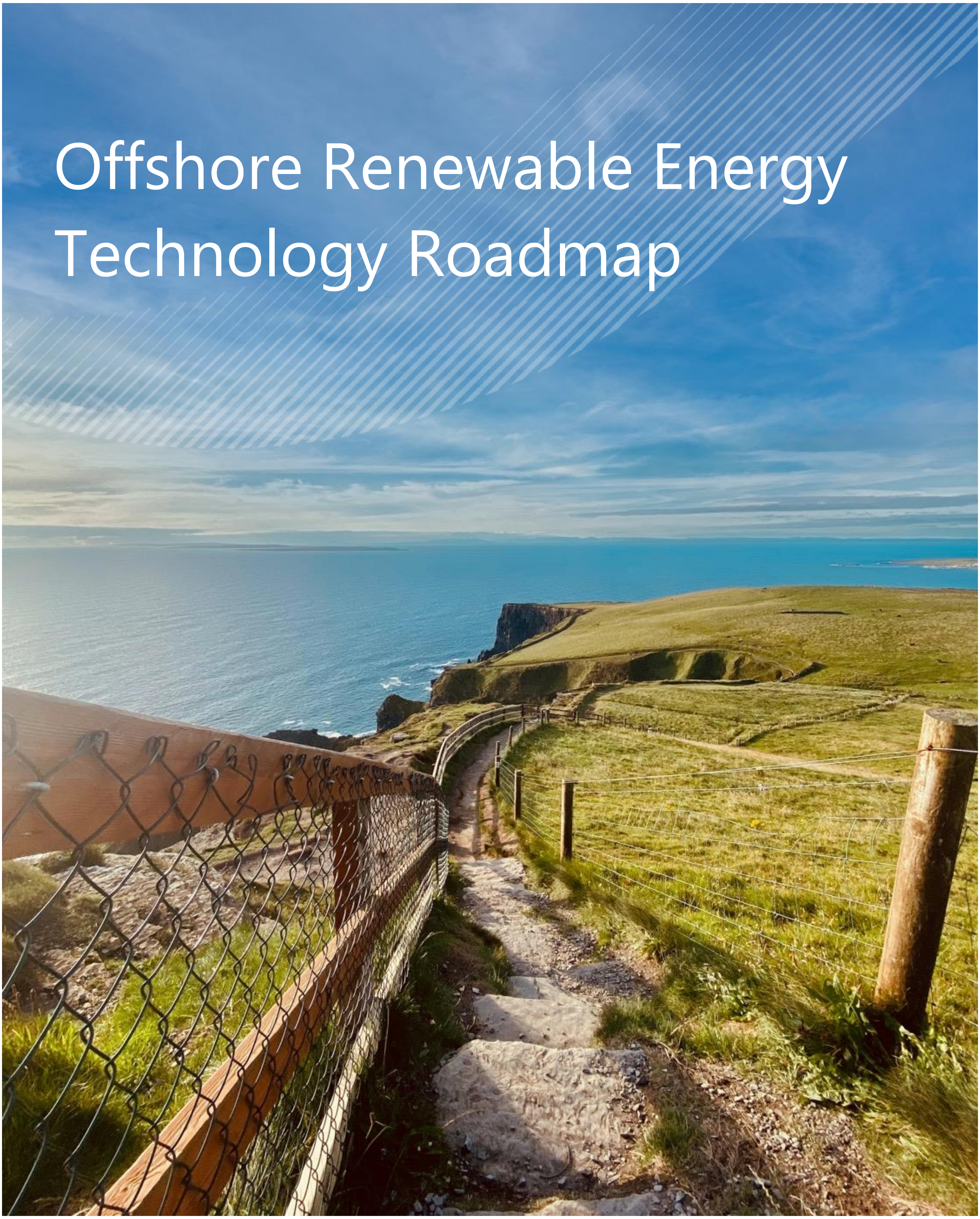
seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND

Rialtas na hÉireann
Government of Ireland

Offshore Renewable Energy Technology Roadmap



Offshore Renewable Energy Technology Roadmap

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Report prepared for SEAI by:
BVG Associates supported by Beauchamps

BVGA provides strategy consulting in renewable energy, helping clients to do new things, think in new ways and solve tough problems. Acting globally and with deep technical and market knowledge, it is a leader in growing offshore renewable energy in established and emerging markets. Beauchamps is one of Ireland's top full service commercial law firms.

