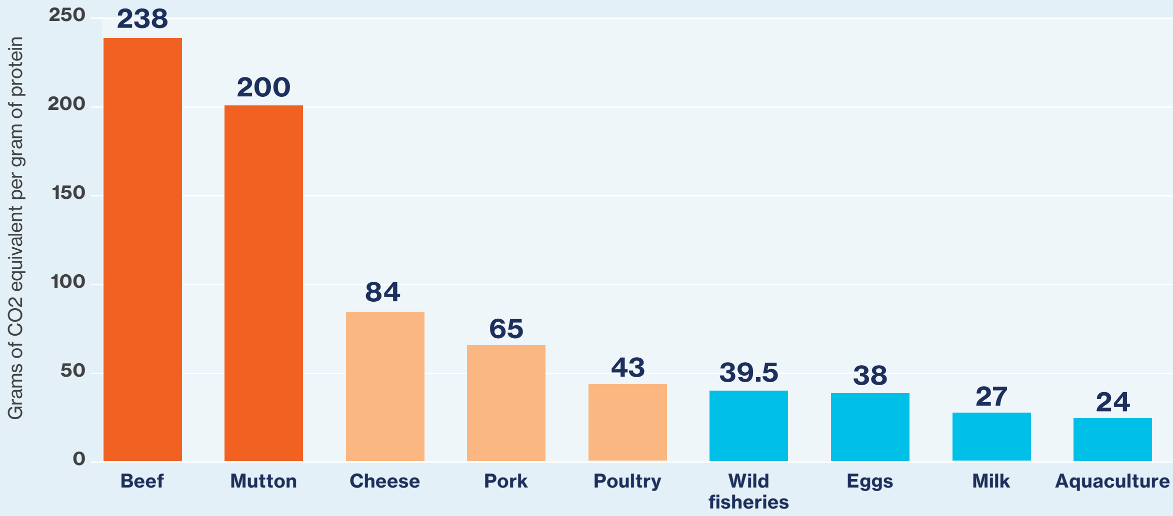
It takes a garden

The world is concerned about the impact overfishing is having on global fish stocks, with good reason: between $10 billion and $23 billion worth of fish are taken through illegal, unreported, and unregulated fishing annually, according to the Food and Agriculture Organization—perhaps 20% of the world's commercial fishing output. The global trajectory's direction is clear, according to Ghislaine Llewellyn, deputy oceans leader at the WWF in Sydney, Australia. "Similar to the mapping of deforestation fronts on land, scientists are now mapping fish biomass depletion fronts in the ocean. The picture that is emerging, is one of serial and systematic depletion of targeted fisheries across the world's oceans." Llewellyn makes this comparison, she explains, as the ecosystem pyramids on land and in the sea are inverses of one another: trees and vegetation constitute the majority of biomass on land at the bottom of the pyramid, while fish and sea animals form the bulk of the biomass at the top of a marine ecosystem. This means that the impact of overfishing on the equilibrium of the ocean chemistry balance is profound, and may even be as great as the direct impact of global warming, according to recent research published in Nature.[18]

Rapid advances in fishing technology, Llewellyn says, are partially to blame for the overfishing crisis: "Fleets can pinpoint where schools are, and fish-aggregating devices have beacons which will relay volume data in real time. On a global level we've become very good at finding, concentrating, and catching fish." Overfishing is making conditions worse in developing countries in the tropics, where impoverished coastal communities feel increasing pressure on dwindling ocean resources, as well as the impact of extreme weather events and changing ocean conditions, Llewellyn says.

As well as catching fish and other seafood, you can also grow or farm aquatic foods: aquaculture production levels have grown more than 500% over the last 30 years, the Food and Agriculture Organization estimates, and since 2019 have exceeded the production of wild-caught fish, even with the growth in industrial fishing volumes (see Figure 9).[19] Moreover, the world's increasing fish consumption, whether from farmed or wild-caught sources, has potential decarbonization benefits: the average carbon emissions per gram of beef is eight times greater than a gram of aquaculture and six times greater than a gram of wild-caught seafood (see Figure 10).[20] Llewellyn believes sustainable fishing can be achieved by maintaining a coordinated balance between fishing and aquaculture. "We should be mindfully gardening: our fishing should be precise, catching the things that we go out to the ocean to catch, in amounts that the health of the underlying populations can withstand."

Figure 10: Carbon dioxide emissions of protein sources

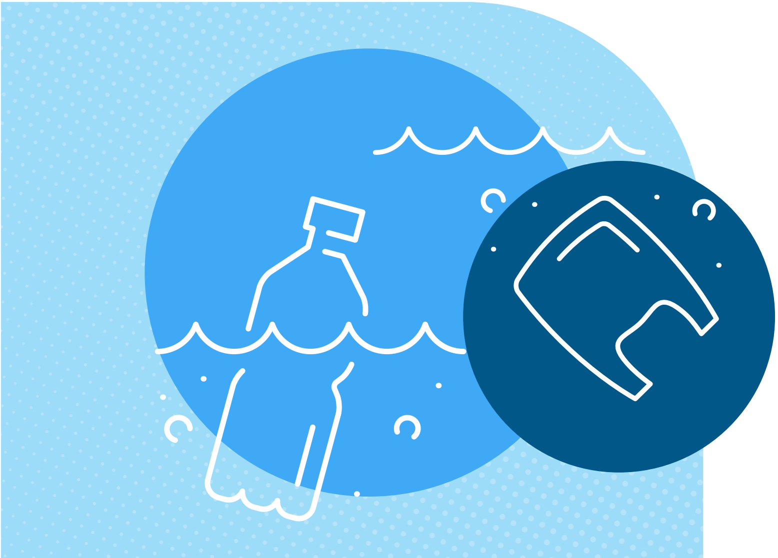


Source: Compiled by MIT Technology Review Insights using data from Oceana, 2021[22]

> "Satellite tracking, sonar, and remote piloting all make industrial fishing very efficient. But these technologies can also enhance sustainability, by monitoring vessels or catches."
>
> Tony Long, CEO, Global Fishing Watch

The same technologies that are making deep-water fishing so efficient–satellite-based monitoring, sensing infrastructure, and data analytics–are among the main tools that can manage "gardened" production into sustainability and combat illegal, unreported, and unregulated fishing. "Innovation in the wild-catch industry is largely in surveillance and location technologies," says Tony Long, CEO of Global Fishing Watch, a UK-based nongovernmental organization that develops AI-enabled analytics capabilities to track and visualize global fishing activities of roughly a quarter of the 350,000 vessels that fish in international waters. "Satellite tracking, sonar, and remote piloting have all combined to make industrial fishing very efficient at drawing more fish out of deeper waters at further distances from the coast." But Long notes that these technology advances can also be applied to enhance sustainability, such as the ability to monitor vessels or limit or monitor catches. Other technologies are helping fishing vessels target fish in more sustainable manner, such as creating "escape hatches" for bycatch–unintentionally caught fish and mammals–or providing track-and-trace certificates so companies can validate the sustainability of their catch at market.

