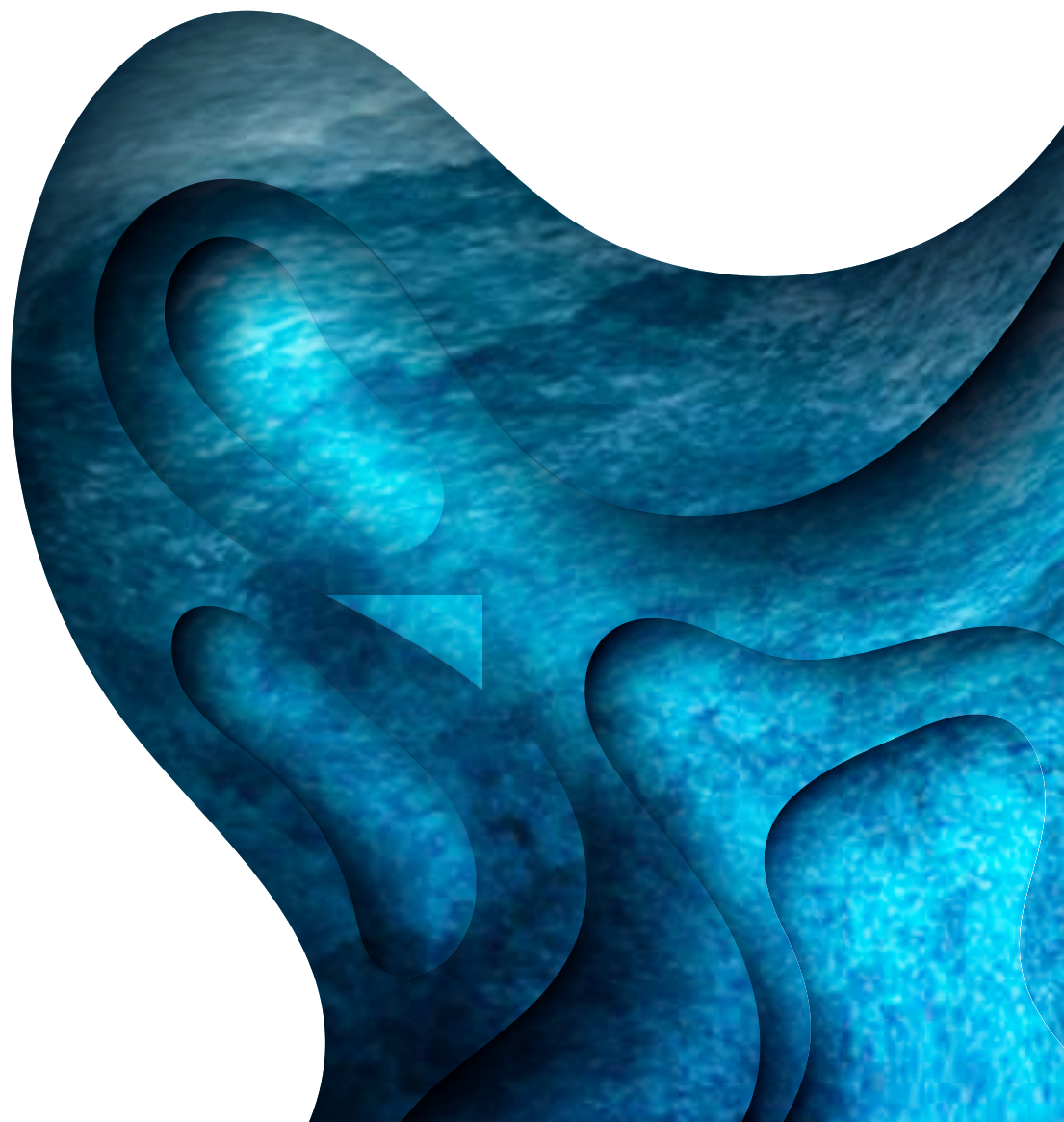




# OFFSHORE RENEWABLES

An action agenda for deployment

A CONTRIBUTION TO THE G20 PRESIDENCY



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The International Renewable Energy Agency (IRENA) serves as the principal platform for international co-operation, a centre of excellence, a repository of policy, technology, resource and financial knowledge, and a driver of action on the ground to advance the transformation of the global energy system. An intergovernmental organisation established in 2011, IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. [www.irena.org](http://www.irena.org)

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***The G20 is well placed to foster offshore renewables deployment worldwide. Its members account for the vast majority of global economic activity and trade and are home to over three-quarters of total renewable installed capacity. In 2020, 99.3% of total offshore wind capacity and nearly all installed ocean energy capacity globally was found in G20 countries***

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# ABBREVIATIONS

<b>°C</b>	Degree Celsius
<b>AWES</b>	Airborne wind energy system
<b>CAD</b>	Canadian dollar
<b>DC</b>	Direct current
<b>EIA</b>	Environmental impact assessment
<b>EMEC</b>	European Marine Energy Centre
<b>EU</b>	European Union
<b>EUR</b>	Euro
<b>FPV</b>	Floating solar photovoltaics
<b>G20</b>	Group of Twenty (comprising of 19 countries and the European Union)
<b>GBP</b>	British pound
<b>GDP</b>	Gross domestic product
<b>GHG</b>	Greenhouse gases
<b>GW</b>	Gigawatt
<b>HVDC</b>	High voltage direct current
<b>IEC</b>	International Electrotechnical Commission
<b>IRENA</b>	International Renewable Energy Agency
<b>ISO</b>	International Organisation for Standardisation
<b>kW</b>	Kilowatt
<b>kWh</b>	Kilowatt hour
<b>LCOE</b>	Levelised cost of electricity
<b>LDC</b>	Least-developed country
<b>MW</b>	Megawatt
<b>MSP</b>	Marine spatial planning
<b>NDC</b>	Nationally Determined Contribution
<b>NREL</b>	National Renewable Energy Laboratory
<b>OTEC</b>	Ocean thermal energy conversion
<b>PV</b>	Photovoltaics
<b>R&amp;D</b>	Research and development
<b>RD&amp;D</b>	Research, development and demonstration
<b>SIDS</b>	Small island developing states
<b>SWAC</b>	Sea water air conditioning
<b>TRL</b>	Technology readiness level
<b>TWh</b>	Terawatt hour
<b>UK</b>	United Kingdom of Great Britain and Northern Ireland
<b>UN</b>	United Nations
<b>USA</b>	United States America
<b>USD</b>	United States dollar





# HIGHLIGHTS



# MARKET STATUS AND OUTLOOK

## Offshore wind

- **At the end of 2020, the global installed offshore wind capacity was more than 34 gigawatts (GW)**, up 6 GW from 2019 and an increase of around 11-fold from 2010, when the installed capacity was nearly 3 GW.
- **More than 70% of the installed offshore wind capacity is in Europe, either in the North Sea or in the Atlantic Ocean.** Over the past two decades, Belgium, Denmark, China, Germany and the United Kingdom (UK) have led the offshore energy deployment in the global market.
- **In 2020, China recorded the highest capacity of new offshore wind installations with more than 3 GW**, followed by the Netherlands with 1.5 GW, Belgium with 0.7 GW and the UK with 0.4 GW. European countries dominate in both floating wind foundations and airborne wind energy demonstration projects.
- **Amid the COVID-19 pandemic, policy makers are setting ambitious targets for offshore wind, in line with climate targets and thanks to falling costs.** Targets include a new offshore renewable energy strategy of the European Commission as part of the EU Green Deal aiming for 60 GW of offshore wind by 2030 and 300 GW by 2050. Ireland aims to develop 5 GW of offshore wind by 2030; the Netherlands 11 GW; and Poland 3.8 GW by 2030, 10 GW by 2040 and 28 GW by 2050. France is planning tenders of 1 GW per year until 2028. Outside Europe, Japan is a key emerging market with 45 GW targeted by 2040, followed by the United States (USA) with a target of 30 GW by 2030, the Republic of Korea with 12 GW targeted by 2030, and India with 5 GW targeted by 2022 and 30 GW by 2030.
- **France, Japan, Spain, the Republic of Korea and the USA are key emerging markets for floating wind foundations.** For example, the Republic of Korea targets 6 GW of floating wind starting in 2023.
- **In an energy transition scenario aligned with the Paris Agreement target to keep the average global temperature rise below 1.5 degrees Celsius (°C),** IRENA's analysis indicated that an offshore wind cumulative installed capacity of more than 380 GW by 2030 and more than 2 000 GW by 2050 can be deployed globally.

## Ocean energy

- **By the end of 2020, cumulative global installed ocean energy capacity – including tidal and wave energy as well as ocean thermal energy conversion (OTEC) and salinity gradient – was more than 515 megawatts (MW).** More than 98% of this capacity was operational, with 501.5 MW consisting of two large tidal barrage projects.
- **Globally, 31 countries are pursuing ocean energy projects.** At the forefront are European countries such as Finland, France, Ireland, Italy, Portugal, Spain, Sweden and the UK, in addition to Australia, Canada and the USA. However, these technologies have various degrees of maturity.

- **The tidal barrage segment is dominated by France, the Republic of Korea, Canada and the UK**, while the wave energy segment consists of 9 small projects with a total capacity of around 2.3 MW globally, across 8 countries and 3 continents. Hawaii (USA) hosts the only wave project over 1 MW since 2020. Other ocean technologies are in research stages.
- **The technology trend is moving from tidal barrage to tidal stream and wave.** In 2020, 12 countries were pursuing tidal and wave energy projects. For example, the UK plans six tidal stream projects between 2021 and 2026, while Canada is financing its first grid-connected tidal stream project of 9 MW. Overall, the European Commission targets at least 1 GW of installed capacity in the European Union (EU) for wave and tidal energy by 2030, and 40 GW by 2050. Beyond Europe, where developers are seeking to install projects outside their borders, emerging innovations are taking place in China, Japan and the Republic of Korea. The world's largest tidal stream turbine with a capacity of 2 MW recently became operational in Orkney, Scotland.
- **In an energy transition scenario aligned with the 1.5°C Paris Agreement target**, IRENA's analysis indicates that an ocean energy cumulative installed capacity of more than 70 GW by 2030 and more than 350 GW by 2050 could be installed globally.

#### Floating solar photovoltaics (PV)

- **As of the end of August 2020, the cumulative installed floating solar PV capacity was around 2.6 GW from 338 active projects in 35 countries globally** mainly on **freshwater artificial reservoirs**. The installed capacity has more than doubled from 1.1 GW in 2018. The 10 largest projects are in China, Japan and the Republic of Korea. The largest plant globally is located in China with 150 MW.
- **In Asia, India, Indonesia, Singapore, Thailand and Viet Nam are actively pursuing the development and deployment of floating solar PV.** In Africa, Ghana installed its first floating solar plant of 5 MW in 2020. In Europe, France, Italy and the Netherlands have large plants. For example, the Netherlands hosts a 27.4 MW plant. In total, **more than 60 countries are exploring floating solar PV installations.**
- **The future demand for floating solar PV is expected to be driven by Asian countries such as China, India, the Republic of Korea, Thailand and Viet Nam.** India is planning a 1 GW project, while the Republic of Korea is planning a 2.7 GW project in the Yellow Sea. The trend is also expected to grow in Europe thanks to supportive policies and many ongoing demonstration projects. For example, the Netherlands aims for 2 GW by 2023, while Germany started building a 1.5 MW plant in 2020.
- **South American countries such as Brazil have the potential to take up floating solar PV thanks to large water bodies and the benefits of reducing evaporation on hydropower dams.** Islands could also benefit greatly from this technology. Maldives, Seychelles and Singapore are planning floating solar PV arrays of 5.8 MW, 11 MW and 50 MW, respectively.

## Competitiveness

Offshore renewables are rapidly approaching economic maturity and are already cost-competitive relative to fossil fuel generation in some geographies. Record reductions in the levelised cost of electricity (LCOE) have been registered for offshore wind, as shown in Table 1, and costs for other forms of offshore renewables are expected to drop even further.

For example, IRENA expects fixed-bottom offshore wind to reach an LCOE as low as USD 0.05 to USD 0.08 per kilowatt-hour (kWh) by 2023 – a nearly 50% drop from the 2020 LCOE of USD 0.084/kWh, whereas floating offshore wind is expected to reach USD 0.13/kWh by 2024, lower than the current LCOE for its fixed counterpart. Floating PV is expected to become closer to onshore ground-mounted solar PV prices by 2030. For ocean energy technologies, tidal energy is expected to reach USD 0.11/kWh between 2022 and the early 2030s, while wave energy costs may reach USD 0.22/kWh by 2025 and USD 0.165/kWh by 2030.

Table 1  
LCOE comparison of offshore renewables

Technology	Sub-technology	LCOE
Offshore wind	Fixed offshore wind	<ul style="list-style-type: none"> <li>· 2020 global average: USD 0.089/kWh</li> <li>· 2023 outlook based on auction data: USD 0.05-0.08/kWh</li> </ul>
	Floating offshore wind	<ul style="list-style-type: none"> <li>· 2019 global average: USD 0.160/kWh</li> <li>· 2024 outlook based on auction data: average USD 0.13/kWh</li> </ul>
Ocean energy	Tidal energy	· 2019 range: USD 0.20-0.45/kWh
	Wave energy	· 2019 range: USD 0.30-0.55/kWh
Floating solar PV	Freshwater PV	· 2020 estimated: USD 0.354/kWh



## EMERGING TECHNOLOGICAL TRENDS

### Offshore wind

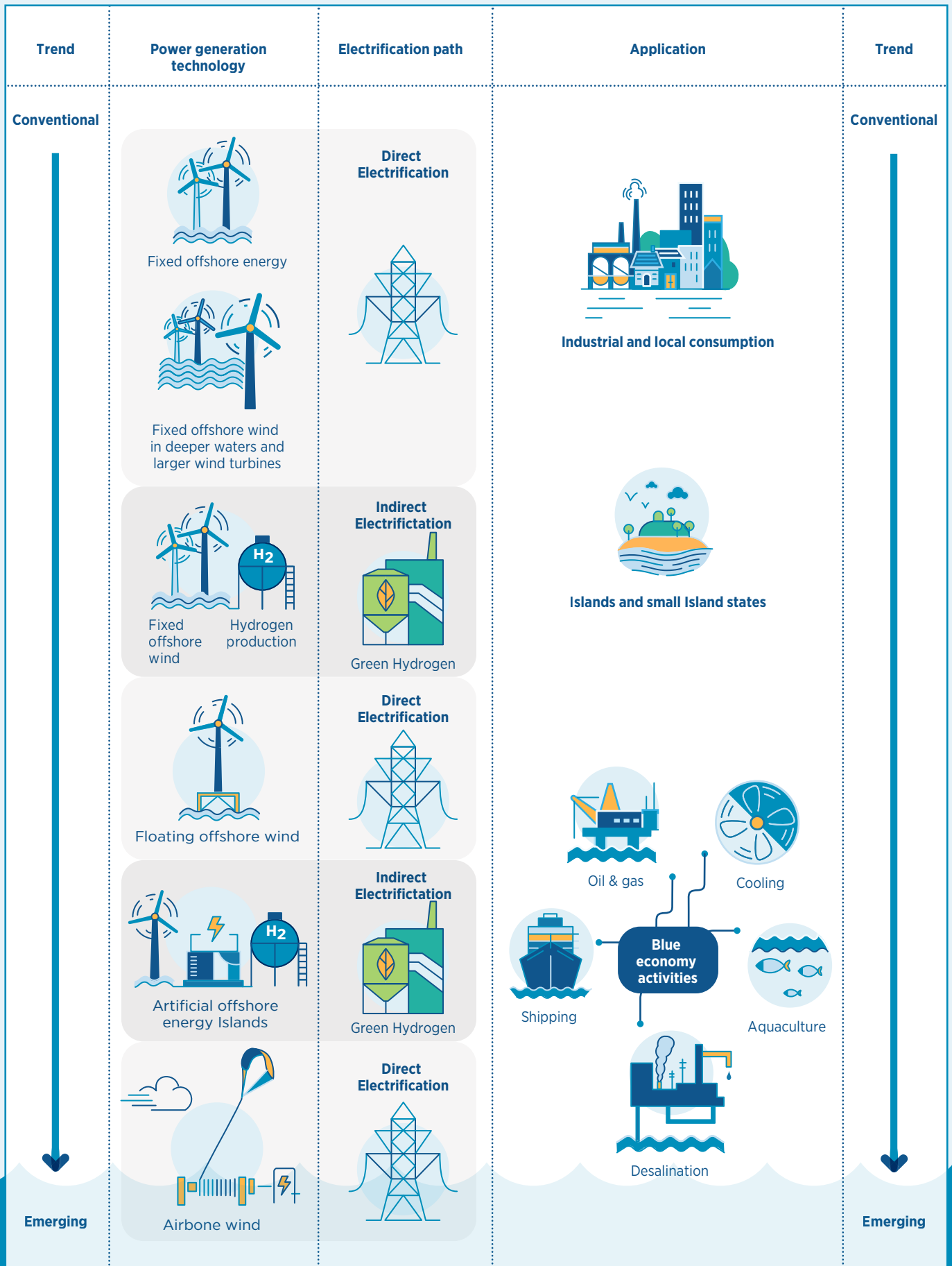
The key emerging trends for offshore wind from a technological, location-specific and technological coupling perspective are as follows (also visually presented in Figure 1):

- Manufacturing of larger offshore wind turbines; for example, Vestas recently announced the development of a 15 MW offshore wind turbine to be installed in 2022 and to begin production in 2024.
- Floating foundations enabling installations in deeper waters and farther from shore; for example, Norway's Hywind Tampen floating offshore wind farm will be located 140 kilometres from shore in depths between 260 metres and 300 metres.
- Use of versatile foundations and structures; for example, concrete sub-structures.
- Creation of combined-technology power generating plants such as the Eco Wave Project (see Box 9); for example, offshore wind could be coupled with floating solar PV and/or ocean energy technologies.
- Creation of offshore energy hubs for renewable power production; for example, two artificial wind energy islands are being developed in Denmark (the first phase of 3 GW plans to be operational by 2033 with a total investment of EUR 29 billion (USD 34.4 billion)).
- Powering and decarbonising sectors of the "blue economy"<sup>1</sup> through direct and indirect electrification; for example, the BIG HIT project in the Orkney Islands in Scotland.
- Generation of green hydrogen through coupling with different offshore renewable technologies; for example, the AquaVentus consortium in Germany, with an electrolyser capacity of 10 GW, is currently the largest planned offshore wind and green hydrogen project.
- Airborne wind energy systems, which are currently undergoing demonstration projects; for example, the Skysails Skypower100 pilot project is under way in northern Germany (see Box 3).

---

<sup>1</sup> The blue economy is defined by the World Bank as the "sustainable use of ocean resources for economic growth, improved livelihoods and jobs, and ocean ecosystem health", which encompasses many activities, including renewable energy, fisheries, maritime transport, waste management, tourism and climate change (World Bank, 2017)

Figure 1  
Key emerging technological trends for offshore wind



## Ocean energy

The key emerging trends for ocean energy are the following (also visually presented in Figure 2):

- Gaining momentum for wave and tidal energy technologies, with around 49 announced<sup>2</sup> wave projects with a cumulative planned capacity of 150 MW and more than 79 announced tidal stream projects with a cumulative planned capacity of 1.9 GW.
- Technology convergence in tidal stream; for example, towards a horizontal-axis turbine design for tidal stream generators.
- Pursuit of multiple wave energy prototypes in parallel; for example, oscillating water column, point absorber, oscillating water surge converter and submerged pressure differential.
- Creation of combined-technology power generating plants, thereby maximising the energy yield and achieving better techno-economic performance and higher profitability; for example, ocean energy technologies coupled with offshore wind and/or floating solar PV.
- Business models based on powering sectors of the blue economy through direct and indirect electrification, thus creating new revenue streams and maximising profitability; for example, aquaculture, cooling, shipping, oil and gas.
- Positioning small island developing states (SIDS) to be the main benefactors of ocean energy technologies, where ocean energy would compete with diesel imports; thus, these technologies could reach grid parity faster than in other contexts.

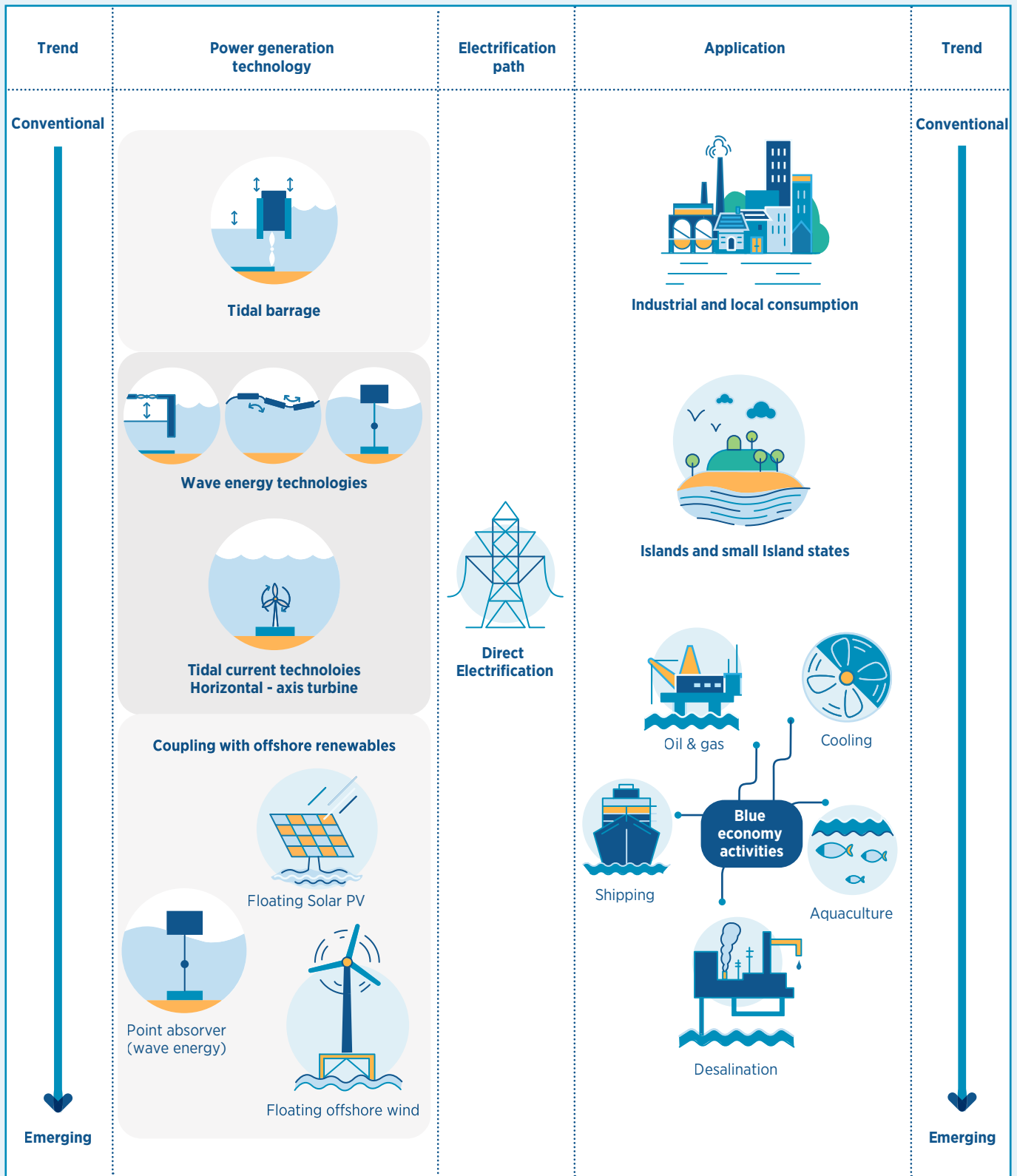


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<sup>2</sup> Including projects undergoing permitting process and projects under construction.



Figure 2  
Key emerging technological trends for ocean energy



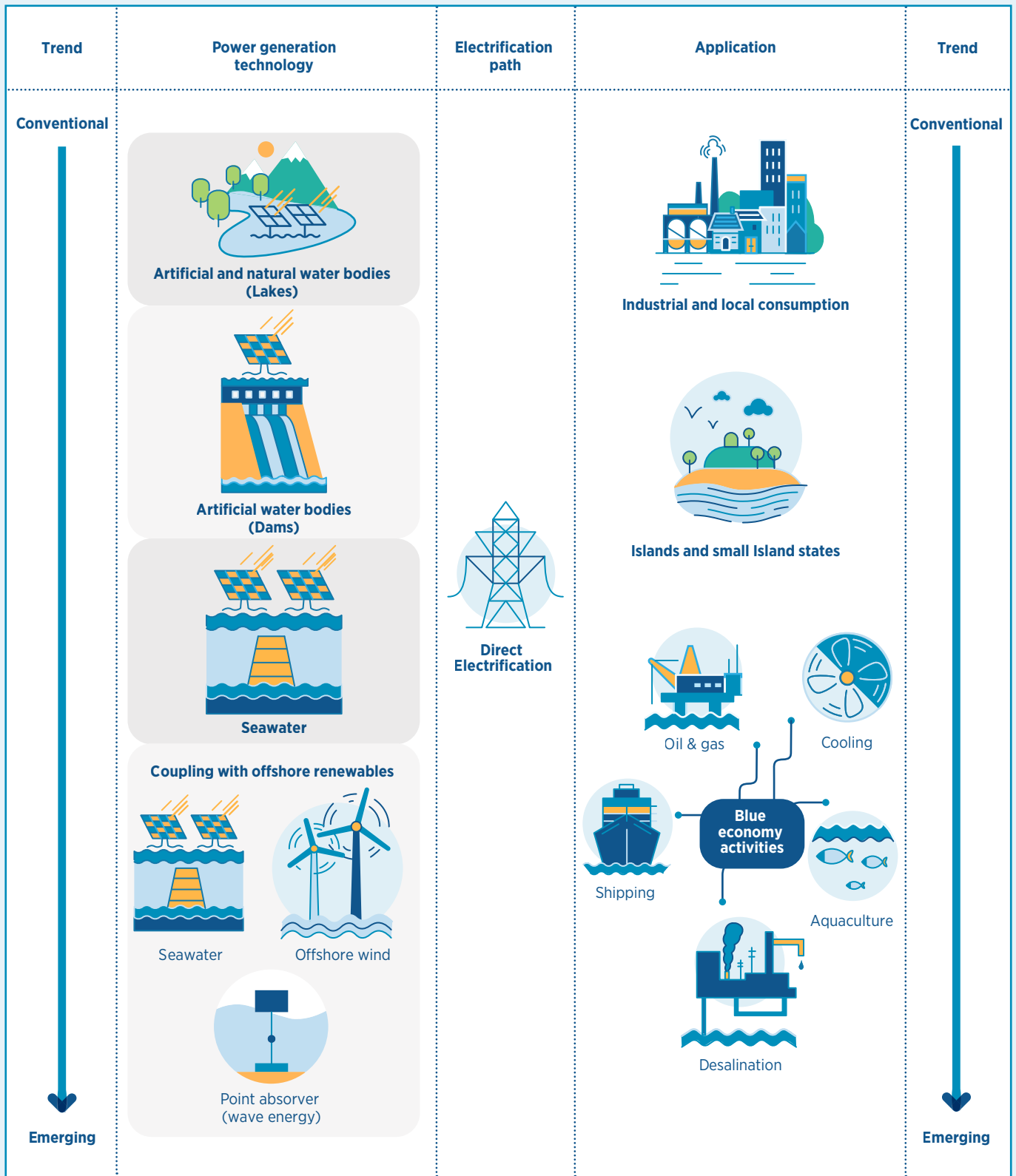
### Floating solar PV

The key emerging trends for floating solar PV technology (FPV), from a location-specific deployment perspective and from a coupling perspective, are the following (also visually illustrated in Figure 3):

- Deployment over water reservoirs and dams; for example, the announced 2.1 GW of FPV plants on five dams across the Republic of Korea.
- Increasing deployment in seawater; for example, the East African nation of Seychelles is planning to install a 5.8 MW FPV array on a lagoon on its main island.
- Creation of combined-technology power generating plants, such as FPV sharing foundations with ocean energy technologies and/or offshore wind devices; for example, the Maasvlakte 2 project in Rotterdam will include a combination of FPV, offshore wind, batteries and electrolyzers by 2023.
- Powering sectors of the blue economy, especially in the context of islands and SIDS; for example, a feasibility study was announced for a 1.53 MW FPV plant in Gran Canaria Island that will power the Piedra Santa desalination plant.



