The Economist Group

WORLD OCEAN INITIATIVE

A sustainable ocean economy in 2030:

Opportunities and challenges

Executive summary

What will the sustainable ocean economy look like in 2030? What risks and opportunities face companies and investors? Will the post-coronavirus recovery help or hinder the ocean's potential to create economic growth and jobs?

In this report the World Ocean Initiative assesses the challenges facing key sectors in the ocean economy, including seafood, shipping, tourism and renewable energy. We look at the role of banks and investors in financing the transition towards clean, low-carbon technologies, as well as opportunities in data and analytics. We examine solutions to marine plastic pollution from source to sea, and the ocean's potential to remove carbon from the atmosphere and increase resilience to the impacts of climate change.

Drawing on the latest data and in-depth interviews with experts in government, business, finance and conservation, this report provides valuable insights for all stakeholders working to achieve a sustainable ocean economy.

In **chapter one**, we look at the profound impact that covid-19 has had on the ocean economy. Before the pandemic the OECD forecast that by 2030 the ocean economy would double in size to US$3trn. Yet 2020 could see the global economy hit worse than during the global financial crisis more than a decade ago. Despite the gloom, there is hope that a green-blue recovery is possible.

In **chapter two**, we find growing interest among investors in financing the sustainable ocean economy. But many challenges remain. Investors need to channel capital away from damaging activities such as overfishing and towards opportunities in zero-carbon shipping, marine conservation and bio-technology.

Chapter three shows how over the next decade satellite imaging, remote sensors, big data and artificial intelligence will generate unprecedented quantities of information on the ocean, helping policymakers, businesses and investors make better-informed decisions to sustainably manage marine ecosystems.

Fisheries and aquaculture offer enormous potential to solve a plethora of global sustainability problems. However, as **chapter four** demonstrates, they must first address a number of their own challenges, including tackling illegal fishing and developing sustainable feeds.

As we discover in **chapter five**, decarbonisation is the greatest sustainability challenge facing shipping companies, creating a trillion-dollar opportunity for investment in zero-carbon fuel and engine technologies to 2030 and beyond. In doing so, the industry has a pivotal role to play in decarbonising energy use in the wider economy.

In **chapter six**, we see that offshore wind technology has come a long way from the niche, expensive option it was seen as just a few years ago. It also has the potential to be integrated with other industries, such as green hydrogen manufacturing. Wave and tidal-stream energy generation have also risen significantly over the past decade. The main challenge is to reduce technology costs so these sources can compete with other renewable-energy technologies.

Mass tourism may be good for the bottom line, as we find in **chapter seven**, but it can be ruinous for the coastline. The tourism industry is increasingly aware of these risks and is responding with a variety of corporate-responsibility initiatives. But to achieve a sustainable blue economy, the sector needs to play an active role in marine conservation.

By 2050 there could be more plastic than fish in the ocean. **Chapter eight** discusses the opportunity to create a circular economy for plastic in which we end its unnecessary use, implement effective waste management, develop alternative materials, and reuse and recycle the plastic in the system.

In **chapter nine**, we see how scientists and businesses are looking at ocean-based natural and technological ways to remove carbon from the atmosphere and reduce the impact of climate change, creating opportunities in the blue economy.

No one doubts the significance of the challenges facing the ocean economy. But our report shows that the momentum for innovation, change and sustainable growth need not be lost. Even in the uncertain times of 2020, opportunities abound for government, industry and investors to develop the ocean economy for the well-being of people and our planet over the next decade and beyond.

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- Kristian Teleki, director, Sustainable Ocean Initiative, World Resources Institute
- Peter Thomson, UN special envoy for the ocean
- Chever Voltmer, director for plastics initiatives, Ocean Conservancy

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Chapter 1: The blue economy and covid-19

The coronavirus crisis has severely affected many marine industries. But the fundamentals driving the transition to a sustainable ocean economy remain strong.

The ocean makes a large and growing contribution to the global economy, driving growth in economic activity, jobs, innovation and business opportunities. In a 2016 study the OECD estimated that the size of the ocean economy was around US$1.5trn in 2010, equivalent to some 3% of global GDP. By 2030 its contribution is projected to double in size from 2010 levels to US$3trn, providing full-time employment for around 40m people.

Blue transition derailed?

This was supposed to be the "ocean super year", with the first set of ocean-related targets under UN Sustainable Development Goal (SDG) 14 coming due and a string of important international conferences on marine conservation and climate change. However, the global coronavirus pandemic led to the cancellation or postponement of many events including the World Ocean Summit, the UN Ocean Conference and the COP26 climate negotiations.

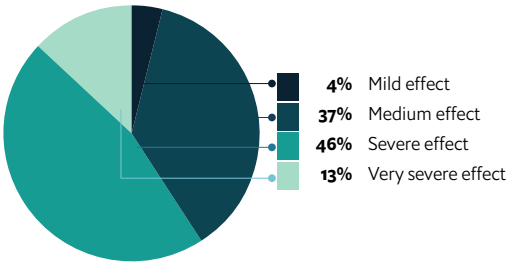
Many organisations have shifted to virtual gatherings to fill the gap. Nevertheless, the pandemic has undeniably slowed progress towards international agreements that would help build a sustainable ocean economy. It has also shifted focus away from long-term sustainable development to the need for short-term cushioning of the economic and social blows. The Economist Intelligence Unit forecasts global output and global trade to contract by larger margins in 2020 than during the global financial crisis more than a decade ago.

The effects on the ocean economy are profound. The pandemic has disrupted key ocean industries such as shipping, fisheries and tourism. In a recent webinar by the World Ocean Initiative, Karin Kemper, global environment director at the World Bank, highlighted the impact on fishing in developing countries: around 10% of the world's population rely on fishing for their livelihoods but can no longer bring their fish to market. In the same webinar Lars Robert Pedersen, deputy secretary-general of ship-owners' association BIMCO, highlighted the plight of 150,000 seafarers around the world who are "effectively imprisoned on ships" as they cannot be relieved from their duties and are not being paid.

More than half of the webinar audience (59%) thought that coronavirus would have a severe or very severe impact on the ocean economy. Tourism was seen as the sector most severely affected (71%) (see figures on next page).

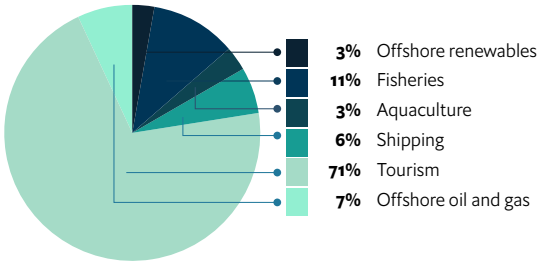
In its 2016 study the OECD had predicted that maritime and coastal tourism would replace offshore oil and gas as the top ocean-based industry in terms of gross value added by 2030. Claire Jolly, head of the STI Ocean Economy Group at the OECD, says that the halt in tourism following the coronavirus outbreak has been "dramatic" and is putting investment in sustainable tourism at risk. Chapter 7 of this report analyses the wider transition towards sustainability that the blue-tourism industry has seen.

What impact do you think the coronavirus pandemic will have on the ocean economy?



Source: World Ocean Initiative

Which ocean-based industry will be worst affected by the pandemic?



Source: World Ocean Initiative

The pandemic also threatens to slow progress in other areas vital to building a sustainable ocean economy, such as blue finance and investment in ocean-energy projects, shipping decarbonisation and aquaculture, as policy priorities shift towards health care and welfare.

'Building back bluer' after the pandemic

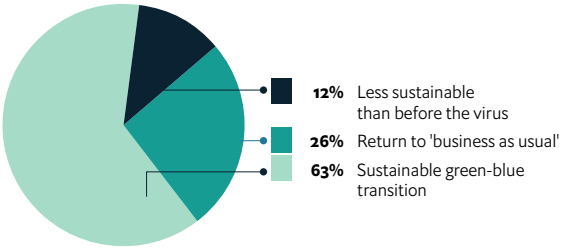
However, policymakers and business leaders are increasingly focusing on the post-coronavirus recovery and how to set the economy on a sustainable footing. EU leaders, for example, have called for the post-pandemic recovery plan to include the continent's "green transition", and the European Commission is pressing ahead with its renewed sustainable-finance strategy. Meanwhile, in the US, a "green stimulus" package has been promoted by activists and academics.

A study from Oxford University compared green-stimulus projects with traditional stimulus, such as measures taken after the 2008 global financial crisis. It found that green projects create more jobs, deliver higher short-term returns per dollar spent by the government and lead to increased long-term cost savings compared with investment in carbon-intensive infrastructure.

The extent to which the ocean economy will benefit from such fiscal stimulus remains unclear. Countries will be eager to return to growth as soon as restrictions ease. There are concerns that the opportunities to accelerate the blue transition as the virus recedes may not materialise.

But there is optimism that a green-blue recovery is possible. Almost two-thirds (63%) of our webinar audience thought that the post-coronavirus economic recovery would support a sustainable green-blue transition rather than "business as usual" or a less sustainable future.

What type of recovery will we see for the ocean economy?



Source: World Ocean Initiative

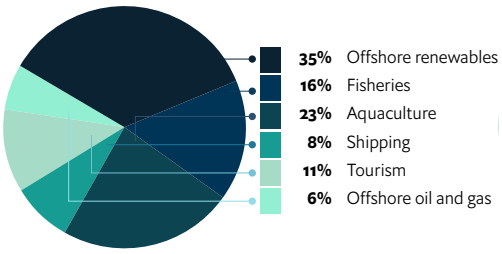
Peter Thomson, UN special envoy for the ocean, has called for the post-pandemic recovery to support ecosystem restoration, for example by planting mangroves, conserving coral reefs and establishing marine protected areas (MPAs). These activities would

not only reduce carbon emissions and boost climate resilience in coastal communities but would also create jobs in the tourism, fishing and aquaculture sectors.

Dr Kemper says the recovery should "build back bluer", for example by redirecting harmful fishing subsidies that encourage overfishing towards smaller-scale, more sustainable fisheries and by boosting waste-management systems in developing countries.

More than one-third (35%) of webinar participants thought offshore renewable energy would benefit most from the post-pandemic recovery, ahead of aquaculture (23%) and fisheries (16%).

Which ocean-based industry will benefit the most from the post-pandemic recovery?



Source: World Ocean Initiative

Fundamentals still strong

Much of this optimism stems from the fact that the fundamentals driving growth in the ocean economy identified by the OECD remain valid. Ms Jolly says that covid-19 has stopped the pre-pandemic acceleration in areas such as maritime coastal tourism, port activities, marine equipment and offshore wind. But she also highlights that the global megatrends around food, climate and decarbonisation that are driving the ocean economy are not going away.

For example, with the world's population set to reach 10bn by 2050, there is increasing demand for food. The ocean could provide over six times more food than it does today, equal to more than two-thirds of the animal protein needed to feed the future global population, according to research commissioned by the High Level Panel for a Sustainable Ocean Economy. The need for sustainable seafood will be as pressing as ever in the post-pandemic world. Chapter 4 of this report explores the prospects for sustainable seafood.

Climate change is another megatrend that must be addressed. The Paris climate agreement is driving decarbonisation across all ocean sectors. BIMCO's Mr Pedersen confirms that the shipping industry's commitment to decarbonise its fleet by 2050 by switching to zero-carbon fuels "will happen because it has to happen". Chapter 5 takes a deeper look into the prospects for decarbonising the sector, while Chapter 9 examines the ocean's role in tackling climate change more broadly.

The prospects for offshore renewable power remain positive, as it offers a clean-energy solution to climate change. Although offshore wind makes up only a tiny fraction (0.3%) of total global energy generation, it has experienced a boom, rising by 20% in 2018 after record 32% growth in 2017, according to the International Energy Agency. Ms Jolly highlights the strong growth that the OECD expected for wind energy by 2030, with a compound annual growth rate for gross value added of 24.5% between 2010 and 2030—by far the largest growth rate of any ocean industry examined in its 2016 study. Chapter 6 puts the spotlight on the business opportunities in ocean energy.