SafetyNet Technologies is a UK-based company that develops precision fishing tools, which include tracking systems to help locate lost fishing equipment, and Pisces, a system of LED lights that fishing boats attach to their nets to simultaneously attract targeted fish and repel bycatch. Daniel Watson, co-founder and CEO at SafetyNet, explains that while sustainability is his company's core mission, making these sustainability tools an integral part of the fishing industry means everything must be underpinned by a business case. "If you catch over your quota, you can incur fines, get your license revoked, and if you are in a shared fishing environment, you can have the entire area shut down for months. Now there is a real incentive to catch the right thing," says Watson. But he



> "Financial service companies now have stricter ESG guidelines, and fishing companies will need data to show their lenders that they maintain a sustainable, responsible operation."
>
> Daniel Watson, Co-founder and CEO, SafetyNet Technologies

believes that in the future, the business case will be defined more by the data captured, analyzed, and shared, in several contexts. One is its use by vessel operators, who increasingly have to provide their environmental, social, and governance (ESG) bona fides to banks when they seek funding. "Financial service companies now have stricter ESG guidelines, and fishing companies will need data to show their lenders that they maintain a sustainable, responsible operation," says Watson. Another business use of data is operational: data on weather, fuel consumption, catch levels, and other metrics will give operators a level of intelligence that can help guide future activities and save money in the near term. Ultimately, Watson believes, "all this data will create exponential value, as we can use it multiple times to support other sustainability and conservation efforts."

Sharing data is the ultimate blue technology innovation, says Long. "We must drive towards data transparency, so that everyone has a great idea of what is being fished where. Many countries have the technology to track and trace, but it's largely used for their own domestic enforcement activities, and it's rarely shared across borders. Many others do not have the monitoring systems at all." Shifting the focus of data gathering away from enforcement activities and toward open collaborative systems in which participants opt in and willingly share data will help break down those silos and improve compliance. Such active participation in open sharing, he believes, could contribute to a rapid turnaround in fish stocks. "The current system is not working. About a third of fisheries globally are overfished and most of the rest are fished to capacity. However, there is evidence that heavily overfished areas bounce back to abundance with a sustained good stewardship," says Long, meaning concerted sustainability action could quickly produce a multiplier effect globally.

Plastic ocean waste management: The importance of mindshare

Ocean plastic is a key factor affecting marine conservation efforts. The Pew Charitable Trusts calculate that more than 11 million tons of plastic waste flow into our oceans annually, a significant portion (11%) in the form of microplastics, which seep into ecosystem food chains.[23] But there's some sense that the optics of a trashy beach drive a disproportionate amount of investment and attention. Nitrogen nutrient pollution, created by river runoff from over-fertilized soil by increasingly industrial agricultural activity and untreated wastewater from cities, "gets far less attention than plastics but is equally, if not more, impactful in terms of the socioeconomic costs," says the United Nations Development Programme's Andrew Hudson, head of water and ocean governance. He reckons the burden of nitrogen to the world's ocean has tripled since preindustrial times, "and this has created a huge disruption in the earth's nitrogen cycle and exponential growth in hypoxic low-oxygen areas, due to the eutrophication of the coastal ocean ecosystems." (Eutrophication refers to the minerals and nutrients enriching a body of water.) His team at UNDP estimates that this costs the global economy between $200 billion and $800 billion annually. "That iconic photo of a turtle with a six-pack ring around its neck is an old picture, and we have moved the conservation conversation way beyond it," says Millicent Pitts, CEO of Ocean Exchange, a US-based nonprofit that promotes ocean and

> "Plastic is a massive, multi-trillion-dollar global industry. The burden of addressing this issue has historically fallen to municipalities and consumers. But it must shift to the producers, with incentives to own the problem, from the design of resins and products to their recovery, recycling, and reuse."
>
> Andrew Hudson, Head, Water and Ocean Governance Programme, UNDP

coastal system sustainability. "But that's still what's visible to people, and people respond to what they see."

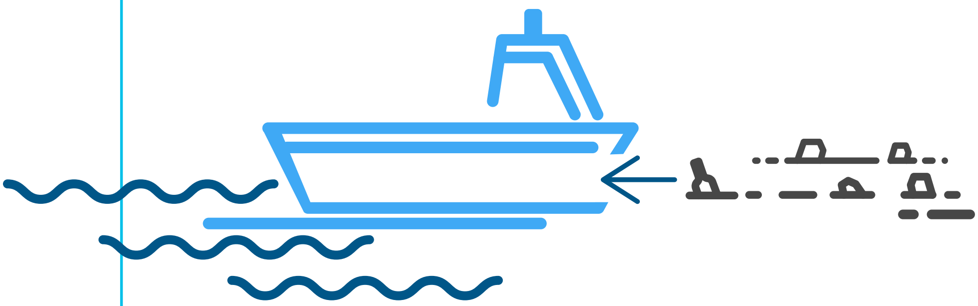
There are probably other serious, yet fundamentally unknown, environmental costs of plastic waste, such as harm to wildlife, according to Ocean Recovery Alliance's Woodring. "There is no body count in the ocean, and until recently we weren't doing autopsies on beached whales or sea mammals" to determine how much plastics are contributing to their demise. Yet Woodring notes that while it may not be high up on the hierarchy of the ocean's health challenges, "litter is the most solvable of all our problems." Carbon capture projects such as planting seaweed beds or reforesting mangroves to create carbon sinks "are very doable, but they take time and geoengineering and legislation," Woodring says, whereas waste collection initiatives can be simple grassroots efforts to clean up beaches and rivers. "Most people can't influence shipping or fishing, but they can influence pollution. Consumer engagement in turn makes it easier to get corporate brands to invest in pollution and waste and get more engaged in ocean conservation," he adds.

The bearers of the pollution burden are the countries that are doing the polluting, says Boyan Slat, founder and CEO of Netherlands-based The Ocean Cleanup. "Our models shows that every month, 80% of the plastic that's been emitted though a country's rivers washes back onto its own shores." The Ocean Cleanup, a blue technology non-profit organization, has a two-pronged approach to addressing the challenge: tackle ocean plastic pollution at its entry point, and mitigate legacy trash. The first effort targets rivers; the company believes 1,000 rivers globally are responsible for 80% of all plastic emissions coming from land. The company is active in four rivers, plying mouths and deltas with trash-picking Interceptors—solar-powered robotic catamarans—in cooperative projects with governments in Indonesia, Malaysia, and the Dominican Republic. It has already collected more than 2 million pounds of trash and plans to have Interceptors in 10 rivers by the end of 2021. For the second part of its approach, The Ocean Cleanup has recently put the second generation of its ocean cleanup system that mimics an artificial coastline, into service collecting waste from the Great Pacific Garbage Patch, a giant, floating vortex of trash. A third generation of the system, which will span 1,800 meters, will be introduced next year. Slat reckons that such an approach will put the ocean waste mitigation movement on track to remove some 90% of surface plastics by 2040.

Once garbage is collected, The Ocean Cleanup must actively engage in broader recycling and reuse supply chains. "We need to demonstrate that collected waste can be handled properly and that participants in cleanup efforts have opportunities to create value and participate in a revenue model," Slat says. The organization aims to do start-to-finish "waste repurposing," developing proofs of concept to show early value. These efforts include manufacturing and selling 14,000 pairs of recycled-plastic sunglasses at $200 each. Such a single-product focus is not very scalable, Slat says, "so going forward, we will partner with big consumer brands where we supply plastic from the Great Pacific Garbage Patch to them to integrate into their products and their marketing." On river collection projects, in which local governments and private operators run Interceptor programs, Slat explains that the process will run much like franchises, with local sustainability firms running their own operations.