Figure 3  
Key emerging technological trends for floating solar PV



## CONTRIBUTIONS TO THE BLUE ECONOMY AND THE ENERGY TRANSITION

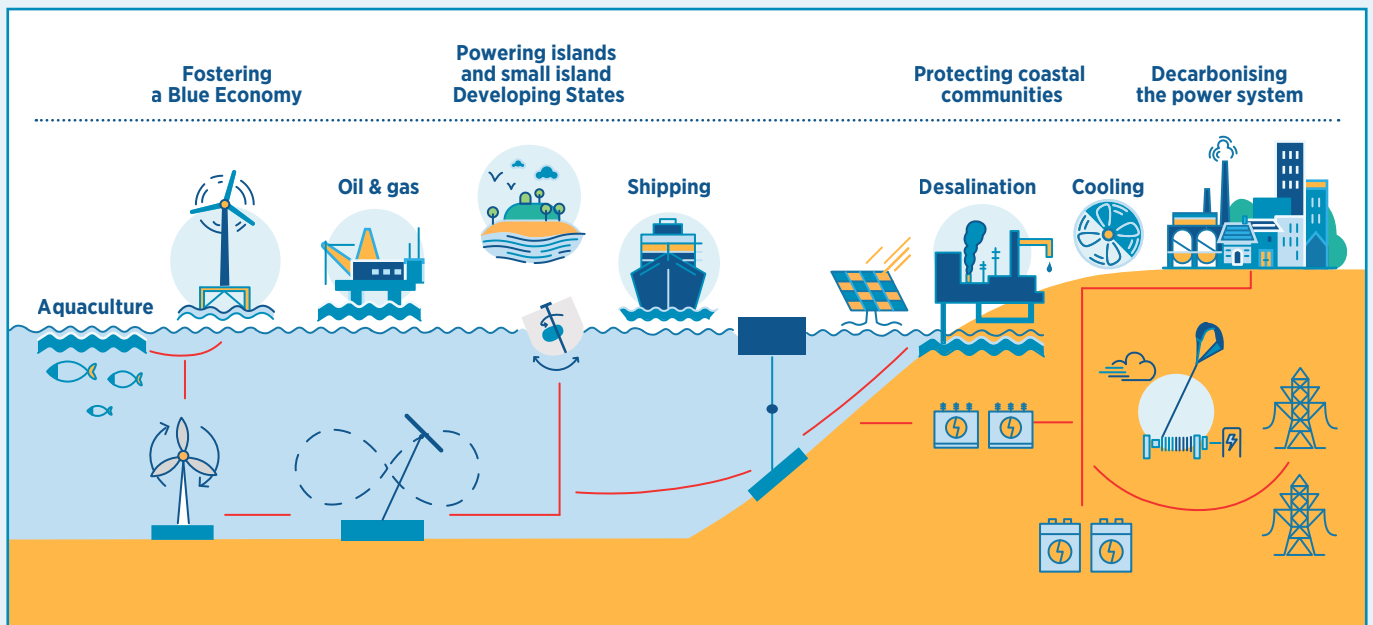
In addition to decarbonising the power system, offshore renewables have the potential to greatly contribute to the creation of a global blue economy and to the energy transition. This would help countries meet international policy goals, including those set in the Paris Agreement, their Nationally Determined Contributions (NDCs) and the United Nations Sustainable Development Agenda for 2030. Simultaneously, islands and coastal communities could benefit from climate-safe recovery options amid the COVID-19 pandemic and coastal protection thanks to ocean energy devices.

Figure 4 illustrates the key contributions of offshore renewable power generating technologies towards:

1. Fostering a blue economy
2. Powering islands and SIDS,
3. Protecting coastal communities, and
4. Decarbonising the power system

Figure 4

### Contributions of offshore renewables to the blue economy and the energy transition

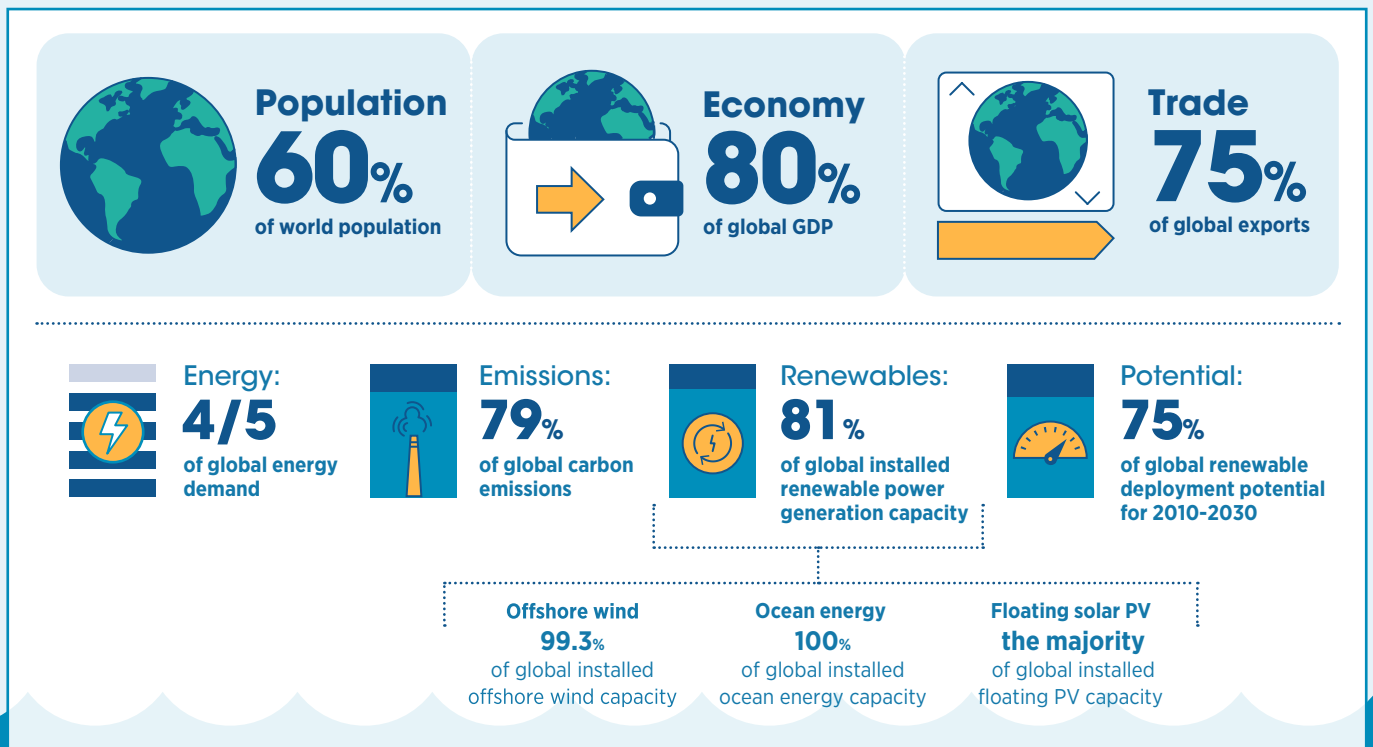


## RECOMMENDATIONS TO THE G20

The G20, being an influential forum for global and financial co-operation, is well positioned to foster the commercialisation at large scale of innovative offshore renewable power generating technologies, while amplifying emerging opportunities based on the latest technological developments. The G20 members account for the vast majority of economic and trade activity at a global level. They are also home to more than three-quarters of total installed renewable energy capacity, 99.3% of total installed offshore wind capacity, and nearly all installed ocean energy capacity, as illustrated by the key statistics in Figure 5.

### G20 members account for 99.3% of total installed offshore wind capacity, and nearly all installed ocean energy capacity

Figure 5  
G20 in key figures



Source: G20, 2020; IRENA, 2016a; Palmer and Jeyaratnam, 2014; IRENA, 2019a

This report explores several possible actions that G20 countries could explore in support of their offshore renewable deployment strategies. Notably, every country is in a different stage of the energy transition and has different priorities; therefore, countries are to consider these possible actions while taking into account:

- their own energy sector context; and
- other uses of ocean space.

Table 2 provides a summary of the action-oriented options identified for the G20, addressing the key areas of consideration for the commercialisation of offshore renewable energy technologies. Both challenges and opportunities, with suggested actions, are detailed in Chapter 7, where examples of best practices and lessons learned from the international experience are provided.

Table 2: **Summary of recommended actions for the G20**

Area of intervention <b>Socio-political</b>	
Challenges and opportunities	Actions that countries may consider based on country context
<b>A_</b> Ocean governance and international co-operation	<b>1_</b> Observe the UN Law of the Sea Convention for ocean governance and multilateral co-operation for the deployment of transnational offshore renewable projects
	<b>2_</b> Promote the further development of marine spatial planning (MSP) incorporating offshore renewable plans
	<b>3_</b> Co-operate with IRENA's Collaborative Framework to collect and disseminate key data on offshore renewables
	<b>4_</b> Foster co-ordination on planning of offshore grid infrastructure
	<b>5_</b> Conduct joint research projects on technical potential, industrial development and other topics within the G20 countries, and with other countries
	<b>6_</b> Foster international co-operation among countries with shared interest in advancing the technological development of offshore renewables, as well as countries interested in adopting these technologies
<b>B_</b> Public awareness, social acceptance and community readiness for implementation	<b>7_</b> Conduct public consultations early in the development process to ensure harmonious co-existence of the offshore renewables industry with other ocean users
	<b>8_</b> Seek implementation approaches that increase the acceptability of local communities
	<b>9_</b> Quantify and communicate the expected welfare benefits
	<b>10_</b> Raise awareness through public availability of detailed mapping of technical potential and relevant data (e.g., wind resource, seabed, bathymetry)
<b>C_</b> Higher technological awareness by relevant stakeholders	<b>11_</b> Shift thinking from the narrow power sector to the whole economy
	<b>12_</b> Organise capacity building among countries with offshore renewable expertise and those interested in adopting these technologies
	<b>13_</b> Engage with industry-led organisations to gain awareness of the latest technological developments

## Area of intervention **Policy & regulation**

Challenges and opportunities	Actions that countries may consider based on country context
D_Best practices in policy frameworks considering offshore energy technologies	14_Set long-term offshore renewables deployment and cost reduction targets to 2030 and beyond
	15_Provide public revenue support via feed-in tariffs, feed-in premiums, technology-specific auctions, power purchase agreements, Contracts for Difference, quotas, certificates, fiscal measures, etc.
	16_Provide public capital investment support through grants, equity, loans, etc. for earlier-stage technologies such as floating solar PV and ocean energy
E_Establish enabling regulatory frameworks (permitting, grid enhancement/connection, revenue support instruments, marine spatial planning)	17_Design enabling regulatory frameworks specifically for offshore renewables
	18_Establish long-term strategies for infrastructure build-out to deploy and integrate ocean renewables, including repurposing ports and modernising grid and transmission infrastructure
	19_Streamline the permitting and consenting process, including formation of a cohesive marine spatial planning strategy
	20_Ensure that the regulatory frameworks regarding management of space and resources are able to foster the sustainable long-term development of offshore renewables, in particular through marine spatial planning

## Area of intervention **Technology & infrastructure**

Challenges and opportunities	Actions that countries may consider based on country context
F_Developing the required grid infrastructure	21_Plan for integrated offshore network plans based on long-term energy targets
	22_Invest in new power transmission lines for offshore renewables
	23_Adapt existing grid codes to take into account offshore renewables
	24_Develop international standards for interoperability of multi-terminal and multi-vendor high-voltage direct current (HVDC) systems.
	25_Consider the creation of offshore renewable energy hubs by coupling offshore renewables with power-to-X technologies
G_Access to comprehensive resource site assessment	26_Establish and improving offshore resource mapping
	27_Consider adequate sites based on resources but also grid connection potential
	28_Consider oceans and seas but also lakes, dams and rivers as potential sites
H_Withstanding harsh offshore environment (salinity, corrosion, extreme forces, etc.)	29_Apply international standards to overcome the technical challenges of harsh offshore environments (salinity, corrosion, extreme forces, etc.).
	30_Invest in research and development (R&D) for innovative designs that withstand extreme weather conditions and that take into account local environmental conditions
I_Enhancing technology maturity and reaching commercialisation	31_Increase public investments in research, development and deployment (RD&D) for all offshore renewable technologies
	32_Invest in RD&D in close co-operation with industry
	33_Invest in RD&D for airborne wind energy and the creation of artificial islands
	34_Invest in offshore renewables demonstration projects located in developing countries to foster technological maturity
	35_Develop new international standards for technological assessment, as well as data collecting and sharing for offshore renewables
	36_Encourage private investments in enabling technologies for operation and maintenance of offshore renewable technologies
	37_Invest in combined-technology renewable floating platforms
	38_Bring in the knowledge, skills and installations of the offshore oil and gas industry
	39_Support emerging ocean energy start-ups through R&D investments and access to test centres

## Area of intervention **Economic & financial**

Challenges and opportunities	Actions that countries may consider based on country context
J_Enhanced cost-competitiveness	40_Create hybrid projects where offshore renewables are coupled with interconnectors linking neighbouring countries
	41_Create offshore renewable energy hubs by coupling offshore renewables with power-to-X technologies
	42_Power blue economy sectors with offshore renewables
K_Securing funding by mitigating risks	43_Reduce risks for lenders by ensuring the bankability of projects through improved technical due-diligence of projects
	44_Share the risk of early movers through private-public partnerships
	45_Improve the bankability through innovative financing mechanisms and criteria
L_Robust supply and value chains	46_Facilitate cross-sectoral knowledge and skill transfer among offshore industries
	47_Promote undistorted trade, improved market access and uninterrupted supply chains

## Area of intervention **Environmental**

Challenges and opportunities	Actions that countries may consider based on country context
M_Addressing potential environmental impact	48_Exchange experience with environmental impact assessments, including the determination of cumulative environmental effects
	49_Encourage data collection by public institutions, researchers and private companies alike
	50_Establish joint environmental research programmes between governments and industry

## G20 ACTION AGENDA

To support economic recovery from the COVID-19 pandemic, IRENA outlines the following action agenda for possible consideration by the G20 (also further elaborated in Chapter 7):

- 1. Acknowledge the important role of offshore renewables at the G20 ministerial level:** Collaborate within the “Troika” – *i.e.*, Italy (holding the current Presidency), Saudi Arabia (its predecessor) and Indonesia (its successor) – to include offshore renewables on subsequent G20 agendas as a key innovative technology for resilient and sustainable economic growth, in a post-COVID-19 context.
- 2. Increase co-operation between the G20 and IRENA’s Collaborative Framework to collect and disseminate key data on offshore renewables.** The G20 and IRENA’s Collaborative Framework on Offshore Renewables have the possibility to facilitate access to updated information on offshore renewables development. Data may include, *inter alia*, cost competitiveness, best practices in policy and regulation, resource potential and environmental impact assessments.



- 3. Lead by example for countries with resource availability:** Clear and long-horizon policy frameworks for offshore energy technologies provide a positive signal to private developers, research institutions and financial actors. For mature technologies such as fixed-bottom offshore wind, the lack of transparent goals and fit-for-purpose regulation are the primary obstacles to investment and project development. For earlier-stage technologies such as floating solar PV and wave/tidal energy, long-term policy targets also increase trust in the possibility to commercialise these innovative technologies. Nationally Determined Contributions (NDCs) and other national policies provide appropriate prominence for such long-term goals (e.g., investment amount, capacity additions, infrastructure build-out, etc.) and raise public awareness.
- 4. Support collaboration and exchange of experiences in ocean governance, environmental impacts and technical standards:** G20 national experts could consider engaging in international dialogues in relation to, for example, the Law of the Sea Convention, international standards for ocean energy technologies and international guidelines for environmental impact assessment, as well as fostering transfer of knowledge from G20 countries to developing countries.
- 5. Include offshore renewables in the G20 Working Group on Energy Transition and Climate Sustainability:** The Working Group could build on a high-level acknowledgement of the role of offshore renewable technologies in fostering a blue economy, decarbonising the economy, reducing greenhouse gases (GHG) emissions and ensuring resilient and sustainable economic growth, through efforts to:
- a. Promote best practices in policy and regulatory frameworks, such as permitting schemes, national roadmaps and procurement programmes, which can increase the volume of foreign and domestic inward investment in market-ready offshore renewable technologies such as offshore wind;
  - b. Increase public investments in RD&D for all offshore renewable technologies, including combined technology power-generating systems and systems that need to withstand extreme weather conditions;
  - c. Design and conduct joint RD&D projects, aimed at developing the less-mature technologies, such as airborne wind energy systems<sup>3</sup> and combined technology renewable energy systems (wave-solar PV, wave-wind, wind-hydrogen, etc.); and
  - d. Promote public-private partnerships for innovative offshore renewables such as offshore wind-to-hydrogen generation units, including those located in developing countries and SIDS.
- 6. Identify and promote innovative financing mechanisms for offshore renewable technologies within the “Finance Track” of the G20:** Given that one of the main challenges that these innovative technologies face today is the difficulty in securing funding due to high perceived risks, the “Finance Track” could identify and promote innovative financing and de-risking mechanisms, including – but not limited to – capital investment support (grants, equity, loans, etc.) and revenue support mechanisms (technology-specific auctions, fiscal measures, quotas, etc.).

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<sup>3</sup> Technology that employs flying tethered wings or aircraft in order to reach winds blowing at atmosphere layers that are inaccessible by traditional wind turbines.

The background features several abstract, organic shapes in shades of blue and teal. A large, wavy shape is at the bottom, with a smaller, bean-like shape above it. In the top right corner, there is a circular shape. The overall aesthetic is clean and modern.

**01**

# **INTRODUCTION**

## 01.1

# KEY DRIVERS OF OFFSHORE RENEWABLE DEVELOPMENT

Climate change is one of the greatest threats of this century and is already affecting many regions around the globe. Such impacts are driven by rising GHG emissions, especially from the energy sector, which is responsible for two-thirds of the global total (IRENA, 2019a). Therefore, energy systems worldwide need to transition to renewable and clean energy sources and to undergo radical changes, driven by a combination of technological breakthroughs, the need to provide affordable energy sources and the pressing need to put an end to climate change.

To transform the energy sector, a shift towards renewable energy sources is required. The world's oceans are a source of abundant renewable energy, which can be tapped by offshore renewables – including offshore wind (with fixed and floating foundations, or airborne), floating solar photovoltaics (PV) and various forms of emerging ocean energy technologies – to decarbonise the energy sector. The benefits of offshore renewables go beyond the energy sector, as the energy harnessed from oceans has the potential to drive a vigorous global blue economy for a variety of end-use applications, including shipping, cooling, aquaculture and water desalination, among others. Offshore renewables are expected to provide significant socio-economic benefits and to improve the livelihoods of islands, and especially small island developing states (SIDS) and least developed countries (LDCs) through job creation, local value chains and enhanced synergies among the different blue economy actors.

## 01.2

# KEY CHALLENGES OF OFFSHORE RENEWABLE COMMERCIALISATION

Despite the noticeable potential and various benefits, offshore renewables are emerging technologies with varying degrees of maturity. Offshore wind power is the most mature technology and is already commercialised, while ocean energy technologies are still in the research, development and demonstration (RD&D) phases. Because these technologies are immature, they are bound to face a series of challenges that could encumber the commercialisation that would realise their full potential.

Offshore renewables will be located mostly in harsh environmental conditions, and in areas with almost non-existent power grids. This corresponds to high capital costs and electricity prices. The limited established supply chains and low cost-competitiveness with other mature renewable energy sources, in addition to the lack of regulatory frameworks and inclusion in national policies, creates a gap to commercialisation. Such barriers have adverse effects on social awareness of offshore renewables, which shapes both the public and investors' trust in these technologies.

## 01.3

# THE ROLE OF THE G20 AND IRENA

G20 countries<sup>4</sup> are well positioned in their leadership capacity and economic power to drive a global energy transition and to foster emerging renewable energy technologies. Together, the G20 accounts for more than 80% of the global nominal gross domestic product (GDP), three-quarters of global trade and around 60% of the world's population (G20, 2020). In addition, the G20 accounts for four-fifths of global energy consumption (IRENA, 2016a) and therefore is responsible for around 79% of global carbon emissions (Palmer and Jeyaratnam, 2014). G20 countries are playing a pivotal role in the global energy transition as they host around 81% of the global installed renewable power generation capacity in addition to 75% of the global potential for deploying renewables between 2010 and 2030, according to estimates from the International Renewable Energy Agency (IRENA) (IRENA, 2019a).

The G20 Italian presidency of 2021 has set the planet as one of its three priority pillars. It aims to reduce global GHG emissions and to foster a sustainable energy reality by embracing modern and clean energy sources (G20, n.d.). Italy has acknowledged the importance of offshore renewables in the energy transition and is actively contributing to the advancement of these technologies by co-facilitating IRENA's Collaborative Framework on Ocean Energy / Offshore Renewables.

IRENA is playing a leading role in the energy transformation globally as it acts as a centre of excellence for knowledge and innovation, a global voice for renewables, a network hub and a source of advice and support for countries. In addition, IRENA has been working closely with the successive G20 presidencies since 2015 on renewable energy deployment, lessons learned and applicable policies. In this context, IRENA has collaborated with G20 working groups on specific publications relevant to the energy transition and the circular economy. Through active support of the G20 meetings, IRENA continues to provide science-based solutions for the decarbonisation of the energy sector. IRENA's latest support to the G20 includes the present report, *Energy from the sea: an action agenda for deploying offshore renewables worldwide*.

### Box 1: IRENA's Collaborative Framework on Ocean Energy / Offshore Renewables

Members at the 10th Assembly session requested IRENA to expand its work on ocean energy and other offshore renewables, and to facilitate targeted collaboration tailored to reflect opportunities and challenges for the future deployment of these technologies. In response to this request, IRENA has established a Collaborative Framework on Ocean Energy / Offshore Renewables including:

- offshore and floating wind technology;
- wave, tidal, ocean thermal conversion and salinity gradient technologies; and
- floating solar PV.

<sup>4</sup> Argentina, Australia, Brazil, Canada, China, France, Germany, Japan, India, Indonesia, Italy, Mexico, the Russian Federation, South Africa, Saudi Arabia, the Republic of Korea, Turkey, the United Kingdom (UK), the USA, and the EU, with Spain as a permanent guest.

The Collaborative Framework is based on the offshore renewables work already undertaken by IRENA, the wealth of knowledge and expertise that exists within IRENA's membership and the advantages that may be reaped through wider global co-operation with other entities. The Collaborative Framework serves as an effective vehicle for dialogue, co-operation and co-ordinated action to accelerate the uptake of offshore renewables in benefit of the global renewable energy transformation, and to feed into the ongoing work of IRENA. In addition to its membership, relevant stakeholders, such as the Global Wind Energy Council and Ocean Energy Europe are also engaged in discussions.

In 2020, the Collaborative Framework on Ocean Energy / Offshore Renewables met twice virtually due to the COVID-19 pandemic:

- *25 June 2020*: first meeting was attended by 38 delegations across IRENA's membership, with a total of 88 participants; and
- *14 October 2020*: second meeting was attended by 40 delegations across IRENA's membership, with a total of 69 participants, including 5 participants from stakeholders.

With a mandate of one year, with the possibility of extension, the **Kingdom of Tonga** and **Italy** have been designated as co-facilitators of this Collaborative Framework.

## 01.4

# OBJECTIVES AND STRUCTURE OF THE REPORT

The objective of this report is two-fold. First, the report provides insights on various emerging offshore renewable energy technologies and their underlying potential. Second, it outlines a possible Action Plan for the G20 countries to drive offshore technologies closer to the commercialisation phase. The report is structured as follows:

- **Chapters 2-4** present the latest status on offshore technology development, the deployed capacity, the underlying theoretical energy potential, the technological outlook based on a projected pipeline, current market status and market leaders – while highlighting the potential future markets and concluding with innovative emerging trends. Each technology is covered in a distinct chapter, with offshore wind in **Chapter 2**, ocean energy in **Chapter 3** and floating solar PV in **Chapter 4**.
- **Chapter 5** addresses cross-cutting issues for all offshore renewables, such as the environmental impacts, MSP and resilience to extreme weather conditions.
- **Chapter 6** discusses the contributions of offshore renewable technologies to the energy transition by highlighting innovative business models for the decarbonisation of the power system and a blue economy. It also focuses on the role of offshore renewables in powering islands and SIDS as well as in protecting coastal communities.
- **Chapter 7** identifies the potential technological, environmental, societal, financial and policy barriers that could hinder the commercialisation process of these emerging technologies and prevent them from reaching their full potential. It then presents action-oriented recommendations for the G20 to materialise offshore renewables and bridge the commercialisation gaps identified.

**02**

# **OFFSHORE WIND**



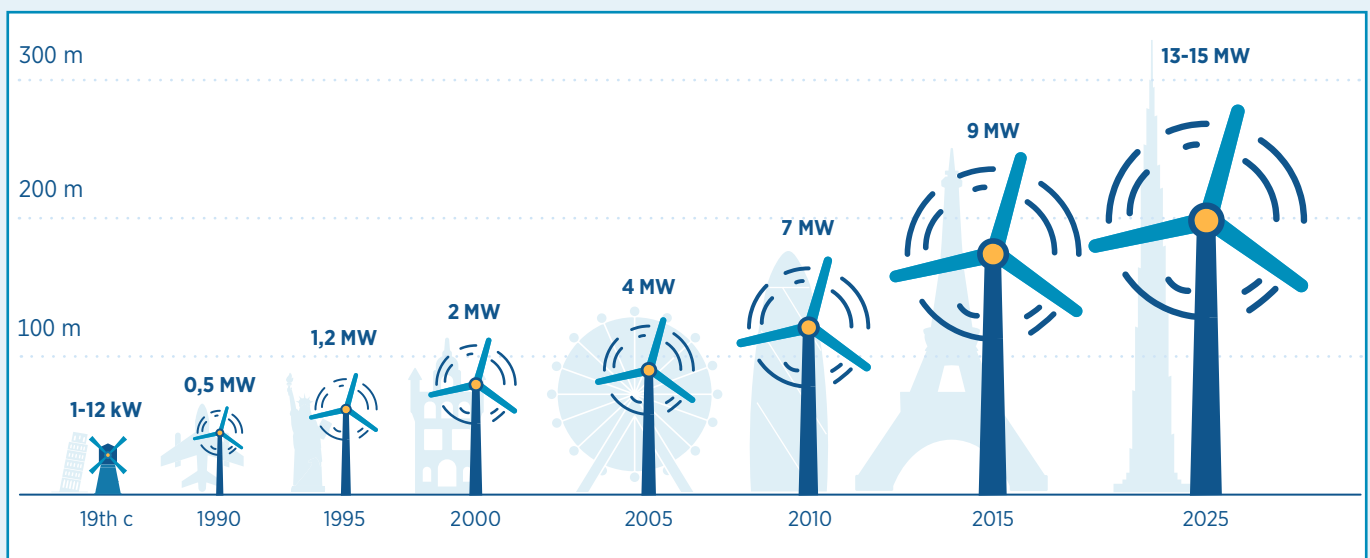
## 02.1

# TECHNOLOGY STATUS AND OUTLOOK

Due to its offshore location, its high energy output per square metre and its ability to be built up quickly at gigawatt-scale, offshore wind is a valuable option to provide electricity to densely populated coastal areas in a cost-effective manner. Developments in turbine technologies as well as in foundations, installation, access, operation and system integration have made possible the move into deeper waters and farther from shore, in order to reach sites with greater energy potential. Over the past 5-10 years, offshore wind has reached maturity, making it the most advanced technology among offshore renewables (IRENA, 2019b).

Historically, wind turbines have been increasing in size and rated capacity as a result of continuous research and development (R&D) processes. These were targeted at driving down costs by reducing the costs of foundations and cabling, as well as at increasing the energy captured per megawatt (MW) of nameplate capacity. Recently, the Danish wind turbine company Vestas announced a breakthrough in offshore wind turbines designed specifically for typhoon-prone areas. The 15 MW turbine has the highest wind turbine rating in the world and will be first tested in 2022, with scheduled production in 2024 (Hanley, 2021). Figure 6 illustrates the evolution of offshore wind turbines over time.

Figure 6  
Evolution of wind turbines sizes over time

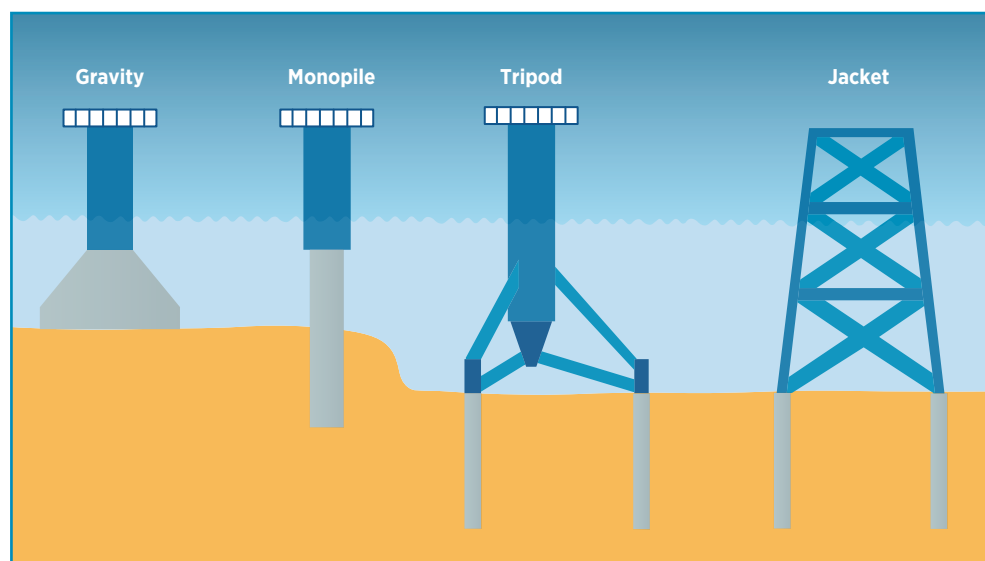


Source: Pisanò, 2019

## Offshore wind with fixed foundations

Offshore wind farms with fixed foundations are the most common type of installation, with nearly 34 GW of cumulative installed capacity by the end of 2019 (IRENA, 2019b); they are also by far the most mature of the offshore renewables technologies. Such turbines, as a result of R&D, are being routinely deployed in water depths of up to 40 metres, and in some cases up to 60 metres, and at up to 80 kilometres' distance from shore. A variety of fixed offshore wind turbine foundations have been developed over time, with the most common types being gravity-based foundations, monopile foundations, tripod foundations and jacket foundations, as shown in Figure 7.