Previously obscure industries are also experiencing a boom as a result of a combination of these megatrends—and the pandemic is unlikely to stop this momentum. Seaweed is one of those industries, says Erik Giercksky, head of the UN Global Compact's Action Platform for Sustainable Ocean Business. He says that the sudden industrialisation of seaweed has been spurred by its potential to provide good sources of food, feed, biofuel and for carbon sequestration.

Investments in areas such as sustainable aquaculture, offshore renewables and tackling marine plastic pollution (discussed in more detail in Chapter 8) will require a substantial mobilisation of capital. A trend that started before the pandemic and is set to continue—potentially with increased vigour if a green-blue recovery takes hold—is the rise of blue finance. Banks and investors want a green shift: this is the "clear message we are getting", says Mr Giercksky. Chapter 2 explores the potential for the rise in blue finance that is required in the 2020s.

Policy frameworks

Another key enabler of a sustainable ocean economy is ocean science, boosting better data, technology and innovation. The UN Decade of Ocean Science for Sustainable Development (2021-30) offers a framework for renewed emphasis on ocean science to facilitate many of the business opportunities identified in this report. "We have work to do to protect the well-being of the ocean", says Mr Thomson. "There can be no healthy planet without a healthy ocean—and no healthy ocean without better ocean science and blue innovation." Chapter 3 looks at the outlook for ocean data in the coming years.

The 2020s will also be crucial in achieving the SDGs, most of which have clear targets to be achieved by 2030. SDG14 contains targets in areas such as reducing marine pollution and ocean acidification as well as supporting small island developing states.

Moreover, since 2018 the UN has been negotiating a new treaty on the conservation and sustainable use of marine biodiversity in waters beyond national jurisdiction. The treaty could create more clarity on using and sharing the resources of the high seas.

Beyond UN frameworks, there are alliances for ocean sustainability that wield some influence on business opportunities in the ocean. For example, the International Union for Conservation of Nature has called for 30% of each marine habitat to be set aside by 2030 in robust MPAs. The "30by30" call has been taken up by several countries in the Global Ocean Alliance, spearheaded by the UK. Meanwhile, the European Green Deal for 2019-24 will continue to influence the transition to a circular economy, the drive to protect biodiversity and cuts in pollution.

UN and other international policy frameworks will provide the context and also a driving force behind business opportunities in a sustainable ocean economy by 2030. Political willingness and the related need to create better policy frameworks for the ocean economy will be important enablers for many of the opportunities discussed in this report—and will also be crucial in overcoming some of the challenges that businesses still face in their quest to harness the ocean economy while protecting ocean health.

Chapter 2: Financing ocean sustainability

To finance a sustainable ocean economy, investors need to channel capital away from damaging activities such as overfishing and towards opportunities in zero-carbon shipping, marine conservation and bio-technology.

Finance has a crucial role in enabling the sustainable blue economy. Building new offshore wind farms, developing zero-carbon ship fuels and restoring coastal ecosystems to sequester carbon and secure the livelihoods of local communities—all will require a huge amount of "blue finance" over the next decade.

Yet the evidence suggests that companies and investors have been slow to see the opportunities in the sustainable blue economy. Research by PWC found that, of the 17 UN Sustainable Development Goals, SDG14 on the conservation and sustainable use of the ocean and its resources has consistently attracted the least interest from companies.

The OECD found that SDG14 attracts the joint lowest share of investment (3.5%) compared to the other SDGs. What investment there is comes mostly from philanthropy and development aid. Since 2009, ocean-sustainability projects have received just US$8.3bn in grants from philanthropic donors and US$5bn in financing from development banks, according to Funding the Ocean—an insufficient sum given the scale of the challenge.

Now the tide is turning. There is growing recognition of the opportunities in blue finance. Nine out of ten institutional investors are interested in financing the sustainable ocean economy, according to a survey by Responsible Investor. Driving the market are government targets for offshore renewable energy, commitments to decarbonise shipping, industry agreements to switch to reusable and recyclable packaging materials, and consumer demand for sustainably sourced seafood.

Understanding ocean finance

Nevertheless, several challenges need to be overcome in order to channel the finance necessary to create a sustainable ocean economy. One of these is establishing a mutual understanding of blue finance. "Lots of people speak finance and lots of people speak ocean, but very few people speak ocean finance," says Kristian Teleki, ocean director at the World Resources Institute.

To answer this need for a common language, in April the Friends of Ocean Action published a guide to blue finance called the Ocean Finance Handbook. It aims to show those seeking finance where it can be raised and to offer insight to investors on where opportunities lie in the blue economy. The handbook illustrates how different types of financing align with a range of ocean-related activities (see figure on next page).

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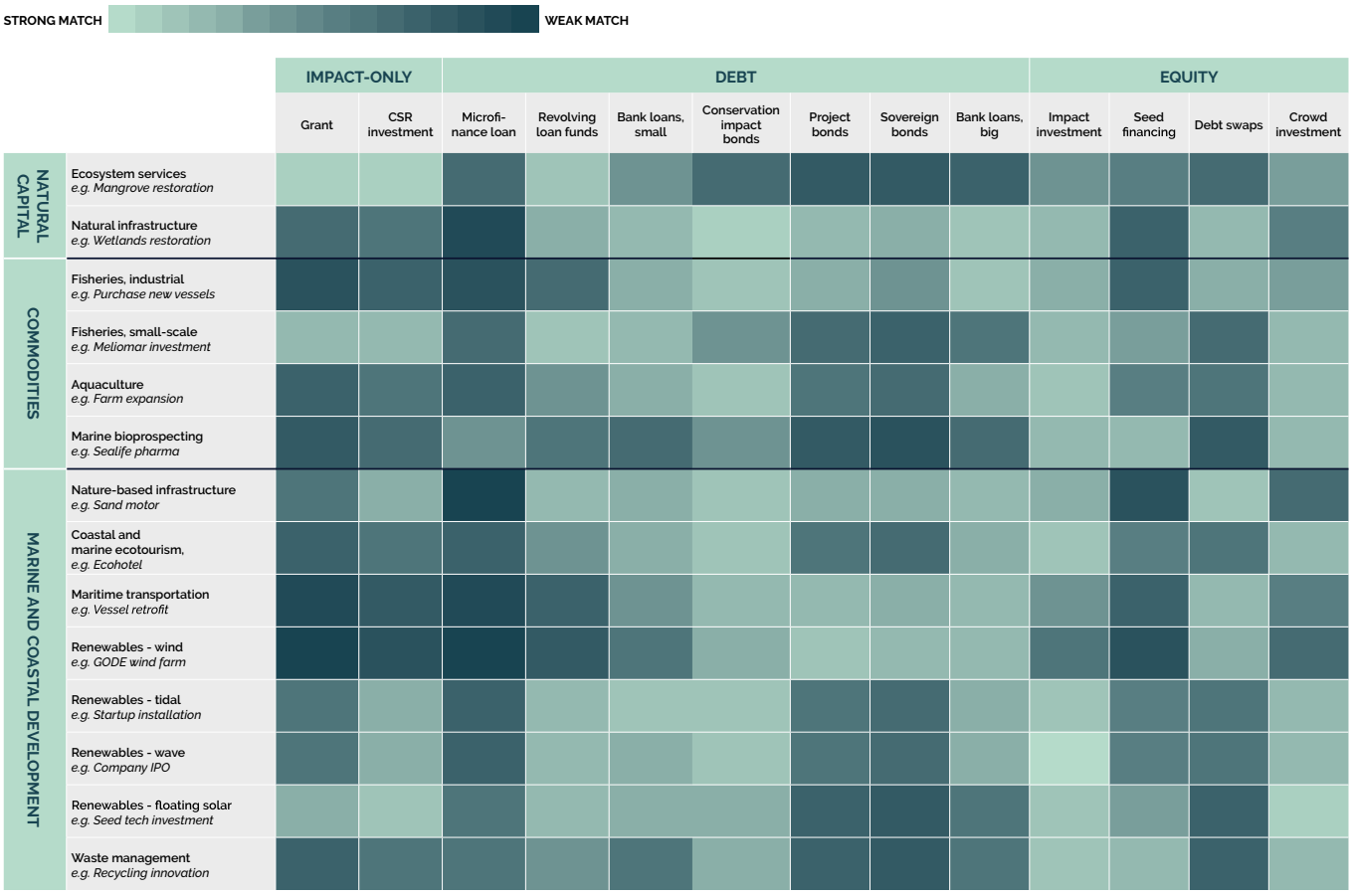
> Kristian Teleki, ocean director, World Resources Institute

How different types of financing align with a range of ocean-related activities



Source: Friends of Ocean Action

The handbook highlights the need to distinguish between well-established sectors such as shipping and fisheries, and emerging sectors focused on nature-based activities such as marine conservation and ecosystem restoration.

For the established sectors, the financing challenge is to redirect capital away from socially and environmentally harmful activities towards sustainable activities. The Responsible Investor survey found that three-quarters of investors have not assessed the impact of their investment portfolios on ocean sustainability, and a fifth are completely unaware of ocean-related risks to the value of their investments.

Many investors have made progress in assessing and reducing general climate-related risks in their portfolios, encouraged by initiatives such as the Task Force on Climate-related Financial Disclosure and the Portfolio Decarbonisation Coalition. Investors need to extend this type of analysis to ocean-related risks and make clear commitments to end financing of activities that damage the ocean environment.

In shipping this transition started last year

with the launch of the Poseidon Principles by a group of banks including Citi, Société Générale and DNB. These incentivise decarbonisation by requiring banks to report annually on the carbon intensity of their shipping portfolios and assess their climate alignment relative to established decarbonisation trajectories.

Investors in fisheries and aquaculture need to follow suit, according to an analysis by Planet Tracker, a non-profit financial think-tank. With almost all global fish stocks fully exploited or overexploited, increasing competition and climate change threaten to drive dramatic declines in fish catches, resulting in revenue losses and increased operating costs. Shrimp farming in Asia, which contributes to mangrove deforestation, faces tighter regulatory and supply-chain controls. Salmon farms in countries such as Norway and the UK are confronting production losses from disease and parasites.

"Financial goals which maximise high returns to investors today are generally not taking proper account of planetary boundaries or placing fair value on ecological resources," says Robin Millington, Planet Tracker's executive director.

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Robin Millington, executive director, Planet Tracker

"Unless capital markets embrace greater transparency and disclosure, they risk higher exposure to production and price shocks due to nature-related supply- and demand-side constraints, exacerbating investors' inability to calculate company valuations accurately. This disclosure gap could compound environment-related top-line revenue and gross profit margin risks," she says.

Mobilising private capital

For emerging sectors in the blue economy, the challenge is to attract private finance. This is not easy because nature-based activities are often seen as too small, too risky and not offering an attractive return.

Investment from public bodies such as the European Investment Bank can help mobilise private capital by building confidence and reducing risk. "The private sector has a critical role to play to provide finance needed to achieve sustainable development goals and a sustainable blue economy," says Emma Navarro, vice-president of the EIB.

In 2019 the bank committed to more than double its lending to sustainable ocean projects to €2.5bn (US$2.7bn) over the next five years. The bank expects it to mobilise at least €5bn in investments from private-sector companies and investors, among other partners.

There is also an important role for impact investors. These are private-sector investors that seek to make a profit from their investments as well as generating environmental and social benefits. As such they will typically tolerate longer investment horizons than mainstream investors.

One such investment is the Dominican Republic's Arrecifes del Sureste marine sanctuary. Established in 2009 as a marine protected area (MPA), it covers 8,000km^2, including 100km of coastline, coral reefs and two tourism centres receiving some three million visitors a year. However, due to a lack of adequate funding and effective management, the MPA has been little more than a "paper park".

In 2018 a social enterprise called Blue Finance agreed a deal with the Dominican Republic to manage the MPA through a public-private partnership which includes the government, conservation groups and tourism associations. Blue Finance raised US$3m of investment from a group of investors including Mirova Natural Capital, part of sustainable investment manager Mirova, an affiliate of Natixis Investment Managers.

"This investment is pure impact," says Nicolas Pascal, director of Blue Finance. "We are trying to make marine conservation profitable, which is the opposite of all the other blue-economy sectors, which are profitable and you look to make it more sustainable." Revenue for the MPA will come from charges on divers exploring the coral reefs and from other tourists, giving it an independent income stream.