Disclaimer

Sustainable Energy Authority of Ireland

SEAI is Ireland’s national energy authority investing in, and delivering, appropriate, effective and sustainable solutions to help Ireland’s transition to a clean energy future. We work with the public, businesses, communities and the Government to achieve this, through expertise, funding, educational programmes, policy advice, research and the development of new technologies.

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Contents

Executive summary

With a seabed area seven times its landmass and excellent wind and wave conditions, Ireland has access to a huge offshore renewable energy (ORE) resource to help decarbonise the economy. Indeed, Ireland's ample scope for ORE deployment means that ORE can potentially provide far more energy than is needed by the people and businesses of Ireland, and Ireland has the potential to export significant low-carbon power to consumers across Europe.

This roadmap maps the pathway to harnessing Ireland's ORE potential. ORE deployment has a crucial role to play in driving the decarbonisation of the Irish electricity system whilst also unlocking economic and societal benefits for Ireland.

It supports a coordinated Government approach to realising the potential of each key ORE generation technology. This is achieved by assessing the readiness of technologies and considering both the latest relevant technology innovations, and key future innovations, for ORE technologies relevant to the Irish context.

Technology trajectories are examined through techno-economic modelling scenarios where metrics such as annual deployment rates, technology performance and costs are utilised to produce projections of technology performance in the Irish market up to 2050. Techno-economic projections provide a basis for comparing the impact of different deployment pathways which vary the mixture of technologies utilised and the volumes of offshore renewable energy being delivered. In turn, the scenario analysis elucidates the critical decision points and options mapping, for successful delivery of Irish offshore renewable energy targets.

By reviewing the Irish policy and regulatory landscape in addition to international best practices, the roadmap process examines the required policies, regulatory frameworks, Government supports, standards and skills for delivery that need to be established, and when, to achieve the technology's decarbonisation potential. It also highlights the research opportunities for Ireland and identifies the skills needed to deliver this**.**

BVG Associates, with support from Beauchamps, has prepared this advisory report for the Sustainable Energy Authority of Ireland (SEAI) to inform strategic planning and policy development. It captures the frameworks for ORE delivery in Ireland, recommending areas for further consideration, informed by international best practice and industry expertise. It is not a statement of Government policy. This roadmap will remain under review by the Department of Environment, Climate and Communications (DECC) and will be updated every 5 years, or as significant technology or ORE market developments demand it. It considers generating technologies only, and does not examine the development of wider enabling technologies such as interconnection, hydrogen, efuels, battery storage and other grid flexibility technologies. It does not assess the capacity of the existing or future Irish onshore transmission network to accommodate additional ORE deployment.

Technology

This report concludes that fixed and floating offshore wind should play the dominant role in providing energy from our ocean.

Fixed offshore wind is already playing a significant role in many markets, with 61 GW operating globally across about 250 projects by the start of 2024. This technology has a high degree of commercial readiness, and is considered fully bankable, enabling access to significant volumes of finance. Cost of energy has reduced significantly since early projects, with more room for further reductions as wind turbines, project sizes and the global market continue to increase in scale. Ireland has capacity to develop at least 10 GW of fixed offshore wind.

Floating offshore wind, which can be deployed in deeper water than fixed offshore wind, has a lower degree of commercial readiness than fixed offshore wind, but efforts to deploy the technology at scale are gathering pace globally, with many countries setting ambitious multi-Gigawatt deployment targets. Although cost of energy is higher than fixed offshore wind in shallower water, there is significant room for innovation to drive this down, and the technology can also benefit from many technological developments in fixed offshore wind. Ireland has capacity to deploy significant quantities of floating offshore wind in its maritime area off the Atlantic coast in the west and south, where mean wind speeds are higher than in shallower areas suitable for fixed offshore wind. Constraints to deployment of floating offshore wind in Ireland are much more likely to be driven by constraints on Ireland's capability to economically export excess generation than its capability to deploy additional turbines.