Figure 7  
Fixed offshore wind turbine foundations



Source: Adapted from Bhattacharya *et al.*, 2020

## Offshore wind with floating foundations

Floating wind farms are one of the recent developments in offshore renewable energy technologies and offer several opportunities. In contrast to the fixed offshore wind farms that are limited to shallow water depths, floating foundations enable access to waters more than 60 metres deep. In addition, they facilitate setting up turbines even for mid-depth sites (30-50 metres), which could potentially become a lower-cost alternative to wind farms with fixed foundations (IRENA, 2016b). Another advantage is the reduced activity on the seabed during the installation phase, which lowers the impact on marine life (IRENA, 2019b).

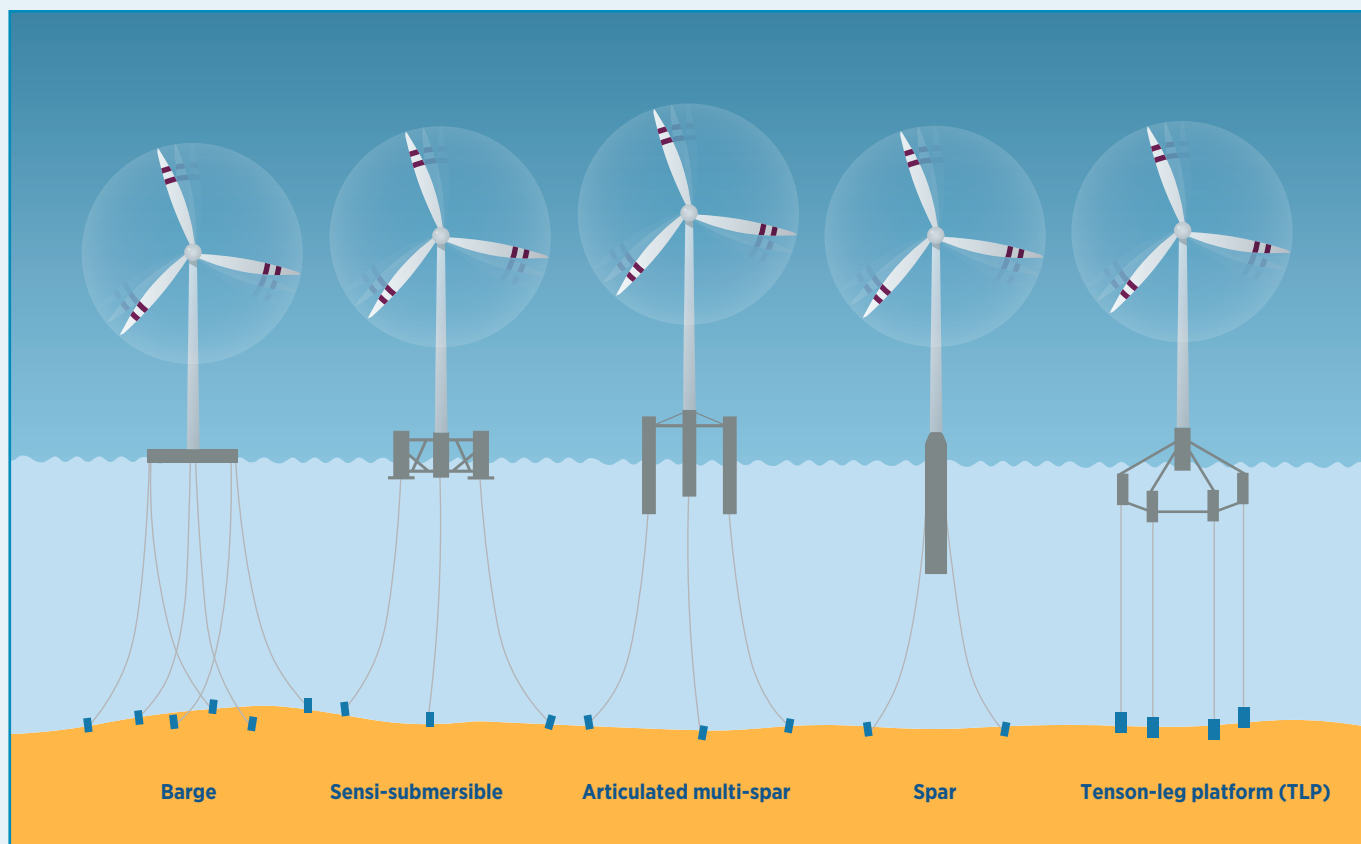
By the end of 2018, a total of nine floating offshore farms were installed globally, five in Europe and four in Japan, with a cumulative installed capacity of around 50 MW (IRENA, 2019b; World Oil, 2020).

Figure 8 provides a visual representation of the main floating foundation technologies.





Figure 8  
Floating offshore wind turbine foundations

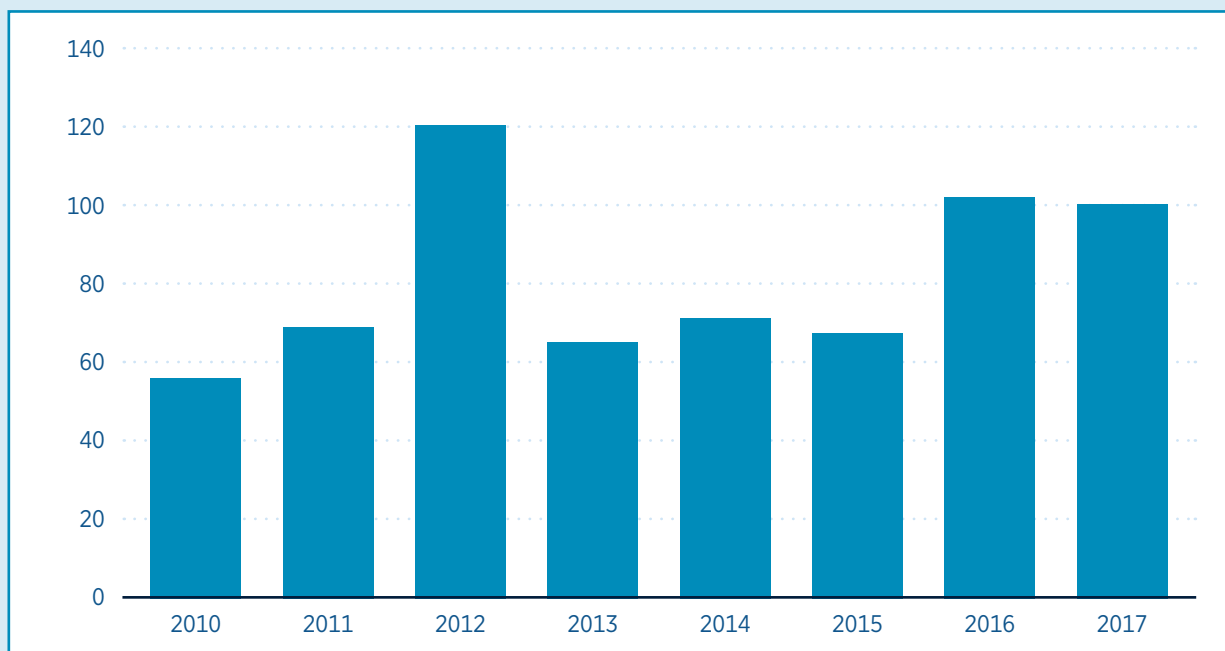


Source: Based on Mint Selection, 2019

## Box 2: Patent data for offshore wind towers

Development in offshore wind technology can be evaluated and explored by analysing patenting activity, as patents play a crucial role throughout the technology life cycle, from early R&D phases up to successful commercialisation. When analysing towers (a key component of offshore wind installations), the overall patent family activity increased in a sustained manner from 2010 until 2015, followed by a slight peak in 2016, and then stabilised in 2017\*. This trend indicates the interest in offshore wind technology.

Figure 9  
Offshore wind tower patent families



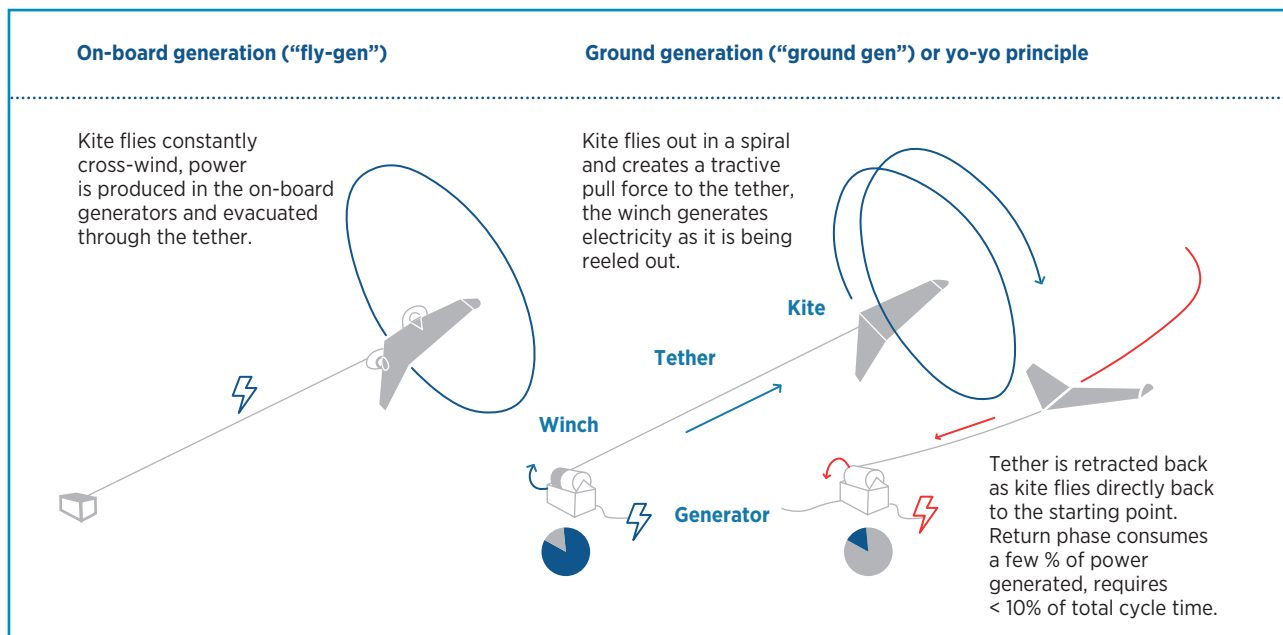
Source: IRENA 2021c

\* The filing process for patents normally takes around two years or longer, so data in the last three years are not as reliable because a patent filed in 2017 may be reflected in the data two years later. Consequently, data for 2017 are to be treated with caution, as they are incomplete because the data gathering process is still ongoing

### Airborne wind energy systems

Airborne wind energy systems (AWES) are based on blades or wings, at altitudes from 200 metres up to 450 metres (potentially even higher), attached to the ground via a tether which turns a winch that drives a generator (Hill, 2017). They follow two principles for producing electricity: either through small propeller turbines, with the generators being mounted on the flying wing, or by having the tether unwind from a drum located on the ground platform that drives the generator (AWE, 2020). Figure 10 illustrates the different AWES operating principles.

Figure 10  
**Airborne wind energy systems operating principles**



Source: Based on Mint Selection, 2019

Airborne wind energy is in the early stages of development. However, it has the potential to become a game changer, as it is a flexible and mobile technology that can be easily set up. It requires little material, which results in a lower environmental impact than other wind energy technologies. In addition, the technology is scalable from a few kilowatts (kW) to several megawatts (AWE, 2020). The number of research institutes developing this technology, from academia and industry, is increasing; they include TU Berlin, ETH Zürich, Fraunhofer IWES, ABB corporate research and many others. As of 2018, more than 60 research institutes were involved in AWE R&D activities around the globe, as shown in Figure 11.

Figure 11  
Research institutes participating in airborne wind R&D activities



**Disclaimer:** This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

Globally, the majority of the installed AWES are below 1 MW of capacity (see Box 3), as the technology is still in the RD&D stages (Zillmann and Petrick, 2020).

### Technology trends

Plenty of room remains for further improvements in wind energy technology. R&D activities are focused on pursuing bigger turbines, as illustrated by the actions of turbine manufacturers. For example, the Danish wind turbine company Vestas is researching a bigger offshore wind turbine with a rated capacity of 17 MW that could come into existence in the future (Hanley, 2021). Given the recent progress, turbine sizes could reach up to 20 MW in a decade or two (IRENA, 2019b). In addition to bigger turbines, enhanced capacity factors of 36% to 58% are expected to be realised by 2030, and of 43% to 60% by 2050, in comparison to the average of 43% as of 2018 (IRENA, 2020a).

Wind energy is expected to become one of the dominant energy sources in the future, and offshore wind is an essential pillar of this transition. The growth in offshore wind installed capacity is expected to increase at a much more rapid rate than over the past two decades, following the latest technological developments in turbines and the deployment of floating wind units.

### Box 3: Skysails Skypower100 pilot project

In 2020, Skysails Power partnered with EnBW Energie Baden-Württemberg AG, EWE Offshore Service & Solutions GmbH, and Leibniz Universität Hannover under financing from the German Federal Ministry of Economics and Energy to develop the Skypower100 pilot project (Skypower100, 2020, p. 100). The project was developed in northern Germany and had a rated capacity of 100 kW (Engie, 2020). Figure 12 captures the system under operation.

Figure 12  
Skypower100 pilot project in northern Germany



Source: Skysails, n.d.

The development of Skypower100 has led the path for further deployment as two 200 kW systems are being shipped to Mauritius and an undisclosed location in Asia for commercial use (Engie, 2020; McCorkell, 2021).



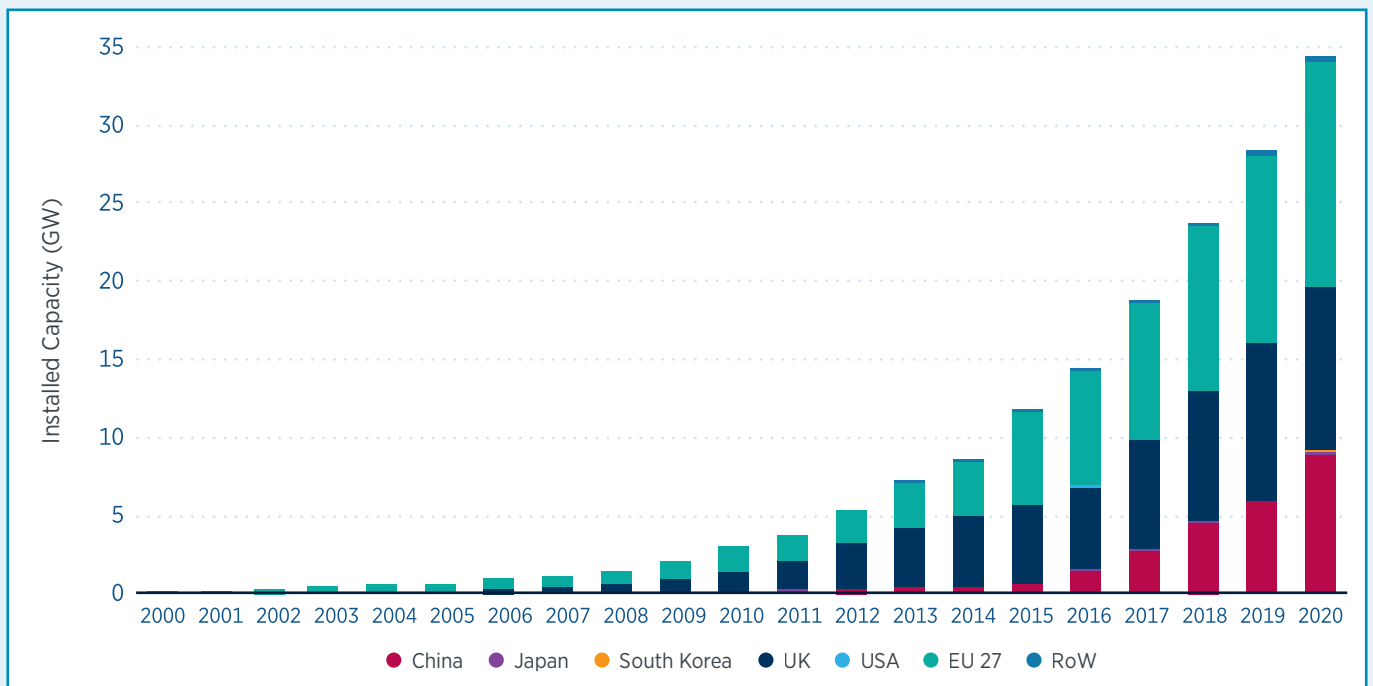
To maximise the power output and drive down the costs of floating wind turbines to a competitive level, focus should be directed beyond turbine sizes – for example, towards innovations and optimisation of mooring systems, anchoring systems and dynamic cables for floating structures. A European Union (EU) funded project, Corewind, carried out virtual simulations in two different floating offshore wind sites in the Canary Islands and the USA, and it concluded that cost reductions of 60% and 55% respectively in the mooring systems can be achieved (REVE, 2021a).

AWE is also gaining interest and will have further presence besides just small demonstration projects as several companies aim for a scale-up of between 1 MW and 3 MW for commercial use in the upcoming years (Zillmann and Petrick, 2020). AWE could hold huge potential, as wind resources at higher altitudes (where the wind resource potential tends to be greater) have not been exploited so far. What further distinguishes AWE is the ability to continuously adjust the harvesting altitude to the best available wind resource, which maximises generation. In addition, the creation of combined-technology systems (for example, with solar systems or floating solar PV) in turn enhances systems integration.

## 02.2 MARKET STATUS AND OUTLOOK

The first commercial-scale offshore wind farm came into operation in 2002 in Denmark with a capacity of 160 MW. Since then, global installed offshore wind capacities have spiked rapidly over the past two decades. By the end of 2020, the overall installed capacity of offshore wind was around 34 GW (IRENA, n.d.), which represents a more than 10-fold increase from 2010, as shown in Figure 13. To date, the world's largest offshore wind farm is the UK's Hornsea 1, with 1.12 GW of capacity (Shin, 2021).

Figure 13  
Cumulative offshore wind capacity installed worldwide, 2000-2020



Source: IRENA, n.d.

Offshore wind has the potential to play a pivotal role in achieving renewable energy targets in many countries around the globe. Over the past two decades, Belgium, China, Denmark, Germany and the UK were the leading countries in offshore energy deployment in the global market. In terms of new offshore wind installations, China and the UK have been leading this trend since 2018 and are expected to grow even further (Fortune Business Insights, 2019); this in turn will lead to growing jobs and benefits domestically. In 2020, China recorded the highest offshore wind installations with more than 3 GW of installed capacity, followed by the Netherlands with 1.5 GW, Belgium with 0.7 GW and the UK with 0.4 GW. To date, around 90% of the global installed offshore capacity is commissioned in the North Sea and nearby Atlantic Ocean (IRENA, 2019b).

For floating wind turbines, only a handful of countries have pursued the technology globally, and most of the projects have been in Europe, followed by Japan (IRENA, 2019b). For the emerging AWE technologies, Europe dominates the market with the highest number of demonstration projects (Zillmann and Petrick, 2020).

**Box 4: RD&D collaboration and international conferences on offshore wind**

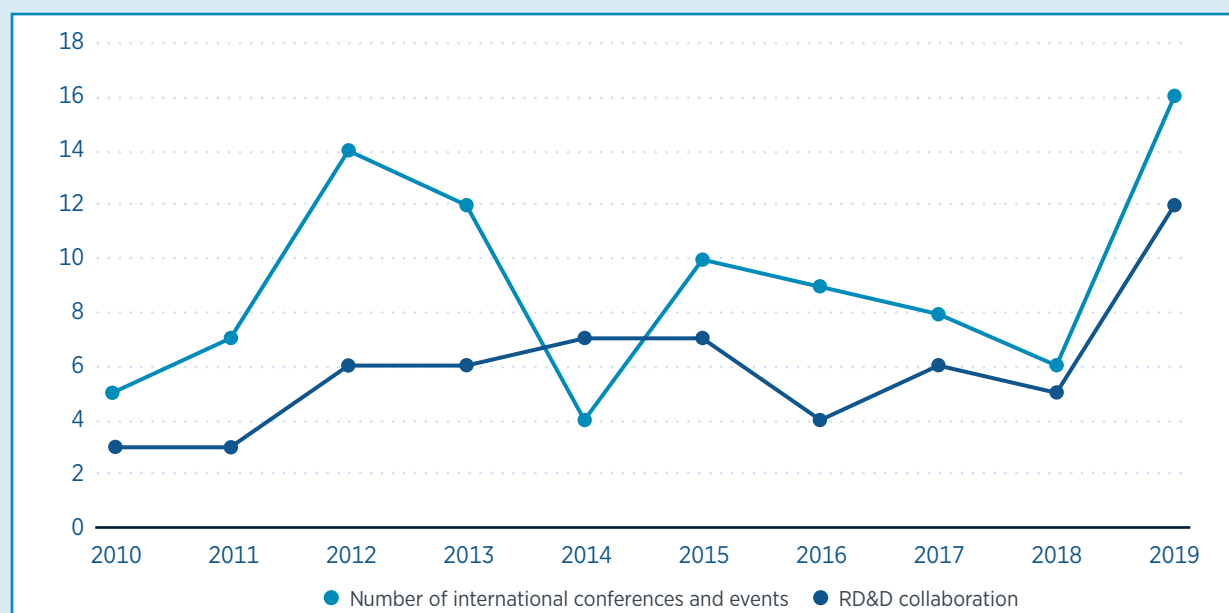
RD&D collaboration has become an important vehicle to share knowledge, jointly advance innovation, understand barriers in different contexts, and help cross the valley of death and bring research to the market. Between 2010 and 2019, more than 90 **national and international RD&D collaborations** were formed that focused exclusively on offshore wind technology. The overall trend was positive, but annual additions declined slightly between 2015 and 2018, followed by a steep surge in 2019, with 14 newly formed RD&D collaborations in offshore wind.

Most of the collaborations were public-private, and they occurred mostly among **European** partners and were funded by the European Framework for Research and Development or by European national programmes. Nearly 75% of these collaborations took place between 2010 and 2015, after which international collaboration decreased substantially. One explanation is that the collaboration happened at lower technology readiness levels (TRLs); however, as technology moves towards maturity and the market becomes more competitive, the interest in collaborating declines.

The past five years saw slow steady growth, followed by a surge, in **international events and conferences** focused specifically on offshore wind. While other events and conferences were focused on the wind industry and also included offshore wind, the growth in events focused specifically on offshore wind indicated both rising interest and a market heading towards maturity.

Figure 14

**Offshore wind RD&D collaborations and international conferences and events**



According to IRENA's 1.5°C Scenario,<sup>5</sup> as shown in Figure 15, offshore wind could reach a total installed capacity of around 382 GW by 2030 and around 2 002 GW by 2050 (IRENA, 2021a).

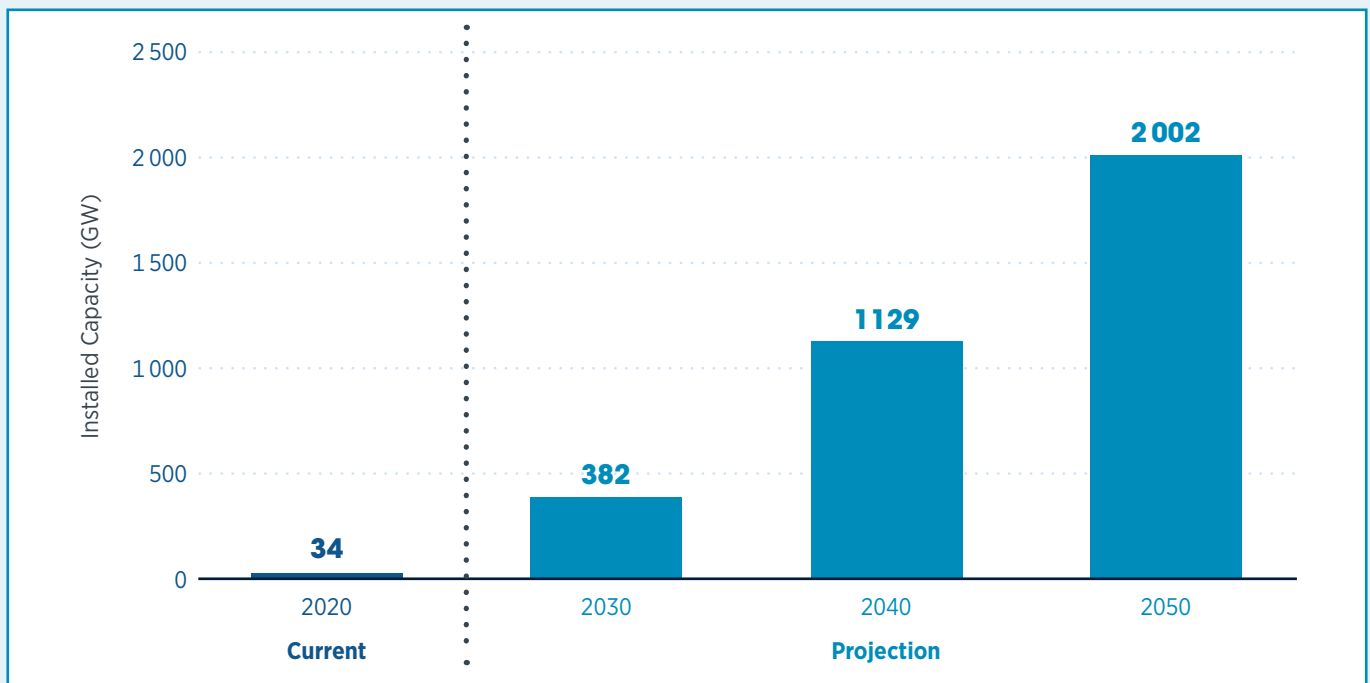
As of 2020, more than 26 GW of offshore capacity was planned and expected to be operational in the coming years, according to the USA Department of Energy's National Renewable Energy Laboratory (NREL) (NREL, 2020a).

As demonstrated in the last two years, the offshore wind market is witnessing an accelerated growth, which is expected to continue in upcoming years. The main reason is the sharp decline in technology costs of roughly 9% year-on-year, reaching USD 0.089/kWh in 2019 (IRENA, 2021b). Ambitious goals are being set globally to increase offshore wind and offshore renewables installations. For instance, Europe aims to retain its leadership in this renewable technology area, maximising the benefits for the region. The European Commission is giving offshore renewables a prominent role in its plans to realise the European Green Deal. The offshore renewable energy strategy of the European Commission released on 19 November 2020 (European Commission, 2020a) sets ambitious plans, which include:

- 60 GW of offshore wind by 2030 (from 12 GW today); and
- 300 GW offshore wind by 2050.

Figure 15

### Offshore wind current and projected capacity in the IRENA 1.5°C Scenario, 2020-2050



Source: IRENA, 2021a

<sup>5</sup> The IRENA 1.5°C Scenario (1.5-S) has been developed as a part of the World Energy Transition Outlook and constitutes a pathway for the world to achieve the Paris Agreement goals – including limiting global temperature rise to 1.5°C above pre-industrial levels – and halt the pace of climate change by transforming the global energy landscape



On a national level in Europe, recent developments of offshore wind in France – for example, the Dunkirk wind farm tender with a capacity of 600 MW – have led the country to raise its annual tendering target for offshore wind to 1 GW by 2028 (Durakovic, 2019). Other ambitious projects set in motion by the French National Commission for Public Debate (CNDP) will take place in the Mediterranean Sea. Two projects are to be awarded by 2022 with an installed capacity of 250 MW, and each plans to obtain extensions of 500 MW that are to be tendered from 2024 onwards, bringing the total project capacity to 1.5 GW (Randall-Smith, 2020). In Norway, Hywind Tampen, which began construction in 2020, is projected to be one of the largest floating offshore wind facilities worldwide, with 88 MW of installed capacity. It is expected to power around 35% of the annual demand of five offshore oil and gas platforms (World Oil, 2020).