UNDP's Andrew Hudson agrees that the visibility of the plastics problem helps efforts to combat related effluent challenges, but he's less sanguine about its solvability. "Plastic is a massive, multi-trillion-dollar global industry, from the petrochemical companies to feedstock producers to consumer goods and packaging companies." He believes a global regulatory regime for plastics, like the one for climate, is the key to codifying fundamentally different behaviors. "The burden of addressing this issue, which has historically fallen to municipalities and consumers, must shift to the producers of the materials," Hudson says. "There must be significant incentives for the private sector to own the problem, from the design of resins and products to their recovery, recycling and reuse." He points to the efforts of the environmental ministers of the five countries in the Nordic Council of Ministers to introduce a new global agreement on plastics as an important beginning step in international efforts to create such incentives.[24]

Trash-picking autonomous robots unite



Sidhant Gupta, founder and CEO of Clearbot, a startup that builds AI-enabled waterborne trash-collection robots, explains how the autonomous cleanup concept got its start during a conservation assistance project trip he and his fellow University of Hong Kong engineering students took to Bali. Local surf shop owners and government workers were using hand-thrown nets to clean up coastal waters plied by paddle boats, because the plastic waste clogged the propellers of motorboats. "We realized that there was money, willpower, and resources to remove plastic waste, but not the tools to scale up cleanup activity." A prototype robotic ocean trash picker, cobbled together in a surf shop, led to a research project in Hong Kong, where subsequent iterations of robots were developed in part to help address the territory's large marine construction sector.

To accelerate scale and visibility, Clearbot is aligning with international corporations, such as the Singaporean-US gaming company Razer, which is helping "co-build" the robots and also adding large municipal clients to its roster, including a contract with the Hong Kong government to clean up waste resulting from the construction of a cross-harbor tunnel. While the robot is kitted out with sensors and photographic technology, Gupta says Clearbot's primary value to waste reduction is its ability to analyze data and integrate it with municipal and government systems. "The software that we use to train the robot and the AI capabilities that detect and classify waste can be collected, analyzed, and plugged into traditional waste management center capabilities."

While waste management is now Clearbot's core mission, Gupta says the technology is fast evolving to address a wider range of ocean sustainability challenges, such as monitoring marine ports for vessel leakages and analyzing current flows to optimize cleanup action. The company is working with consumer goods researchers to prioritize sustainability changes to packaging: "They need detailed underwater data to figure out where to invest resources to make the highest ocean sustainability impact," says Gupta. "Macro-scale satellite imaging is insufficient; we're giving them great insight into what kind of materials are ending up in the water and what collection processes actually work best to remove it."

Morgan Stanley

How Morgan Stanley is working to combat plastic waste in our oceans and the environment

The plastic waste littering our oceans and waterways is a concern that goes beyond the disturbing images we see of beaches covered end-to-end in debris. According to Professor Jenna Jambeck, an expert on the problems of marine debris and plastic pollution, an estimated 8 million metric tons of plastic trash find their way into our oceans each year.[1] That's the equivalent of dumping a garbage truck filled with plastic waste in the ocean every minute.[2]

Plastic waste comes with a multitude of problems: it threatens marine life, it affects human health, it is an economic drain, and it contributes to climate change. Disturbingly, the problem has only gotten worse as people have turned to disposable items such as masks and latex gloves, as well as single-use objects such as plastic bags and food containers during the pandemic causing even greater quantities of plastic waste to find its way into our oceans.[3]

A key component to solving complex problems involves forming partnerships and facilitating cooperation among researchers, scientists, explorers, and innovators at the forefront of seeking solutions. That is why Morgan Stanley is supporting Jenna's research which is focused on issues of solid waste and finding a better understanding of how plastic waste reaches our oceans and waterways.

Among the many fascinating aspects of her work, Jenna helped create the Marine Debris Tracker—an app that allows anyone with a smartphone to log plastic waste pollution they encounter. Already data has been collected in 34 countries about more than 5 million pieces of debris,[4] and the app is presently being used along the Mississippi River as part of the "Mississippi River Plastic Pollution Initiative" to help create the first-ever snapshot of plastic pollution flowing into the Gulf of Mexico.[5]

Another piece of innovative technology Jenna and her team are using involves launching plastic bottles containing GPS devices into the Mississippi River and following their path. While this is the first time this has been done in the U.S., her team has used the technology along the Ganges River in 2019 to help fill "data gaps" in estimating the overall quantity of plastic in rivers and oceans (one bottle traveled more than 1,200 miles).[6]

There are many non-traditional ways a financial institution can contribute to scalable solutions. In 2019, we announced our Plastic Waste Resolution—a commitment to help facilitate the prevention, reduction, and removal of 50 million metric tons of plastic waste from rivers, oceans, landscapes, and landfills by 2030, and already as of the end of 2020, we have reached more than 5 million metrics tons of our overall goal.[7]

Forming key partnerships and supporting innovative action is an important way to utilize the power of the capital markets to help solve our most pressing climate-related challenges. Only when we look outside of our silos and support a broad range of work will we begin to solve our problems at scale—and that includes stemming the flow of plastic waste into our rivers and oceans.

Audrey Choi
Chief Sustainability Officer and CEO, Morgan Stanley Institute for Sustainable Investing