"We know that in the future this MPA has the potential to become financially sustainable, but we need some up-front capital to buy vessels, buoys, moorings and recruit staff," he says. The resources are needed to achieve agreed improvements in the MPA, including creating a plan to improve the health of marine life and enforce the rules of the MPA on activities such as fishing. Blue Finance has four more MPA management agreements nearing completion and others in the pipeline.

With intergovernmental plans under the UN Convention on Biodiversity to increase the coverage of MPAs to 30% of the ocean by 2030, there is a need to ensure they are financed to deliver effective protection. Mr Pascal says there is some suspicion among environmentalists over the involvement of private investors. Nevertheless, "we have to face reality," he says. "The public sector and philanthropic investors will not be able to finance 20,000 MPAs."

Venture capital

Impact-oriented venture capital is another important source of investment in the blue economy. These are private investors interested in financing startup companies developing new technologies, usually through a combination of equity and loans. They also provide practical business support and networking opportunities through an accelerator programme or blue cluster. A notable example is Norway's Katapult Ocean, which has invested in 23 ocean-tech startups from 14 countries in a range of blue-economy sectors, including green shipping, sustainable seafood, and information and communications technology.

In November this year BioMarine is due to launch a new investment fund focused on companies developing marine-biological resources for use in pharmaceuticals, cosmetics, nutrition, bioplastics and biofuels. The organisation runs a network of some 6,500 companies, investors and scientists interested in developing marine bio-resources

such as seaweed and microalgae. The fund will be managed by Seventure, an affiliate of Natixis Investment Managers, which has expertise in life sciences.

BioMarine and Seventure are seeking to raise €100m-150m for their Blue Forward fund to invest in 15-20 companies at various stages of development, from startups to profitable SMEs with a turnover of less than €50m. Each company will receive €5m-15m over 1-3 financing rounds. The BioMarine network provides a flow of potential investment deals as well as the potential for collaboration and acquisitions.

Pierre Erwes, founder and principal partner of BioMarine, says Blue Forward will be the first private-equity fund dedicated to the growth of companies in the blue bio-economy. It is seeking investment from family offices and larger companies in the sector which share the long-term vision of realising the sector's potential. Companies in marine bio-resources have an annual turnover of around US$200bn, he says.

Build back bluer

As the world emerges from the coronavirus crisis and starts to rebuild, many experts are urging governments to prioritise investment in clean and renewable industries—including sectors in the sustainable ocean economy—to create growth and employment.

"This pandemic is a reminder of the need to listen to experts and to address the climate and environmental threats we are facing before it is too late," says the EIB's Emma Navarro. "Once the health emergency is under control we need to make sure that we kick-start the economy by supporting investments consistent with the EU's climate neutrality objective. This means that we need to ensure that the recovery is green".

The World Resources Institute's Kristian Teleki agrees: "We want to be sure that any kind of green recovery includes a blue dimension." With investment opportunities in the sustainable-ocean economy about a decade or so behind terrestrial investments, the post-pandemic recovery could help it catch up.

"I hope that by 2030 there's a real vibrant ocean-finance investment community that is seeing a return on investments and doing right by both ocean health and human health," he says.

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Emma Navarro, vice-president, European Investment Bank

Chapter 3: Welcome to the blue data revolution

Data, analytics and digital tools offer myriad opportunities to protect the ocean from illegal and unsustainable activities, while companies can benefit from increased efficiency and transparency.

It was in the 15th century, during the Age of Discovery, that humans first started charting the ocean. However, until recently much of what happens on and below the waves remained a mystery. This is changing. Over the next decade satellite imaging, remote sensors, big data and artificial intelligence will generate unprecedented amounts of information on the ocean—data that are essential for the stewardship of this precious ecosystem.

With increasing access to data, there is enormous potential for everyone from policymakers and non-governmental organisations to businesses and investors to make more informed decisions, whether on how to prevent overfishing or where to install offshore wind turbines to minimise their impact on ocean ecosystems.

Understanding the ocean

Monitoring the ocean is a complex business. This was highlighted by a recent report from the High Level Panel for a Sustainable Ocean Economy, a coalition of leaders and experts promoting policy, governance, technology and finance solutions for healthy oceans.

According to the report, since the ocean is 10 trillion times more opaque to light than the atmosphere, it often demands a different monitoring approach from that used on land, requiring data-capturing devices to be placed on or inside the ocean.

Some of the techniques for monitoring the ocean can be relatively straightforward. At the University of Massachusetts Dartmouth, the School of Marine Sciences and Technology (SMAST) is measuring the impact of offshore wind developments in New England using traditional fisheries survey techniques, such as net tows.

With a net towed behind a vessel, fish are collected for a certain period of time. "You know the dimensions of the net, so you can estimate how much water is being sampled and the abundance of fish. And with elaborate modelling you can estimate the stock of the fishery, its age structure a nd its health," explains Steven Lohrenz, dean and professor at the school.

In addition, his colleagues are developing video technology and open nets to sample larger areas without having to catch the fish, and combining this with artificial intelligence algorithms. "They've reached pretty high standards in terms of the reliability of being able to count the number of fish and categorise them in species," he says.

Philanthropic dollars are also supporting advances in ocean-data collection, as is the case with the Ocean Observatories Initiative (OOI), which is funded by America's National Science Foundation. The OOI's platforms and sensor systems measure the ocean's physical, chemical, geological and biological properties to help inform action on climate change, ecosystem variability, ocean acidification, and carbon cycling and make this available via an online portal.

Information technology is also essential to the UN Decade of Ocean Science starting in 2021. Its aim is to ensure that science can

fully support efforts by countries to achieve a sustainable and healthy ocean. Among its key outputs will be a comprehensive digital atlas and observation system for the ocean to improve understanding of marine ecosystems and the many pressures on it.

Cracking down on illegal fishing

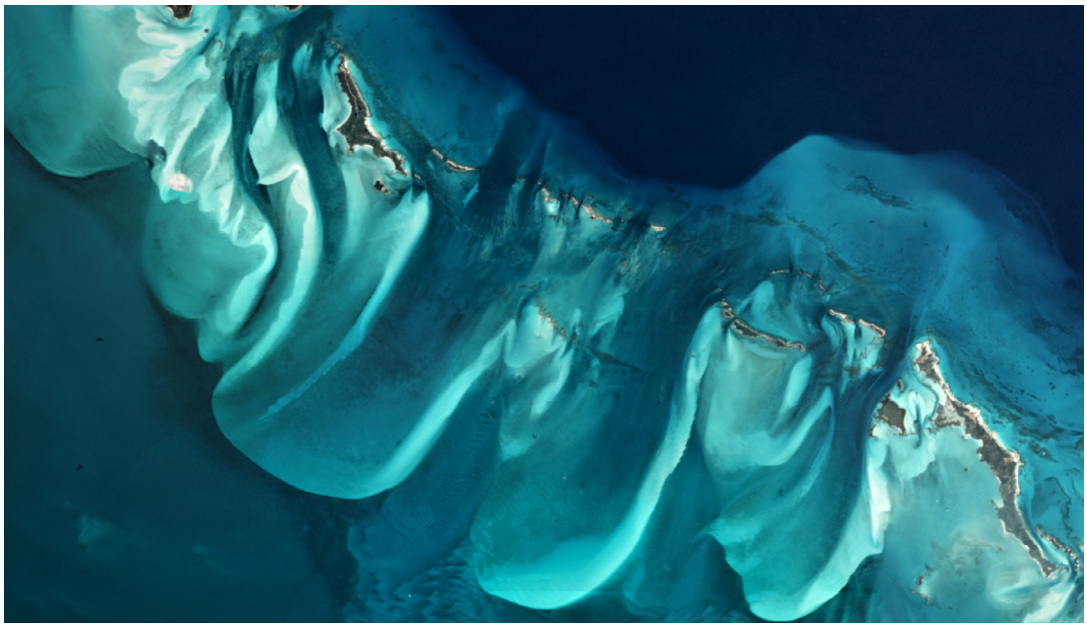
Monitoring environmental sustainability is not the only application of new technologies. They are increasingly being used in efforts to crack down on the human-rights abuses known as seafood slavery, which take place on unregistered "ghost ships".

This is among the roles of Global Fishing Watch, the result of a collaboration between Google, Oceana, a conservation non-profit, and SkyTruth, an environmental watchdog. The Global Fishing Watch platform—initially a project with the Chilean government and now an independent non-profit—visualises, tracks and makes freely available data on fishing activity in near real-time.

The technology compares satellite imagery of vessels with data generated through the automatic identification system, a tracking system that operates through transponders on ships.

"Historically fisheries operated out of sight, over the horizon where you couldn't track it. Now we're moving to a world where everything is knowable, and that totally shifts the way you manage things," says David Kroodsma, director of research and innovation at Global Fishing Watch. "Because if everyone is transparent, you don't need as much enforcement."

Global Fishing Watch's technology and analysis also makes it possible to detect potential instances of overfishing. During the initial



Satellites can detect changes to marine ecosystems such as coral reefs

Photo credit: Planet

stages of development, the team realised it was possible to tell the difference between a vessel's movement when it was heading out from port and when it was engaged in "gear-in-the-water" fishing activity.

"Then you could say not only that you had a fishing vessel in your waters but that it was putting gear down and fishing in your waters—that was transformational," says John Amos, president of SkyTruth, which uses technologies such as satellite imagery and remote sensing data to identify and monitor environmental threats such as oil spills and overfishing.

By collecting vast amounts of data and applying artificial intelligence to it, the technology can determine vessel types, sizes, what kind of fishing gear it is using and where, enabling the creation of "heat maps" showing patterns of commercial fishing activity.

"If you hope to manage fisheries for sustainability, you need to know how much fish you're taking out of that system and when and where," says Mr Amos. "Up till now, fisheries managers had to rely on reporting by the fishing community and observer programmes. Being able to directly measure from a distance offers tremendous advantages in creating robust, sharable data sets."

Ocean-tech innovators

Demand for these data sets is also spurring the growth of companies that recognise the value—both environmental and financial—of being able to capture accurate, real-time information about what is happening in the world's oceans.

For example, California-based Saildrone designs and manufactures wind and solar-powered autonomous sailing vehicles embedded with sensors and works with governments and companies around the globe to deploy fleets to monitor the ocean.

Among other things, the company's technology can establish a baseline of natural conditions ahead of planned commercial activity. South-east of Hawaii, for example, it enabled the study of the behaviour of micronekton (small mid-water fish, squids, and crustaceans) ahead of proposed deep-sea mining in the region to assess how ecosystems might be affected by mining operations.

Another company, Planet, has deployed the world's largest constellation of satellites, collecting more than 250 million square kilometres of imagery a day across the planet, including the oceans, and detecting in real time where degradation is taking place.

Of course, the vast amounts of information being generated by sectors ranging from government and academia to startups and the private sector present their own problem: data overload.

"It's about how you integrate increasingly exploding amounts of data across disparate locations and make sense of it," says Dan Harple, chief executive of Context Labs and its subsidiary, SphericalAnalytics.io, a firm he founded in partnership with Jeremy Grantham's Environmental Trust.

The company's Immutably platform uses machine learning to capture and measure data from five key sources—industry, local government, academia, regulators and the local community—and create a consolidated view that it calls a "knowledge

graph". Applying artificial intelligence to this, predictions can be made and scenarios run.

In partnership with the New Bedford Port Authority and SMAST, the company is launching a Marine Databank, which will allow stakeholders to share data, analytics and other digital tools to promote sustainable fisheries, ocean health and coastal community resilience. "Machine learning connects the academic research to industry work—in this case maritime—so it pulls together things that aren't normally connected," says Mr Harple.

Enabling transparent supply chains

And while regulators and conservationists are among those that want to make use of data and analysis, strong demand is also likely to come from the private sector.

Mr Amos predicts that suppliers wanting to maintain access to lucrative markets such as the EU, the UK and the US, where the seafood market is governed by environmental and human-rights legislation, will have to ensure that their fleets have clean, traceable records.

Meanwhile, seafood retailers need to meet the demands of consumers who want to know that the products they are buying come from sustainable, ethical sources. And with much of the data publicly available—including to journalists and activists—retailers who promote their products as sustainable and ethical are under increasing pressure to demonstrate that reality meets their rhetoric.