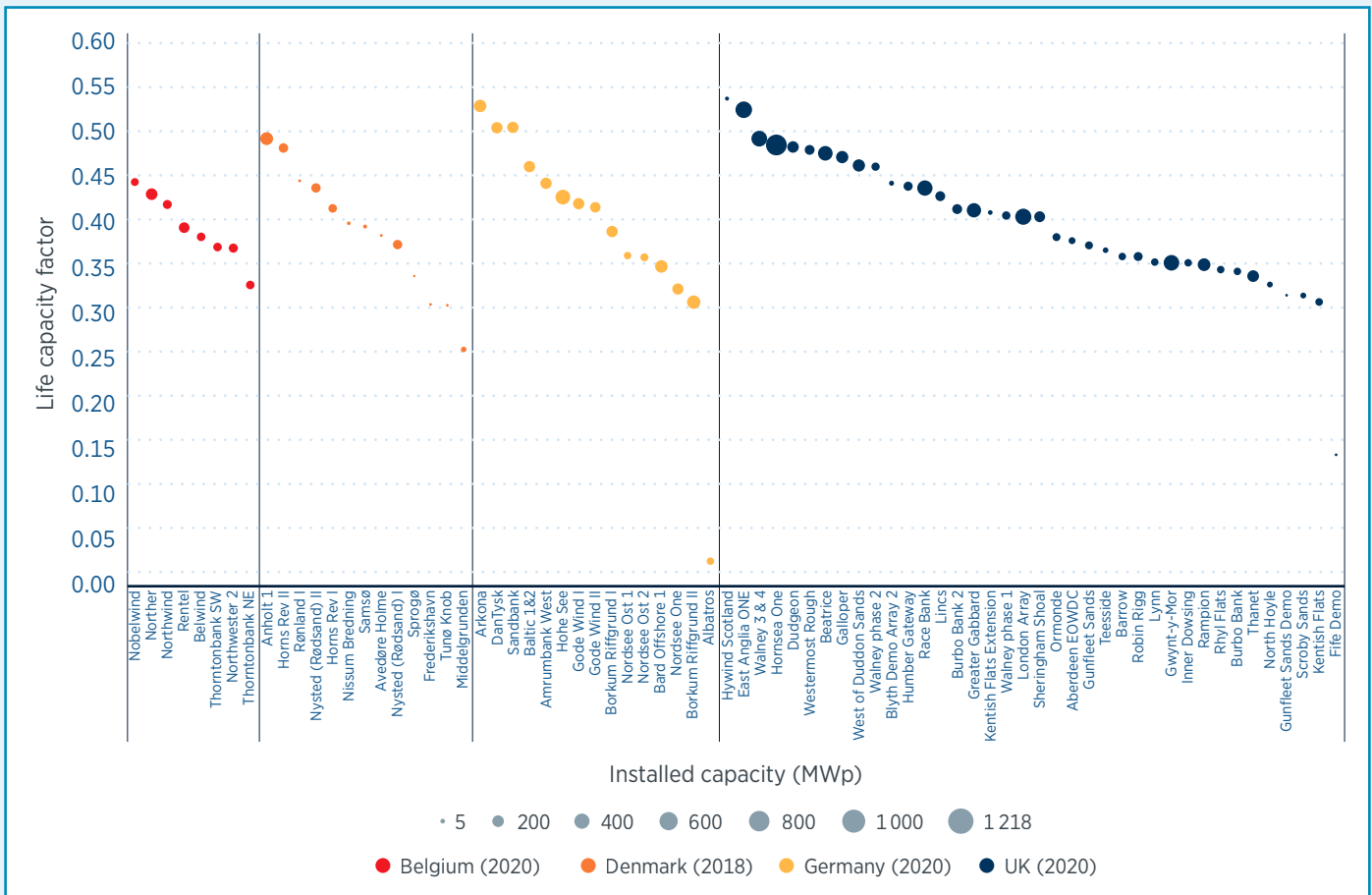
Global efforts and major developments are also taking place outside Europe. In Asia, the Republic of Korea has announced a 300 MW offshore farm as part of a large renewable energy complex behind the Saemangeum Sea wall (Radowitz, 2019). The country also is planning one of the largest floating wind complexes, comprising three projects of 500 MW each with a combined installed capacity of 1.5 GW, located off Ulsan (REVE, 2020). The Korean ambitions are overarching, as the country has unveiled a plan of USD 43.2 billion for the world's largest offshore wind farm with a capacity of 8.2 GW in the southwestern coastal town of Sinan by 2030 (Shin, 2021).

Japan is also raising ambitions for offshore wind to 45 GW by 2040, from 10 GW in 2030 (Takada, 2020). Iberdrola, a Spanish multinational electric utility company, announced that it would join a 600 MW offshore wind project in Japan, in collaboration with Cosmo Eco Power and Hitachi Zosen (Durakovic, 2021a). Similarly, the Indian government has set ambitious goals of 5 GW of offshore wind by 2022 and 30 GW by 2030 (REVE, 2021b). In addition to the European and Asian markets, the USA has set an ambitious target of 30 GW of offshore wind by 2030 (Buljan, 2021).

### **Floating foundations opening new markets and higher capacity factors**

The first commercial-scale floating wind farm, Hywind Scotland, was commissioned in 2017 with a total capacity of 30 MW. This project is a major successful operational large-scale floating wind farm, and during its first two years of operation it achieved an average capacity factor of 54%, which is significantly higher than the average 40% capacity factor for offshore wind in the UK (Skopljak, 2021a). A comparison between the operational offshore wind farms in Belgium, Denmark, Germany and the UK is provided in Figure 16. Another large-scale floating offshore wind project, WindFloat Atlantic, with a capacity of 25 MW, was installed in Portugal by the end of 2020. This project is a milestone in the floating offshore wind industry and uses an innovative floating platform comprising a moored semi-submersible platform (Beaubouef, 2020).

Figure 16  
Offshore wind capacity factor comparison



Source: Adapted from Energy Numbers, 2021a, 2021b, 2020, 2019

In the near future, an accelerated emergence of floating wind turbines is expected due to the convenience of the technology for certain countries that lack access to shallow waters, such as Japan and the USA. Other reasons are the increased demonstration activity globally along with the ambitious targets being set. For example, France has four floating wind demonstration projects under development (Durakovic, 2021b). In Spain, Iberdrola is planning the first industrial scale floating offshore wind farm with a capacity of 300 MW. This project will lead the development of up to 2 000 MW of floating offshore wind off the coasts of Galicia, Andalusia and the Canary Islands (Iberdrola, 2021). The Republic of Korea is also joining the trend and has announced the development of the Donghae 1 floating offshore farm with a capacity of 200 MW, which is expected to be operational by 2022 (Durakovic, 2020a)

Global efforts are being made to increase the market penetration of floating offshore wind specifically, as it is being included further in national goals and strategies. Table 3 provides an overview of some of the regional and national targets for offshore wind deployment.

Table 3  
**Floating offshore wind capacity deployment targets**

Country	Target	Target year	Source
Chinese Taipei	1 GW	2030	Carbon Trust, 2015
Europe	N/A*	N/A	European Commission, 2020a
Japan	18 GW**	2050	JWPA, n.d.
Republic of Korea	6 GW	Starting from 2023	Durakovic, 2020a
USA	N/A***	N/A	IRENA, 2019c
UK	1 GW	2030	Durakovic, 2020b

\* The EU has no specific target capacity for floating offshore wind; however, around 150 MW of floating capacity is expected to be commissioned by 2024. More capacity can be expected as a result of the recent European offshore renewables targets.

\*\* This is not a government target and is a target set by the Japan Wind Power Association. Floating offshore wind is part of the 45 GW offshore wind target set by the Japanese government by 2040.

\*\*\* An investment of around USD 1 billion has been made to develop the technology and to realise demonstration projects across the USA. The ambitious target of 30 GW of offshore wind by 2030 also entails floating offshore wind projects.

Despite Europe's ambitious goals to maintain its leadership in offshore wind, Asia is expected to take the lead in the coming decades, with a more than 60% share of global installations by 2050, followed by Europe with 22% and North America with 16% (IRENA, 2019b).



## 02.3

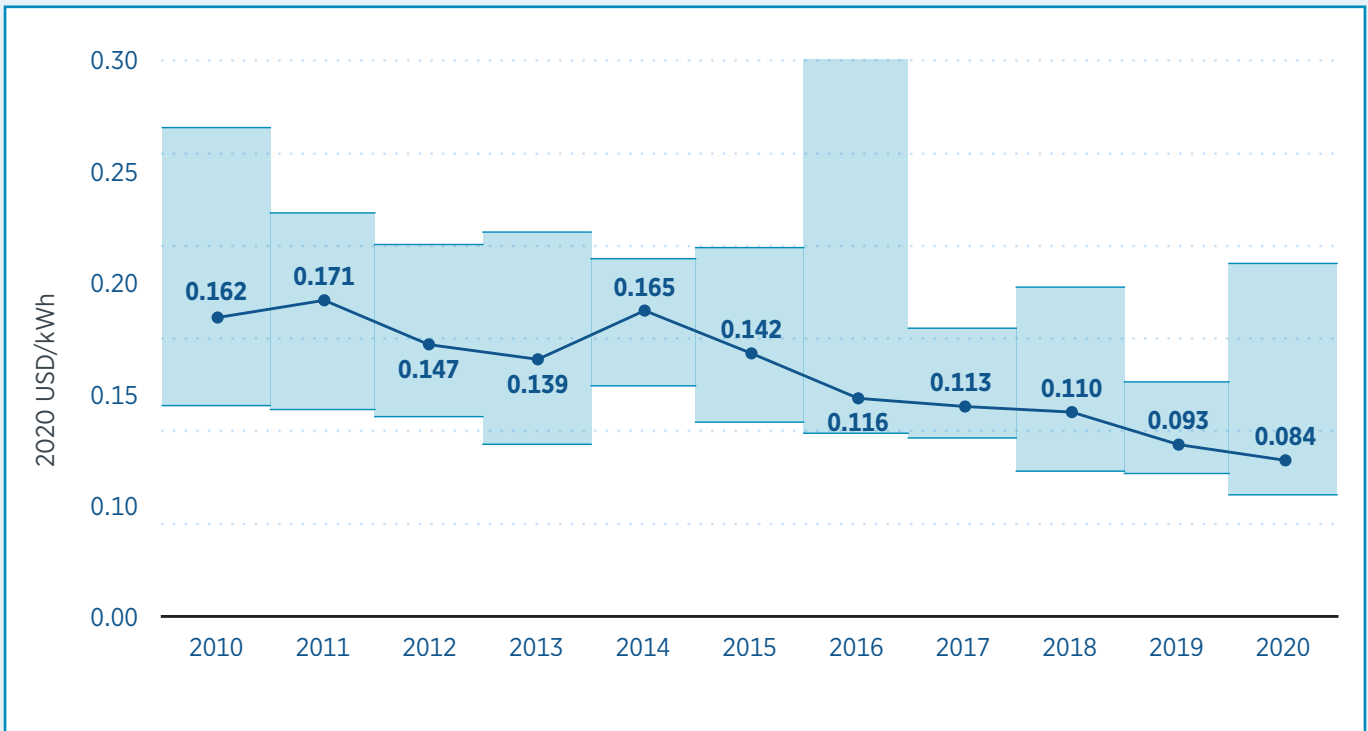
# COMPETITIVENESS

The global weighted average levelised cost of electricity (LCOE) for offshore wind has decreased overall, from USD 0.162/kWh in 2010 to USD 0.084/kWh by 2020. However, the LCOE increased between 2010 and 2014 as projects started shifting more into deeper waters, reaching a peak of USD 0.171/kWh in 2011 and USD 0.165/kWh in 2014, followed by a sharp decline to 2020, as shown in Figure 17.

The LCOE for offshore wind decreased sharply in frontrunner countries, with the lowest weighted average LCOE reported in China at USD 0.084/kWh in 2020 followed by Germany and the UK. Table 4 highlights the declining LCOE trends for the frontrunners between 2010 and 2020.

## The global weighted-average LCOE of offshore wind declined by 48% between 2010 and 2020

Figure 17  
LCOE of offshore wind, 2010-2020



Source: IRENA, 2021b

Table 4

**LCOE of offshore wind in selected countries between 2010 and 2020 (USD/kWh)**

Country	2010	2015	2020
Denmark	0.111	N/A	N/A
China	0.178	0.115	0.084
Germany	0.166	0.140	0.093
Japan	0.215	0.199	N/A
UK	0.162	0.161	0.115

Note: N/A = data not available

Source: IRENA, 2021b

## 02.4

**EMERGING TRENDS FOR OFFSHORE WIND**

The key emerging trends for offshore wind from a technological, location-specific and technological coupling perspective are as follows:

**Manufacturing of larger offshore wind turbines**

As part of pursuing higher energy yield and lower costs, larger turbines are being pursued globally. For example, Vestas recently announced the development of a 15 MW offshore wind turbine that will be installed in 2022 and begin serial production in 2024, followed by an announcement of pursuing even larger turbines with 17 MW capacity in the near future. (See section 2.1.)

**Floating foundations**

Floating foundations enable installations in deeper waters and farther from shore. For example, Norway's Hywind Tampen floating offshore wind farm will be located 140 kilometres from shore in depths between 260 metres and 300 metres. It will be capable of harnessing greater wind resource, potentially resulting in higher energy yield. (See section 2.1.)

**Use of versatile foundations and structures**

Due to the growing deployment of offshore wind, increasing turbine sizes and the pursuit of higher wind resources in deeper waters and farther from shore, versatile and adjustable foundations and structures are being pursued. These include, for example, concrete sub-structures and the Saipem floating wind solution, which does not require a platform change but rather an adjustment of the pendulum size to accommodate turbines of various sizes. (See section 2.1.)

### **Creation of combined-technology power generating plants**

Pursuit of increasing energy yield along with reducing capital and generation costs have led to the coupling of offshore wind technology with other offshore renewable technologies. These include, for example, offshore wind coupled with floating solar PV, such as the Maasvlakte 2 project, and/or with ocean energy technologies, such as the Floating Power Plant offshore wind project coupled with a point absorber wave converter. (See section 6.1.)

### **Creation of offshore energy hubs for renewable power production**

Due to limited land availability and the higher wind resource availability offshore, artificial islands for harnessing wind energy are being explored, such as the two artificial wind energy islands being developed in Denmark. (See Box 5.)

### **Powering sectors of the blue economy**

Offshore wind is being used for direct and indirect electrification of different blue economy activities. For example, Denmark's port of Esbjerg uses offshore wind in its shore-to-ship plants, which is used to power up docked vessels instead of using diesel generators (Ajdin, 2021). (See section 6.2.)

### **Generation of green hydrogen through coupling with different offshore renewable technologies**

Offshore wind is witnessing coupling with electrolyzers and other offshore renewables to produce green hydrogen due to the underlying potential of reducing costs and providing a clean energy source for different activities. An example is the Maasvlakte 2 in Rotterdam, which will include a combination of floating solar PV, offshore wind, batteries and electrolyzers by 2023. (See section 2.5.)

### **Airborne wind energy systems**

Airborne wind energy systems are being researched on an international level and are attracting the attention of different countries and organisations. AWES also are getting more demonstration and pilot projects, for example the Skysails Skypower100 project in Germany. (See Box 3.)

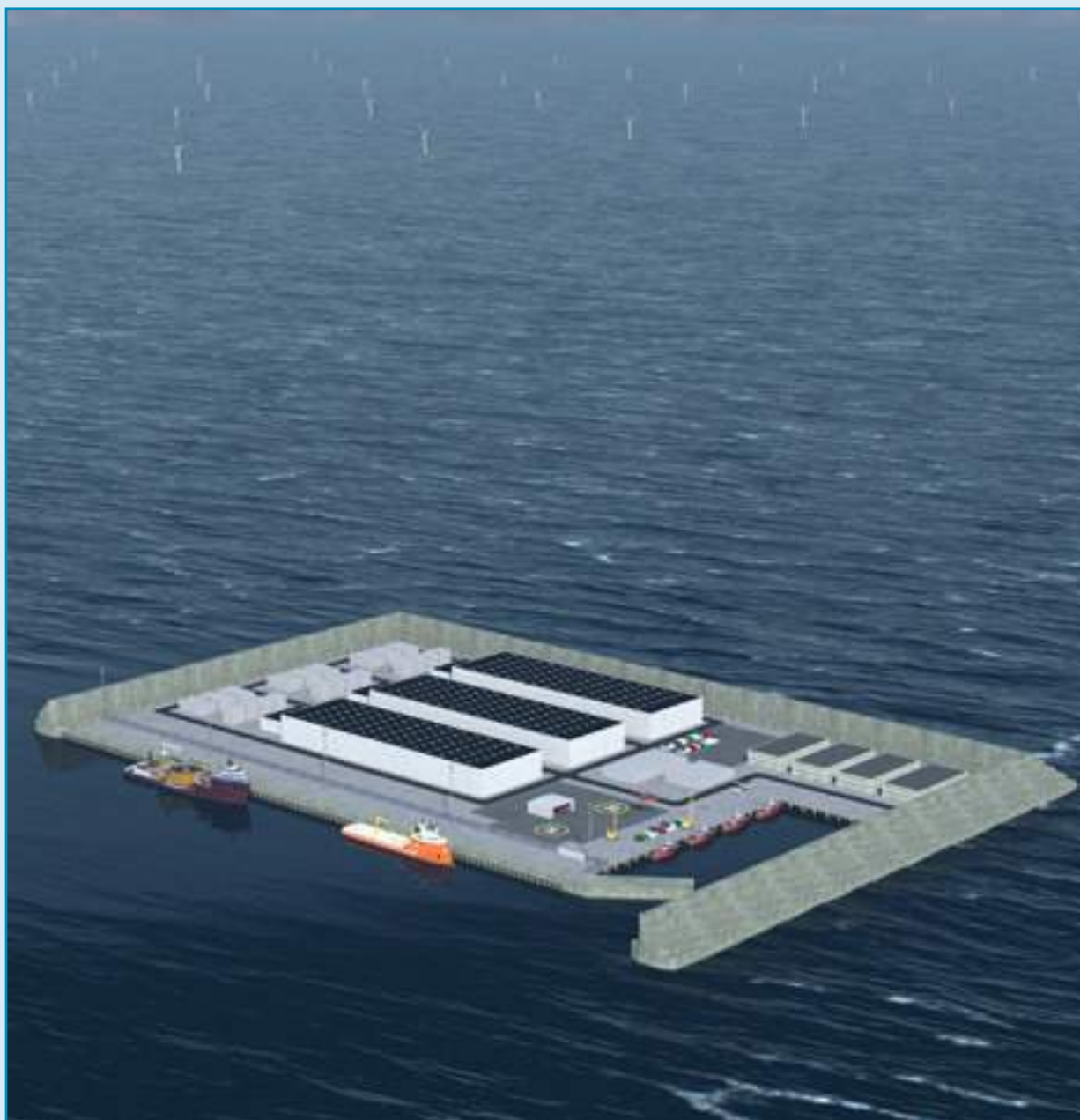


### Box 5: Artificial island for offshore wind-to-hydrogen in Denmark

In the second half of 2020, the Danish parliament agreed to realise an artificial energy island that will be located west of Jutland in the North Sea, roughly 80 kilometres from the town of Thorsminde. The artificial island will connect and distribute power from the surrounding offshore wind farms and will initially have a minimum capacity of 3 GW with the potential to be expanded later to 10 GW of offshore wind (Danish Energy Agency, 2021a). Generated electricity will be used to meet Denmark's electricity needs, to export to other European countries and to produce green hydrogen (Broom, 2021). A second island is also planned.

Figure 18 provides an illustration of the artificial offshore wind island hub.

Figure 18  
**Artificial energy island prototype in Denmark**



Source: Danish Energy Agency, 2021b

## 02.5

## OFFSHORE WIND AND GREEN HYDROGEN

Of the emerging trends discussed above, the production of green hydrogen using offshore wind electricity is an innovative business model that received the most attention in 2020. Future developments of offshore wind are witnessing a coupling with hydrogen production through electrolyzers, and more than a dozen projects have been proposed since 2019. Such projects are attracting global interest, and from the total pipeline of planned projects of more than 200 GW, at least 17 GW of projects coupled with offshore wind have already been proposed, mainly in Europe. This capacity holds a share of 53% of the overall announced electrolysis projects from various electricity sources (BloombergNEF, 2021).

The near- or medium-term pipeline of electrolysis projects powered by offshore wind (2021-2035) is dominated by countries in north-western Europe, namely Germany with 10 GW, followed by the Netherlands with 4.3 GW, Denmark with 2.3 GW and the UK with 112 MW. The AquaVentus consortium in Germany, with a capacity of 10 GW, is the largest planned project followed by NorthH2 and Massvlakte 2 in the Netherlands with capacities of 200 MW each (BloombergNEF, 2021). The AquaVentus project highlights the importance of cross-country co-operation to maximise wind yields and enhance coupling opportunities with enabling technologies.

The rising interest in coupling offshore wind with hydrogen production can be attributed to multiple factors:

- **Offshore wind has one of the highest capacity factors among all renewables.** This corresponds to a higher electrolyser utilisation rate (run time) and therefore increased hydrogen production and ultimately decreasing overall costs and increasing revenues.
- **Locational advantage near demand centres.** Industrial clusters are located in coastal areas, which positions them to be the main benefactors of the produced hydrogen for their operations.
- **Elimination of land availability constraints and improved power system flexibility.** Development of gigawatt-scale green hydrogen projects onshore requires noticeable land resources in contrast to those of offshore development.

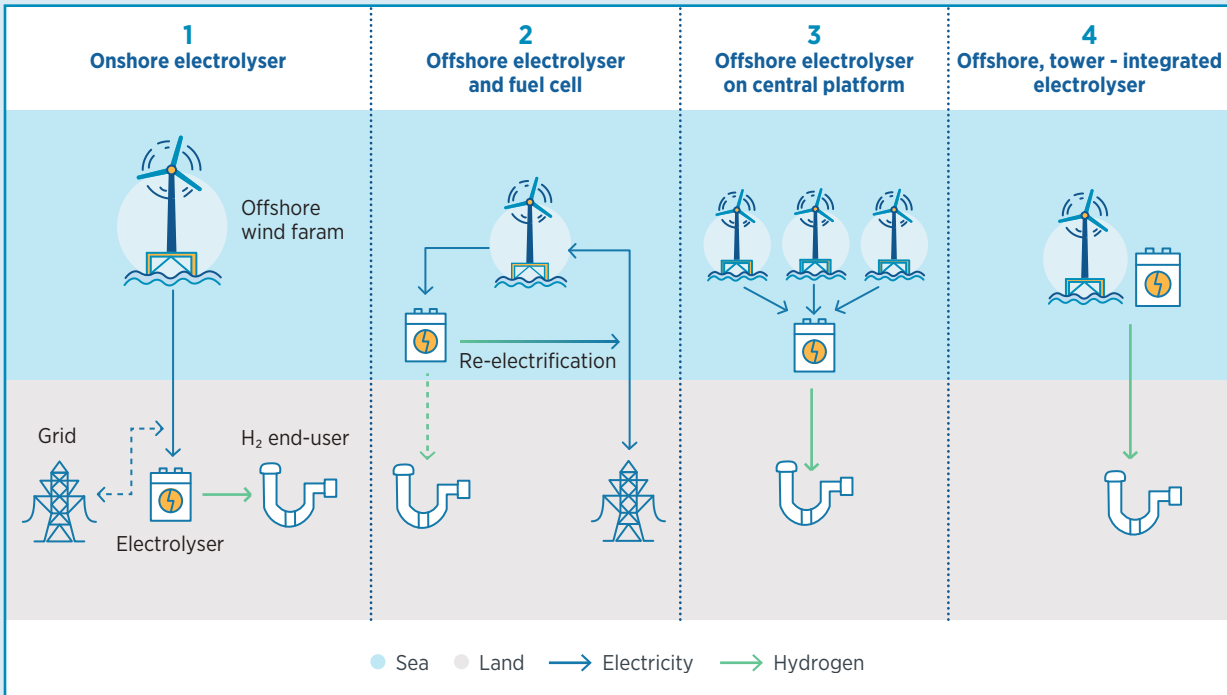
One challenge that still needs to be overcome is the higher electricity price. The average global LCOE of USD 115/MWh (IRENA, 2020b) would translate to a hydrogen price of around USD 5.5 per kilogram even without considering the investment cost of the electrolyser, transport to shore and other components. To put this in perspective, fossil-based hydrogen costs USD 1.2-2.4/kg (depending on the gas price) (IRENA, 2020c).



**Box 6: Configuration of offshore wind and hydrogen production**

Recent developments and innovative business models have led to the emergence of different methods for coupling offshore wind and hydrogen production. A study done by BloombergNEF (2021a) has categorised the different configurations based on electrolyser location and the need for a sub-sea cable. Figure 19 illustrates the four main emerging configurations.

Figure 19  
**Offshore wind to hydrogen configurations**

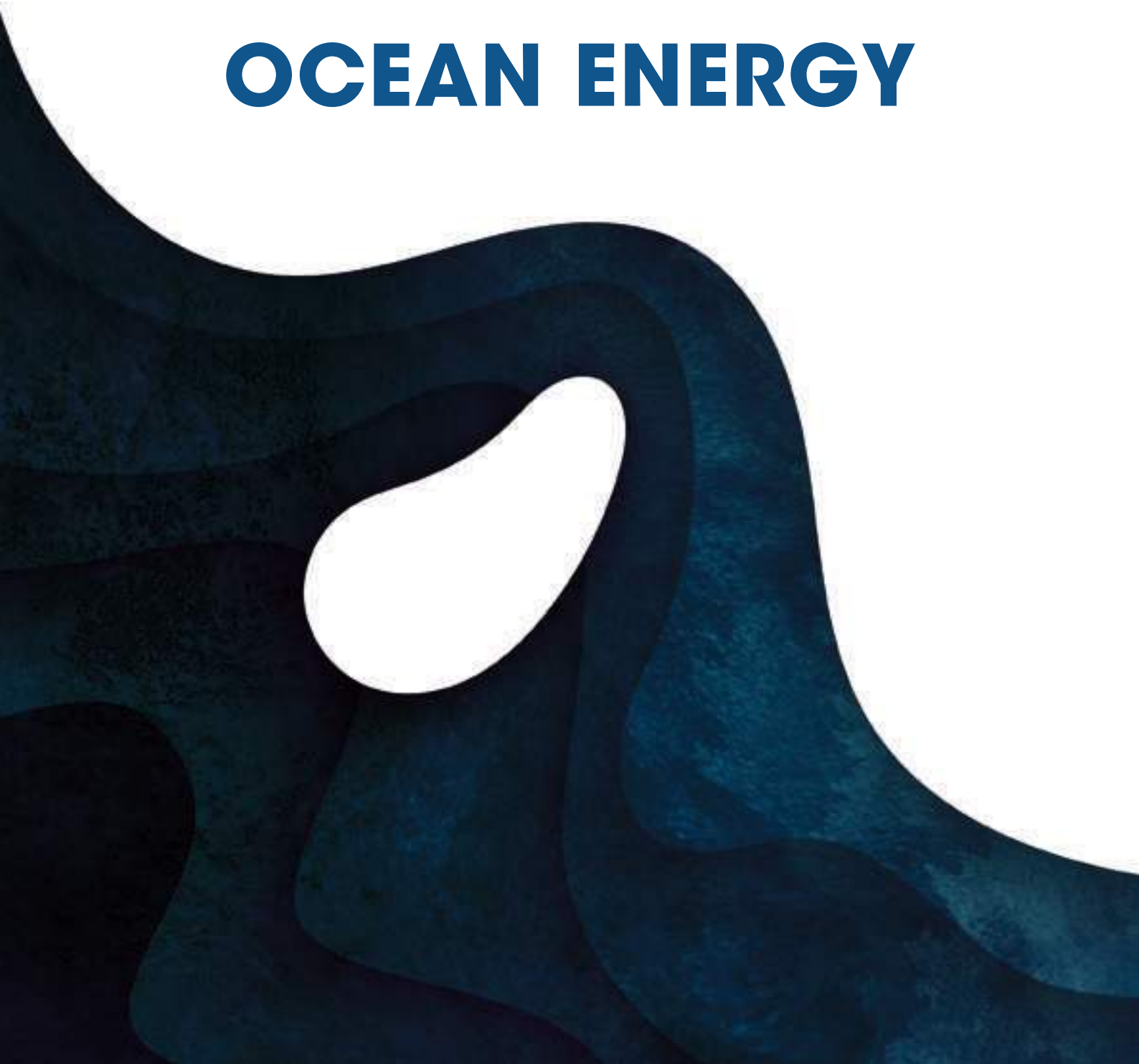


Source: Danish Energy Agency, 2021b



**03**

# **OCEAN ENERGY**



## 03.1

# TECHNOLOGY STATUS AND OUTLOOK

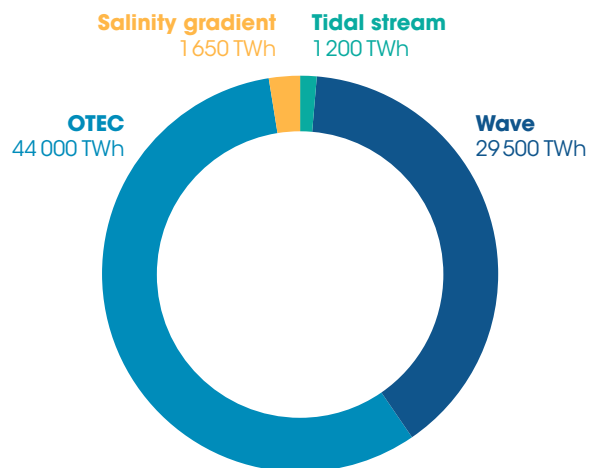
Ocean energy technologies are niche and emerging technologies with the potential to power coastal communities, as well as to drive a blue economy. Globally, 40% of the population, around 2.4 billion people, live within 100 kilometres from the coast (UN, 2017). Those communities are in need of various economic activities and reliable power sources, which can be provided by predictable ocean energy technologies as a baseload source. Moreover, ocean energy technologies could facilitate the integration of variable renewable energy sources such as solar PV and wind.