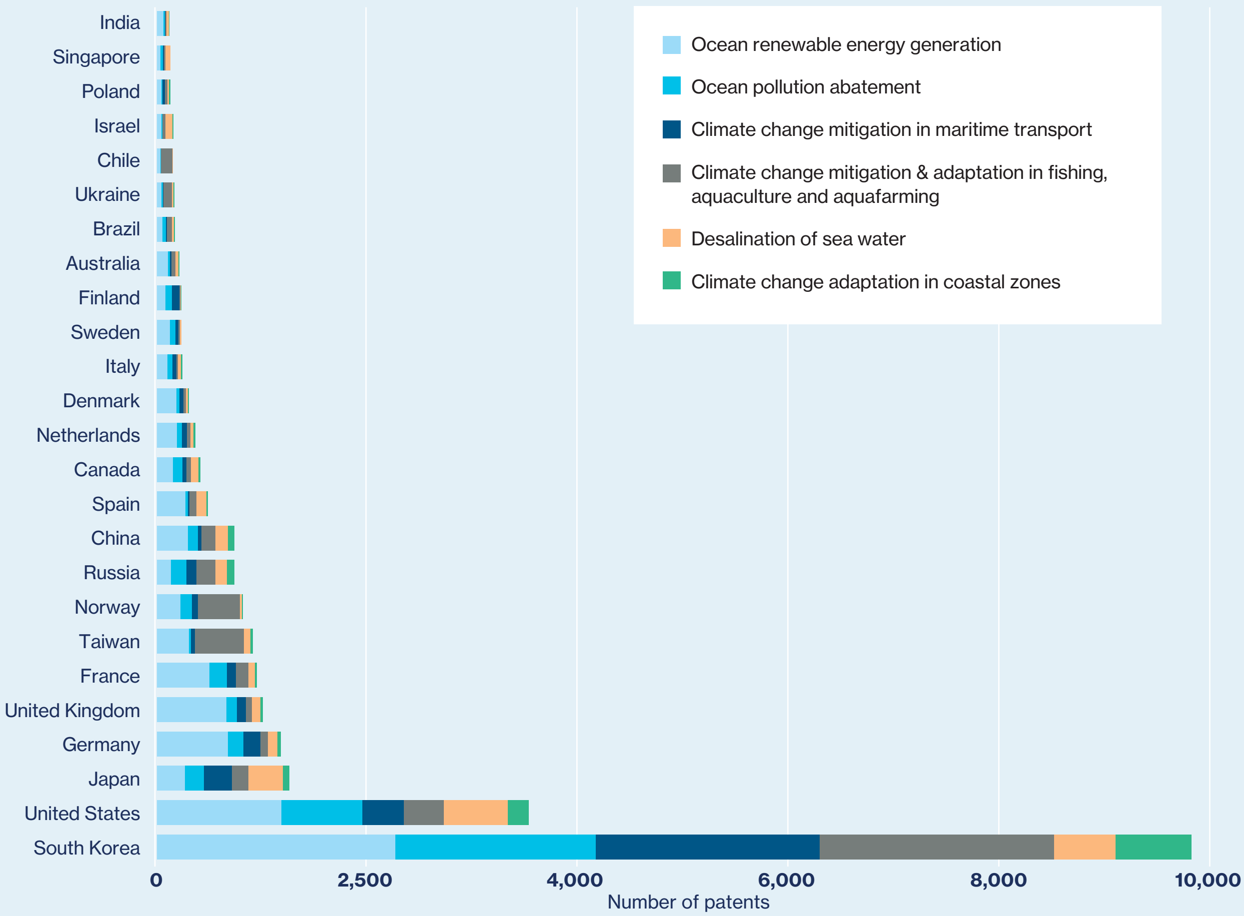
Disclosures.

1. Jenna R. Jambeck, "Plastic waste inputs from land into the ocean," Jambeck Research Group, February 12, 2015.
2. James Pennington, "Every minute, one garbage truck of plastic is dumped into our oceans. This has to stop, " World Economic Forum, October 27, 2016.
3. Janis Searles Jones, "Assessing PPE Pollution's Impact on the Ocean," Ocean Conservancy, March 30, 2021.
4. Marine Debris Tracker's "Debris Tracker App," Marine Debris Tracker.
5. UN Environment Programme's "The Mississippi River Plastic Pollution Initiative," United Nations Environment Programme.
6. Lea Skene, "Scientists Put GPS in Trash to Find Out How Far It Travels," US News, April 18, 2021.
7. "Real Progress in Tackling Plastic Waste," Morgan Stanley, April 20, 2021.

04 Blue technology innovation

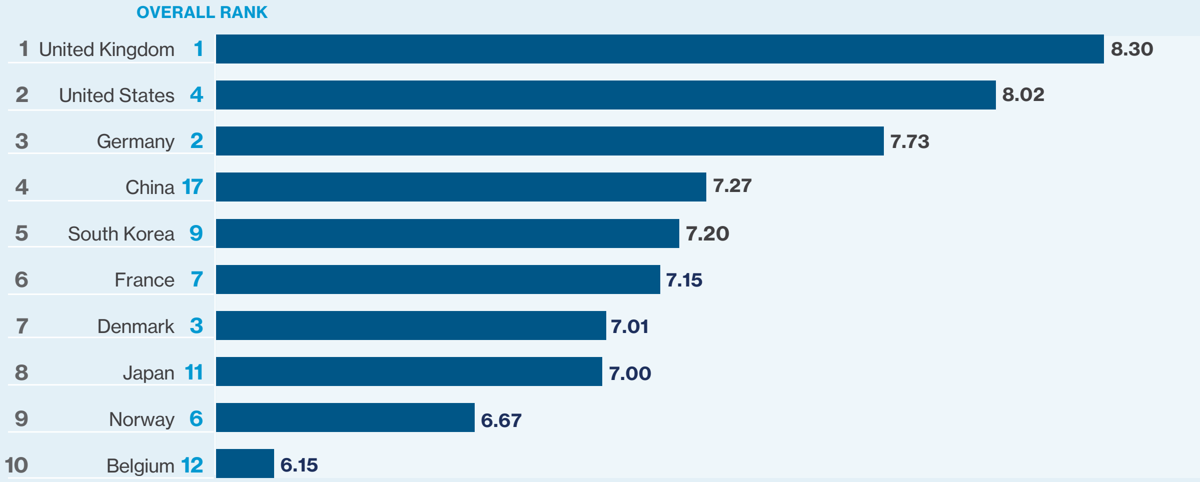
The technology innovation pillar, which contributes half of each country's overall score, measures progress in fostering the development of sustainable ocean technologies across several fields. This includes the number of patents filed in a half-dozen categories relevant to ocean sustainability, including renewable energy, pollution abatement, maritime transport, aquaculture, desalination, and coastal zone adaptation (see Figure 11). As mentioned in Chapter 1, this indicator is dominated by South Korea's blue technology innovation sector: over the last decade, the country has registered nearly 9,700 patents for technologies related to ocean sustainability– more than the next seven

Figure 11: Maritime sustainability patents filed by category, 2011-2020



Source: Compiled by MIT Technology Review Insights using data from the European Patent Office, 2021[5]

Figure 12: Top 10 in the blue technology innovation pillar



Source: MIT Technology Review Insights, 2021

economies combined. Other assessment indicators in this pillar include data collected on the number of maritime technology startups registered in each country and also the country's overall green innovation scores, derived from MIT Technology Review Insights' Green Future Index 2021. Finally, the pillar examines each economy's existing use of technologies that allow a country to incorporate the ocean in its overall climate change agenda: this includes a ranking of efforts to use the ocean as a "platform" for clean energy production and the satellite communications infrastructure the country has, which is an important component of its ability to promote the maritime data gathering and dissemination necessary to accelerate ocean health initiatives.

Blue technology leaders show growing levels of government funding incentives to the maritime innovation economy, and other government-coordinated efforts to develop ocean sustainability efforts (see Figure 12). Norway's government is a blue innovation investment leader: SkatteFUNN, the Research Council of Norway's innovation fund, is helping marine energy company Teco 2030 fund the development of a semi-automated production line for hydrogen fuel cells.[26] Italy's National Agency for New Technologies, Energy and Sustainable Economic Development and its National Research Council have established a living laboratory, the Santa Teresa Smart Bay, using aquatic invertebrates as live sensors to monitor ocean temperatures and other conditions.[27] Spain's rank in the top 10 in this pillar is largely due to a government-curated blue technology ecosystem, which has a large number of startups working on reuse applications for plastic, industrial, and agricultural waste.

Science-based approaches to ocean health challenges can be difficult to develop and scale effectively "because there are differences between the global systems of the atmosphere, the land, and the ocean," says Pierre Lermusiaux, associate department head for operations at MIT's Department of Mechanical Engineering. He specializes in ocean data projects, such as simulations of internal tides to help improve sonar communications and predict ecosystems and fishery populations.