As the technology becomes more ubiquitous—with vast numbers of imaging satellites being launched in space—so does the ability to detect bad actors. "It's going to shine a spotlight on the dark fleet and make it impossible for operators to continue to hide their behaviour out on the high seas," says Mr Amos. "That will be a game-changer in terms of our ability to know what's happening on the ocean and to manage for sustainability."

> **It's going to shine a spotlight on the dark fleet and make it impossible for operators to continue to hide their behaviour out on the high seas**
>
> John Amos, president, SkyTruth

An autonomous sailing vessel on its way to collect data in the Pacific

Photo credit: Saildrone

Chapter 4: Sustainable seafood solutions

From traditional wild-capture fisheries to aquaculture and cell-based production, the ways that humans derive food from the sea are evolving fast.

Fish and seafood have enormous potential to solve a plethora of global sustainability problems. Experts convened to explore the issue by global leaders on the High Level Panel for a Sustainable Ocean Economy found that, as well as meeting more than 65% of the animal protein needed to feed future populations, food from the sea is more nutritious, cheaper and has a lower carbon footprint than meat, and could relieve pressure on land and water needed for meat production.

However, the sector must first solve a number of significant problems. The UN Food and Agriculture Organisation (FAO) estimates that one-third of wild fisheries are overfished and no longer biologically sustainable, while campaign group Greenpeace says that 640,000 tonnes of ocean plastic pollution is caused annually by fishing equipment becoming lost or abandoned at sea. Fortunately, technology firms have identified opportunities to solve several of these problems.

Illegal, unreported and unregulated (IUU) fishing is a major cause of the depletion of wild stocks. Fishing without a license, with prohibited gear, above a quota, or taking prohibited species is estimated by the FAO to cost the world's economy some US$23bn a year.

IUU fishing disproportionately impacts poorer countries that are less able to monitor their waters, and where typically a higher proportion of the economy relies on the sector, such as countries in west Africa, where two out of every five fish are likely to come from IUU sources, says Peter Horn, project director of international fisheries at the Pew Trusts, a non-profit organisation. IUU fishing is also often accompanied by violations of human and labour rights, he adds.

The main challenge is monitoring the vast spaces of the ocean. Patrolling with coastguard vessels or aircraft is resource-intensive. "There's 378 million square kilometres of ocean—you're looking for a grain of sand in Hyde Park. If you try and monitor all areas at all times you won't necessarily see what you're looking for," Mr Horn says.

Eyes on the sea

But the monitoring sector is now undergoing a "democratisation of data", Mr Horn says. Sensors and satellite technology that were previously only available to the military can now be used by campaign groups.

In 2014 the Pew Trusts partnered with the UK innovation company Satellite Applications Catapult to pioneer Project Eyes on the Seas, which combined satellite monitoring and artificial intelligence (AI) with imagery, fishing-vessel data and oceanographic data to help authorities detect suspicious fishing activity almost in real time. In 2018 the project relaunched as Ocean Mind to provide services to governments and seafood buyers.

Another user of AI is Moroccan startup Atlan Space, which is twinning it with drone technology to scan large areas of sea for illegal activities. US-based HawkEye 360 has developed technology that can geolocate a diverse set of radio signals emitted by ships, including marine radar, very high frequency radio, and emergency beacons.

But to really combat IUU fishing, such technologies need to be integrated with policies and regulations, says Mr Horn. For example, the 2016 Ports State Measures Agreement was specifically designed to stop IUU fish entering the market. The 87 countries that have signed the pact require ships to declare what species they are landing and where they were caught. Port authorities can then use technology to verify this information.

Aquaculture to the fore

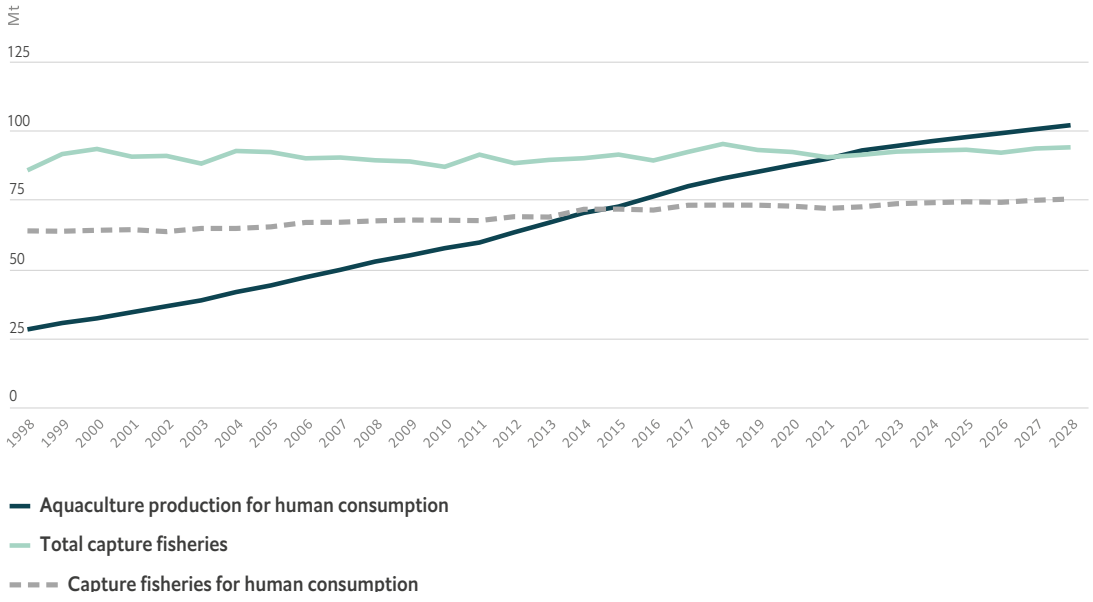
Even if the fishing industry can solve its many sustainability problems, it has been overtaken by another source of food from the oceans—aquaculture. The FAO calculates that the amount of seafood sourced from aquaculture will increase by two million tonnes per year to 102.2 Mt in 2028, an increase of 28% since 2019 (see figure).

"A rising population and increasing demand for more sustainable, healthy protein with less CO_2 impact are all megatrends that are driving the growth of aquaculture," says Ingrid Kylstad, chief operating officer of impact investor Katapult Ocean.

The US$243bn industry employs 20m people worldwide, according to the FAO, many of whom live in emerging economies. Indeed, the report for the High-Level Panel for a Sustainable Ocean Economy found that fed aquaculture—defined as finned fish bred in captivity, rather than other species such as bivalves and mussels that do not require food from humans—had by far the strongest potential to expand the production of fish from the sea.

However, this conclusion is dependent on the sector freeing itself from an over-reliance on wild-caught fish to feed those that are farmed. This has been blamed for damaging the marine

World aquaculture production overtakes fisheries



Source: OECD/FAO, 2019

environment, overfishing, illegal fishing and human-rights abuses by campaign groups such as Compassion in World Farming.

Sustainability challenges associated with fish feed, coupled with the fact that the supply of wild stocks is severely constrained, have led many companies to investigate alternatives. The use of fish oil and fishmeal has fallen from constituting 70% of fish feed in the 1990s to around 30% now, with soy a popular substitute.

Insects and algae

But soy does not solve the sustainability conundrum, since it is a driver of deforestation. Many aquaculture firms are now investigating novel feedstocks, such as insects and algae. These include Dutch company Protix, which in 2018 announced that it had full-grown salmon raised on insect-based protein, and US-based biotech company Calysta, which is planning to start production in 2022 of a protein feed derived from gas fermentation.

Technology to help fish farmers make operations more efficient is also a major trend, according to Ms Kylstad. For example, X, the research and development arm of Alphabet, has launched Tidal, an underwater camera system that can track thousands of fish, observe their behaviours and monitor temperature and oxygen levels, to help farmers monitor the health of their fish and make better decisions about how to manage pens. They hope this will reduce pollution and save farmers money.

Norwegian start-up Fishency Innovation uses cameras lowered into fish pens combined with AI to detect lice on salmon. Lice infections are a huge inhibitor to the growth of salmon farming, Ms Kystad explains, since on average 20% of fish in a cage will die if the problem is not managed properly. "Previously, they would check salmon handpicked out of the pen each week, and base a decision on whether to treat the entire pen based on that," she says.

Overall, the aquaculture sector is quite conservative and take-up of such technology is slow, notes Ms Kystad. "Some of the more sophisticated farms will already use this type of product, but we think there's a huge market for less complicated technology to be used by smaller farmers with lower budgets."

However, products would need to deliver results, be good value and easy to use in order to avoid technology fatigue among fish farmers, she says. In addition, regulation must permit the use of technology—for example, in Norway, fish farmers are currently required to carry out manual spot checks.

Lab-grown fish

While the fisheries and aquaculture industries grapple with technology to remove long-standing problems, a new approach aims to remove the need for either part of the sector. Cell-based, or lab-grown, fish is hot on the heels of the cell-based meat industry, which has been estimated to have a market worth US$593m by 2032.

"It's predicted that the cost of a kilo of lab-grown meat will be down to US$20 in a couple of years. If you can get to the same with lab-grown seafood, I think we'll see much more of it in the next decade," Ms Kylstad says.

One of the pioneers is Finless Foods, a California-based startup which is using

Sustainable aquaculture can feed a growing population

Photo credit: The Kampachi Company

cellular-agriculture technologies to grow fish cells. The firm developed the technology to produce bluefin tuna in around 12 months and predicts that the process for other species will become quicker and cheaper.

Another California-based start-up is BlueNalu, which in February 2020 secured US$20m of investment from five investors to finance a pilot production facility in San Diego, expand its team, and prepare for market launch. Meanwhile, in Singapore Shiok Meats is researching how to create shrimp, crab and lobster, and has plans to set up at least five manufacturing plants in the next five to seven years within several Asian countries.

Cost is a major challenge for the burgeoning sector. Finless Foods co-founder Michael Selden believes there is plenty of potential to reduce expenses, mainly by making the feed for the cells more cheaply, and using it more efficiently through selective breeding of cells and by recycling elements of the feed that are not eaten.

Other obstacles include consumer and regulatory acceptance. According to Mr Selden, Singapore is likely to be the first country to approve cell-based fish, while the US could follow before the end of the year. Japan, where 80% of bluefin tuna is consumed, as well as Canada and China, are also promising, he says. The EU, however, classifies cell-based fish as genetically modified due to the way the cell feed is produced, making it an unlikely market, Mr Selden believes.

"This technology can create seafood that tastes better, is cheaper and more nutritious and convenient than seafood. It could take the entirety of the seafood market, and on top of that be able to expand it, so the potential is massive," he says.

Chapter 5: Shipping and the energy transition

Shipping has the opportunity not only to decarbonise its own business, but to help other energy-intensive sectors move away from fossil fuels and towards zero-carbon hydrogen and renewable electricity.

Decarbonising the global shipping fleet is the greatest sustainability challenge facing shipping companies, creating a trillion-dollar opportunity for investment in zero-carbon fuel and engine technologies to 2030 and beyond. In doing so, the industry has a pivotal role to play in decarbonising energy use in the wider economy.

Shipping carries some 90% of world trade and is responsible for around 2-3% of global carbon emissions—the equivalent of a large economy such as Germany. Growing demand for freight transport could see shipping emissions increase by 50-250% by 2050.

In 2018 the International Maritime Organisation (IMO), the UN body responsible for regulating the shipping industry, agreed to a 50% absolute cut in carbon emissions from ships by 2050 compared with 2008 levels, while pursuing efforts to phase out carbon emissions consistent with the Paris Agreement on climate change, even though it does not cover shipping.

Achieving these ambitious goals while continuing to grow as an industry means that ship operators need to decarbonise the global shipping fleet of some 50,000 merchant vessels by 2050. With the typical lifespan of a ship being more than 20 years, the first zero-carbon vessels need to be launched by 2030 (see figure).

"Even using conservative estimates for trade growth, a 50% total cut in CO_2 by 2050 can only be achieved by improving carbon efficiency of the world fleet by around 90%. This will only be possible if a large proportion of the fleet is using commercially viable zero-carbon fuels," says Simon Bennett, deputy secretary-general at the International Chamber of Shipping. "In practice, if the 50% target is achieved, with a large proportion of the fleet using zero-carbon fuels by 2050, the entire world fleet would also be using these fuels very shortly after, making 100% decarbonisation possible—which is the industry's goal."