Generally, ocean energy technologies are categorised based on the source used for power generation. For instance, tidal stream and tidal barrage are referred to when tidal energy is used, whereas the term wave energy is used when power is produced from ocean waves. Other sources that harness energy from temperature difference or salinity difference are ocean thermal energy conversion (OTEC) and salinity gradient, respectively.

Ocean energy holds an abundance of untapped resource potential that could meet the current global electricity demand and the projected demand well into the future. The theoretical potential differs greatly among different technologies (Figure 20). Based on IRENA's analysis, the global cumulative resource potential ranges from 45 000 terawatt-hours (TWh) to well above 130 000 TWh annually (IRENA, 2020d). Therefore, ocean energy alone has the potential to meet more than twice the current global electricity demand.

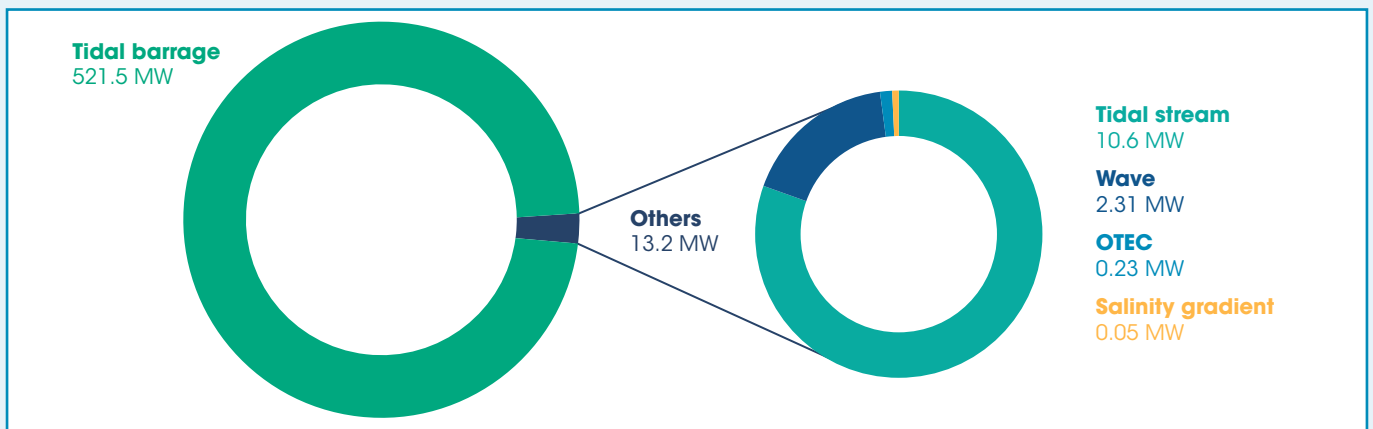
Currently, most ocean energy technologies have not reached commercialisation and are still in developmental stages, with the majority of technologies being in the prototype phase with the exception of some reaching early commercialisation. The growth in the ocean energy sector has been slower than expected. However, the past decade has witnessed noticeable progress in tidal and wave energy. As shown in Figure 21, the current global cumulative installed capacity across all ocean energy technologies is more than 515 MW.

Figure 20  
**Ocean energy resource potential**



Source: IRENA, 2020d

Figure 21  
Total ocean energy deployment



Source: IRENA, 2020d

### Tidal energy

Tidal energy, further categorised into tidal barrage (also known as tidal range) and tidal stream (also known as tidal current), includes different types of technologies with different technology readiness levels (TRLs),<sup>6</sup> which refer to their maturity levels.

As shown in Figure 22, tidal barrage is the most mature technology, not just among the two main tidal technologies, but among all ocean energy technologies. Some tidal barrage power plants have been operational since the 1960s. However, since the theoretical electricity generation potential of tidal energy is the lowest among all ocean energy technologies – with around 1200 TWh annually (OES, 2017) concentrated in a limited number of sites – only a few dozen countries have deployed this technology.

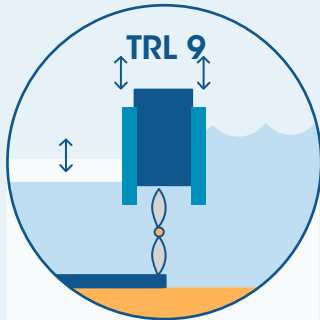
Due to the limited site availability, along with high capital investment and high environmental impacts, tidal barrage technology has witnessed limited growth, while other tidal current technologies such as horizontal-axis turbines are expected to gain momentum. Tidal turbines are also increasing in size: in contrast to past turbines of 100 kW, in the past few years 1.5 MW units have been successfully deployed, and developers are pushing to scale up turbines further (2 MW) (IRENA, 2020d).

Tidal energy technologies represent the majority of the global installed ocean energy capacity with around 512 MW, of which 501.5 MW is operational tidal barrage plants. However, due to the different level of maturity for tidal barrage in comparison to other ocean energy technologies, and to the stagnant development in the past decade, tidal barrage is often excluded from modern ocean energy discussions (IRENA, 2020d).

<sup>6</sup> The technology readiness level (TRL) is a scale from 1 to 9 where 1-3 represents the research phase, 4-5 the development phase, 6 the demonstration phase and 7-9 the deployment phase (with 7 representing prototype demonstration and 9 a fully deployed, proven and operational technology).

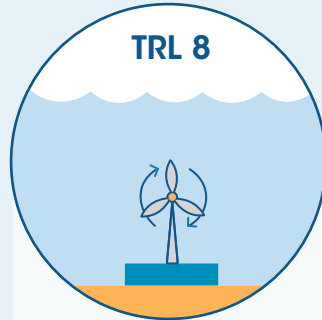
Figure 22

Different tidal energy technologies



**Barrage**

Water that entered an enclosed tidal basin with high tide is released in low tide and generates electricity by passing through turbines.



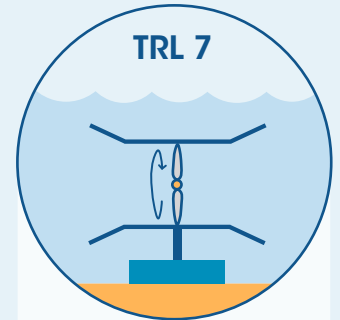
**Horizontal-axis turbine**

The tidal currents flow past blades that are radially attached to a horizontal shaft and cause rotation, thus generating power, much like a wind turbine underwater. Either the hub or blades need to turn 180 degrees to accommodate a reverse flow direction.



**Vertical-axis turbine**

The tidal currents flow through a set of blades parallel to a rotating shaft, generating power irrespective of the direction of the flow.



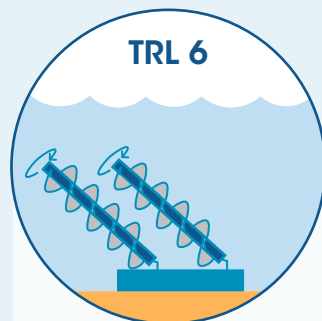
**Enclosed tips (venturi)/ open-centre**

The tidal stream's velocity is increased by concentrating it in a funnel or duct, in which a turbine is placed to generate energy.



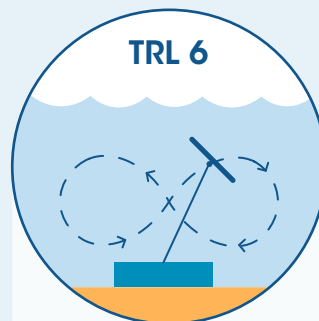
**Reciprocating device/ oscillating hydrofoil**

the tidal flow lifts an oscillating hydrofoil attached to an arm. This up-and-down movement drives a shaft or pistons to generate energy.



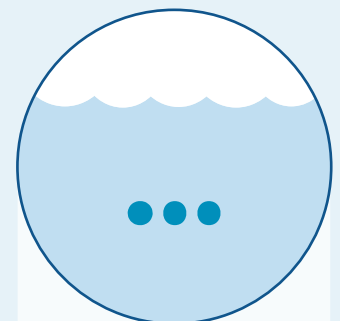
**Archimedes screw/ spiral**

a tidal stream passes through the spiral of a helical-shaped impeller. The device starts to turn, and the rotation is converted into energy.



**Tidal kite**

A kite connected to the sea bed or to a floating platform moves through the tidal stream in an eight-shaped or linear trajectory. The relative velocity is increased and with it the electricity output.



**Other**

Other technologies have been investigated that either fit in none of the categories or incorporate various aforementioned characteristics.

### Wave energy

Wave energy is mainly influenced by the wave height, wave speed, wavelength (or frequency) and wave density, and such characteristics are most powerful in latitudes between 30 degrees and 60 degrees and in deep water (greater than 40 metres). Although waves vary seasonally and in the short term, they are considered a reliable source of energy as they can be forecasted in the future with a significant degree of accuracy. Wave energy resources are better distributed than those of tidal energy resources. This can be seen directly in their huge resource potential of around 29 000 TWh annually, which would be capable of meeting the current global electricity demand (Mørk *et al.*, 2010).

Unlike offshore wind, wave energy technologies have not witnessed a convergence towards one type of design, but rather different types of technologies are being pursued. Historically, three main working principles to harness energy from waves have been developed: oscillating water columns, oscillating bodies and overtopping devices (IRENA, 2014a). Figure 23 provides an overview of the different wave energy technologies.

Recently, despite the absence of a clear technology convergence for wave technologies, many deployments are of the “point absorber” type, in which the energy is generated from the movement of a buoy caused by waves coming from all directions, relative to the base connection. The TRL of wave energy in general is lower than that of tidal energy, and the majority of its deployments are restricted to demonstration and pilot projects (Boshell *et al.*, 2020). This has led to a global installed capacity of only 2.5 MW. However, similarly to tidal energy, wave energy devices are increasing in size and power ratings, and around 100 MW of installations are expected in the upcoming years.

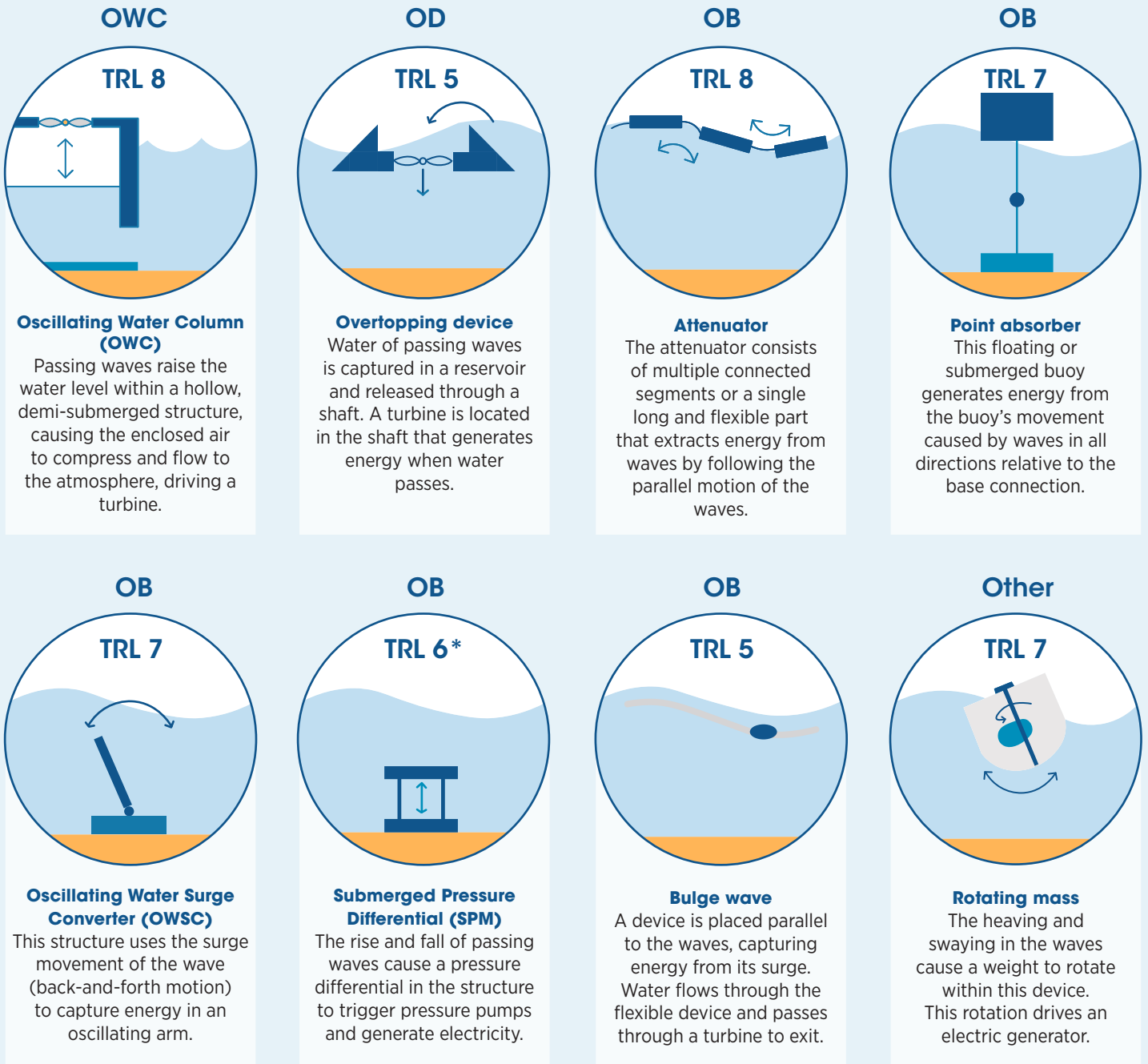
### Ocean thermal energy conversion (OTEC)

The OTEC working principle is based on the temperature difference of ocean waters between the surface and deeper layers (800 to 1000 metres depth), as energy is produced using cycles with heat exchangers and turbines. In order for the OTEC to be in operation, the temperature difference must be around 20 degrees Celsius (°C), which indicates that the surface temperature must be around 25°C as the water temperature tends to stabilise to around 4°C at 1000 metres depth. Globally, three thermal energy conversion processes are pursued to harness ocean thermal energy: open cycle, closed cycle and hybrid devices.

OTEC holds the largest resource potential among all ocean energy technologies at around 44 000 TWh annually (Nihous, 2007), which is also capable of meeting current global electricity needs. Besides OTEC’s huge power generation potential, OTEC can provide continuous non-intermittent baseload electricity, making it a reliable power source. In addition, OTEC can be coupled with different economic activities, thus driving a vigorous blue economy. However, OTEC is still in the R&D phase with current implementation limited to 100 kW demonstration plants in Hawaii (USA) and Japan.

Figure 23

Prototypes of wave energy technologies



**Other**

Certain technologies have other unique, not commonly used ways of capturing energy from the waves.

\* Only attempted but not achieved

Source: IRENA, 2020d

### Salinity gradient

Salinity gradient technologies harness energy through pressure retarded osmosis (PRO) or reverse electrodialysis (RED), in which energy is generated as a result of the difference of salt concentration between two fluids. This can be found in riverbeds where freshwater flows into the sea, as the difference in salt concentration is significant, thus holding higher potentials for energy generation (IRENA, 2020d). Energy can be harnessed naturally based on the difference in salt contents, or it can be used as a hybrid system in industrial energy-recovering purposes, which uses saturated brine instead of seawater (for example, desalination or wastewater treatment) (IRENA, 2014b).

While estuaries can be found globally, and salinity can theoretically provide continuous baseload power, geographical requirements pose great limitations to the overall potential, which is relatively small in comparison to other ocean energy technologies, at 1650 TWh annually. Salinity gradient is the least mature ocean energy technology, and globally only one project with a capacity of 50 kW was operational in 2020, in the Netherlands.

## Tidal stream technology is reaching maturity, further R&D and large demonstration projects for wave and other ocean energy technologies are needed

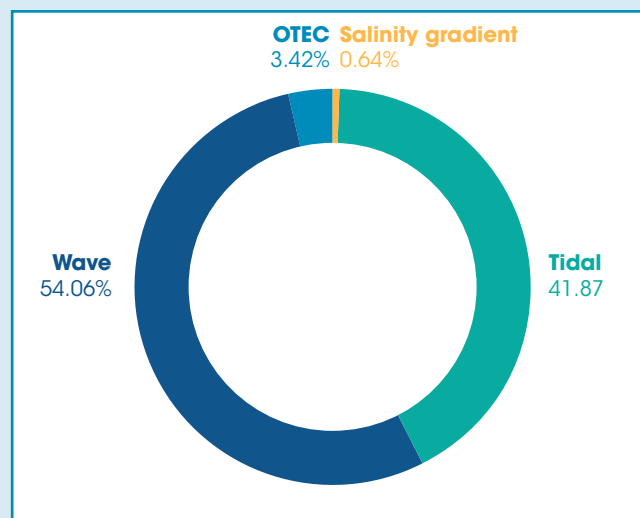
### Box 7: Innovation paving the way towards ocean energy technology uptake

In the past two decades, tidal and wave energy technologies have witnessed various technology readiness levels (TRLs), which was accompanied by a rise in invention activity. This has led to tidal and wave energy holding the majority of the internationally filed patents among ocean energy technologies, as shown in Figure 24.

Since the early 2000s and up until 2017, invention activity in ocean energy technologies reached more than 24 000 filed patents by local intellectual property authorities. These technology breakthroughs were accompanied by an annual compound growth rate of 15% between 2007 and 2017, with wave and tidal energy demonstrating the fastest growth rates. Other ocean energy technologies, such as OTEC and salinity gradient, have achieved rapid progress rates.

Europe is leading the way in patents for ocean energy technologies, with 66% of all patents in tidal energy and 44% of all patents in wave energy (Science Business, 2021).

Figure 24  
Filed patents in ocean energy technologies (cumulative), 2000-2017



Source: Based on IRENA, n.d.



## 03.2

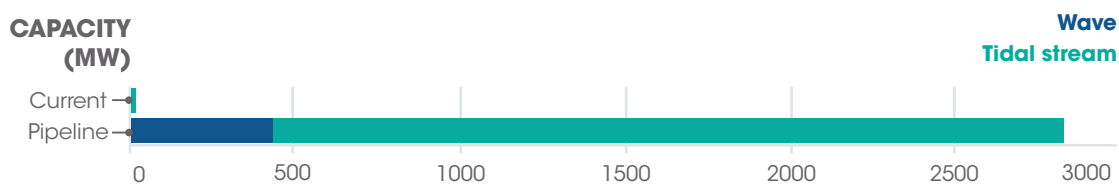
# MARKET STATUS AND OUTLOOK

Ocean energy technologies are being developed and pursued globally in 31 countries. However, despite the global presence, only a few countries are at the forefront of the ocean energy market, namely European countries such as Finland, France, Ireland, Italy, Portugal, Spain, Sweden and the UK, in addition to Australia, Canada and the USA. These countries hold the largest number of projects tested, deployed and planned as well as the most project developers and device manufacturers.

Although the majority of ocean energy technologies are in the RD&D stages, an increasing number of companies, research institutes, universities and investors are showing interest in ocean energy technologies and are allocating resources to further develop them and to increase the installed capacity in the coming years. For example, the cumulative capacity of planned ocean energy projects, with the exclusion of tidal barrage projects, is around 3 GW (Figure 25). The breakdown by technology of the projected capacities for tidal stream and wave energy, including the number of projects in the pipeline and the number of developers involved, is shown in Figure 26.

Figure 25

### Active and projected tidal stream and wave capacity beyond 2020



*Note: While their capacity is too small to appear on this chart, additional projects are planned for the other ocean energy technologies beyond 2020. For example, a 2 MW ocean thermal energy conversion plant and a 1 MW salinity gradient energy plant are planned in the Netherlands*

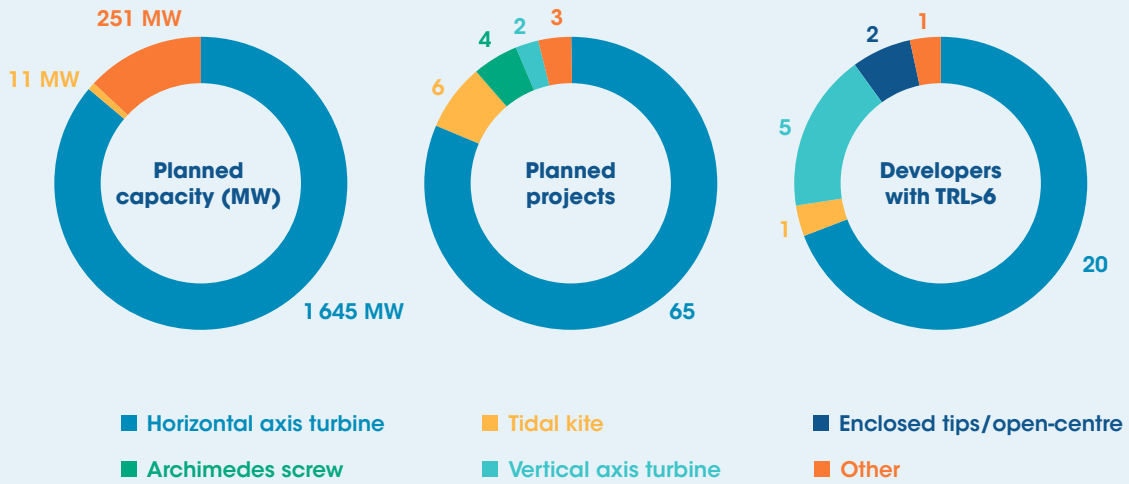
Source: IRENA, 2020d

Markets for ocean energy technologies differ significantly according to the technology being used. For example, tidal energy, and more specifically tidal barrage, is mainly prominent in France, the Republic of Korea, Canada and the UK. Three main tidal barrage projects constitute around 98% of the total installed ocean energy capacity: the 254 MW Sihwa Lake Tidal Power Station in the Republic of Korea, the 240 MW La Rance Tidal Power Station in France and the 20 MW Annapolis Tidal Station in Canada (currently being decommissioned and no longer operational). Other countries that house smaller tidal barrage power plants include the Russian Federation and China.

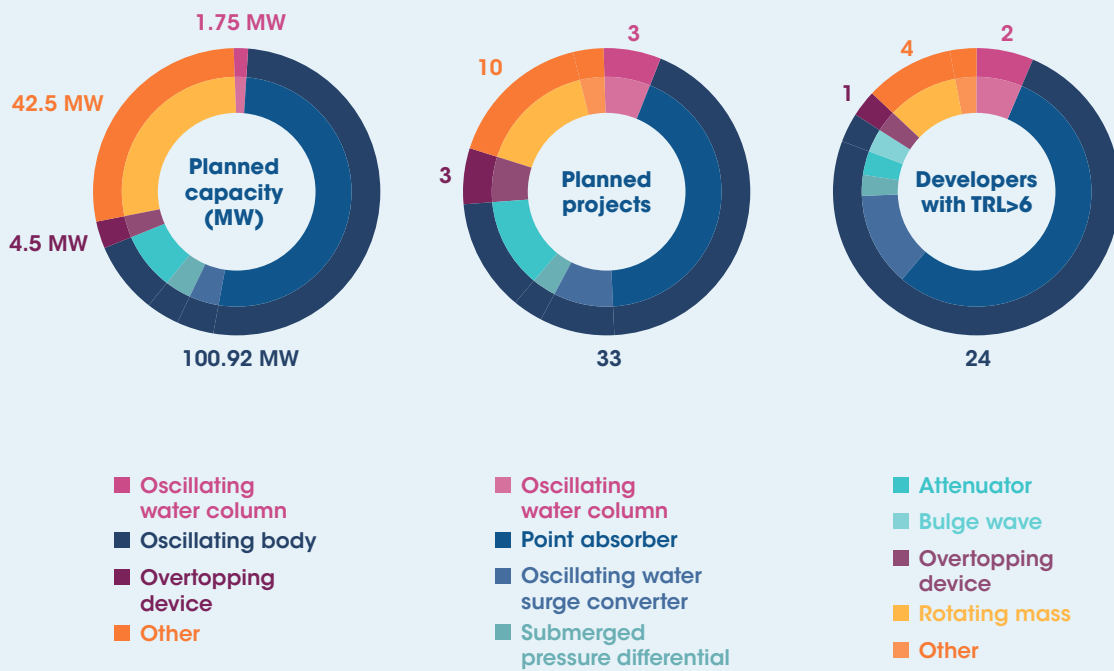
While tidal barrage holds the highest share in terms of capacity, tidal stream holds the second largest installed capacity among all deployed ocean energy technologies, and the number of deployed projects is far greater than for tidal barrage technology. The world's largest tidal stream turbine, with a capacity of 2 MW, recently became operational in Orkney, Scotland (BBC, 2021).

Figure 26  
Different tidal energy technologies

TIDAL STREAM ENERGY



WAVE ENERGY



Source: IRENA, 2020d

For wave energy, around 9 operational projects with a total capacity of around 2.3 MW were deployed globally across 8 countries and 3 continents. The projects are relatively small in capacity, with only one project with an installed capacity that exceeds 1 MW deployed in late 2020 (in Hawaii). The majority of wave energy projects were developed in European waters. However, some were installed as demonstration projects and only stayed in the water for a few months. For example, the UK has deployed the most projects, but none of these were operational by the end of 2020.

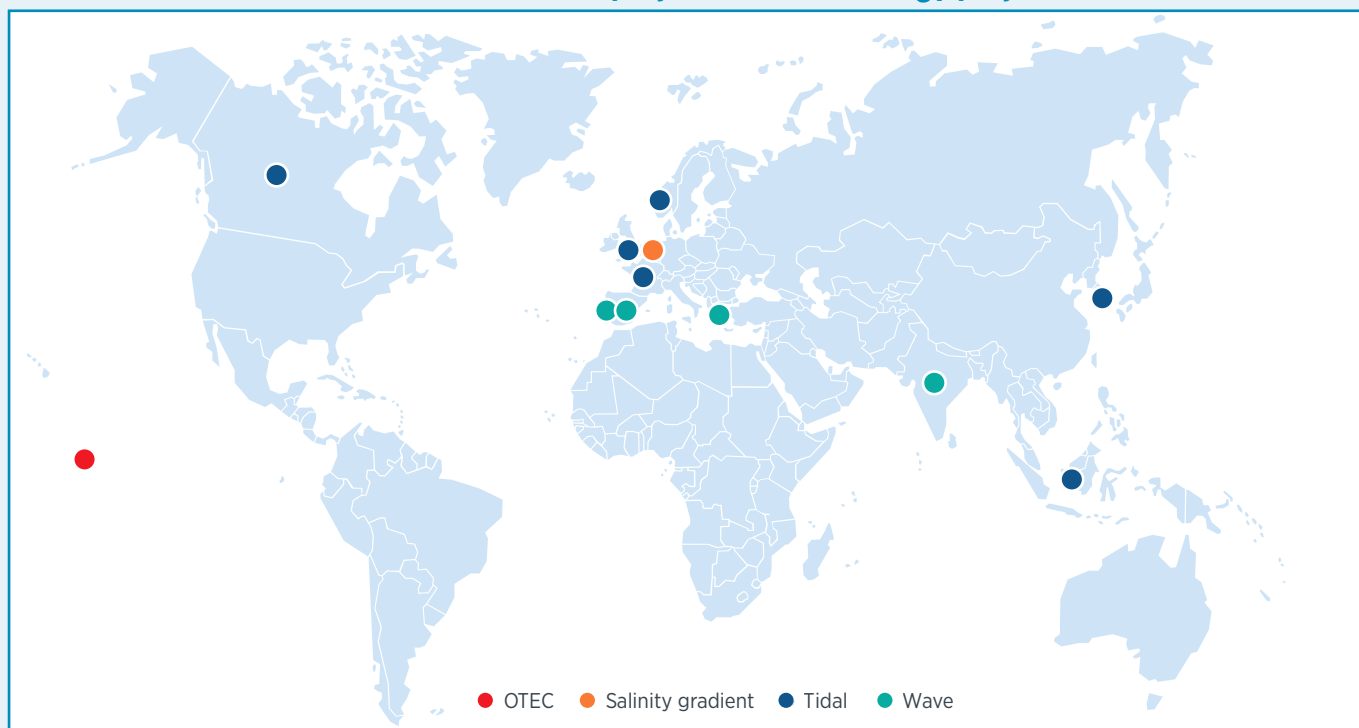
Other ocean energy technologies, such as OTEC and salinity gradient, are far less mature and still in the R&D and conceptual phases. Thus, their market actors are not commercial but rather research institutes and universities.