On the land, "pollution events" don't move—whether mining is done in Afghanistan or in the Congo, it largely affects only the local environment. In the air, pollutants move relatively quickly—smoke from the summer's forest fires in California, for example, made its way to Boston in a few days. "The ocean is in-between, with multiple time and space scales. If you pollute off the coast of Massachusetts, it only takes a little time before these problems become global. Coastal oceans are a globally interconnected system," Lermusiaux says. "We can't see and measure what's going on in the ocean as much as we can in the atmosphere or on land."

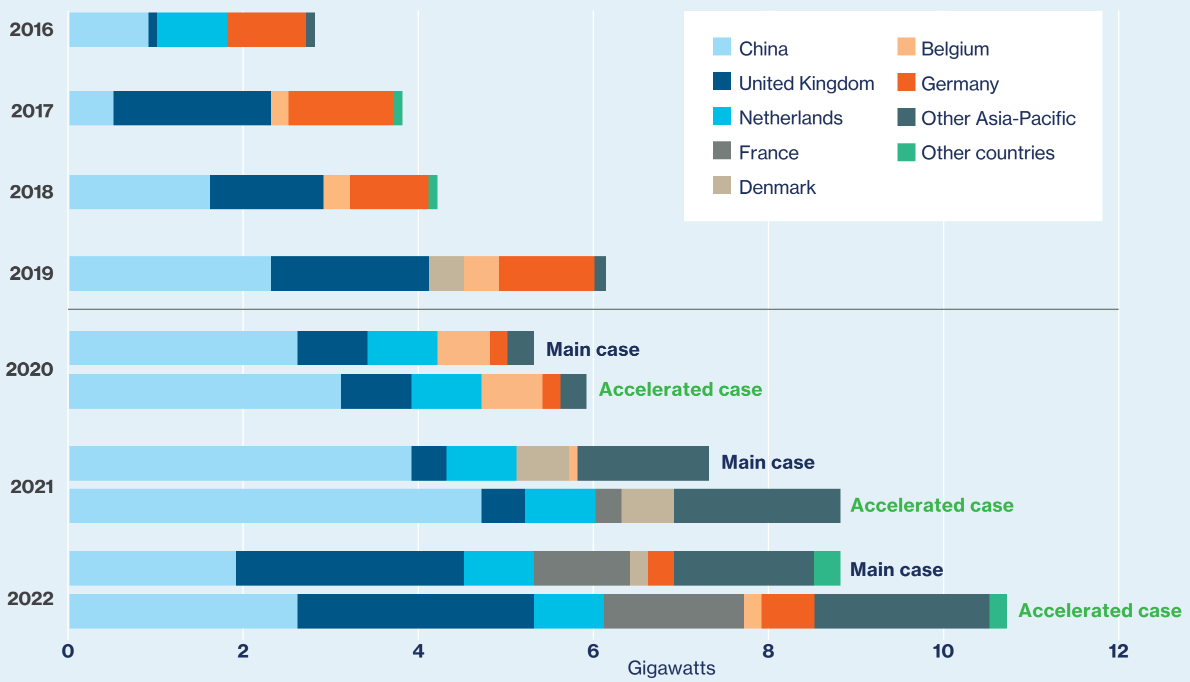
To combat effectively with technology, the science needs to be interconnected, Lermusiaux says. "The ocean's environment is dynamic, so we need to interconnect the modeling, then you need to interconnect the sampling." He points to efforts to bring increased modeling and observation activities along the African coast, and among small island nations of the Pacific, which in turn create an information and education balancing act. "Local populations are both sensitized to global problems, and local communities feel that their local problems are also being addressed through such research," says Lermusiaux.

Ocean Exchange's Millicent Pitts notes that while the pace of innovation in the maritime sector is growing, real systemic change still requires time. "The kind of technologies that will solve the zero-emission and decarbonization challenges of ocean mobility have long, long lead times," she says. "We're not talking about just building an app; these are very difficult material science and chemistry problems on which scientists can spend a decade or more working on solutions."

The complex and long development cycles of blue technology create several implementation challenges, Pitts says. These include a lack of patience and cooperation among ecosystem participants, particularly in the use of data. "There's a lot of data created by governments and private institutions, but it's not always readily available and we often don't have the means to pull it together in useful ways," Pitts says. That's because any number of maritime industry participants collect data, but many of these efforts don't have a clear business model.

Occasionally, sufficiently concerted efforts to solve a marine sustainability challenge can create a new business model in in the process. The global industry for treating the ballast water that's discharged by ocean-going vessels when docked at port is perhaps the most prominent example. "The international shipping sector is a huge vector for the transfer of aquatic invasive species, through the five billion tons of ship ballast water that is moved around the planet every year, and through the biofouling of the exterior of ships," says UNDP's Hudson. Both issues have had considerable industry resources aimed at mitigating them, particularly ballast water, thanks in large part to the ratification of the International Convention for the Control and Management of Ships' Ballast Water and

Figure 13: Offshore wind production by country or region, 2016-22



Source: Compiled by MIT Technology Review Insights using data from the International Energy Agency, 2020[29]

> “It’s been 30 years since the first offshore wind farm was installed in Denmark. A tremendous amount of research, economies of scale, and supply chains have been created, all of which help shave a lot off costs in the construction of foundations.”
>
> Britta Bienen, Professor, Oceans Graduate School and Centre for Offshore Foundation Systems, University of Western Australia

Sediments in 2004, one of the world’s first systemic efforts of an industry to establish common environmental waste standards. It did so at such a scale as to “possibly create the world’s largest new industry since World War II,” says Mackenzie of BIMCO. Hudson notes that there is a similar coordinated effort to control ship hull biofouling, which increases ship drag (and thus increases its carbon emissions): the GloFouling Project is funded jointly by UNDP, the International Maritime Organization, and the Global Environment Facility and started in 2018.

The ocean is a key source for many advanced nations’ renewable energy generation programs, particularly wind, and perhaps tidal wave energy in the future (see Figure 12). But climate change itself may be complicating those aspirations: weather modeling group Vortex recently released data showing that wind speeds across Europe have slowed by 15% in 2021, possibly because of a climate change-induced phenomenon called global stilling.[28]

Britta Bienen, professor at the University of Western Australia’s Oceans Graduate School and Centre for Offshore Foundation Systems, notes that the maturity of the offshore wind sector provides the renewables industry with distinct advantages. “It has been three decades since the first offshore wind farm was installed in Denmark, and over this long history a tremendous amount of research, economies of scale, and supply chains have been created, all which help shave a lot off costs in the construction of foundations,” says Bienen. This, she notes, can significantly lower the price of delivering wind-generated electricity.

The efficiencies and scale of offshore production have served as a catalyst for further exploration by governments globally; the Australian government in September introduced legislation to create incentives for offshore wind infrastructure investment.[30] Wind sources from the country’s onshore production have 7.4 gigawatts of capacity and supplied 10% of Australia’s power in 2020; the 10 offshore projects the country is planning will produce three times as much electricity.[31] Similarly, US Secretary of the Interior Deb Haaland recently announced that the Bureau of Ocean Energy Management plans to auction up to seven new offshore platform locations nationwide in a bid to generate 30 gigawatts of wind energy.