Shipping's 2050 decarbonisation challenge

Source: UMAS, 2019

No silver bullet

The challenge is that there is no consensus in the shipping industry over which low-carbon

alternative fuel to switch to. For decades, most ships have run on heavy fuel oil—the cheap and dirty dregs of oil refineries that emit high levels of air pollutants, including particulate matter, nitrogen oxide and sulphur. There are a range of cleaner alternatives such as hydrogen, ammonia, electric motors, liquified natural gas (LNG) and biofuels, but all have pros and cons, according to an analysis by the Energy Transitions Commission.

"It is our sense that there will likely not be a silver-bullet fuel of the future for shipping, but rather a selection of fuels suited to resource availability, local policies and ship type," says Johannah Christensen, managing director at the Global Maritime Forum, a not-for-profit coalition of more than 100 shipping companies, engine manufacturers, fuel and chemical suppliers, financial institutions and other organisations in the maritime value chain.

For short-haul journeys, electric motors are a promising option. Norway, with its many ferries and a plentiful supply of hydroelectricity, has taken an early lead in rolling out this technology. But the weight and limited range of existing battery technology means it cannot be used on longer journeys.

LNG, with much lower emissions of air pollutants, has seen interest among cruise-line operators driven by the need to meet the IMO's 0.5% limit on sulphur emissions, which came into force in 2020. But LNG only cuts carbon emissions by 9-12% and there are concerns about leakage of methane, a potent greenhouse gas, from LNG infrastructure.

For transporting cargo long distances across the ocean, ammonia appears to be the front-runner. It is almost twice as energy-dense as hydrogen by volume, although less dense than heavy fuel oil, meaning that some cargo space would have to be taken to store fuel. Another advantage of ammonia is that it is already widely available and used to make fertiliser for agriculture. Indeed, the first ammonia-powered ships are likely to be ammonia tankers which could use some of their cargo as fuel. However, there are safety concerns over the toxicity of the chemical.

There are currently several projects developing ammonia-fuelled ships and the supply chain to support it. The Global Maritime Forum is involved in a partnership including two Danish companies—shipping firm Lauritzen and energy generator Ørsted—as well as Norway-based ammonia producer Yara and Finnish marine-engine manufacturer Wärtsilä.

In January Malaysian shipping company MISC Berhad, Korea's Samsung Heavy Industries, German engineering firm MAN Energy Solutions and Lloyd's Register in the UK announced a partnership to develop an ammonia-fuelled tanker. And by 2024 Norwegian ship owner Eidesvik Offshore is to install and test a two-megawatt ammonia fuel cell onboard one of its vessels under contract to Equinor, Norway's state-owned oil and gas company.

Energy transformation

A study commissioned by the Global Maritime Forum estimates that the total investment needed between 2030 and 2050 to achieve the 50% emissions target is US$1trn-1.4trn, or an average of US$50bn-70bn annually for 20 years. To fully decarbonise by 2050, shipping would require further investments of US$400bn over 20 years, bringing the total to $1.4trn-1.9trn (see figure on the next page).

Although the sum seems large, global energy investments in 2018 alone amounted to US$1.85trn, according to the International Energy Agency.

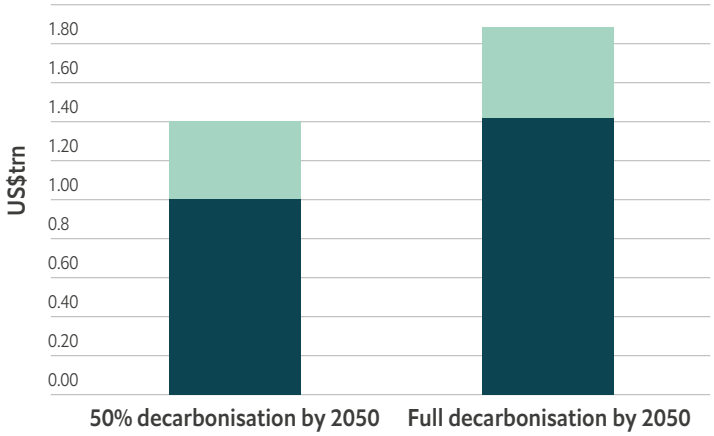
Only 13% of this investment is needed in the shipping sector for new vessels, engines and onboard fuel storage. Some 87% of the expenditure must take place in the fuels supply chain, specifically in developing low-carbon hydrogen and ammonia, as well as land-based storage and fuelling infrastructure.

"Shipping has potential to be a catalyst that brings scale to the deployment of zero-emission fuels and enable a broader energy transition in other sectors," says Ms Christensen.

At present, ammonia is produced by converting natural gas (methane) into hydrogen, which is then reacted with nitrogen to form ammonia. Investment is needed to develop a new hydrogen production process based on electrolysis of water powered by renewable energy. Yara is developing such a process at its ammonia plant in Pilbara, Western Australia, with French energy firm Engie. Yara is also working with Oslo-based Nel Hydrogen to develop new water-electrolyser technology at Yara's ammonia plant in Porsgrunn, Norway.

Sustainably produced hydrogen is likely to have many additional uses in a greener economy, for instance as a fuel for heating, energy storage, road transport, and steel, cement and plastics manufacturing. Marrying up these demands creates a much stronger business case for the investment needed in new production-plant and supply infrastructure.

Investment needed to halve shipping's carbon emissions and to achieve net-zero by 2050



Source: UMAS, 2019

Closing the price gap

"One of the key challenges in shipping's energy transition is how to close the competitiveness gap between traditional marine fuels and zero-carbon fuels," explains Ms Christensen. At present, alternative low- and zero-carbon fuels are 2-3 times as expensive as heavy fuel oil. "A price on carbon is probably one of the best ways to close that gap," she says.

At its 2019 annual conference the Global Maritime Forum's cross-sectoral group of stakeholders proposed a carbon levy on shipping emissions starting at US$10 per tonne of CO_2 and ramping up to US$50-75 per tonne of CO_2 by 2030, creating a fund of US$70bn. "At the lower price level you raise funds for R&D, while the higher level would be enough to change behaviour and investment patterns," says Ms Christensen.

However, this is twice as much as is being proposed by the International Chamber of Shipping and other ship-owner associations. Its proposed levy of US$2 per tonne of fuel would raise only US$5bn over ten years, as a fund for R&D rather than to influence investment decisions. The proposal was due to be discussed in March by the IMO's environment committee, but the meeting was cancelled due to the coronavirus pandemic.

Full steam ahead

The shipping industry does not have years to spend wrangling over a carbon price sufficient to drive innovation and investment in zero-carbon propulsion technology. The IMO's 174 member countries will need to reach agreement at an unprecedented pace. But once agreed, having a global regulator such as IMO that can apply carbon-pricing rules across the industry without damaging competitiveness is an advantage that other sectors do not have.

A further advantage are the Poseidon Principles, launched in June 2019 by banks that finance the shipping sector. These incentivise decarbonisation by requiring banks to report annually on the carbon intensity of their shipping portfolios and assess their climate alignment relative to established decarbonisation trajectories. Membership of the principles has grown rapidly to include 18 banks representing more than a third of global ship finance—around US$150bn. In March Japan's Sumitomo Mitsui Trust Bank became the first Asian bank to join.

Can the shipping sector grasp the opportunity not only to decarbonise its own business, but to help create a zero-carbon economy? "I am optimistic that it absolutely can be done," says Ms Christensen. Since the IMO agreed on its climate change strategy in 2018, "the narrative within the sector has changed from 'It can't be done' to 'How do we do it?'."

A price on carbon is needed to incentivise the shift to zero-carbon shipping

Photo credit: Shutterstock

Chapter 6: Ocean renewables come of age

Offshore wind technology has come a long way from the niche, expensive option it was seen as just a few years ago, while other marine renewables are showing promise.

The numbers associated with offshore wind are staggering—6 gigawatts (GW) of turbines were installed in 2019, taking the global total to 29GW. The industry is now targeting 190GW by 2030, by which time it hopes to be deploying turbines 125 metres high, with capacity to generate 11 megawatts (MW) each—nearly six times more than those built in 2000. Although its potential is vast, offshore wind currently provides just 0.3% of global power generation.

As the technology has grown, costs have fallen. Just five years ago the levelised cost of energy—the price of electricity including construction, operation, maintenance and fuel— was US$150-200 per megawatt hour (MWh)—roughly four times that of onshore wind. Prices fell below US$100/MWh in a series of competitive tenders in Europe in 2017, and in September 2019, a UK offshore wind farm won a contract at US$49.6/MWh.

The plummeting costs have been partly due to economies of scale, technological improvements, maturation of supply chains and better procurement. Markets have so far been overwhelmingly in Europe and China, but the tumbling costs mean that other regions are now getting in on the act.

"It's been a breakthrough year," says Ben Backwell, chief executive of industry body the Global Wind Energy Council (GWEC). "Offshore wind was growing anyway, but what's apparent now is the policy momentum," he adds.

New markets for offshore wind include the US, Taiwan, Japan and South Korea, all of which have ambitious targets, he notes. In a recent report, the World Bank identified significant potential for offshore wind in Brazil, India, Morocco, the Philippines, South Africa, Sri Lanka, Turkey, and Vietnam. Many governments are turning to offshore wind as a solution to growing energy demand, Mr Backwell says.

"For example, Vietnam had a plan based largely on coal even up to a couple of years ago. But now it's increasingly based on renewable energy and offshore wind as they have a fantastic wind resource and a long coastline," he says.

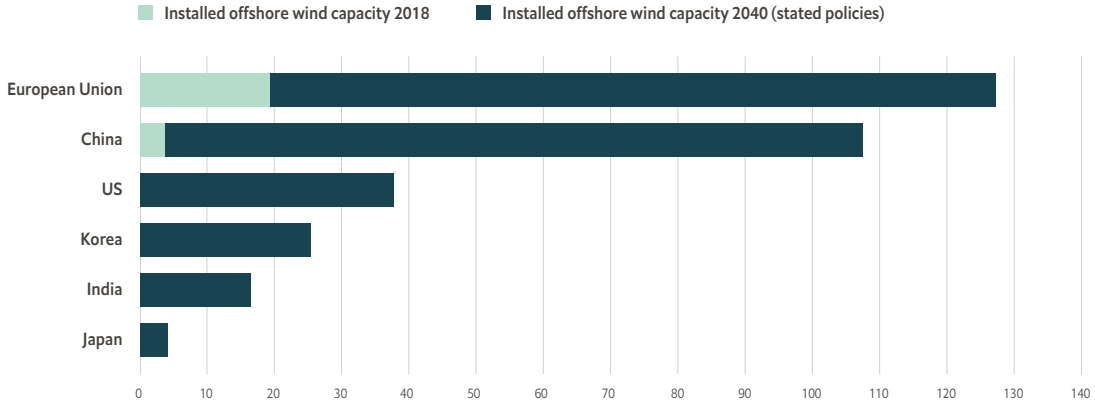
As well as helping to decarbonise energy systems, offshore wind has a number of tangible environmental and social benefits, with fewer of the limitations faced by onshore wind, such as competition for land use, and transportation and infrastructure constraints.

The International Energy Agency (IEA) forecasts that global offshore wind capacity will increase fifteen-fold by 2040, becoming a US$1trn industry (see figure on next page). How the coronavirus pandemic and countries' economic recovery plans may affect investment is uncertain. However, the IEA's executive director, Fatih Birol, urges governments to "make sure clean-energy transitions are front of mind as they respond to the fast-evolving covid-19 crisis."

Integrating renewables into the blue economy

Offshore wind also has potential to be integrated with other industries, such as green hydrogen manufacturing. This could prove financially beneficial since the hydrogen could be produced with excess power from the turbines that would otherwise be wasted.

Offshore wind capacity growing fast



Source: International Energy Agency

Several companies, including Danish wind giant Ørsted, oil company Shell and hydrogen manufacturer ITM Power, have plans to launch combined plants in countries including the UK, the Netherlands, Germany and Australia, some as early as this year.