Looking forward, ocean energy technologies are expected to become pivotal elements in the electricity mix of various countries and particularly small island developing states (SIDS). For example, ocean energy and in particular tidal energy has the ability to meet around 20% of the UK's electricity needs (Ross, 2021) and is currently being pursued in the country, with six projects planned between 2021 and 2026. Canada is also supporting the funding of its first floating tidal energy array of 9 MW, which is planned to be connected to Nova Scotia's power grid, with a total investment estimated at USD 21.7 million (Renews, 2020). Overall, ocean energy projects planned beyond 2020 are spread over 12 countries, with most projects being tidal and wave energy as shown in Figure 27.

As part of the European offshore renewable energy strategy, mentioned in section 2.2, ocean energy technologies also have defined targets as follows:

- at least 1 GW of wave and tidal energy by 2030; and
- 40 GW of wave and tidal energy by 2050.

Figure 27  
Global distribution of projected ocean energy projects



Source: IRENA ocean energy database

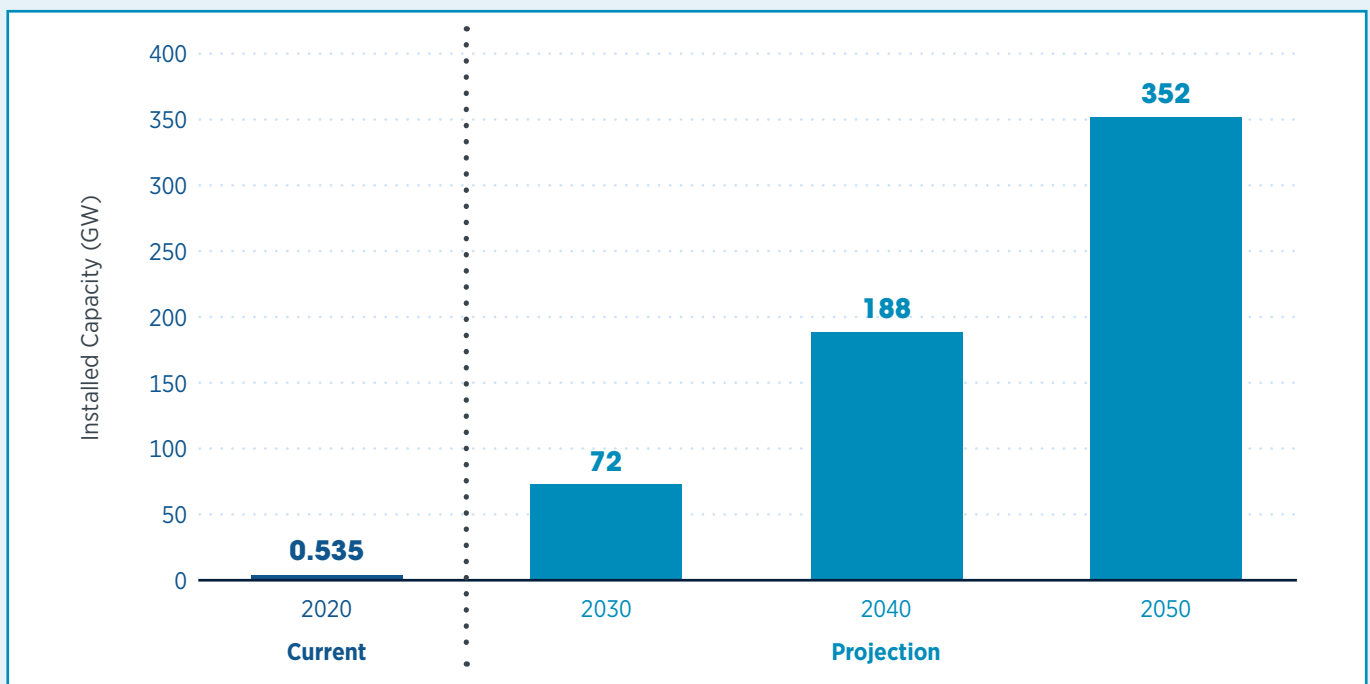
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.



A deep dive into ocean energy markets reveals two competing trends for ocean energy technologies. On the one hand, Western countries, which are currently leading the ocean energy front, and which have more experience, are exporting their expertise and technologies through project development outside their borders. On the other hand, new innovations are taking place outside of Europe, mainly in China, Japan and the Republic of Korea.

Overall, due to the recent market expansion and increased deployment, IRENA's 1.5-S projects that ocean energy technologies could reach an installed capacity of around 70 GW by 2030 and 350 GW by 2050 globally (Figure 28).

Figure 28

**Ocean energy current and projected capacity according to IRENA 1.5-S, 2020-2050**

### 03.3

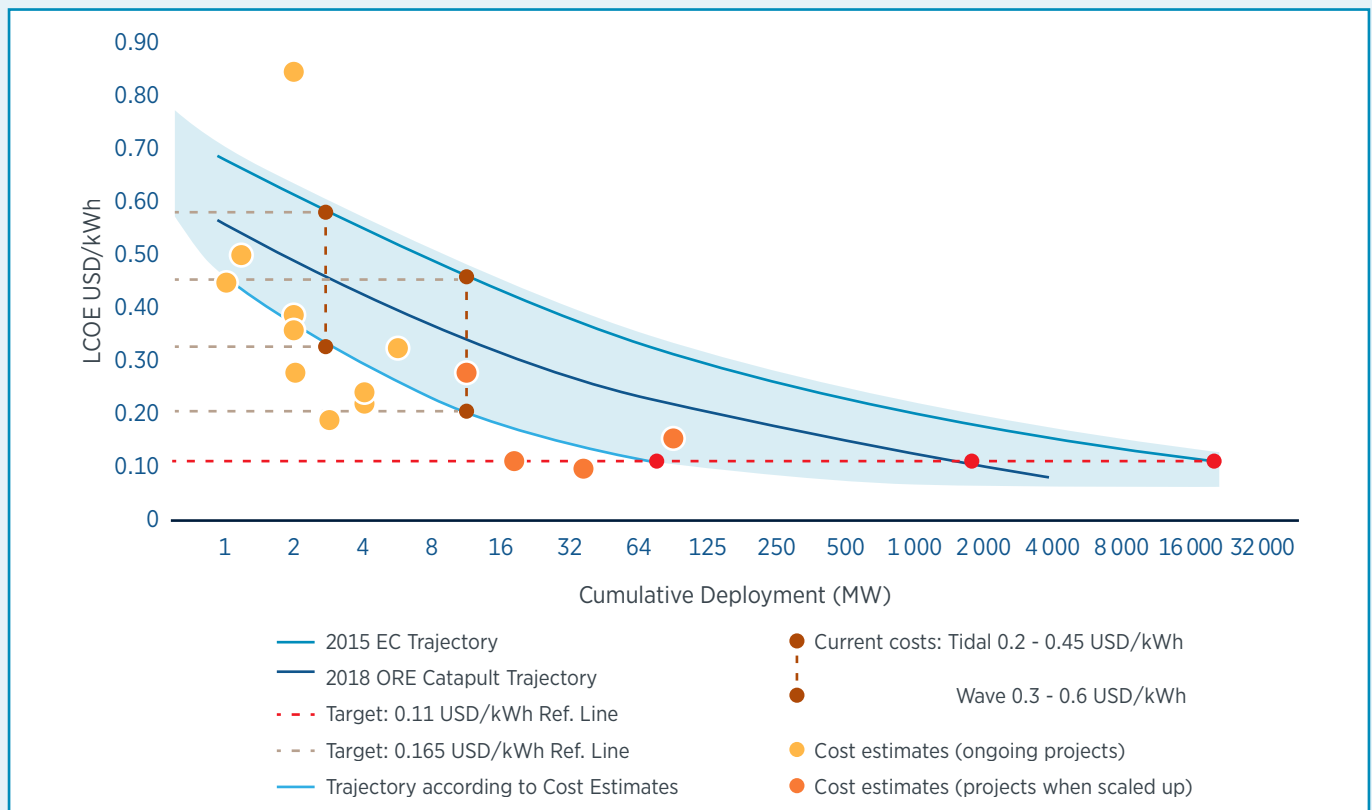
## COMPETITIVENESS

Since ocean energy technologies are still at relatively early life-cycle stages, their LCOEs are uncertain and are difficult to estimate with accuracy. Currently, the LCOE for tidal energy is estimated between USD 0.20/kWh and USD 0.45/kWh and for wave energy between USD 0.30/kWh and USD 0.55/kWh. Figure 29 provides cost estimate projections and targets based on technology deployment.

Although current estimates are still not competitive with conventional energy and with mature renewable energy sources such as ground-mounted solar PV and onshore wind, recent estimates by developers with active projects show that costs may be lower. For instance, the LCOE of tidal energy is expected to reach USD 0.11/kWh between 2022 and the early 2030s, whereas wave energy will experience a lag of five years and is expected to reach USD 0.22/kWh by 2025 and USD 0.165/kWh by 2030 (European Commission, 2016; Magagna, 2019a; ORE Catapult, 2018).

Small island developing states (SIDS) are positioned to be the main benefactors of ocean energy technologies, where ocean energy would compete with diesel imports. Thus, these technologies could reach grid parity first.

Figure 29  
Global distribution of projected ocean energy projects



Note: EC: European Commission, ORE: Offshore Renewable Energy Catapult

Source: IRENA, 2020d

## EMERGING TRENDS FOR OCEAN ENERGY

The key emerging trends for ocean energy are the following:

### **Gaining momentum for wave and tidal energy technologies**

The shift from the tidal barrage-dominated global market is converging towards wave and tidal stream technologies, with around 49 planned wave projects and more than 79 announced tidal stream projects. (See sections 3.1 and 3.2.)

### **Technology convergence in tidal stream**

Tidal stream technology is gaining further momentum with more than 79 planned projects, the majority of them using the horizontal-axis turbine design for tidal stream generators. (See section 3.2.)

### **Pursuit of multiple wave energy prototypes in parallel**

Unlike tidal stream technology, wave energy has not witnessed a convergence towards one type of technology, but rather multiple configurations/technologies are being pursued in parallel, namely oscillating water column, point absorber, oscillating water surge converter and submerged pressure differential. (See section 3.1.)

### **Creation of combined-technology power generating plants**

Ocean energy technologies are being coupled with offshore wind and/or floating solar PV. Examples include the Eco Wave Power plant coupled with floating PV and the Floating Power Plant offshore wind project coupled with a point absorber wave converter (Box 9). (See section 6.1)

### **Business models based on powering sectors of the blue economy**

Ocean energy technologies are being used to power different blue economy activities such as aquaculture, cooling, shipping, oil and gas through direct and indirect electrification. (See section 6.2 and Table 8.)

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**There is a strong case for offshore renewables in islands, as they face issues around limited land availability to install renewable generation onshore**

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**04**

**FLOATING  
SOLAR PV**



## 04.1

# TECHNOLOGY STATUS AND OUTLOOK

Floating solar PV (FPV) is a fast-emerging technology with a high potential for rapid growth. FPV panels, by definition, are mounted on buoyant platforms or membranes on a body of water without being fixed on piles or bridges. Floating solar PV, either on freshwater or on seawater, can be considered as the third pillar of the global PV market alongside ground-mounted and rooftop solar PV, due to the increasing demand for such a technology, especially for countries with limited land availability such as densely populated countries and islands (IRENA, 2020a).

### Freshwater FPV

To date, most of the installed FPV capacities are on artificial freshwater surfaces. According to a study done by NREL, a total of around **7.6 TW** of power could be installed from hydro-linked floating PV globally. In this scenario, FPV on freshwater holds an annual power generation potential of around **10 600 TWh**, which would represent 50% of the global electricity consumption in 2018 (Hopson, 2020). Another study suggests that an installed capacity of **20 GW** would be possible if only 1% of the artificial water bodies in Europe were to be equipped with floating solar PV (Juch and Rogoll, 2019).

### Seawater FPV

To accommodate the specific needs of islands and lands with limited water surfaces, R&D is being done near seawater shores. Another factor driving interest in this technology is that, in theory, FPV at sea performs, on average, 13% more efficiently (in kWh/m<sup>2</sup> installed) than solar PV on land, due mainly to lower temperatures and less cloud cover (Golroodbari and van Sark, n.d.). Most of the seawater FPV projects are currently in RD&D stages. However, several commercial projects are expected to become operational in the next few years (see section 4.2). There are no current estimates on the underlying potential of seawater FPV, but it could be used in innovative applications to power the blue economy (see section 6.2).

Although FPV is still a niche technology, it is gaining more interest, and the pace of individual installations has been picking up since 2013. Based on observed trends, annual growth of over 20% is expected up to 2024 (Bhambhani, 2019a). Energias Market Research estimates that the global cumulative installed capacity of FPV will be around 4.2 GW by 2024 (Energias Market Research, 2019).

## 04.2

# MARKET STATUS AND OUTLOOK

The first<sup>7</sup> commercial FPV power plant, with a capacity of 175 kW, began operations in 2008 in California (USA), and since then the FPV market has witnessed a rapid increase in installed capacities (Juch and Rogoll, 2019). The FPV market has spread globally, with more than 60 countries (Table 5) pursuing future deployment of FPV plants (Haugwitz, 2020); of these, 35 countries are already harbouring 338 FPV power plants (Bhambhani, 2019a).

## The commercial market for floating solar PV power plant operations witnessed a rapid increase in installed capacities.

Table 5  
Countries pursuing deployment of floating solar PV plants

Country	Country	Country
Afghanistan	Indonesia	Portugal
Albania	Italy	Qatar
Australia	Japan	Republic of Korea
Bangladesh	Kenya	Russian Federation
Belgium	Kyrgyzstan	Seychelles
Brazil	Lao People's Democratic Republic	Singapore
Burkina Faso	Liberia	South Africa
Cambodia	Malawi	Spain
Chile	Malaysia	Sri Lanka
China	Maldives	Sweden
Colombia	Mali	Switzerland
Costa Rica	Morocco	Thailand
Ecuador	New Zealand	Tunisia
Finland	Norway	UK
France	Pakistan	Ukraine
Germany	Panama	United Arab Emirates
Ghana	Paraguay	USA
Greece	Peru	Viet Nam
India	Philippines	

Source: Haugwitz, 2020

<sup>7</sup> The world's first floating PV project was built in Japan in 2007 and had an installed capacity of 20 kW (Ong, Tay and Hammer, 2020).

As of the end of August 2020, around **2.6 GW** of global installed FPV capacity in over 35 countries was operational (Haugwitz, 2020). The current installed capacity reflects a significant increase from the **1.1 GW** of installed capacity in 2018 (ESMAP and SERIS, 2018).

FPV installations are dominated by the Asia-Pacific region, which is home to the world's top 10 plants, particularly in China, Japan and the Republic of Korea. Other Asian countries such as India, Indonesia, Singapore, Thailand and Viet Nam are also actively pursuing FPV development and deployment. In Africa, Ghana installed its first FPV plant unit of 5 MW in 2020, which is planned to be expanded into a 250 MW plant, located on the hydropower dam of the Black Volta River (Deboutte, 2020).

China is the largest market for FPV and houses one of the largest FPV power plants to date, with a capacity of 150 MW in Anhui (Lee, 2020). To satisfy the growing demand for FPV in the Chinese market, Datang Power, a state-owned enterprise and one of the country's five large-scale power generation enterprises, released a tender for a total capacity of 820 MW of FPV to be installed across China by the end of 2021 (Haugwitz, 2020).

The demand for FPV in Asia is expected to surge due to its high potential, and the region is expected to account for nearly two-thirds of the global FPV demand, driven mainly by China, India, the Republic of Korea, Thailand and Viet Nam (Haugwitz, 2020). For example, an FPV array with a capacity of 1 GW is planned to be installed at the Indira Sagar Dam in Madhya Pradesh in central India, on the country's largest reservoir (Lee, 2019). An ambitious FPV project is planned in the Republic of Korea with a target capacity of 2.1 GW behind the Saemangeum sea wall in the waters of the Yellow Sea (Bellini, 2019a). Indonesia is planning a 145 MW FPV project that will be installed on Cirata reservoir in West Java, which will start operation by 2022 (Collins, 2020). Thailand is setting ambitious plans, as the Electricity Generation Authority of Thailand (EGAT) announced that it is planning to build a total of 2.7 GW of FPV on the country's dam reservoirs by 2037 (Bhambhani, 2019b).

Western developed countries such as the USA, Canada and various European countries are likely to develop and grow a market for FPV due to the ambitious policies and attractive regulations supporting the use of solar power (GVR, 2020). Europe holds significant potential for FPV, and several European countries are pursuing multiple demonstration projects. Already, FPV is being used at scale in countries such as France, Italy and the Netherlands.

For example, the Netherlands launched a 27.4 MW FPV farm on a sandpit lake in the city of Zwolle in March 2020, which is the largest such installation in the country and the largest FPV plant outside China (Lee, 2020). Due to the abundance of inland shallow water reservoirs and the exposure to sea, the Netherlands has set an ambitious target of 2 GW of FPV installed capacity by 2023 (Marine Energy, 2019). Around 15% of this ambitious target, or around 200-300 MW, is already being developed, making the country the largest market in Europe (Marine Energy, 2019). Germany started building two FPV installations of a combined capacity of 1.5 MW on a quarry pond in Rhineland-Palatinate in 2020 (PV Europe, 2020).

South America is also positioned to be a key market actor as it holds the potential to deploy around 36 GW of FPV, according to a study from the World Bank (Bellini, 2019b). Brazil has the potential to accommodate the largest market share of FPV in the region (Gilligan, 2020), due to the high availability of water bodies; in addition, the country could gain indirect benefits from covering its water surfaces with FPV, helping to reduce the rapid evaporation from already challenged water bodies (Bellini, 2019b).

FPV technology has captured the interest of island territories. For example, the East African nation of Seychelles plans to install a 5.8 MW FPV array on a lagoon on its main island. Upon completion, the project will be the world's largest FPV to be built on salt seawater (IRENA, 2020a). Singapore, being an island city-state, is also pursuing deployment of FPV as part of its target to maximise the deployment of solar panels. Currently, a 5 MW FPV project is being deployed in the northern coastal waters between Malaysia and Singapore. Upon completion, this will be the world's largest coastal FPV installation, acting as a pilot and a proof-of-concept for the islands around Singapore (O'Neill, 2020).

FPV is undergoing feasibility proofing to power up blue economy activities in islands. For example, a feasibility study was recently announced for a 1.53 MW FPV plant in Gran Canaria island in Spain, which will be used to power the Piedra Santa desalination plant (Rosell, 2021). Swimsol and Enerwhere are also developing modular FPV units of up to 200 kW in island states for commercial and residential consumption in Malaysia, Maldives and the Persian Gulf region (Bellini, 2020a; Swimsol, n.d.).

Other developers, such as SolarDuck, are in their pilot phase with innovative floating platform models suitable for seawater operation. They claim that their projects will be able to reach utility-scale plants of up to 500 MW, targeting megacities with limited space (see Box 8)

### Box 8: SolarDuck innovative floating solar PV systems

The Dutch offshore renewables start-up SolarDuck has developed an innovative triangular floating solar PV platform that resembles an oil and gas offshore platform. The unique platform has dimensions of 17 x 17 metres, which elevates the PV modules and associated electrical components around 3 metres above water level.

In April 2021, SolarDuck's demonstration installation King Elder, which consists of four units and 65 kW of peak power, was connected to the grid in IJzendoorn, Netherlands (Figure 30).

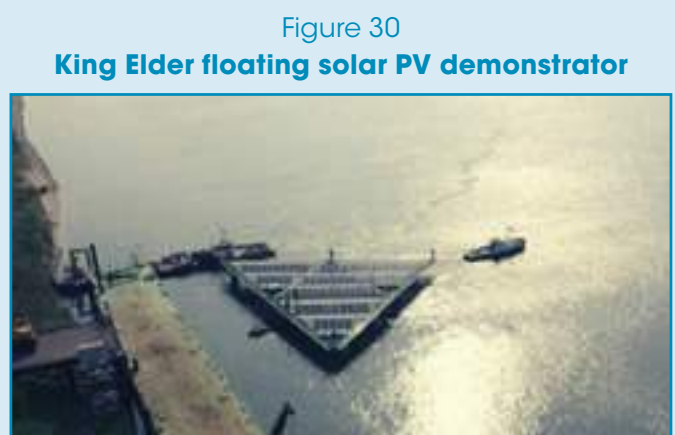


Figure 30

#### King Elder floating solar PV demonstrator

Source: Danish Energy Agency, 2021b

Table 6 provides a summary of some of the planned FPV projects globally in the coming years.

According to a study by Energias Market Research, the global FPV market is expected to maintain its rising trend with a compound annual growth rate of around 30% until 2024 (Energias Market Research, 2019). A variety of forecasts estimate the market potential to accommodate between 4 GW and 10 GW of installed FPV capacity over the next five years (Energias Market Research, 2019; Hopson, 2020).

Table 6  
Planned floating solar PV projects globally

Country	Project	Capacity (MW)	Planned date of operation
France	Châteauneuf-du-Rhône	30	2021
Germany	Erdgas Südwest	1.5	2021
Ghana	Bui hydroelectric dam	250	Unknown
India	Omkareshwar dam	600	2022/2023
Indonesia	Cirata	145	2022
Italy	Brindisi FPV	14.19	Unknown
Maldives	Addu	11	Unknown
Norway	High seas floating solar project	1	2021
Portugal	Alqueva dam FPV	4	2020
Seychelles	Mahé saltwater Lagoon	5.8	2021
Singapore	Tengah reservoir	50	2021
Republic of Korea	Saemangeum sea wall renewables complex	2100	Unknown
	5 dams FPV farms	2100	2030
Spain (Canary Islands)	PLOCAN's offshore platform	0.25	2021
	Piedra Santa Desalination plant FPV plant	1.53	Unknown
Sri Lanka	Maduru Oya reservoir	100	2020
Thailand	Ubolratana dam	24	2023
USA	Duke Energy Fort Bragg floating solar array	1.1	Unknown

Source: Bellini, 2020b, 2019a; Bhambhani, 2021; De Leonardis, 2020; Merchant, 2020; IRENA, 2020a; Keating, 2020; Kenning, 2020; Martin, 2019a, 2019b, 2019c; Power Technology, 2021; PV Europe, 2020; Deboutte, 2020; Rollet, 2020; Rosell, 2021; Scully, 2021; Snieckus, 2021

## 04.3

### COMPETITIVENESS

FPV development has led to a decline in the LCOE for the technology, which is currently estimated to average around USD 0.354/kWh (Bellini, 2020c). However, in some countries FPV has achieved record levels of competitive LCOE with ground-mounted and rooftop solar PV. For example, a 13 MW floating PV array in the Selangor, Malaysia achieved an LCOE of USD 0.051/kWh (Bellini, 2020d). Such records indicate that FPV could potentially reach competitive prices of USD 0.05/kWh in 2030 and USD 0.04/kWh in 2050 (Bellini, 2020c).

## 04.4

### EMERGING TRENDS FOR FLOATING SOLAR PV

The key emerging trends for floating solar PV technology from a location-specific deployment perspective and from a coupling perspective are the following:

#### **Deployment over water reservoirs and dams**

Due to the large potential of using the surface area of water reservoirs and dams to produce electricity from floating solar PV, and the possible coupling with hydropower plants, many countries have announced projects for such deployment. These include, for example, the announced 2.1 GW of FPV plants on five dams across the Republic of Korea. (See sections 4.1 and 4.2.)

#### **Increasing deployment in seawater**

Due to the pressing challenge of land availability as well as the large potential of FPV for islands and SIDS, the technology is now being developed in open seawater, in contrast to the conventional deployment in artificial water reservoirs and lakes. For example, the East African nation of Seychelles is planning to install a 5.8 MW FPV array on a lagoon on its main island. (See section 4.1.)

#### **Creation of combined-technology power generating plants**

In order to save on foundations and on capital and operation costs, floating solar PV started sharing foundations with ocean energy technologies and/or offshore wind devices. For example, the Eco Wave Power plant couples ocean energy (wave converters) with FPV (see Box 9), and the Massvlakte 2 project couples offshore wind with FPV (BloombergNEF, 2021). (See section 6.1.)

#### **Powering sectors of the blue economy**

FPV is not being used only for electricity provision, but rather, similar to offshore wind and ocean energy, it is being evaluated for direct and indirect electrification of different blue economy activities. For example, a feasibility study was recently announced for a 1.53 MW FPV plant in Gran Canaria island that will power the Piedra Santa desalination plant (Rosell, 2021). (See section 6.2.)



**05**

**CROSS-CUTTING  
CONSIDERATIONS  
FOR OFFSHORE  
RENEWABLES**





## 05.1

# OCEAN GOVERNANCE

Oceans are a crucial resource for the planet's ecosystem and human economic activities. Sound international governance related to oceans and their use and protection is of paramount importance. The United Nations Convention on the Law of the Sea (UN, 2020) entered into force on 16 November 1994 and governs nearly all aspects of international law relating to the sea, including (German Federal Foreign Office, 2019):

- demarcation of the various maritime zones, such as the territorial sea, exclusive economic zone, and continental shelf and the high seas;
- use of these areas by shipping, overflight, the laying of pipelines and cables, fishing and research;
- protection of the marine environment;
- development and transfer of marine technology;
- seabed mining; and
- settlement of disputes.

Therefore, it is critical that countries observe the legal provisions in the Law of the Sea while developing their national offshore renewables plans. The Convention also facilitates international collaboration as it already addresses many aspects to be considered while developing cross-border joint activities related to oceans.

## 05.2

# MARINE SPATIAL PLANNING

In response to the increased use of ocean resources due to technological advancements and competitiveness in different economic sectors, governments need to establish frameworks and plans on how to best govern the use of their seas among different actors. Marine spatial planning (MSP) brings together all ocean users from energy, industry, government, regulations, conservation, protection and recreation to formulate best practices and come up with optimal decisions on how to efficiently use marine resources.

A variety of marine spatial plans globally are being developed, and good practices are emerging in different regions. However, good practice in a certain region is not necessarily applicable to another region; therefore the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (UNESCO) published a step-by step guide to MSP (see Figure 31).

Figure 31

**Summarised steps for the planning and development of marine spatial plans**



Source: IOC, 2009

Belgium was a pioneer in integrating offshore wind in MSP, with its 2014-2020 marine spatial plan allocating 7% of the country's territorial waters for the development and deployment of offshore wind. Furthermore, Belgium's new marine spatial plan for the years 2020-2026 provides a useful example on how the country unlocked a 2 GW offshore wind potential in a densely crowded sea area through a multiple-use approach. Other European countries, such as Germany and Finland, have also managed to unlock large potential allocation of their territorial waters. Germany has allocated 20 GW of priority areas for offshore wind deployment but is still undergoing the final consultation phase of its marine spatial plan, which is expected to be submitted by September 2021. Finland allocated around 15 GW of offshore wind in its 2020 marine spatial plan; however, national defence requirements might set important limitations (WindEurope, 2021).

MSP optimises the opportunity to co-locate offshore wind or ocean energy technologies so they can co-exist with marine life by creating refuges and new habitats. For example, China's state-owned Three Gorges started construction on a pioneering combined offshore wind and fish farming project in Bohai Bay, Shandong province. The first stage is set to be completed later in 2021 with 300 MW of installed capacity and surrounded by six artificial reefs breeding oysters, sea cucumber and several fish types (Yu, 2019).

According to the Ocean Renewable Energy Action Coalition (OREAC), an effective marine spatial plan should address the following aspects (OREAC, 2020):

- identifying areas with low energy costs;
- reducing and avoiding sectorial conflicts and establishing sectorial synergies;
- encouraging investments through providing predictable, transparent and clear actions;
- increasing cross-border co-operation to develop infrastructure, energy grids, shipping lanes, pipelines, submarine cables, etc.;
- protecting the environment and offering benefits; and
- enable and driving co-location where possible.

### 05.3

## ENVIRONMENTAL IMPACT ASSESSMENT

Coastal areas are characterised by a very fragile environmental equilibrium both geomorphologically and biologically. Modifying wind streams, ocean currents, sea and riverbanks can have significant environmental impacts locally. The environmental impact of ocean energy technologies is still uncertain. Relatively little is known about the effects of these technologies on marine life due to the early stage of technology deployment. Negative impacts could arise in the form of habitat loss, animal-turbine interactions, noise and electromagnetic fields produced by sea cables, which may have effects on aquatic species.

As an example, the pioneer tidal barrage of La Rance (France) led to the complete siltation of the estuary of the river Rance, considerably impacting the fish population behind the barrage, limiting boat circulation and ultimately reducing the maximum power output of the plant (ENS, n.d.). Similarly, the Annapolis tidal station (Canada) increased bank erosion both upstream and downstream and adversely impacted local biodiversity, in particular by allegedly killing two whales (Tethys, n.d.). Meanwhile, the visual aspects of offshore wind farms have been at the centre of multiple debates, especially in France (Ouest-France, 2016) and the USA (White & Case, 2019a). These environmental impacts are likely to greatly hamper public acceptance, especially at the local level (White & Case, 2019b).

However, work is ongoing to ensure that such risks can be properly managed. Some studies indicate that ocean energy may have positive impacts as well and support biodiversity through the use of artificial reefs, fish aggregation devices and marine protected areas. As for any infrastructure project, proper environmental impact assessment studies and best practices must apply and, as these technologies mature, help to mitigate any potential risk while maximising their benefits.