Bienen notes that other sustainable activities can be co-located with offshore renewable energy facilities, furthering their efficiency. “Floating wind turbines can be constructed with another power takeoff to convert some of the wave energy,” Bienen says. “And there are several co-locating seaweed farming projects under discussion globally.” Much of this co-location innovation is happening in the North Sea, with some three-dozen facilities operated by seven European countries. EU Scores, a European consortium of companies and research institutions, is building its first offshore energy park–combining wind, solar, and wave generation infrastructure–off Belgium this year.[32] And an offshore solar farm combined with seaweed production was launched off the Dutch coast of Scheveningen last December–one of several EU-funded offshore platform projects under an initiative, dubbed UNITED, to boost sustainable marine energy and aquaculture.[33] Another offshore farm project, led by Germany’s Kiel University of Applied Sciences, combines blue mussel and seaweed cultivation at a wind energy production site.

Infosys

As a company with a global footprint, we see the impact of the climate crisis from countless angles and understand that we have a role and responsibility to create a more sustainable and equitable future. We strive to be an industry leader by embedding sustainability into the digital landscapes we build for our clients.

2020 was a year of unprecedented challenges. Borders closed, air traffic stalled, and global supply chains faltered—although never completely stopped. The shortages of vital goods like food, medicine, and household items brought heightened awareness to the worldwide flow of commerce.

Although mostly unseen by consumers, maritime shipping is critical to the global supply chain. About 80% of trade by volume, and more than 70% by value, is transported across water into ports around the world.[1] And maritime freight volume is projected to triple by 2050.[2] During this same period, there will be a global push toward carbon neutrality.

At the same time, pressure from government regulators (potential fines) and business partners and clients (potential loss of business) are exerting great pressure on shipping firms. Shipping companies are answering the call with decarbonization commitments, while still meeting their expected service levels. For example, Maersk—the world's largest container shipping company—has set a target to reduce carbon emissions 60% by 2030 and to be carbon neutral by 2050.[3]

Shipping companies are looking toward alternative fuels and larger vessels, to carry larger loads, as initial steps to decarbonize. These offer marginal improvements, but are not sufficient to meet international goals.[4] Shipping must use every tool at its disposal or risk emissions growing by 250%.[5]

Ships can switch to hydrogen and other alternative fuels as well as utilize batteries for auxiliary power, airfoil sails to capture free wind energy, or even alternative materials for container and ship construction. Beyond these physical changes, digital technologies play an essential role in these efforts. Sensors can capture wind speed, water currents, and engine efficiency, while intelligent systems raise and optimally position sails. Predictive analytics are able to combine operational, geospatial and social data to chart and optimize routes—minimizing disruptions and maximizing efficiency. Connected systems share critical operational and feedback data throughout and between ships to identify patterns and develop shared intelligence.

Operational data and digital solutions are also vital for tracking and reporting numerous decarbonization metrics demanded by stakeholders, both inside and outside the company. This reporting demonstrates the successes or failures of critical-path programs, ensures continued support and investment, and will be increasingly demanded by regulatory bodies. Infosys's Ecowatch solution supports organizations in these efforts by creating a digital foundation for measuring and improving decarbonization initiatives.

Decarbonizing maritime shipping is not only an environmental responsibility but a sound business opportunity and necessity for survival. Most global companies have set net-zero targets, and it will be imperative for shipping companies to provide logistics that match those goals. Maritime providers that offer such services can gain a competitive edge, earn higher revenue through differential pricing, and increase their market share.

1. United Nations Conference on Trade and Development, "Review of Maritime Transport 2018," UNCTAD, October 3, 2018
2. "Global Freight Demand to Triple by 2050," The Maritime Executive, May 27, 2019
3. Taylor Johnson, "Towards a zero-carbon future," Maersk, June 26, 2019
4. "Review of Maritime Transport 2020," UNCTAD, November 12, 2020
5. Alem Tedeneke, "New Coalition Aims to Make Zero-Emissions Shipping Plain Sailing," World Economic Forum, September 2019

05 Policy and regulation

The policy and regulation pillar looks primarily at the ratification and implementation of the United Nations Convention on the Law of the Sea (UNCLOS) and its two implementing agreements (see Figure 14). UNCLOS provisions are largely focused on efforts to establish sustainable fishing and marine activity. As in other digital technologies, regulatory formulation and enforcement in blue tech often lag innovation. Nauru's deep-sea mining gambit in the Clarion-Clipperton Zone, as well as India's blue economy adventurism in the Antarctic, are examples of how much work is still needed to codify and harden the convention's agreements, and also how extreme economic and resource security pressures weaken a country's resolve to comply with the spirit of these agreements.

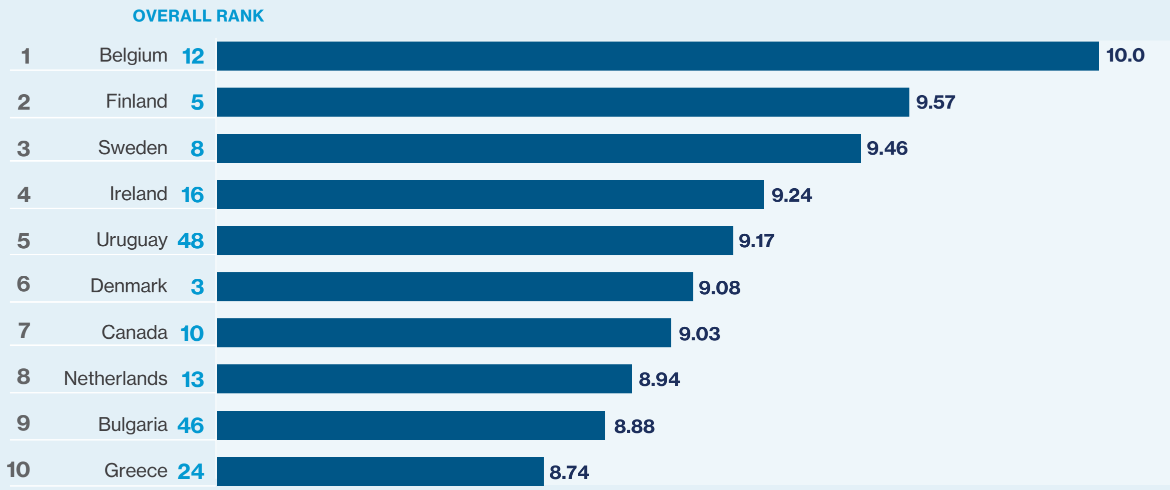
These pressures are usually felt by blue technology strivers, but even advanced challenger economies can succumb to them. Iceland (27th) is a global leader in carbon reduction innovations and policy implementation, but scores poorly on commitments to marine conservation and has a poor record of reaching sustainable fishing agreements with its neighbors (fish still accounts for three-quarters of the country's exports).

On the other hand, a few strivers have seized on international collaboration as a single ocean sustainability issue in which they can excel. Uruguay (48th) is the breakout example: it holds the pillar's fifth-highest score, thanks to its leadership role in international efforts to combat illegal, unreported, and unregulated fishing and enforce marine protected areas. It was the first country (and the only one in Latin America) to support an EU proposal to designate East Antarctica and the Weddell Sea as marine protected areas.