The International Renewable Energy Agency (IRENA) is encouraging the integration of offshore wind with other renewable-energy technologies, as well as industries such as aquaculture and desalination. "We tell our members that when we talk about ocean energy, we have to explore the coupling of ocean energy with other sectors, and look at complementarities of other renewable-energy technologies. A holistic blue-economy approach can bring economies of scale," says Roland Roesch, deputy director of innovation and technology at IRENA.

Offshore wind also has the potential to create a large number of jobs. In Europe some 113,000 people are estimated to be directly or indirectly employed in offshore wind. Meanwhile, GWEC has estimated that over 77,000 trained workers will be needed to deliver 31GW of offshore wind by 2024 in just the six markets of North America, China, Taiwan, Japan, Vietnam and South Korea.

Responsible use of the sea

With the significant growth forecast, the industry has become more mindful of the need to work closely with local economies such as fishing and with environmental organisations to avoid any potential impact on wildlife. Disagreements over these issues can damage reputations, as well as causing lengthy delays to projects or denial of permits.

The cheapest and most space-efficient way to build the 450GW of offshore wind power needed by 2050 to meet the goals of the Paris climate agreement is the combined use of the same space by different sectors, such as

fishing and nature conservation, according to trade body Wind Europe. The organisation is developing plans with environmental organisations, industry and governments.

In the UK, Ørsted is collaborating with the government environment and energy departments to plan for the next phase of development. "We're looking to build three times more in the next ten years than we've built in the past 15. Finding the right places to build offshore wind is a big challenge—we want to make sure we use the seas responsibly," says Benj Sykes, the firm's head of UK market development.

Sustainability is also on the agenda of the Ocean Renewable Energy Action Coalition (OREAC)—a coalition of offshore wind operators, manufacturers and GWEC, formed to advance the technology in the global climate debate.

Experts working under the High-Level Panel for a Sustainable Ocean Economy have predicted that ocean-based renewable energy could meet nearly 10% of the annual greenhouse-gas emissions reductions needed by 2050 to keep global temperature rise within 1.5°C above pre-industrial levels, with the lion's share coming from offshore wind power.

But that would require installation of 1,200GW of offshore wind, which requires some serious global scale-up, says GWEC's Mr Backwell. "Europe has a credible track record, so 450GW could happen, but you're still looking at the rest of the world providing 550-750GW. There's a lot of regulation and market-building that needs to happen," he says.

It took Europe 20 years to grow expertise and cut the costs to current levels, he notes. "Because we have that, it won't take as long for the rest of the world to get there, but that doesn't mean there's not a lot to do," he says.

OREAC is creating a model to help other countries identify whether they have the right conditions for offshore wind, how to set up regulatory processes, measure the economic opportunities and coexist with other marine industries, says Ørsted's Mr Sykes. "It's really about accelerating something that makes absolute sense," he says.

Floating wind on the horizon

Conventional offshore wind turbines have foundations fixed to the seabed, but this restricts them to waters less than 50 metres deep. Bases that float on the water's surface can be deployed at sites further out to sea where the strongest winds are often found, opening up additional markets.

While the capital costs of floating wind farms are more than double those with fixed foundations, they are expected to drop substantially, from around €180-200/MWh to €80-100/MWh in 2023-25, according to Wind Europe. It expects installed capacity in Europe to pass 1GW during that time, after which costs will decrease faster, reaching €40-60/MWh by 2030.

So far the market has been dominated by European companies and projects. The world's first floating offshore wind farm—the 30MW Hywind project—was installed in Scotland in 2017 by Norway's state energy company, Equinor. There are now some 45MW of floating wind turbines installed in European waters, with the UK, France, Norway and Portugal taking the most interest.

In March, a consortium of European companies and institutions led by Spanish energy firm Iberdrola unveiled plans for a 10MW floating turbine in Norway's North Sea, using a €25m grant from the European Commission. Iberdrola is also planning another pilot near the Canary Islands. French oil major Total has teamed up with energy specialist Total Blue Energy to build a 96MW floating wind pilot project in the Celtic Sea. Another 88MW project by Equinor was approved in April to power its offshore operations in Norway's North Sea.

There are approximately 30MW of floating wind in other parts of the globe, and the World Bank believes there is significant potential for the technology in emerging markets, in particular Brazil, but also India, Morocco, the Philippines, South Africa, Sri Lanka, Turkey and Vietnam.

Wave and tidal energy make headway

Meanwhile, wave and tidal-stream energy generation have risen significantly over the past decade, from less than 5GWh in 2009 to 45GWh in 2019, according to a report from Ocean Energy Systems (OES), a programme set up by the IEA.

Interest in the technologies is growing around the world, with the governments of Canada, the US, Spain, Scotland, Australia, South Korea and China all announcing policies or targets aimed at the sector, according to the OES. Estimates for the size of the market for wave and tidal energy range from 100GW to 300GW globally, according to OES chairman Henry Jeffrey from the Institute for Energy Systems at the University of Edinburgh.

Projects installed last year include WaveRoller—a 350-kilowatt wave energy project in Portuguese waters by Finnish company AW Energy, and a 1MW tidal device in Brittany by French developer Hydroquest.

The main challenge for the sector is to reduce technology costs so they can compete with other renewable-energy technologies, he says. Wave energy in particular is being held back by a lack of technology domination, with several designs under development by different companies.

"Wave energy resources are a much bigger global prize than tidal, but there isn't the same design convergence, so there can't be technology transfer into the sector and supply chain. That is a real hindrance to its development," Mr Jeffrey says.

However, Mr Jeffrey believes that there is plenty of scope for costs to reduce with economies of scale as technologies mature. Tidal stream is aiming for a levelised cost of energy of €0.1 per kilowatt hour, while wave technology is targeting €0.15/kWh. Wave and tidal technologies can be competitive for islands, where energy is typically more expensive, and can help balance the grid by complementing the intermittent nature of wind energy, he says.

> **"Wave energy resources are a much bigger global prize than tidal, but there isn't the same design convergence, so there can't be technology transfer into the sector and supply chain.**
>
> Henry Jeffery, chair, Ocean Energy Systems

Chapter 7: Sun, sea, sand...and sustainability?

Coastal and marine tourism relies on a clean and healthy environment. What are companies doing to protect their greatest resource? Is there such a thing as sustainable "blue" tourism?

For most coastal resorts and cruise-ship operators, mass tourism is good for the bottom line—but it can be ruinous for the coastline. Coastal development destroys habitats, including mangroves and coral reefs. Tourists on beaches and divers in the shallows cause pollution through litter, noise and water contamination from sunblock. Cruise ships emit air pollutants and greenhouse gases.

Tourism is also among the sectors most at risk from climate change, according to Eco-union, an environmental organisation. Extreme weather events can devastate coastal areas and threaten lives, rising sea levels can flood properties and resorts and higher temperatures can bleach coral reefs and harm marine life. The economies of small-island developing states (SIDS) are particularly vulnerable. The Seychelles and Maldives, for example, rely on tourism for 26% and 39% respectively of their annual economic output, according to the World Bank.

The tourism industry—particularly coastal resorts, diving operators and cruise lines—is increasingly aware of these risks and is responding with a variety of corporate-responsibility initiatives. But to achieve a sustainable blue economy, the sector needs to play an active role in protecting coastal and marine environments.

"Businesses that benefit from nature are beginning to recognise [its value]," says Robert Brumbaugh, executive director in the Caribbean for The Nature Conservancy (TNC), an environmental advocacy group. "What we need to do now is create new pathways that go beyond the philanthropic efforts, which are fantastic, to those that are more systemic investments in ocean health."

Ecotourism: The ideal model for sustainable blue tourism?

Ecotourism refers to small-scale and low-impact activity which reduces negative environmental impacts and supports local communities. It emphasises procurement from local sources and can provide a way to conserve natural and cultural resources. Revenues from tickets to marine parks or on-site accommodation provide funds to protect these habitats and benefit local economies.

"We're already seeing trends in the market towards a much more experiential product, focused on local experiences," says Jeremy Sampson, chief executive of The Travel Foundation. "There's a real opportunity within that space to innovate and evolve the actual products." For example, MEET Network, an association which has supported 50 Mediterranean protected areas, has developed an "eco-travel portfolio" across 10 countries in the region. This curates sustainable travel options for consumers and creates a revenue stream for conservation of these habitats.

This may be more important in a post-pandemic world. "People may begin travelling first to local destinations and small-scale resorts," Mr Brumbaugh anticipates. Travellers may seek less crowded, more intimate options, in line with what ecotourism

offers. While no one predicts the end of the mass tourism model anytime soon, once governments ease lockdown measures the recovery may be an opportune time to roll out ecotourism products.

But ecotourism lacks the scale of mass tourism, which leaves a question mark over its financial attractiveness. Hoteliers view investments in infrastructure through a short-term lens, explains Julien Rochette, ocean programme director at the Institute for Sustainable Development and International Relations, a think-tank. Established ecotourism operators will need to find a way to scale up in order to disrupt the market. In the interim, government support could bolster this segment of the tourism sector, weaving it into economic development plans to promote inclusive growth.

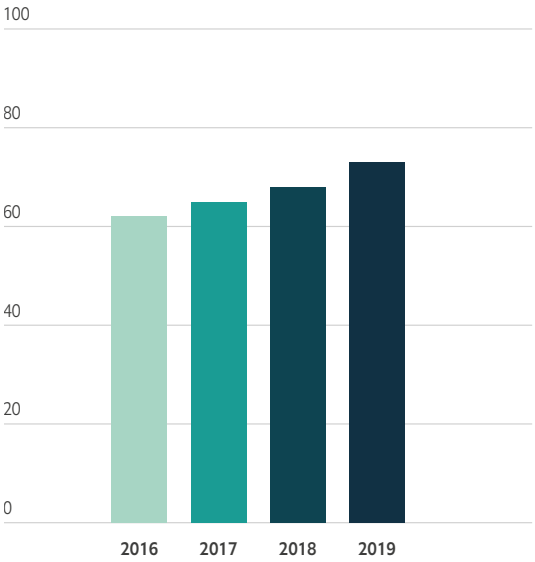
Greening mainstream tourism

While ecotourism may be the ideal, the rest of the marine and coastal tourism industry should not be written off. Even though they are reliant on mass tourism, hotels and cruise lines have a role to play in the transition to a sustainable global economy. This entails reducing emissions, improving energy efficiency, using sustainable materials and conserving the natural environment.

These initiatives are sometimes perceived as a cost, although energy efficiency and waste reduction often pay for themselves quite quickly. But with the help of a host of eco-labels, they can be used to attract the growing number of environmentally conscious travellers (see figure).

The growing base of eco-conscious travellers

Share of respondents who intend to stay in eco-friendly accommodation at least once that year



Source: Booking.com

"I'm seeing evidence of [travellers] switching brands because of values that they align with," says Megan Morikawa, global sustainability office director at Iberostar, a hotel group. "I've also seen a few studies where they are willing to pay more for that product."

Iberostar Group, under its "Wave of Change" programme, has made commitments to move away from single-use plastics, source seafood sustainably and protect the marine environment surrounding its properties. It has also launched a coral reef nursery, although such efforts to encourage marine conservation in the tourism sector are still in their infancy.

The challenge for each hotelier will be to determine the appropriate level of investment. Here, TNC's study on ocean wealth may be useful. It estimates the tourism revenue generated per square kilometre of coral reef in different parts of the world.

Globally, this amounted to US$35bn per year from 65.5m visitors in 2010—roughly 10% of the total revenues from marine and coastal tourism. Of this, US$19bn was from on-reef activities such as diving and US$16bn from reef-adjacent tourism, which includes beach activities, swimming, sailing, eating seafood and recreational fishing.

> **We're finding that it is a lot easier to align our goals with biological goals when it's a carrot, rather than when it becomes a stick. And the sticks are coming.**
>
> Megan Morikawa, sustainability director, Iberostar

Governments have yet to implement regulations to compel hoteliers to contribute to marine conservation. This gives the industry a unique opportunity to define its own approach to marine conservation that works for its business and achieves the desired sustainability objectives. "We're finding that it is a lot easier to align our goals with biological goals when it's a carrot, rather than when it becomes a stick," says Ms Morikawa. "And the sticks are coming."