Wave energy is the next ORE technology that could impact. Current cost of energy is higher than floating offshore wind and the path to potential commercial viability is less certain, but Ireland has the potential to have a greater influence on the market than in offshore wind, hence securing a larger fraction of that market for local suppliers. This is because there is much less focus on wave energy technology, globally.

Deployment

Ireland has 25 MW of fixed offshore wind capacity installed to date in one small project of 7 turbines, installed in 2004. A further 3.1 GW has been awarded an offtake agreement in the Offshore Renewable Energy Support Scheme (ORESS) round 1 auction of 2023, and is expected to be constructed in the coming years.

Four ORE deployment scenarios to 2050 are considered in this report:

1. **Decarbonising through offshore wind.** This scenario sees domestic demand progress according to the National Energy Projections 2022. Offshore wind is deployed to meet Ireland's domestic energy needs and there is little net export of energy.
2. **Delivery of 37 GW ambition.** In this scenario, Ireland delivers its stated ambition of 37 GW offshore wind by 2050, which sees Ireland become a significant net exporter of energy.
3. **Stretch wind target.** In this scenario, Ireland goes beyond its currently stated offshore wind ambition, delivering 50 GW by 2050, which sees Ireland export an even larger share of its energy.
4. **Meeting 37 GW ambition with wind and wave.** In this scenario, wave technology progresses sufficiently to make a significant contribution to ORE deployment targets, adding 4 GW generating capacity by 2050.

These scenarios represent indicative deployment pathways only, based upon Government ambition statements, observed deployment growth trajectories in other markets, and domestic demand projections from National Energy Projections 2022. They are not intended to represent a forecast, and pace and scale of deployment may differ in practice.

Table A shows the total operating capacity of each ORE technology and key sources of additional offtake under each of the four scenarios.

Table A: 2050 operating capacity of key ORE and offtake technologies under each scenario

Scenario	Fixed offshore wind (GW)	Floating offshore wind (GW)	Wave (GW)	Other ORE technologies (GW)	Interconnection (GW)	Hydrogen electrolysis (GW)

Scenario 1: Decarbonising through offshore wind	6	3.3	0.15	0	3.1	0
Scenario 2: Delivery of 37 GW ambition	10	27	0.15	0	13	11
Scenario 3: Stretch wind target	10	40	0.15	0	18	16
Scenario 4: Meeting 37 GW ambition with wind and wave	10	24	4	0.1	13	11

The report concludes that, due to a high level of technical and commercial readiness, there can be confidence that offshore wind can deliver the pathways set out in scenarios 1-3. This assumes the right policies and frameworks in place, as discussed in Sections 4.3 to 4.12.