Countries that score high in this pillar generally also have strong domestic policy frameworks that support the

A few strivers have seized on international collaboration as a single ocean sustainability issue in which they can excel. Uruguay (48th overall) holds the 5th highest score in policy and regulation thanks to its leadership role in enforcing marine protected areas and combating illegal, unreported, and unregulated fishing.

Figure 14: Top 10 in the policy and regulation pillar



Source: MIT Technology Review Insights, 2021

development of blue technologies that complement their overall decarbonization agendas, largely in renewable energy production and marine conservation efforts. Ireland's maritime innovation efforts include two projects to generate wave energy with the Sustainable Energy Authority of Ireland: new prototypes are being field tested in a SmartBay site in Galway and a commercial wave production facility off the Mayo coast.

By contrast, most blue technology strivers lack commitment to international cooperation in the deep sea, and their attention to domestic ocean conservation is often poor. There is also a lack of attention to broad-based ocean sustainability policy among blue ocean challengers as well. Brazil (19th overall) scores well on marine sustainability and conservation measures, although this is eroding: in 2020, the Jair Bolsonaro administration removed the country's two-decade-old "permanent protection zone" for tropical mangroves and sand-dune scrublands.

06 Conclusion

Bringing it all together

Blue technology leaders are committed to a holistic approach to ocean sustainability, both in their domestic maritime economies and the ecosystems within them, and in upholding international conventions and sustainable activities in the deep ocean. Managing emissions in their maritime industries through investment in clean power and clean fuels also informs a large part of their efforts, and it's here that we see the emergence of a trend to combine efforts, or co-locate sustainable activity, primarily to quicken the overall pace of ocean-related climate action.

Combining blue technology innovation with "green," land-based efforts is important, but the notion needs to be greatly expanded to integrate ocean-oriented efforts to those of the world at large. "The environmental community is hindered by factionalism and compartmentalization," Ocean Visions' Ack argues. "One thing that we all should be focused on in the ocean is reversing the climate crisis—you can't have a healthy ocean at these levels of carbon dioxide. The environmental community separates their climate teams from their ocean teams, which typically work on fisheries and plastics and marine protected areas. But ocean and climate are inexorably linked and need to be addressed together." Those who understand this linkage can create more transformative change, Ack says, citing the example of the efforts of small island states, which sit precariously at the crossroads between global warming, rising sea levels, and depleted oceans, and, as a result, played a key role in getting the Paris Agreement goal to limit global warming down to 1.5 °C. "To fight the climate crisis and save the ocean, we all need to be singularly focused on one number—parts per million of carbon. If we were, we would collectively be looking at every single pathway to reduce that number, and we'd be measuring them against each other and not caring whether they were in the ocean, on the land, or in the atmosphere," Ack says. "But at present we just don't have that kind of system thinking."

> "We should all be focused on reversing the climate crisis—you can't have a healthy ocean at these levels of carbon dioxide. Ocean and climate are inexorably linked and need to be addressed together."
>
> Brad Ack, Executive Director and Chief Innovation Officer, Ocean Visions

Ecosystems to help the ecosystem

"System thinking" will compel governments to look to things like mangrove and seaweed bed rejuvenation efforts not just for their immediate benefits to maritime ecosystems (enhancing coastline preservation and marine protected area decarbonization), but also the extended benefits they bring to broader-based climate change action beyond the ocean. These benefits could include

Data-gathering and analysis technologies are emerging as one of the blue economy's greatest areas of innovation. In the fishing industry, electronic catch, documentation, and traceability technologies are increasingly widespread and resistance to their use is lessening as consumer concerns about the sustainable provenance of seafood grow.

enhanced aquaculture that can lessen society's dependency on carbon-intensive protein production on land. It would integrate efforts to speed up national energy generation transition efforts by expanding offshore wind and solar installations, using the ocean as a platform to generate clean energy with an operational scale and consistency often greater than land-based projects have. The ocean's contribution to clean energy is a critical part of the world's efforts to meet collective carbon emission targets under the Paris Agreement–particularly as the realization sets in that to do so, renewable energy investment levels over the next decade must more than double from current levels.[34]

Such efforts require transnational cooperation, which is why compliance and enforcement of UNCLOS or the tremendous levels of cooperation in the international shipping industry to bring about global standards in ballast water management and descaling of vessels are such important indicators of the resolve with which an economy seeks to achieve a blue technology-driven future. They also require collaboration across globalized industries and value chains, particularly in the realm of shared data and analytics capabilities, so logistics and fishing companies, retailers, and others can assess and report the carbon and sustainability impact of their activities with greater precision.

Fortunately, a broad swath of data-gathering and analysis technologies is emerging as one of the blue economy's greatest innovation clusters. Electronic catch, documentation, and traceability technologies are increasingly widespread in the fishing industry, and resistance to their use is lessening as consumer concerns about the sustainable provenance of seafood grow. Just as monitoring and tracking tools have helped the fishing industry make step changes in its efficacy–unfortunately quickening the pace of fish stock depletion in the process–new innovations in digital data analysis have emerged, such as the tracking and sharing efforts of Global Fishing Watch or SafetyNet or new tools such as Fishcoin, a blockchain-based data ecosystem designed to trace seafood back to the point of harvest. It's in these efforts to align scientific discovery and empirical observations on a global scale, in a way that connects the efforts of climate activists–on land and on the ocean–that blue technology leaders will succeed in accelerated and transformative sustainability efforts.