Consequently, it is important to adequately assess the potential environmental impacts and include mitigation measures in the design of the installations and in operations and maintenance. Nevertheless, environmental impact assessment (EIA) requirements and subsequent licencing procedures differ from country to country, especially regarding the list of potential impacts to consider and mitigate (White & Case, 2019a). For example, offshore wind farms visual impacts must be thoroughly studied for projects in the USA, unlike in Germany.

Policy makers and dedicated agencies have also developed EIA guidelines, but mostly at the national level, for example in the UK (British Standards Institution and Innovate UK, 2015). A notable exception is the EU, which included a full chapter dedicated to offshore wind in the *Guidance document on wind energy developments and EU nature legislation* published in 2020 (European Commission, 2020b).

This lack of consistency creates considerable difficulties for project developers and results in added risks for investors and significant delays. Harmonising EIA requirements and procedures at least at a regional level, and establishing a common database of potential impacts, assumptions, hypothesis and parameters to be taken into account as well as possible mitigation measures for each technology, could greatly facilitate the environmental impact assessment of offshore renewables and speed up their deployment worldwide.

## 05.4

# EXTREME WEATHER CONDITIONS

Offshore renewables installations are likely to be built and operated in locations that are prone to extreme climatic conditions and climatic events<sup>8</sup>. The main climatic conditions that adversely impact offshore renewables are the high humidity and high salt concentration in the atmosphere, which may trigger the early corrosion of metallic components. Depending on the location, offshore renewables installations may also face high wind, currents and waves on a regular basis. Climatic conditions may greatly impact offshore renewables plants by triggering early fatigue of their components, decreasing their lifetime, the maximum power output and efficiency. Similarly, offshore renewables installations may be severely impacted by extreme climatic events such as cyclones, tornadoes, storms, tsunamis, etc., which can partially or completely dismantle the installations and/or the power lines.

All of the stakeholders of offshore renewables projects have a role to play in lowering the risk of negative impacts caused by extreme weather conditions and events. In particular:

- The public and private sectors need to invest in technology innovation, particularly RD&D to develop novel components or improve the overall resilience of existing ones. An example is the Vestas extreme weather turbine, which, according to the manufacturer, can resist average wind speeds of 53 m/s (exceeding IEC class I extreme wind speed) (Vestas, 2019).
- Project developers need to accurately assess the risks of extreme weather conditions, taking into account the impacts of global warming and including mitigation measures in the design of the installation as well as in the operating and maintenance procedures.

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<sup>8</sup> *Extreme climatic conditions are defined by extreme levels of one or several meteorological factors (temperature, wind, humidity, etc.) over long periods (several months) as well as potential important variations in amplitude between seasons or between day and night on a regular basis. Extreme climatic events are defined by extreme levels of one or several meteorological factors over short or medium periods (from hours to days) as well as important variations both in amplitude and frequency during these periods.*

- Policy makers need to ensure that an adequate Quality Infrastructure (QI) includes testing laboratories, certification, accreditation and inspection bodies at the national level.
- International bodies such as the International Organisation for Standardisation (ISO) and the International Electrotechnical Commission (IEC) need to develop and update the international standards for offshore renewables that incorporate the risk for extreme weather. Currently, international standards relevant to the extreme weather conditions for offshore renewables include IEC TS 61400-3-1 and IEC TS 61400-3-2, which provide requirements for the safe design of fixed and floating offshore wind farms respectively; IEC TS 62600-2, which covers requirements for the safe design of marine energy converters; and IEC TS 62100-10 (currently being reviewed), which is specifically dedicated to the mooring of marine energy converters. No standards have been developed specifically for floating solar PV.



**06**

**CONTRIBUTION  
TO THE ENERGY  
TRANSITION**



Offshore renewable energy – including offshore wind and solar power, as well as ocean energy technologies – can support sustainable long-term development and drive a vibrant global blue economy. Offshore energy development can therefore align closely with the **Sustainable Development Agenda for 2030**, adopted by the United Nations as global Sustainable Development Goals (SDGs):

- **SDG 7** aims to ensure affordable, reliable, sustainable and modern energy access for everyone.
- **SDG 14** calls for conservation and sustainable use of oceans, seas and marine resources.

At the same time, offshore renewables give island and coastal communities climate-safe recovery options amid the **COVID-19 pandemic**.

For countries and communities around the world, offshore renewables can provide reliable, stable electricity, as well as support water desalination and aquaculture. Islands and coastal territories could adopt renewable-based electric propulsion for short-distance (less than 100 kilometre) sea transport. Further, while islands and remote coastal areas can provide the ideal avenue for market entry, ocean energy could also be coupled with coastal defence structures.

## 06.1

# DECARBONISING THE POWER SYSTEM BY COMBINING OFFSHORE RENEWABLES WITH OTHER RENEWABLE TECHNOLOGIES

Energy harnessed from oceans, through offshore renewables, can contribute to the decarbonisation of the power sector and other end-user applications relevant for a blue economy – for example, shipping, cooling, aquaculture and water desalination, in addition to the conventional oil and gas sector.

More importantly, the predictability of power generation from ocean energy technologies complements the variable character of solar PV and wind (both on- and offshore), which makes them suitable to provide steady baseload power. Combined-technology electricity generating systems is a novel business model that does not view the individual offshore renewable power generating technologies as stand-alone, but rather combines them to reap synergies among them, especially when coupled with storage. Examples of projects being researched, planned or implemented are provided in Table 7.

Table 7

### Combined-technology electricity generating systems coupling various offshore renewable technologies

Ocean energy technology	Solar	Offshore wind	Offshore floating wind	Pumped hydro	Storage	Microgrids	Hydrogen	Examples	Country	Status
Salinity							✓	REDstack	Netherlands	●
Tidal		✓					✓	BIG HIT / Surf 'n' Turf	Scotland	●
	✓							Bluemull Sound Shetland	Scotland	●
	✓	✓			✓	✓		PHARES Ushant Island	France	●
	✓				✓			San Antonio	Philippines	●
					✓			KIOST	Republic of Korea	●
Wave	✓							Eco Wave Power	Israel, Gibraltar	●
	✓	✓			✓	✓		King Island	Australia	●
					✓	✓		Garden Island	Australia	●
					✓	✓		KIOST	Republic of Korea	●
			✓					Canary Islands	Spain	●

Note: ● = in operation, ● = planned, ● = in R&D stage

Source: Adapted from IRENA, 2020d

#### Box 9: Innovative synergies between offshore renewables

Recent innovations have established synergies between various offshore renewables in which they complement each other and increase the power output and efficiency. Figure 32 highlights Eco Wave Power's innovative wave energy converter coupled with solar PV panels, which is a novel representation of coupling ocean energy technologies with solar energy. Another example is shown in Figure 33 in which point absorber wave energy converters are incorporated into a floating wind platform developed by Floating Power Plant.

Figure 32

#### Eco Wave Power plants coupled with solar PV panels



Source: Eco Wave Power, 2020

Figure 33

#### Floating Power Plant's P80 platform combining floating wind turbines and a wave energy converter



Source: Floating Power Plant, n.d.



## 06.2

# FOSTERING A BLUE ECONOMY

Oceans are a source of abundant renewable energy potential, capable of driving a global blue economy based on sustainable use of ocean resources. Energy harnessed from the oceans, through offshore renewables, can contribute to the decarbonisation of the power sector, as well as other end-use applications that are relevant for a blue economy, such as shipping, cooling, aquaculture and water desalination among others (Figure 34).

Therefore, offshore renewables form a crucial component in the world's emerging blue economy thanks to various economic activities and innovative business models, especially when two or more renewable power generating technologies are coupled into combined-technology systems (Figure 35).

Innovative renewable applications for a blue economy are discussed briefly in the following sub-sections (IRENA, 2020a).

Figure 34  
**Sectors relevant for a blue economy**

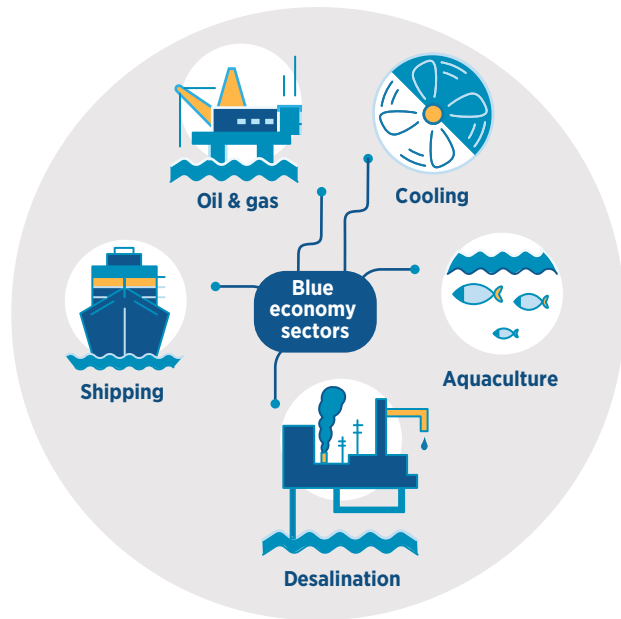
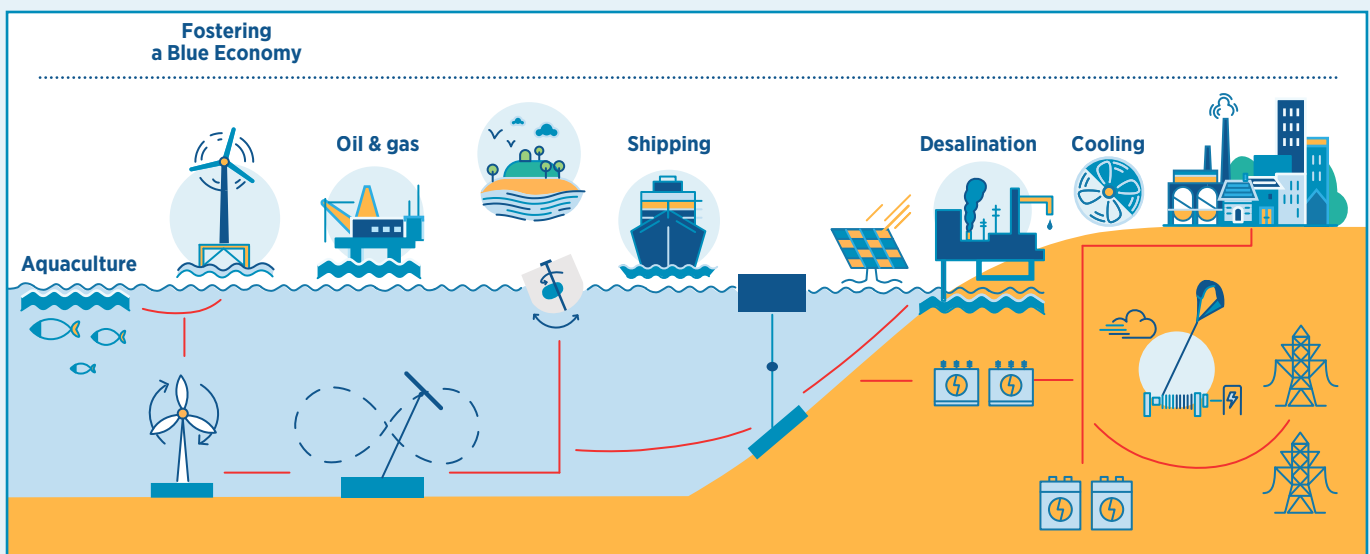


Figure 35  
**Coupling offshore renewable energy sources to power the blue economy**



Source: Adapted from IRENA, 2020d

## Shipping

Greenhouse gas emissions from shipping are estimated to grow 90-130% by 2050 (IMO, 2020). Ships could reduce their footprint if powered with advanced biofuels, green hydrogen-based fuels, synthetic fuels or electric propulsion for domestic navigation as alternatives to oil. The International Maritime Organization has set targets to reduce global GHG emissions from shipping by at least 50% by 2050 (IMO, 2018).

Ocean energy can be deployed in proximity to harbours to provide green electricity for battery-powered ships, offshore charging stations as well as other activities within the ports. Through such charging platforms, range issues for smaller ships can be overcome and auxiliary power can be provided for vessels that spend long times at sea (IRENA, 2019d).

## Cooling

Cooling is an energy-intensive process, and its energy demand is projected to triple globally by 2050 (IEA, 2018) as more people in developing countries have the resources to afford air conditioning and as countries in moderate climate zones increasingly see heat waves due to climate change. Seawater air conditioning (SWAC)<sup>9</sup> is a technology that can provide efficient cooling, while reducing and balancing electricity demand. It is a concept that uses cold water from the depth of the ocean as the refrigerant fluid to cool a freshwater distribution system by means of heat exchangers.

The SWAC technology is widely mature, and it powers air conditioning systems in large parts of entire cities (e.g., Stockholm). By using less electricity compared to conventional air conditioning, SWAC could provide up to 90% savings on electricity costs. Also, fewer refrigerants are needed than for conventional systems (IRENA, 2020d).

## Aquaculture

Aquaculture is a way of domesticating and controlling the growth of ocean species and is gaining significance because of the reduction in the number of fish available for commercial fishing. Whereas aquaculture is traditionally conducted near shore, it is increasingly being moved farther offshore due to greater economies of scale. Most floating farms are heavily reliant on fossil fuels (Muir, 2015), an approach that is carbon-intensive and leads to high shipping and maintenance costs.

Ocean energy systems are well suited to be located near aquaculture farms, as these often consist of a floating structure that is commonly tethered to the seafloor, which could be directly integrated into the aquaculture system. This leads to the development of project revenue streams, thus increasing a project's profitability through sector coupling while supporting food security. Offshore renewables could also benefit aquaculture since it requires energy to power circulation, fish feeders and waste disposal. Aquaculture also needs power for its infrastructure, such as sensors, cameras, and light, and for monitoring and maintenance equipment, especially as these activities are located increasingly farther from shore.

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<sup>9</sup> SWAC is a concept that uses cold water from the depth of the ocean as the refrigerant fluid to cool a freshwater distribution system by means of heat exchangers.

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# Co-benefits and additional revenues streams for ocean energy projects can be harnessed from coupling electricity generation with blue economy activities such as aquaculture, water desalination, shipping, and green hydrogen production

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## Desalination

Reverse osmosis is the dominant process of water desalination, which is a very energy-intensive process. Around 36% of the operating expenses in a seawater desalination plant are related to energy consumption (LiVecchi *et al.*, 2019). In addition, water intake pipelines and ocean pumping systems are capital intensive. Near-shore ocean energy has the ideal prerequisites to deliver solutions to coastal areas that lack a reliable power grid and a reliable drinking water supply, as they are located where seawater is abundant and in proximity of populated areas.

Desalination of seawater using renewables, including solar PV and wind power but also direct solar and geothermal heat, can further enhance the sustainable blue economy. Furthermore, ocean energy technologies and especially OTEC has the most affinity to be combined with desalination. This is done through using the excess resources from deep seawater and hot surface water in a flash water desalination process (Xenesys, n.d.). With 60% of desalinated water being used for domestic consumption, demand is projected to increase significantly with the growing global population (Antonyan, 2019). Seawater desalination is becoming the primary source of potable water in the Middle East and North Africa (MENA) and in various SIDS.

## Synergies with offshore oil and gas industries

Synergies with conventional oil and gas industries can be reaped by offshore renewable energy technologies, including technology and job transition opportunities, because offshore projects tend to require more labour inputs than those onshore. In addition to the construction, assembly and deployment of new equipment such as offshore platforms, they can leverage existing technical capacities and skills from the onshore segments.

On occasion, subsea cables have been installed to reduce a country's carbon footprint by delivering onshore renewable energy to the platforms (e.g., in Norway), but the installation of such cables is complex and costly. Generating power locally thanks to offshore renewables would be more cost-efficient. Currently ocean energy focuses on providing power to monitoring and other supplementary devices (e.g., data analysis) located on and around oil and gas platforms but could be expected to be also used to provide power directly for the extraction process.

A significant number of ocean energy developers are already focusing specifically on electrifying one or more of the blue economy sectors, as shown in Table 8.

Table 8  
Examples of ocean energy developers focusing on powering the blue economy

Ocean energy technology	Power	Shipping/ports	Cooling	Aquaculture	Desalination	Oil and gas	Developer
OTEC	✓				✓		NIOT OWC
	✓		✓				Makai
	✓		✓		✓		Bardot Ocean
	✓		✓		✓		Bluerise
	✓		✓	✓	✓		Bretagne Ocean Power
Tidal	✓	✓					EMEC (through hydrogen)
	✓			✓			Sustainable Marine Energy
Wave	✓			✓			SINN Power, AWS Ocean Energy, WavEC, Albatern, Aqua Power Technologies, GIEC
	✓			✓		✓	Ocean Harvesting
					✓		Oneka Water
	✓					✓	Wave for Energy, Hann-Ocean, Floating Power Plant
	✓				✓		Resolute Marine Energy, Carnegie Clean Energy, Wavpiston, GIEC
	✓			✓	✓		Accumulated Ocean Energy (AOE)

Source: Adapted from IRENA, 2020d

Offshore renewables can also provide significant **socio-economic** opportunities to countries with coastal areas and island territories, such as job creation, improved livelihoods, local value chains and enhanced synergies among blue economy actors. For example, IRENA's energy transition modelling suggests that the wind industry, both onshore and offshore, may employ 3.74 million people by 2030 and more than 6 million people by 2050 (IRENA, 2020a).

## 06.3

# POWERING ISLANDS AND SIDS

Small island developing states (SIDS) could become major beneficiaries of the blue economy, with offshore wind, floating PV and nascent ocean technologies helping to address the acute energy and water supply challenges of small islands. In particular, islands need:

- *Affordable and reliable access to electricity:* renewables can replace costly power generation systems dependent on imported diesel and, with offshore options, reduce land-use pressure and ultimately enhance energy security.
- *Fresh, potable water supplies:* renewable energy technologies can support sustainable local desalination and the production of affordable water.

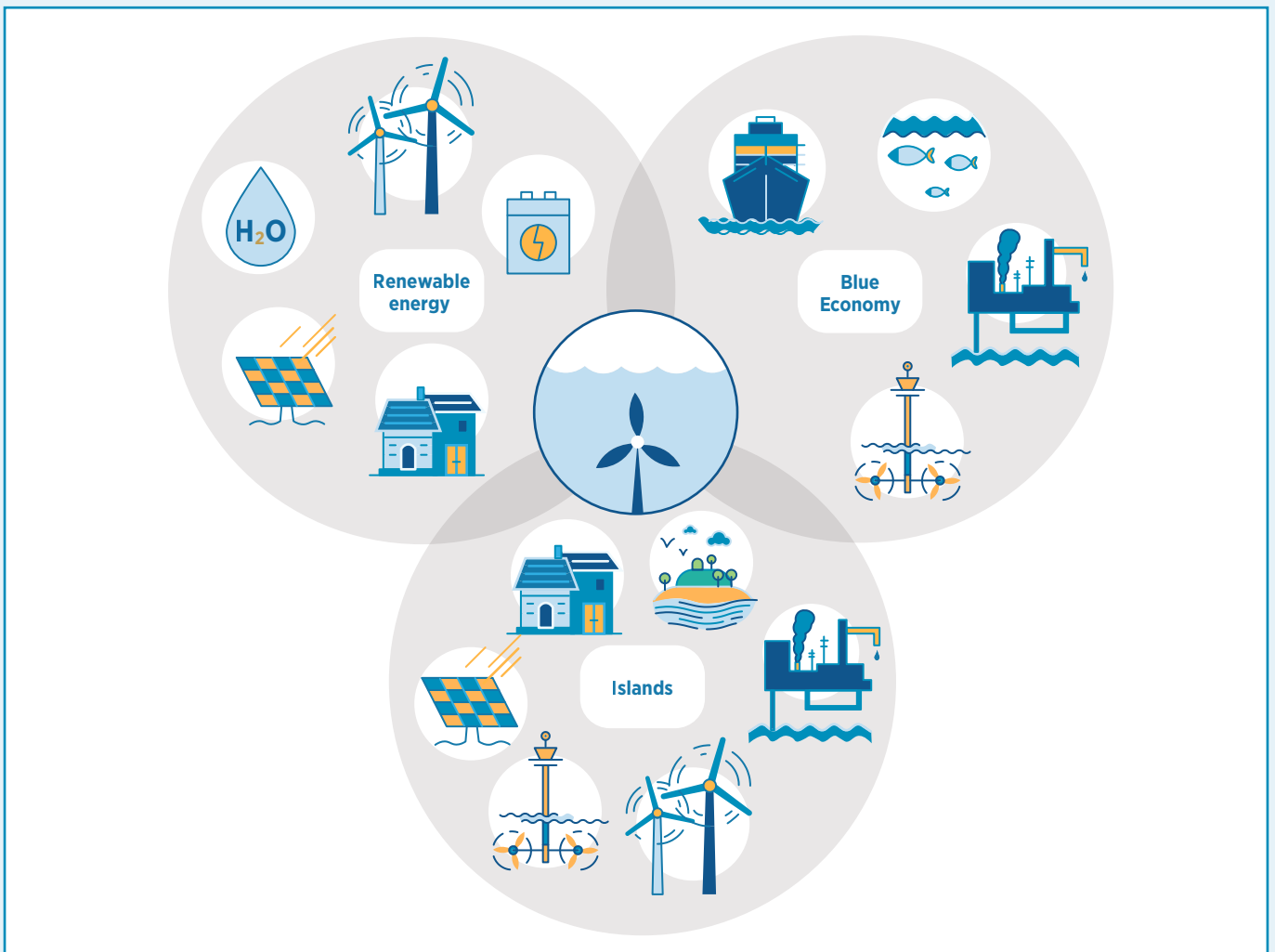
Switching to renewables serves to decarbonise power generation, helping islands cut their CO<sub>2</sub> emissions, fulfil Paris Agreement pledges and contribute to the global fight against climate change. In addition, renewables help to improve power system flexibility along with the integration of variable renewable energy.

Offshore renewables, including ocean energy, can meet needs for shipping and cooling. Remote or isolated coastal areas can face similar energy challenges, especially in least-developed countries (LDCs). Offshore renewables can create jobs, improve health, strengthen people's livelihoods and foster wider socio-economic opportunities, including the provision of power for other offshore markets, such as aquaculture, desalination and cooling, while reducing the need to import costly fossil fuels. Moreover, islands and remote coastal areas can provide the ideal market entry avenue for ocean energy technologies (Figure 36).



Figure 36

**Coupling offshore renewable energy sources with blue economy sectors and on islands**



Source: IRENA, 2020d



## PROTECTING COASTAL COMMUNITIES

Ocean energy technologies could be coupled with coastal protection, offering a new multi-faceted business case addressing multiple societal issues of climate mitigation (energy generation) and adaptation (improve water safety and water quality). These include the development of new infrastructure, in addition to increasing food security through sector coupling opportunities represented in aquaculture.

- **Breakwater dams:** Demonstrated integration of coastal protection and ocean energy are breakwater barriers to protect harbours from wave impact, such as the pilot projects in Mutriku in Spain and in Port of Civitavecchia in Italy. A large part of the capital expenditure of a wave energy project is offset as part of the civil cost of the breakwater barrier.
- **Storm surge barriers:** Storm surge barriers can be used to integrate tidal turbines and shoreline-integrated wave energy converters while providing space for solar and wind power plants. A study (Angelova and de Groen, 2019) revealed that 461 locations worldwide are suitable for dam-integrated tidal energy, based on the fact that these areas 1) are prone to increasing risk of flooding with future sea-level rise and increasing storms, 2) have tidal barrage availability and 3) have a population density with high energy needs. For example, in 2015, the Netherlands installed an array of five turbines in the opening of the Eastern Scheldt Storm Surge Barrier.
- **Bridges:** Dutch project developer TidalBridge is developing a floating bridge in Indonesia including a 20 MW tidal power plant. The innovative financing mechanism for the civil works (low interest rates through international donor funding) allows for relatively favourable financing of the tidal power plant.
- **Increasing land availability:** SIDS in general suffer from land availability constraints, as the deployment of other onshore renewables, such as solar PV and onshore wind, requires significant land for deployment. This positions offshore renewables as a potential solution to provide a reliable energy source and solve land availability constraints.

Several SIDS are also prone to volcanic activities, such as Saint Vincent and the Grenadines; this vulnerability gives ocean energy technologies an edge over onshore renewables such as solar PV and therefore contributes to a more resilient and reliable energy source.



**07**

**RECOMMENDED  
ACTIONS TO  
COMMERCIALISE  
OFFSHORE  
RENEWABLES**





While offshore renewable energy technologies have reached various degrees of maturity, the key challenge of these technologies – which is common across all technologies except for offshore wind with fixed foundations – is their commercialisation. Table 9 summarises the existing challenges faced by the offshore renewable energy sector. Once overcome, commercialisation of these technologies could be accelerated through:

- actions for technology development; and
- actions for improved revenues for project promoters.

Each challenge represents at the same time an opportunity to amplify emerging trends, adopt new business models and advance the technological adoption at scale. Each of the challenges and opportunities are detailed in subsequent sections, together with recommended actions for G20 policy makers.

Table 9: **Key challenges and opportunities in the offshore renewable energy sector**

Area of intervention	Challenges and opportunities
<b>Socio-political</b>	<p><b>A_</b> Ocean governance and international co-operation</p> <p><b>B_</b> Public awareness, social acceptance and community readiness for implementation</p> <p><b>C_</b> Higher technological awareness by relevant stakeholders</p>
<b>Policy &amp; regulation</b>	<p><b>D_</b> Best practices in policy frameworks considering offshore energy technologies</p> <p><b>E_</b> Establishing enabling regulatory frameworks (permitting, grid enhancement/ connection, revenue support instruments, marine spatial planning)</p>
<b>Technology &amp; infrastructure</b>	<p><b>F_</b> Developing the required grid infrastructure</p> <p><b>G_</b> Access to comprehensive resource site assessment</p> <p><b>H_</b> Withstanding harsh offshore environment (salinity, corrosion, extreme forces, etc.)</p> <p><b>I_</b> Enhancing technology maturity and reaching commercialisation</p>
<b>Economic &amp; financial</b>	<p><b>J_</b> Enhanced cost-competitiveness</p> <p><b>K_</b> Securing funding by mitigating risks</p> <p><b>L_</b> Robust supply and value chains</p>
<b>Environmental</b>	<p><b>M_</b> Addressing potential environmental impact</p>

## SOCIO-POLITICAL CONSIDERATIONS

### Issue 1. Ocean governance and international co-operation

Sharing the oceans is becoming more prominent with increased focus on the blue economy. More than two-thirds of the oceans are not governed by specific national governments but are part of the so-called global commons (Ocean Unite, 2019). This leaves much room for uncertainties that can lead to ownership disputes among communities, countries and sectors, particularly in areas where fisheries, conservation, shipping and defence are already in place. To overcome the offshore governance uncertainties, international co-operation can help.

#### ■ Recommended actions:

- **Observe the UN Law of the Sea Convention for ocean governance and multilateral co-operation for the deployment of transnational offshore renewable projects.** This includes developing national offshore renewable plans to observe the provisions in the Law of the Sea Convention. For offshore wind energy, some countries have started to co-operate via collective initiatives to avoid disputes and shift thinking from borders to basins. For example, through the **North Seas Energy Cooperation (NSEC)**, nine countries, in addition to the European Commission, formalised a political declaration on energy co-operation that was initiated in the North Sea in 2009, with the aim of developing interconnections among these countries and jointly building subsea cables.
- **Promote the further development of marine spatial planning (MSP) incorporating offshore renewable plans.** MSP optimises the chance of co-location of offshore wind or ocean energy technologies and co-existence with marine life by creating refuges and new habitats. Belgium was a pioneer in integrating offshore wind in MSP, as its 2014-2020 marine spatial plan allocated 7% of the country's territorial waters for the development and deployment of offshore wind. Furthermore, Belgium's new marine spatial plan for the years 2020-2026 provides an example on how the country unlocked 2 GW of offshore wind potential in a densely crowded sea area through a multiple-use approach.
- Cross-border and sea-basin coherence of marine spatial plans drives the exchange of key information and data between planning authorities in the main interest areas in the seas (energy, shipping, fisheries and aquaculture and environment) in addition to mutual learning of different planning systems, legal frameworks and/or existing marine spatial plans. It could also lead to the identification of key transboundary conflict areas along with key sectoral synergies and/or conflicts. For example, the Baltic SCOPE project funded by the **European Maritime and Fisheries Fund** performed a Coherent Cross-border Maritime Spatial Planning for the Southwest Baltic Sea that involved four countries: Denmark, Germany, Poland and Sweden (European MSP Platform, 2017).