Supporting the transition to sustainability

As businesses in the marine and coastal tourism industry strive to become more sustainable, this creates an immediate business opportunity for those supporting the transition.

There is a need for more information on the state of the environment and the impact of sustainability initiatives, explains Mr Sampson. "On the business side, there are simply not enough practical tools to help businesses truly measure and reduce their footprint or the environmental cost of servicing tourist demand," he says. "Without this it's impossible to know if tourism pays its way."

Consultancies that conduct environmental impact assessments and marine spatial planning, such as Atkins, will be in growing demand over the next decade. So too will technology providers who supply monitoring tools, including conventional water-quality monitoring. An innovative example is Aquaai, an ocean-tech startup, which has developed a robotic fish that swims through waters collecting information on the environment.

Resorts may also increasingly rely on coastal management services such as marine rangers to patrol protected areas. This would create jobs and foster shared responsibility for the environment. A good example is Gökova Bay in Turkey, where restrictions on fishing, enforced by local rangers, have helped marine life to recover.

Just as tourism marks the intersection of several sectors, so do the business opportunities. The move towards a circular economy is driving a rethink about waste management and alternative materials at

hotels; targets to cut air pollution and carbon emissions are pushing cruise-line operators to switch to cleaner ship fuels; and technology developers are offering certification to ensure seafood is sourced sustainably.

Accelerating opportunities in sustainable tourism

The fragmented nature of the tourism sector and the interconnectedness of ocean challenges mean that a multitude of governments, regulators, businesses, multilateral bodies and conservation groups will have to be engaged. There is a need for a common platform led by an organisation outside the industry to bring together the relevant stakeholders. "I really believe there is a lack of capacity to create a common roadmap towards sustainability in the tourism industry," states Jeremie Fosse, co-founder and president of Eco-union. "We don't have global non-industry players that can actually support the transition."

Conservation efforts by resorts and tour operators will likely stem from national and regional efforts to establish marine protected areas (MPAs). The Seychelles MPA and the Caribbean Challenge Initiative are two examples. Governments around the world, and particularly SIDS, must move quickly to demarcate areas for conservation, to contribute to the global goal of conserving 30% of the ocean by 2030 being considered under the Convention on Biological Diversity.

There is no dearth of financing options for tourism companies that wish to offer sustainable products and services. "I think we already have a lot of different tools available like green bonds and different types of credits," says Mr Fosse. "So I think this is not a question of funding." Other experts cite emerging trends such as impact investment and reef resilience insurance.

The albatross of air travel

While efforts within the tourism industry to improve sustainability are commendable, this does not remove the albatross of air travel from around the industry's neck. It does not matter how "environmentally friendly" a destination is if a long-haul flight is required to get there. The solution is likely to lie in the aviation sector developing net zero-carbon aircraft fuels. A report by the Energy Transitions Commission found that achieving net zero-carbon emissions in aviation by 2050 is possible if the industry switches to sustainable biofuels and synthetic fuels.

Nevertheless, the contribution that tourism-sector initiatives make to the emerging sustainable blue economy is crucial. "My concern is that it seems to be too slow," says Mr Fosse. "We have to upscale and disseminate the good practices." These will clear the path towards more environmentally sustainable business models in marine and coastal tourism and allow new models such as ecotourism to thrive. Both will attract tomorrow's traveller, part of a growing base of young, eco-conscious consumers. The time to forge that relationship is now.

Chapter 8: Tackling marine plastic pollution

The need to end marine plastic pollution is driving solutions to improve waste management, develop alternative materials and increase reuse and recycling.

Over the next 20 years, demand for plastic is expected to double. Yet most plastic items are used only once before being discarded, and too often they end up polluting the environment. By 2050 there could be a larger tonnage of plastic than fish in the ocean. The economic waste is significant, too: only around 14% of plastic is recycled, resulting in a loss of material valued at US$80bn-120bn per year to the global economy, according to the Ellen MacArthur Foundation.

The next decade offers a huge opportunity to create a circular economy for plastic in which we end the unnecessary use of plastic, implement effective waste management, develop alternative materials, and reuse and recycle the plastic in the system.

Businesses are participating in these efforts, nudged by government regulation and incentives as well as consumer demand. "We see opportunities across the spectrum, whether it's startups, whether it's companies that are revising their internal processes or supply chains, or companies that are building entirely new external systems to manage waste," says Chever Voltmer, director for plastics initiatives at Ocean Conservancy, a non-profit environmental advocacy group.

Waste management: a safe bet

"If we want to successfully address marine plastic pollution in the long term, we actually have to stop the waste that's flowing into the ocean," says Simon Reddy, director of international environment at Pew Charitable Trusts.

Waste management includes collecting, aggregating, sorting and processing plastic items and manufacturing recycled products. Of these, processing and manufacturing are the most attractive to investors. They offer scale (investment for waste-processing infrastructure is in the range of US$5m-20m) and relatively low risk (waste-processing technologies are tried and tested), according to Rob Kaplan, founder and chief executive of Circulate Capital, an impact investment fund. "Investing in waste and recycling is a pretty safe sector," he says. "It's not rocket science and there's always going to be waste."

Circulate Capital's office in Singapore allows it to target key markets in Asia. China, Indonesia, the Philippines, Vietnam, Thailand and India are expected to contribute over half of the mismanaged waste in 2025. "We're here because this is where the problem is," says Mr Kaplan.

Companies adding value to plastic waste by cleaning or processing it have two main revenue streams: a tipping fee from municipalities or property owners and revenues from the sale of recycled materials. Most of the revenues in emerging markets come from the latter, according to Mr Kaplan.

Tridi Oasis, a manufacturer of recycled plastic bottles in Indonesia, is tapping into this opportunity. It buys used plastic bottles, grinds them into plastic flakes and exports them to packaging producers around the world. Mexico-based FEMSA, Coca-Cola's largest independent bottling company and a shareholder of Heineken, has also recognised the opportunity. "They recycle 3.1bn bottles a year, which is 80,000 tonnes of polyethylene terephthalate (PET)," says Ms Voltmer. "This is the kind of work that we want to scale."

As the lines blur between each segment of the waste-management value chain, there are opportunities for vertical integration, Mr Kaplan observes. "We see companies that have just been processing also looking to get into the aggregation and sorting space; or if you're just aggregating or sorting, now you want to add more value, so you'll add a wash line or flaking line to your existing operations."

Technology providers have an opportunity to drive efficiencies in these systems and reduce operational costs. In developing countries, this will make setting up waste-management facilities a more feasible option for municipalities and investors.

Waste collection conundrum

With the focus on downstream waste-management activities, it appears that upstream waste-collection has largely been ignored by investors.

In many developing countries such as Indonesia and India, waste collection from homes and offices is fragmented, cash-based and left to an informal army of workers. In addition, "most of the opportunities we've seen around ocean clean-up are more philanthropic in nature and can't really attract a financial return," explains Mr Kaplan. Waste collection is thus deemed an unprofitable and complex endeavour.

But efforts in downstream waste management (sorting, processing and manufacturing recycled materials) create demand for plastic waste—collected on land and through ocean clean-ups. "You need to create a market for recycled material to encourage waste collection," says Ms Voltmer.

Coordinating waste-collection efforts is an opportunity for developers of digital platforms. Mr Kaplan cites the Indian company Recyckal, a cloud-based platform that connects waste generators, processors and recyclers. "They're creating a marketplace for companies to buy, sell and match waste plastics," says Mr Kaplan. "Through that process they're optimising the system and also creating transparency and traceability of materials, in terms of value of the material and where it came from."

Such solutions would benefit those leading ocean clean-ups too, coordinating the supply of raw materials for a host of products made from recycled ocean plastic. These include a new line of sportswear from Adidas, packaging for Dell laptops and Lush cosmetics and recycled plastic bottles for Coca-Cola. Creating value for ocean plastic incentivises collection.

In developing countries, there are exciting examples of this. Indonesia Medika provides health insurance in exchange for collecting plastic waste, which is processed and sold to other industries. In India, fishermen are collecting ocean plastic and selling it to a facility that processes it into bitumen for road building.

There is also a social benefit of using digital platforms to coordinate waste collection on land and from the ocean. Pricing transparency provides informal waste pickers, often women, with the chance to secure more value.

Reducing plastic and using alternative materials

In addition to effective waste management, reducing the amount of plastic produced in the first place is critical. Consumer-goods companies

are seeking to use less virgin plastic in their products and for packaging. Restaurants and hospitality businesses are moving away from single-use plastics, replacing them with paper straws, glass bottles and metal cutlery.

The environmental efficacy of some of these replacements is hotly debated. A cotton bag needs to be used 7,000 times to be considered a sustainable replacement for a plastic bag, according to a study by the Danish environment ministry. Energy and water consumption to make paper products are higher than for plastic ones.

"When looking at alternative material, you need to consider, one, what it's made out of, and two, what happens to it after you use it," says Mr Kaplan. If a non-biodegradable alternative to plastic still ends up in the ocean, it does little to address the issue of marine pollution. India-based Ecoware is using bagasse, the pulp left over after sugarcane stalks are crushed for their juice, to make fully biodegradable plates, trays, food containers and cutlery for the food-services industry.

Other firms are exploring bioplastics—materials produced from renewable biomass which have the look and feel of plastic. VTT Technical Research Centre of Finland and US-based Full Cycle Bioplastics have developed packaging made from wood that looks like plastic. Evoware in Indonesia has developed seaweed-based packaging; Delta in the UK, an edible sachet.

The trouble with bioplastics is that most need to be processed at industrial compost facilities and cannot decompose in homes or after use. This adds to the amount of waste needing to be recycled or ending up in a landfill or the environment, explains Mr Kaplan. Exploring alternative materials therefore needs to go hand-in-hand with a rethink of product design and packaging.

Circular economy solutions

"Industry is starting to realise that we can't just recycle our way out of this problem," states Sander Defruyt, who leads the New Plastics Economy Initiative at the Ellen MacArthur Foundation. "We need to start tackling this issue upstream by eliminating plastic we don't need and ensuring that the plastics we do need are reusable, recyclable or compostable."

The Ellen MacArthur Foundation estimates that rethinking products, packaging and delivery models is at least a US$10bn opportunity. Innovations include toothpaste tablets sold in cardboard boxes, eliminating the need for plastic tubes; changing the surface of mobile-phone chargers from a glossy coating to a matte finish, making it less prone to scratches and eliminating the need for a plastic cover; and offering refills for detergent bottles at stores to reduce the number of plastic bottles or sachets that consumers buy.

Opportunities in a circular economy are almost endless. However, many have yet to scale up globally as a result of legacy infrastructure and the cost of change. Facilitating this shift across governance, finance and technology is imperative.

The governance-finance-technology nexus

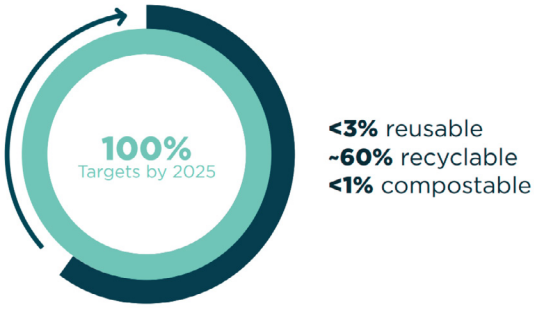
Replacing some of the most problematic packaging items, such as PVC, polystyrene or single-use straws, is the low-hanging fruit.

Over 60% of the 400 or so business signatories of the Ellen MacArthur Foundation's New Plastics Economy Global Commitment that are using these items have already phased these out or have committed to do so. But to significantly reduce plastic waste, businesses must fundamentally rethink how they deliver products to consumers and enable reuse.

Here, there is much work to be done. By 2025 the signatories—consumer brands, retailers and packaging producers—aim to ensure that 100% of their plastic packaging is reusable, recyclable or compostable. Only 3% of the signatories' plastic packaging is currently reusable and only one-third are currently testing reuse models, according to its 2019 progress report (see figure).

"But the great thing is that at our event in Davos in January [2020], we saw CEOs of Walmart, Nestle, Unilever on stage talk about reuse," says Mr Defruyt. "Just 12 months before that, it was unthinkable that reuse would be a CEO subject."