About MIT Technology Review Insights

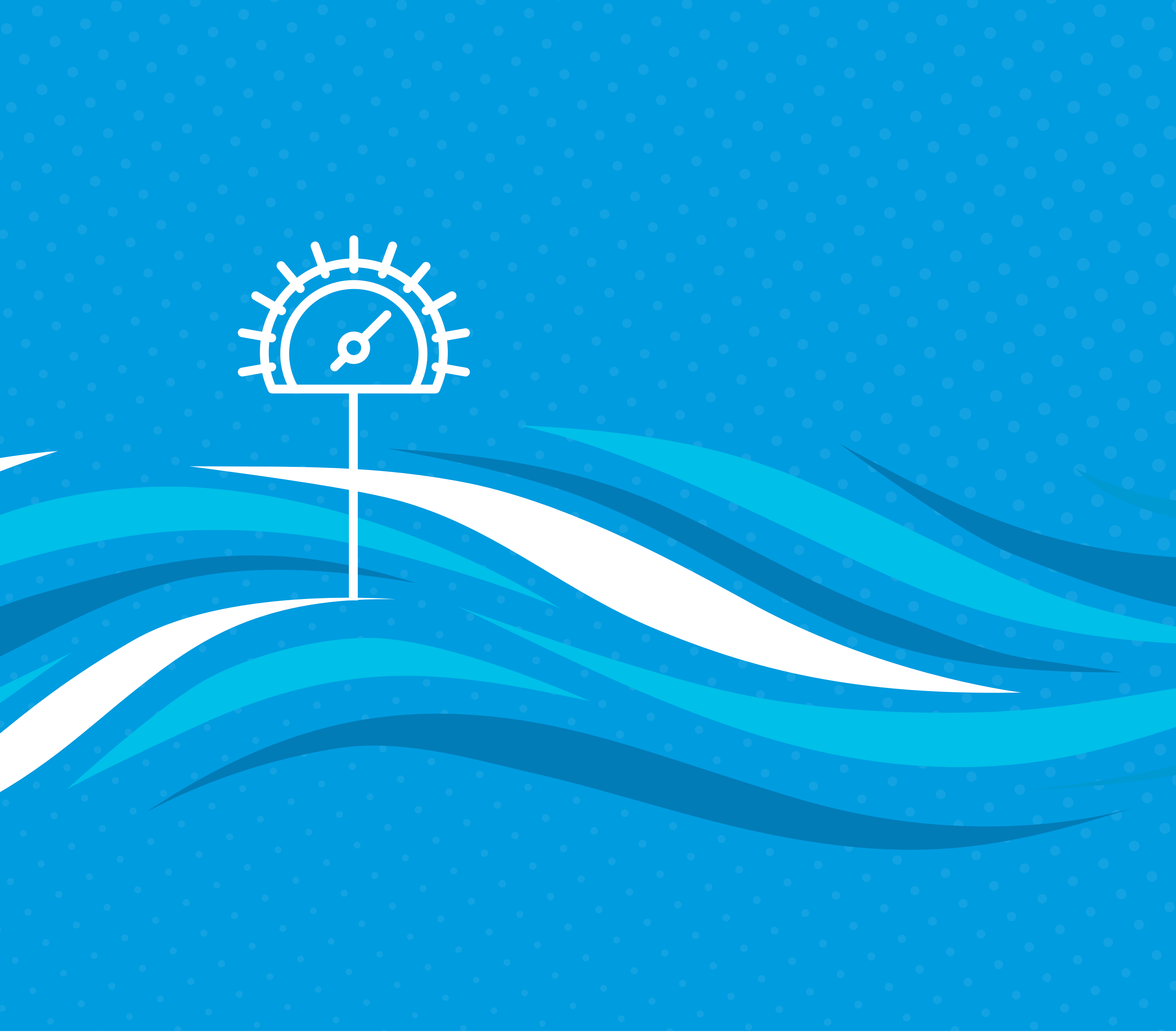
MIT Technology Review Insights is the custom publishing division of *MIT Technology Review*, the world's longest-running technology magazine, backed by the world's foremost technology institution—producing live events and research on the leading technology and business challenges of the day. Insights conducts qualitative and quantitative research and analysis in the US and abroad and publishes a wide variety of content, including articles, reports, infographics, videos, and podcasts. And through its growing MIT Technology Review Global Insights Panel, Insights has unparalleled access to senior-level executives, innovators, and entrepreneurs worldwide for surveys and in-depth interviews.

Footnotes

1. Kate Ramsayer, "Emissions Could Add 15 Inches to 2100 Sea Level Rise, NASA-Led Study Finds," NASA
2. NOAA- need source and link
3. Bob Berwin, "Hamburg's Half-Billion-Dollar Bet," Hakai Magazine, May 5, 2017
4. James Blackman, "Ericsson preps 5G mesh network to break satellite 'monopoly' for maritime comms," Enterprise IoT Insights, December 17, 2020
5. "Government resolution to reduce emissions from maritime and inland waterway transport focus on effective global action," (press release) Ministry of Transport and Communications, June 5, 2021
6. Yoon Ja-young, "INGINE inks Canada deal to develop onshore wave energy system," The Korea Times, November 7, 2021
7. "Roadmap to Zero Emission from International Shipping," Japan Ship Technology Research Association, March 2020, (pdf, p. 17)
8. Environmental Justice Foundation, "At what cost? How Ghana is losing out in fishing arrangements with China's distant water fleet," EJF, March 23, 2021, (pdf, p. 5)
9. Elham Shabahat, "Why Nauru Is Pushing the World Toward Deep-Sea Mining," Hakai Magazine, July 14, 2021
10. Jamie Shutler and Andy Watson, "Guest post: The oceans are absorbing more carbon than previously thought," Carbon Brief (blog), September 28, 2020
11. "Revised estimates of ocean-atmosphere CO2 flux are consistent with ocean carbon inventory," Nature, October 4, 2020
12. "Review of maritime transport 2020," United Nations Conference on Trade and Development, September 2020
13. Anastassios Adamopoulos, "Shipping added to new UK emissions targets," Lloyd's List, April 20, 2021
14. "Greece Supports Emission Fund, Calling for Charterers to Pay for CO2," The Maritime Executive, May 10, 2021
15. "Greenhouse Gases," Transport & Environment
16. General Fisheries Commission for the Mediterranean, "Mediterranean and Black Sea fisheries are turning the corner on overexploitation," Food and Agriculture Organization of the United Nations, December 14, 2020
17. Alejandro Zúñiga, "Costa Rica lawmakers sink trawling project," The Tico Times, September 17, 2021
18. "Our enormous fish catches have skewed ocean chemistry," Nature, October 15, 2021, (requires purchase or subscription)
19. Food and Agriculture Organization of the United Nations, "The State of World Fisheries and Aquaculture 2020," 2020, FAO
20. Emily Petsko, "Wild seafood has a lower carbon footprint than red meat, cheese, and chicken, according to latest data," Oceana.org (blog), September 16, 2021
21. "The state of world fisheries and aquaculture 2020," Food and Agriculture Organization of the United Nations, March 2020
22. Emily Petsko, "Wild seafood has a lower carbon footprint than red meat, cheese, and chicken, according to latest data," Oceana (blog), September 16, 2021
23. John Briley, "Confronting Ocean Plastic Pollution," Pew Trust Magazine, November 16, 2020
24. Karen Raubenheimer and Niko Urho, "Possible elements of a new global agreement to prevent plastic pollution," Nordic Council of Ministers, 2020
25. European Patent Office's "Espacenet: Patent search," European Patent Office
26. Anne Kalosh, "TECO 2030 gets tax break for large-scale production of hydrogen fuel cells," Seatrade Cruise News, September 23, 2021
27. Alex Fraser, "Italy's 'Smart Bay' seeks to tackle Mediterranean climate change," CTV News, October 1, 2021
28. Europe's electricity generation from wind blown off course," Financial Times, (requires subscription)
29. "Renewables 2020: Analysis and forecast to 2025," International Energy Agency, 2020
30. Department of Industry, Science, Energy and Resources "New legislation to encourage investment in offshore renewable energy," Australian Government, September 2, 2021
31. Sonali Paul, "Australia looks to clear way for offshore wind farms, " Reuters, September 2, 2021
32. Sabine Sluijters, "First combined offshore energy park put to the test off the Belgian coast," Innovation Origins, September 11, 2021
33. Amir Garanovic, "Dutch meld offshore floating solar with seaweed cultivation," Offshore Energy, December 3, 2020
34. "World Energy Investment 2021 Executive Summary," International Energy Agency, June 2021

Illustrations

Illustrations assembled by Scott Shultz Design. Cover waves by Lorthos Yuliya; barometer by Rvector, Shutterstock. Map Illustration by pingebat, Shutterstock. Internal report page art elements by Cube29, Freud, Keep Calm and Vector, Zaur Rahimov, Shutterstock. Pollution art elements by Adobe Stock.



MIT Technology Review Insights

www.technologyreview.com

@techreview @mit_insights

insights@technologyreview.com