- **G20 to co-operate with IRENA's Collaborative Framework to collect and disseminate key data on offshore renewables.** The G20 and IRENA's Collaborative Framework on Ocean Energy / Offshore Renewables are to facilitate access to updated information on offshore renewables development. Data may include, among others, cost competitiveness, resource potential and environmental impact assessments.
- **Foster co-ordination on planning of offshore grid infrastructure** Co-ordination in grid planning could potentially foster sustainable regional cross-country electricity generation while integrating electricity markets and ensuring security of supply. For example, the ***Baltic Interreg*** programme funded by the European Regional Development Fund contains a consortium of eight **EU** countries that will apply the meshed grid in the Baltic Sea region to ensure maximisation of the potential and efficiency of offshore wind energy (IKEM, n.d.).
- **Conduct joint research projects within the G20 countries, and with other countries.** This includes fostering international co-operation for technology deployment through joint R&D programmes and supporting the creation of new markets through the promotion of innovative business models. For example, ***Portugal, Sweden, the European Institute of Innovation & Technology InnoEnergy and private investors*** are jointly funding HiWave-5, a demonstration project of developer CorPower for wave energy located in Portugal.
- **Foster international co-operation among countries with shared interest in advancing the technological development of offshore renewables, as well as countries interested in adopting these technologies.** ***IRENA's Collaborative Framework on Ocean Energy / Offshore Renewables*** launched in 2020 provides a platform for exchange, co-operation and co-ordinated action to accelerate the uptake of these technologies by bringing together policy makers among its nearly universal membership of 163 Member States, in addition to other relevant stakeholders such as the Global Wind Energy Council and Ocean Energy Europe (see also Box 1).

## **Issue 2. Public awareness, social acceptance and community readiness for implementation**

Potential visual impacts and the unfamiliarity with the emerging offshore renewable technologies are prone to lead to rejections from surrounding communities, as witnessed with the construction of new transmission lines or some renewable projects (the so-called NIMBY or “not-in-my-backyard” phenomenon). Since social acceptance can have a significant impact on technology deployment, public consultation processes should be considered in a timely manner in the early project development phases.

#### ■ Recommended actions:

- **Conduct public consultations early in the development of offshore renewable projects to ensure harmonious co-existence of the offshore renewables industry with other ocean users.** For example, the *Danish Energy Agency* and the Danish Environmental Protection Agency are conducting public hearings on the strategic environmental assessment and the environmental impact assessment of the Hesselø offshore wind project (Skopljak, 2021b). Other European countries, such as *France*, *Greece* and the *UK*, hold such public consultations. Outside Europe, *Canada* has conducted multiple strategic environmental assessments in the Bay of Fundy, Cape Breton coastal region and Bras d'Or (OERA, 2018, 2014a, 2014b).
- **Seek implementation approaches that increase the acceptability of local communities.** This includes adhering to greater community benefits such as job creation and creating synergies and compatibility with other economic activities such as shipping and fisheries. Currently the offshore wind industry in *Europe* employs around 77 000 workers, which could rise to 200 000 workers if the governments commit to their 2030 plans (WindEurope, 2020).
- **Quantify and communicate the expected welfare benefits from the development of offshore technologies.** For example, ocean energy technologies are expected to create **3 000 jobs in Wales (UK)** alone over the next 10 years with an export **potential of USD 106 billion** (GBP 76 billion) by 2050 (Dickins, 2020).
- **Raise awareness through public availability of detailed mapping of technical potential and relevant data (e.g., wind resource, seabed, bathymetry).** Research results and data collected on offshore renewables that are made publicly available can help raise awareness of the untapped potential of oceans and water bodies (see also actions recommended for Issue 9. Enhancing technology maturity and reaching commercialisation). For example, the National Renewable Energy Laboratory has a **marine and hydrokinetic atlas** that features wave energy resources and OTEC for all USA coastlines (NREL, 2020b).

#### Issue 3. Higher technological awareness by relevant stakeholders

Given the novelty of offshore renewable energy technologies, and especially ocean energy technologies, but also floating PV, floating wind and airborne wind prototypes, it is not uncommon that policy makers, civil servants and regulators are lacking the necessary technological awareness to advance these technologies.

#### ■ Recommended actions:

- **Shift thinking from the narrow power sector to the whole economy.** The blue economy concept (see section 6.3) is not just focused on the renewable energy value chain, but is about powering entire sectors of the economy, creating jobs, increasing welfare, reaping synergies among offshore industries and decarbonising the whole economy. For example, the European Commission estimates that the **European Blue Economy** had a turnover of EUR 750 billion (USD 891 billion) in 2018, with 5 million people working in underlying sectors, including marine renewable energy, fisheries and aquaculture, as well as maritime transport (European Commission, 2020c).

- **Organise capacity building among countries with offshore renewable expertise and those interested in adopting these technologies.** For example, *Tunisian* officials attended a training course organised by the *Netherlands* for offshore wind as a first step in adopting these technologies (Skopljak, 2021c).
- **Engage with industry-led organisations to gain awareness of the latest technological developments.** For example, Australia's industry-led *Australian Ocean Energy Group* aims to engage with the government to educate on the role of ocean energy in the country's energy mix (Science Business, 2021).

## 07.2

# POLICY AND REGULATION

### Issue 4. Best practices in policy frameworks considering offshore energy technologies

The policy frameworks that are needed to adopt most offshore renewable technologies into a nation's energy mix are not yet widely available, including in energy roadmaps or Nationally Determined Contributions (NDCs). Having such frameworks in place helps provide visibility of the technologies available, raise public awareness and signal to investors the need to fund such projects in the future, which in turn raises confidence and reduces the perceived risks.

#### ■ Recommended actions:

- **Set long-term offshore renewables deployment and cost reduction targets to 2030 and beyond.** For example, the European Commission released on 19 November 2020 an ambitious *European offshore renewable energy strategy*, which includes targets for offshore wind, wave and tidal energy by 2030 and 2050 (European Commission, 2020a).
- **Provide public revenue support via feed-in tariffs, feed-in premiums, technology-specific auctions, power purchase agreements, Contracts for Difference, quotas, certificates, fiscal measures, etc.** For example, *China* introduced a temporary feed-in tariff for ocean energy of USD 0.39/kWh (EUR 0.33/kWh) for tidal projects. *Canada* also has a feed-in tariff for ocean energy technologies.
- **Provide public capital investment support through grants, equity, loans, etc. for earlier-stage technologies such as floating solar PV and ocean energy.** For example, *Canada* is investing USD 9.4 million in four tidal projects (Ajdin, 2020), in addition to CAD 28.5 million (USD 23 million) aimed at funding its first grid-connected floating tidal energy array of 9 MW in Nova Scotia (Oedigital, 2020) and CAD 29.8 million (USD 24 million) for another 9 MW tidal project (Hume, 2018). Canada also invested around [CAD?] 30 million (USD 24.3 million) to establish the Fundy Ocean Research Centre for Energy (FORCE). To date, around CAD 150 million (USD 121.5 million) of public investments have been invested in ocean energy in Canada. The *Welsh Government (UK)* is providing USD 1.7 million (GBP 1.2 million) for a tidal energy project off North Wales (Mavrokefalidis, 2020). The *Republic of Korea* plans to invest USD 43 billion for an 8.2 GW offshore wind power plant.

## Issue 5. Establishing enabling regulatory frameworks

Regulatory frameworks regarding permitting processes, grid enhancement or connection, investment and revenue support instruments are lacking because of the novelty of these technologies. Developing such regulatory frameworks is of utmost importance to bring these technologies closer to commercialisation so that they can contribute to the energy transition.

### ■ Recommended actions:

- **Design enabling regulatory frameworks specifically for offshore renewables.** For example, **Scotland** has developed strategies by joining forces between the government and relevant stakeholders, having the European Marine Energy Centre (EMEC) as a dedicated test site for ocean energy technologies. **Canada** and **China** have feed-in tariffs for ocean energy technologies (see also actions recommended for Issue 6. Develop the required the grid infrastructure). In addition, **Canada** has a dedicated test site, FORCE, which has the largest subsea electrical infrastructure in the world for tidal energy with 64 MW of subsea cables already in place and ready for developers (FORCE, n.d.). Nova Scotia, **Canada** also established the Marine Renewable Energy Act, which is legislation specific to the tidal energy sector. The **EU** is working with its Member States to ensure robust marine spatial planning.
- **Establish long-term strategies for infrastructure build-out to deploy and integrate ocean renewables, including repurposing ports and modernising grid and transmission infrastructure.** For example, the Nordic infrastructure fund Infranode prepared an investment of EUR 134 million (USD 159 million) for the establishment of new infrastructure facilities at the port of Esbjerg in **Denmark** that will be used for offshore wind and ultimately for shore-to-ship power units and the decarbonisation of the Danish port (Ajdin, 2021; Skopljak, 2020).
- **Streamline the permitting and consenting process, including formation of a cohesive marine spatial planning strategy.** For example, Belgium allocated 7% of its territorial waters for offshore wind deployment in its 2014 marine spatial plan.
- **Ensure that the regulatory frameworks regarding management of space and resources are able to foster the sustainable long-term development of offshore renewables,** in particular through marine spatial planning.

## 07.3

# TECHNOLOGY AND INFRASTRUCTURE

## Issue 6. Developing the required grid infrastructure

Due to the offshore nature of offshore renewables technologies, the grid connection is typically not already in place and the cable connection needs to be laid out first, which entails high capital costs. In comparison to onshore renewable energy sources, the grid capacity for offshore energy often poses additional challenges because grids can be small and unstable especially in islands or sparsely populated coastal areas. To mitigate this, building and improving onshore and offshore grid capacity is crucial.

#### ■ Recommended actions:

- **Plan for integrated offshore network plans based on long-term energy targets**, taking into account environmental protection and other uses of the sea. Examples include the EU guidelines for trans-European energy infrastructure and repealing Regulation (European Commission, 2020d).
- **Consider investing in joint power transmission lines across political borders.** For example, the transmission system operators from Denmark (Energinet) and Germany (50Hertz) will jointly operate a hybrid offshore asset composed of two wind parks located in the two countries that have a joint cross-border interconnected transmission line of 400 MW (Bauduin, 2021).
- **Consider new power transmission high-voltage direct current (HVDC) and DC technologies**, enabling increased flexibility and manageability of the grid and a high penetration of renewable energy sources in addition to minimised power losses. For example, the **UK's** Dogger Bank Wind Farm will have a 2.6 GW HVDC system to be developed over three phases in 2023, 2024 and 2025 (Hitachi-ABB, n.d.).
- **Develop international standards for interoperability of multi-terminal and multi-vendor HVDC systems.** Future large-scale HVDC systems will most likely have several components from different manufacturers, and multi-vendor operability will be required to ensure smooth operation of different equipment and un-interrupted power transmission. International standards developed / agreed upon with different suppliers such as HVDC transmission would thus greatly reduce interoperability issues and avoid a potential bottleneck in the development of energy infrastructure, as demonstrated in a study in **France** by the French transmission system operator RTE (Cordis, 2018).
- **Invest in new power transmission lines for offshore renewables.** For example, **Japan** is planning to invest USD 9.2 billion for undersea cables between power demand centres and planned offshore wind parks (Suga and Jackman, 2021).
- **Adapt existing grid codes to take into account offshore renewables.** For a better integration of offshore renewables into existing power systems in a cost-effective manner, grid codes need to be updated. For example, the **European Commission** proposed revising Regulation (EU) No 347/2013 of 17 April 2013, also known as the TransEuropean Networks for Energy (TEN-E) regulation, to specifically include onshore and offshore grid projects across European seas (Simson, 2021).
- **Consider the creation of offshore renewable energy hubs by coupling offshore renewables with power-to-X technologies.** The creation of renewable energy hubs has many advantages including the more efficient use of power network infrastructure and an improved business case for offshore renewables by producing green hydrogen. For examples, see recommended actions under section 7.4.

## Issue 7. Access to comprehensive resource site assessment

Finding an adequate site to place ocean energy devices is a complex process. High-resolution maps are not yet largely available, and although research on tidal and wave patterns has progressed enormously, there are still research gaps in site assessments for ocean energy technologies. Where data are available, they are not always open source and are often not accessible to the relevant institutions; if available, their existence may not be widely known.

### ■ Recommended actions:

- **Establish and improve offshore resource mapping for offshore renewable energy.** Data collection and sharing, including satellite and on-site data, can help establish a comprehensive resource mapping. International co-operation and co-ordination with both industry and academia are key for success. For example, the National Oceanography Centre of the UK is exploring a use case of its low-cost Global Navigation Satellite System Interferometric Reflectometry **GNSS-IR technology**<sup>10</sup> for sea state characterisation in collaboration with the EMEC in Orkney, Scotland. The **European Space Agency** is exploring the techno-economic feasibility of applying its earth observation data for power generation from ocean energy.
- **Consider adequate sites based on resources, but also grid connection potential.** Since poor grid connection infrastructure is one of the key challenges identified and given the high capital investments and long lead times required for new transmission lines to come to life, in addition to assessing the resource potential, site assessments should consider the grid connection potential. For example, the **UK** is considering changing its regulatory framework for grid connection for offshore renewables to encourage offshore wind developers to co-ordinate, so as to avoid scattered projects, sub-stations and underground cables (Renews, 2021).
- **Consider oceans and seas but also lakes, dams and rivers as potential sites for offshore renewables.** For example, Verdant Power is planning to install a tidal power plant composed of three 35 kW turbines as part of the Roosevelt Island Tidal Energy project in New York City's East River (USA) (NS Energy, 2020). The Port of London Authority has also approved the test of a tidal energy plant on the Thames River in southeast London (UK) (Frangoul, 2021).

## Issue 8. Withstanding harsh offshore environment (salinity, corrosion, extreme forces, etc.)

Offshore renewable technologies face a harsh marine environment, including continuous water movement, humidity and salinity. The structures need to withstand corrosion for extended periods of time. Offshore renewable technologies must also sustain vastly energetic settings, as the locations are chosen for their high energy potential. In addition, these need to withstand extreme atmospheric conditions such as heavy precipitation, strong winds, heat waves and abrupt temperature changes. Therefore, all components need to be stress resistant. In addition, the subsea environment complicates grid deployment and connection as well as regular operation and maintenance activities.

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<sup>10</sup> GNSS-IR technology can be used for marine applications remotely to measure water levels and sea state.



#### ■ Recommended actions:

- **Apply international standards to overcome the technical challenges of harsh offshore environments (salinity, corrosion, extreme forces, etc.).** For example, **ISO 9223** defines an experimental and a calculation method for measuring corrosivity, while **ISO 9224** provides a technique for extrapolating corrosion values into the future, and **ISO 14713** provides a mathematical formula for calculating the expected lifetime in years. Coatings with zinc aluminium magnesium alloys can increase corrosion resistance. Simulating ultraviolet light for floating PV power plants can be done thanks to **ISO 4892**, while **IEC 60692-2 -11** can be used to test fire hazards (Ong, Tay and Hammer, 2020).
- **Invest in R&D for innovative designs that withstand extreme weather conditions and that take into account local environmental conditions.** A floating PV power plant in Japan of 13.7 MW was damaged after Typhoon Faxai (Ong, Tay and Hammer, 2020), a challenge that could be overcome with innovative designs, enhanced testing and better consideration of local conditions. For example, the **German** company Aerodyn Energiesysteme successfully tested a two-headed floating offshore wind platform with utility EnBW in the Baltic Sea over two months, proving stability in extreme weather conditions (Maritime Executive, 2020).

#### Issue 9. Enhancing technology maturity and reaching commercialisation

As some wave and tidal devices have faced challenges at the initial deployment phase, leading to bankruptcies in the past, technical challenges must be identified at the R&D stages. To overcome these challenges, improvements need to be made through tank testing before wider deployment in the ocean. Given that these are relatively new technologies, their reliability needs to be assessed and improved over time. This would further help address stakeholders' concerns about the technology maturity level and can minimise risks.

#### ■ Recommended actions:

- **Increase public investments in RD&D for all offshore renewable technologies,** to reach technology readiness level (TRL) parity, design convergence, improved reliability and durability of the equipment. For example, the **European Union** invested USD 588 million (EUR 493 million) on R&D for ocean energy, mainly through the Horizon 2020 R&D programme (Science Business, 2021). **Australia** and the **USA** are investing USD 244 million and USD 25 million respectively in R&D for ocean energy. **China** invested USD 160 million (EUR 131 million) in tidal energy between 2010 and 2020 alone (Science Business, 2021).
- **Invest in RD&D, in close co-operation with industry.** For example, the company CorPower Ocean is investing EUR 16 million (USD 19 million) in wave technologies, including R&D, manufacturing and a service centre in Viana do Castelo, **Portugal** (NS Energy, 2020).

- **Invest in RD&D for airborne wind energy and the creation of artificial islands,** which harbour combined technology renewable power generating systems. Since these two emerging technological trends are in less-mature stages compared to other offshore technologies, policy makers could invest in their advancement through RD&D programmes. For example, **Denmark** announced two offshore renewable energy hubs on artificial islands in the North Sea and the Baltic Sea, to provide power to residential consumers and produce green hydrogen for aviation, heavy-duty transport, industry and shipping.
- **Invest in offshore renewables demonstration projects located in developing countries to foster technological maturity.** For example, if floating PV power plants covered 1% of **Africa's hydropower reservoirs**, this could double the capacity and increase power output by 50% (Gabbatiss, 2021).
- **Develop new international standards for technological assessment, as well as data collecting and sharing for offshore renewables.** New standards, metrics and methodologies are needed for environmental impact assessments and technological competitiveness valuations. Modelling and simulation of resource potential and energy outputs, agreed licences, standards and monitoring protocols would increase investor confidence. Standardised data collection and sharing practices would also benefit the industry. For example, IRENA's Technology Collaboration Programme (TCP) on **Ocean Energy Systems** developed an international evaluation and guidance framework for ocean energy technologies (Hodges, Henderson and Ruedy, 2021). Similarly, TC 114 of the International Electrotechnical Commission (IEC) provides different international standards regarding technology performance, installation, product and testing, and analysis, *i.e.*, **IEC TS 62600-10 ED1.0** and **IEC TS 62600-102 ED1.0** (IEC, n.d.).
- **Encourage private investments in enabling technologies for operation and maintenance of offshore renewable technologies.** For example, the **Swedish company** Eco Wave Power developed a software for real-time generation monitoring, as well as preventive maintenance that identifies failures in the wave modules instantly (Engineer Live, 2020). The **information technology company** Hewlett Packard Enterprise Company is working with wave developer Carnegie Clean Energy to adapt and develop artificial intelligence for wave energy for optimised power generation in response to waves (Marine Technology News, 2020).
- **Invest in the development and commercialisation of combined-technology renewable floating platforms,** such as combining ocean energy technologies with floating wind and floating PV. For example, the company **Bombora** is exploring the co-location and integration of wind and wave energy devices for higher power output and reliable supply.
- **Bring in the knowledge, skills and installations of the offshore oil and gas industry.** The offshore oil and gas sectors have developed approaches and assimilated knowledge on how to construct large offshore platforms and rigs that withstand wind, wave actions, and other extreme and harsh weather conditions (see section 5.1), which could be transferred to the offshore wind sector. For example, **USA-based Bentley Systems Incorporated** is continuously evolving

its offshore structural analysis and design software SACS to accommodate offshore wind monopile structure design, analysis and installations based on its knowledge and experience in the offshore oil and gas sectors (Bentley, n.d.).

- **Support emerging ocean energy start-ups through R&D investments and access to test centres.** Ocean energy technologies have not witnessed a convergence towards one type of technology and are mostly still in the demonstration and testing phases. Providing public and private funding support along with access to testing stations and available infrastructure helps start-ups test their technologies for viability and potentially accelerate the race to commercialisation. For example, **Blue Growth and Innovation Fast Tracked project (Blue-GIFT)** has awarded nine ocean energy companies with vouchers allowing them access to test centres under real-water conditions in the Canary Islands, France and Spain to further develop their technologies (Blue-GIFT, 2019).

## 07.4

# ECONOMIC AND FINANCIAL CONSIDERATIONS

### Issue 10. Enhanced cost-competitiveness

Technological improvement will help increase the cost-competitiveness of offshore renewables, compared to conventional energy sources. However, given the high initial capital expenditure and the high levelised cost of electricity, economic and financial support is needed to bring these technologies closer to commercialisation. The nascent offshore renewable market can be supported in its initial phases through capital or revenue support schemes.

- **Create hybrid projects where offshore renewables are coupled with interconnectors linking neighbouring countries.** Hybrid projects as defined by the EU offshore strategy refer to projects that combine generation and transmission elements by linking two or more countries and providing a platform for co-ordination among them. Hybrid projects translate to substantial cost reductions (5-10%), and to direct benefits of the offshore industry and job market benefit where it is operational. For example, the world's first hybrid offshore interconnector, Combined Grid Solution (CGS), was inaugurated in the fourth quarter of 2020. The CGS project can transmit offshore wind power to either **Denmark** or **Germany**, and it supports cross-border electricity trading (Weichenhain, 2019; Windfair, 2020).
- **Create offshore renewable energy hubs by coupling offshore renewables with power-to-X technologies.** The creation of renewable energy hubs has many advantages including the more efficient use of power network infrastructure and an improved business case for offshore renewables by producing green hydrogen. For example:

- **Denmark** announced two offshore renewable energy hubs on artificial islands in the North Sea and the Baltic Sea, located 80 kilometre offshore, with a combined 5 GW of installed wind power capacity, to be scaled up to 12 GW (Slmson, 2021). Wind energy will power residential consumers, while the green hydrogen will be used for end-use sectors such as aviation, heavy-duty transport, industry and shipping.
- **Siemens Gamesa and Siemens Energy** are jointly developing an offshore wind-to-hydrogen solution with 5 MW electrolysers located inside the offshore wind turbine, with the exact location in the North Sea yet to be announced. This is part of Germany's pledge to invest USD 834 million (EUR 700 million) in hydrogen technologies (Schnetter, 2021).
- **Tractebel** announced the development of a new large-scale platform coupling floating wind with hydrogen production, up to 800 MW with novelties in the design of the fabrication, installation and operation of the floating foundations (Buljan, 2020).
- **NorthH2 (Netherlands)**, a consortium composed of Gasunie, Groningen Seaports and Shell Nederland, announced in 2020 a wind-to-hydrogen project of 4 GW by 2030 and 10 GW by 2040 (NorthH2, 2021).
- **A Dutch prototype** of floating PV is undergoing tests in 2021 by SolarDuck and Voyex, with the aim of refuelling ships with hydrogen from the offshore floating solar island (Garanovic, 2021b).
- **Power blue economy sectors with offshore renewables.** Economies of scale provided by the blue economy sectors, in addition to benefiting from joint infrastructure, could bring down the costs of offshore renewable technologies. For example, project promoters are exploring how ocean energy technologies can be coupled with activities such as **shipping** (e.g., EMEC), **cooling** (e.g., Maki, Bluerise), **aquaculture** (e.g., Bretagne Ocean Power, SINN Power), **desalination** (e.g., Bardot Ocean), as well as **oil and gas** (e.g., Ocean Harvesting), as shown in Table 8.

### Issue 11. Securing funding by mitigating risks

Concerns about the technology maturity and performance of offshore renewable technologies (see also Issue 5. Establish enabling regulatory frameworks) can act as a major blockage in securing funding for such projects due to the high perceived risks. In addition to actions targeting technological deployment, such as R&D investments, international standards and the creation of hybrid renewable power generating systems, actions are needed to reduce the investment risks in the project development phases and to improve the access to finance.

- **Reduce risks for lenders by ensuring the bankability of projects through improved technical due-diligence of projects.** For example, for floating PV, **bathymetry** surveys assess the depth variations of locations selected for projects using beam echo sounders on boats/vessels, while **topography** surveys can complement this assessment. Further **geotechnical** survey help measure the soil conditions at anchoring areas, which helps identify the type of anchors needed for the floating PV plants (piles, plates, concrete, etc.). Meteorological surveys, site comparisons (water body, wind speed, water level, etc.) and the identification of suitable grid connection points are equally important to reduce the risks early on (Ong, Tay and Hammer, 2020).

- **Share the risk of early movers through private-public partnerships.** The high initial capital cost and the difficulty in securing funding due to perceived risks could be reduced for developers through public support. For example, the **UK** announced USD 138 million (GBP 100 million) in support of net zero ambitions in Scottish Islands in a post-COVID-19 world, including green hydrogen production from offshore renewables (EMEC, 2020).
- **Improve the bankability of offshore renewables projects through innovative financing mechanisms and criteria.** Innovative mechanisms such as *blended finance* and *stage gate metrics* provide financial support to developers. Blended finance encourages private and public investments that benefit society as a whole in addition to pure financial returns on investment, while stage gate metrics refer to the progressive financing of an innovative project based on stages (milestones) achieved, from inception to completion. For example, **Wave Energy Scotland** engages internationally to develop standardised metrics for ocean energy technologies, such as stage gate metrics (Wave Energy Scotland, n.d.).

## Issue 12. Robust supply and value chains

Some of the major barriers towards commercialisation of offshore renewables, and especially ocean energy, are of an economic nature. The levelised costs of electricity are usually significantly higher than for other renewable energy carriers due to high upfront investment costs, novelty and the lack of economies of scale. Some of these technologies are perceived as risky due to uncertainties that arise from a lack of familiarity and operational experience, which make it difficult to find suitable funding sources. Challenges also appear across the supply and value chains since there are few standardised components available. This means that developers often must take on more roles, such as developing parts of their power electronic components.

### ■ Recommended actions:

- **Facilitate cross-sectoral knowledge and skill transfer among offshore industries.** Lessons learned from the offshore oil and gas sector are valuable for offshore renewables, including those with floating foundations, since these industries have had to face similar challenges in the past (e.g., harsh environments). Moreover, offshore renewables can power the activities of offshore oil and gas platforms. For example, **Norway's Hywind Tampen** floating wind project of 88 MW, developed by the oil and gas company Equinor, is projected to supply around 35% of the power needs of five oil and gas offshore platforms (World Oil, 2020). The **oil and gas company Total** has entered the floating offshore wind sector in France by acquiring 20% of the 30 MW Eolmed floating wind pilot located in the Mediterranean Sea (Total, 2020).
- **Promote undistorted trade, improved market access and uninterrupted supply chains.** Free international trade drives cost reductions and brings onboard international expertise and technologies, thus ensuring a robust supply chain that in turn could drive further deployment and accelerated growth of offshore wind.

## ENVIRONMENTAL ISSUES

### Issue 13. Addressing potential environmental impact

Relatively little is known about the impact<sup>11</sup> of ocean energy technologies on marine life due to the early stage of technology deployment. Negative impacts could arise in the form of habitat loss, animal-turbine interactions (e.g., collision risk, mainly of marine mammals, fish and birds), noise and electromagnetic fields produced by sea cables, which may have effects on aquatic species. While key lessons can be learned from other offshore activities, such as conventional oil and gas as well as offshore wind operation, this is yet to be studied in-depth for ocean energy technologies, whose impacts are location specific.

#### ■ Recommended actions:

- **Exchange experience with environmental impact assessments (EIA) across organisations within the same country and internationally, including the determination of cumulative environmental effects.** Where environmental impact assessments are available, these can benefit other countries that are looking into adopting these technologies, as well as organisations within the same countries. For example, in 2020 the **UK's Environmental Audit Committee** launched an inquiry into the role of tidal energy for the UK's path to net zero emissions, including questions around the environmental impacts and their mitigation (McManan-Smith, 2020).
- **Encourage data collection by public institutions, researchers and private companies alike.** Institutions, researchers and technology developers can co-operate with environmental agencies to better understand the negative and positive impacts of offshore renewable technologies on the environment (underwater sounds, noise for surrounding human settlements, etc.), including on biodiversity. For example, the **Mutriku wave power plant in Spain** identified loud noise, which was heard during a storm and around 3-10 kilometre away, as a key environmental issue (Tethys, 2020).
- **Establish joint environmental research programmes targeting offshore renewables between governments and industry.** Such collaboration enables the funding organisations to manage research in an efficient and effective manner, as it brings together knowledge and expertise on needs and practicalities from industry, regulators, etc. For example, the **UK's Offshore Renewables Joint Industry Programme (ORJIP)** is a nationwide collaborative programme aiming to reduce consenting risks for offshore wind and ocean energy technologies (ORJIP, n.d.).

By implementing and promoting the good practices presented in this section, G20 countries may significantly foster the global deployment of offshore renewables in response to the Climate Change and Sustainable Development objectives.

<sup>11</sup> However, some research has also shown positive impacts such as an increase in biodiversity where ocean energy systems act as artificial reefs or in the absence of fishing activities. Due to the absence of vessels around offshore wind farms an increase in marine mammals has been observed.



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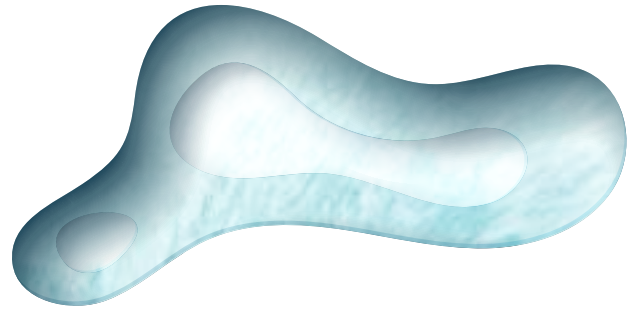
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# OFFSHORE RENEWABLES

An action agenda for deployment

A CONTRIBUTION TO THE G20 PRESIDENCY