Progress by 2018 on packaging targets shows much to be done



Source: Ellen MacArthur Foundation

Regulation on extended producer responsibility has been pivotal in getting large consumer-goods companies to act. Research from Ocean Conservancy has determined that this is an effective way to drive investment in waste collection. Among the investors in Circulate Capital's fund are Danone, Coca-Cola and Unilever. Most of the US$100m raised by the fund will be invested in waste-management facilities.

Such investment is essential to scale up innovative concepts. But there are a few factors holding back investors. For instance, many companies lack the experience in disruptive solutions to reduce plastic production and waste. It is also challenging to assess investment risk when projects lack a track record. Perhaps most importantly, project sizes are small, making them less attractive to investors. Bundling several smaller projects into packages of investable size may resolve this, but the underlying risk associated with each project must not be ignored. Building a track record through a few initial projects is also important. "There's nothing that attracts investors more than other investors making money," says Mr Kaplan.

As businesses scale up, they must find ways to be more efficient. Technology providers have a role to play in this. For waste management, Ms Voltmer explains, advanced technologies such as artificial intelligence can help optimise waste-collection routes and sort waste, while blockchain could be used to create certified waste streams.

More broadly, businesses need clear and stable regulation. Where enforcement of environmental regulation is weak, "it just creates a level of uncertainty which makes investors wait and see how it plays out," says

Ms Voltmer. In some cases, regulation restricts businesses from scaling up solutions. In India, for example, manufacturing food packaging from recycled materials is prohibited. Taxes in the country also make recycled materials more expensive. Removing such barriers will help innovation move forward.

What is certain, however, is the contribution required from the private sector to eliminate marine plastic pollution. "We think businesses have a role to play in contributing part of the cost but also piloting and creating efficient systems," says Ms Voltmer. "In doing this, businesses can lead the way."

> **We think businesses have a role to play in contributing part of the cost but also piloting and creating efficient systems**
>
> Chever Voltmer, director for plastics initiatives, Ocean Conservancy

In a circular economy, plastic would be recycled into new products

Photo credit: Shutterstock

Chapter 9: Can nature and technology help fix the climate?

Scientists and businesses are looking at ocean-based natural and technological ways to remove carbon from the atmosphere and reduce the impact of climate change, creating opportunities in the blue economy.

Celebrity chefs praise its culinary and nutritional properties. Companies are exploring its use in everything from clothing and shampoo to fertiliser and pharmaceuticals. However, the biggest fans of seaweed include scientists and conservationists, who tout its potential to absorb greenhouse gases, reduce ocean acidity and enable oceans to continue acting as the world's most important carbon sink.

With this critical role now at risk, many innovations are being explored as the battle against climate change takes to the high seas. Some, like kelp farming, are nature-based. Others are more radical, and their proponents argue that large-scale technological innovation is urgently needed.

"Many parts of the ocean are like the covid patient who is struggling to breathe," says Brad Ack, founder and chief creative officer of the Ocean-Climate Trust, an alliance of scientists, innovators, entrepreneurs and investors. "It's time to go to the ventilator. It might not be what you wanted to see, but you get to a point in the crisis where you have to expand your arsenal."

When it comes to the climate, saving the patient is essential. The ocean soaks up about one-third of the world's carbon dioxide and keeps the planet cool. "If it weren't for that, our climate would be very different," says Hauke Kite-Powell, a research specialist at the Woods Hole Oceanographic Institution's Marine Policy Center in Massachusetts.

The numbers are striking. Recent research equates the amount of thermal energy the ocean has absorbed over the past 25 years to that generated by 3.6 billion Hiroshima bomb explosions.

"Last year, the world woke up to the fact that the ocean has effectively been keeping our planet safe and stable to live on," says Alec Taylor, head of marine policy at WWF, citing the Intergovernmental Panel on Climate Change's special report on the ocean and cryosphere published in September 2019. "It has a critical role to play in absorbing some of the worst effects of the emissions and heat we've produced." (see figure on next page)

Taking the heat

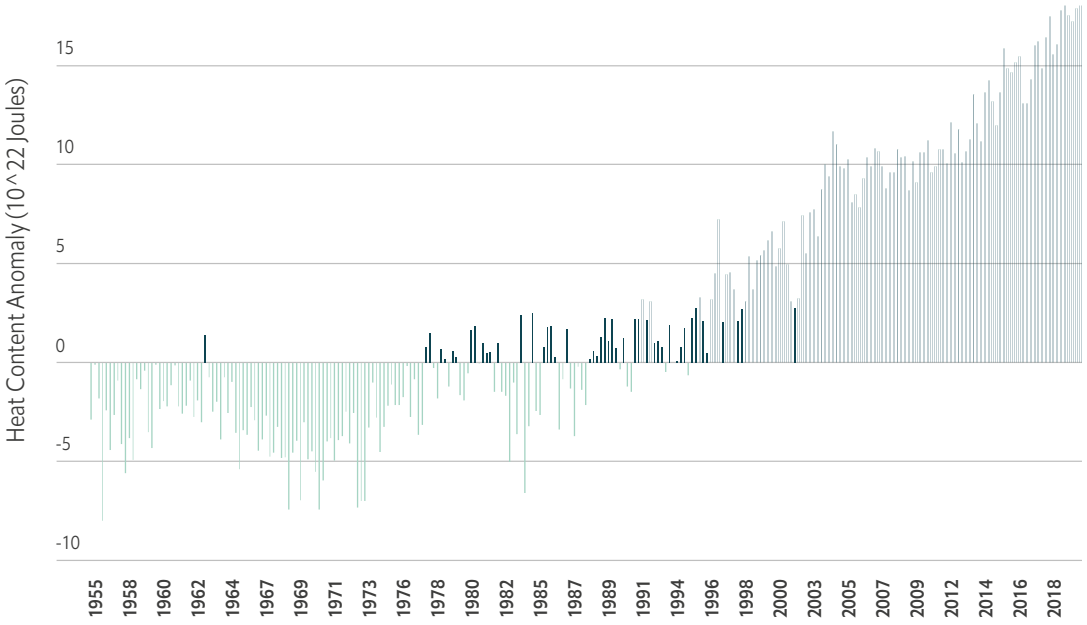
The problem is that this protective force is now reaching its limits. "As a result, the ocean is essentially belching back heat in the form of marine heat waves, bleaching events, atmospheric rivers that dump huge amounts of water on land, and super-storms," says Mr Ack.

Other climate-related problems include sea-level rises and acidification, as the ocean absorbs more carbon dioxide, reducing the availability of the calcium carbonate that shellfish rely on to make their casings.

"The ocean is suffering now because of those impacts," says Mr Taylor. "We need to turn this decade into a decade of recovery and restoration so that the ocean can help to avoid the impacts of climate change."

It's a battle that must be waged on several fronts. First, the quantity of greenhouse gases being absorbed by the ocean must be cut by moving away from fossil fuels, promoting energy efficiency and adopting alternative energy sources such as renewables.

The ocean has heated up over the past 20 years



Source: National Oceanic and Atmospheric Administration

And while much of the action must take place on land, the ocean itself is a focus for emissions reductions, whether through alternative fuels for shipping fleets or offshore wind-farm expansion.

Nature-based carbon sequestration

However, experts believe carbon reduction is no longer sufficient and that other measures are needed to restore the ocean's health.

Some of these build on nature's own resources. And kelp is not the only plant with the potential to sequester carbon. Mangrove swamps also do this, on top of which they provide aquaculture habitats, preventing coastal erosion and protecting coastlines from storms by reducing wave height by as much as two-thirds.

"Mangroves have a very high-value status in terms of carbon sequestration," says Chris Ninnes, chief executive of the Aquaculture Stewardship Council. "Per hectare, mangroves outperform tropical rain forests by six or seven times in times of the amount of carbon they sequester."

To preserve and extend mangroves, the Aquaculture Stewardship Council, Ecuador's Socio Manglar program and Conservation International are launching the Coastal Habitat Stewardship Fund, which will offer local communities annual payments in return for conserving their mangrove swamps. The group hopes others will adopt its model.

Technological solutions

Other solutions being explored are more radical. One is the idea of increasing alkalinity by putting large amounts of minerals such as limestone into the ocean.

Another is to use techniques such as cloud brightening, which would spray seawater into the air to create marine clouds and reduce the heat around vulnerable areas such as coral reefs. "We know this works because we can see it in the tracks that ships make," says Mr Ack, referring to cloud trails that can form around ship exhausts. "They essentially perform that reflective function."

Meanwhile, Arizona State University has been exploring the possibility of using millions of windmill pumps to generate ice in a bid to prevent the thawing of the permafrost and reverse the acceleration of the summer melting of Arctic ice.

The wider consequences of such interventions are uncertain. However, Mr Ack argues that the world can no longer afford to ignore potential solutions. "There's a lot of unknowns, as these are relatively new areas," he says. "But we need to get massively engaged in researching them to see what can be done."

To pursue this kind of research—on both land and sea—the University of Cambridge recently launched its Centre for Climate Repair, led by Sir David King, professor in physical chemistry at Cambridge and former chief scientific adviser to the UK government.

The centre is investigating a range of radical methods and technologies through which to address climate change. One area of exploration—the "greening" of the ocean to enable it to absorb more carbon dioxide—is based on a process already taking place.

"Every time the wind blows over the Sahara desert, for example, it picks up small dust particles that contain iron chloride," explains Sir David. "When the wind dies down over the Atlantic and dumps the dust particles into the sea, that area—maybe 10,000 or 100,000 square kilometres—goes green."

The "greening" is the formation of algae and the creation of small marine creatures that provide fodder for fish larvae. "The average fish in the ocean lays about 100,000 eggs a year but most die because there's no foodstuff available," says Sir David. "Where there is one of these green areas, there's an abundance of foodstuffs. So within a period of months the whole area becomes a living ocean forest."

This has a dual benefit. First, the ocean forest can absorb carbon dioxide in the same way as land-based forests. Second, the process could restock the ocean with fish, creating a vast new supply of food.

Blue economic opportunities

What excites scientists, environmentalists and policymakers about these kinds of solutions—whether nature-based or technological—is that they offer more than a solution to an environmental problem.

"It's a business opportunity," says Mr Kite-Powell of the idea of increasing the farming of algae and aquatic plants. "It's a whole new source of food and feedstocks for other

industrial processes—one that, critically, requires no agricultural land to produce, no freshwater inputs and no artificial fertiliser if we do it in an ecologically sound way."

Similarly, as well as sequestering carbon, large-scale kelp farming can produce bio-digested methane that could generate electricity as an alternative to natural gas. Kelp also has the advantage of growing extremely rapidly (at more than 30 times the rate of land-based plants).

"We have to feed and provide energy for a growing global population, and wherever we can do that and also help the natural system cope with the carbon and nutrient inputs that are wreaking havoc with ecosystem balances, that's a plus," says Mr Kite-Powell.

Of course, with much of the world's ocean areas unregulated, governments will need to come together to agree on the rules. "That's clearly something that has to be sorted out. At the moment, it's a chaotic system," says Sir David. "But the incentive for sorting it out has never been so clear as it is now."

Part of that incentive is financial. Take kelp. Given its potential to provide raw materials for so many products, analysts have put the global market value of commercial seaweeds at almost US$12bn by 2027.

Companies promoting sustainable ocean technologies could also prove attractive to the financial sector, as institutional investors shift increasing amounts of money out of polluting industries. Norway's US$1trn sovereign wealth fund is among them. The fund—the world's biggest—is divesting from companies that are not protecting the ocean, an approach it says could affect about 8% of its global equities portfolio—companies with a combined value of US$56.5bn.

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>
> Hauke Kite-Powell, research specialist, Woods Hole Oceanographic Institution

Sir David also sees interest from venture capitalists, such as firms based in the City of London and Cambridge. "They have a good record of investing in new technologies that are likely to emerge into the marketplace," he says. "They have a critical role to play."

For Mr Taylor, this private-sector interest is encouraging—and particularly important now. "The global economy has had to prop itself up to deal with the coronavirus situation," he says. "So we'll need a joint effort to generate the financial resources needed for ocean recovery and to place a healthy ocean as part of a post-covid future."

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