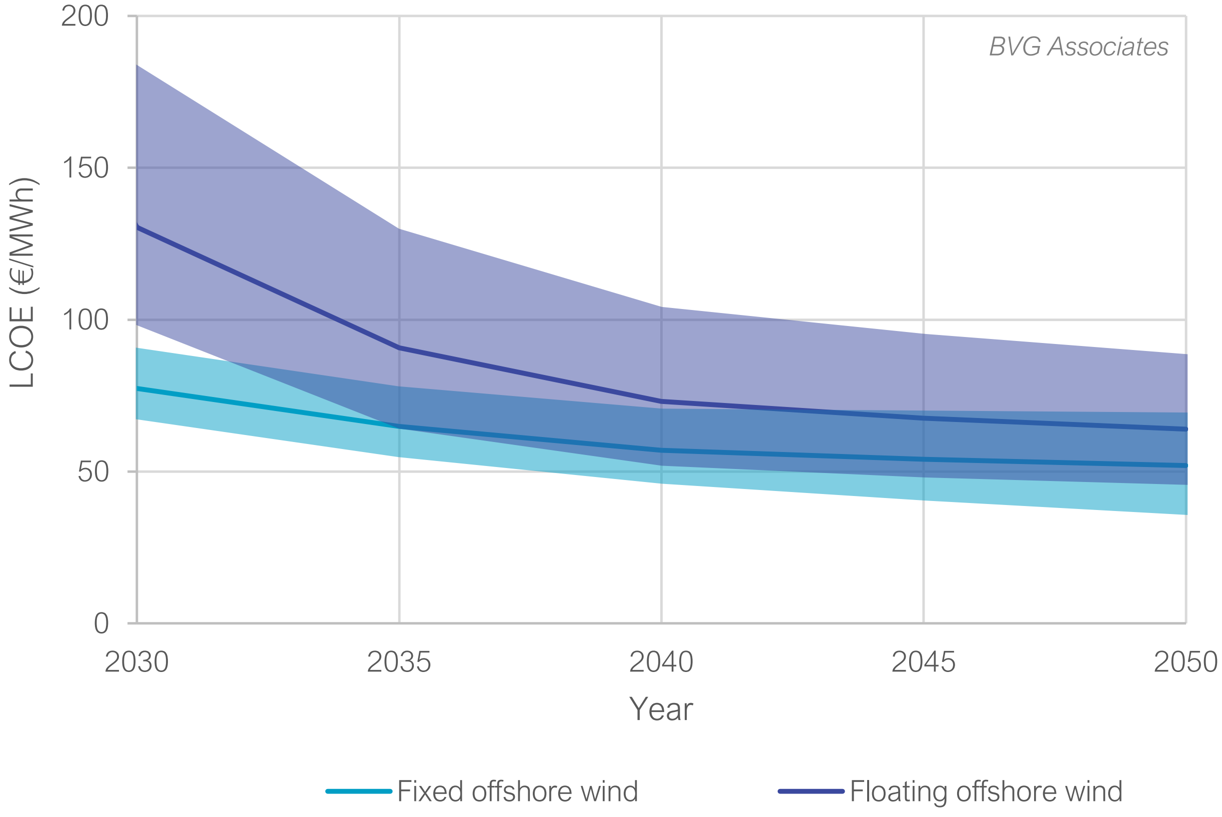
There is less certainty about the wave energy contribution that turns scenario 2 into 4. The cost reduction pathway mapped for wave energy consistent with a scenario 4 pathway represents a target rather than a predicted progression. On current evidence, a cost reduction pathway for wave consistent with scenario 4 may not be possible to achieve.

Levelized cost of energy

Levelized cost of energy (LCOE) for fixed offshore wind is anticipated to fall by just under one third, and for floating to fall by just over 50% for projects installed during the period 2030 to 2050. LCOEs (in real terms) are expected to fall on the back of high volumes of global activity and further technological development, which drive cost savings through drivers including increasing turbine size, economies of scale, improved manufacturing processes and O&M techniques. LCOE trajectories for fixed and floating offshore wind change little with increased Irish deployment, though a small saving is likely in higher deployment scenarios. Ireland's status as a high-wage economy located in close proximity to a well-established supply chain in Europe means that local facilities will not in general offer a substantial cost saving versus non-Irish competitors.

Figure A shows LCOE trajectories for fixed and floating offshore wind. Uncertainty bands represent the range within which the LCOE could fall, assuming consistent macroeconomic conditions. Wider bands are indicative of greater uncertainty over the progression of the technology.

Figure A: Levelized cost of energy trajectories for fixed and floating offshore wind in Ireland



It is currently uncertain whether wave energy has the potential to compete on price with fixed and floating offshore wind in the future, or offer sufficient additional benefits to the energy system to warrant much of a price premium. It is likely that significant investment in R&D will be required if this potential is to be realised, without certainty of success at this stage.

Policy and frameworks

Ireland has stated its ambition to deliver 5 GW of offshore wind by 2030, and 20 GW by 2040, with a view to delivering a long term target of 37 GW by 2050. Ireland has frameworks in place to support first deployment of fixed offshore wind. 3.1 GW of additional fixed offshore wind capacity was brought forward in the ORESS round 1 auction.

Ireland has moved from a developer-led approach to a plan-led approach, with project locations identified by the State through Designated Maritime Area Plans (DMAPs) and the establishment of The Maritime Regulatory Authority (MARA) to oversee the award of Maritime Area Consents (MACs). MACs grant the holder the right to occupy an area of seabed for a given period for specific maritime activities. They replace the former foreshore leasing regime. MARA is also responsible for granting other licenses for maritime activities. Many details of how this new plan-led approach will operate remain subject to consultation. It is important for Ireland to solidify frameworks soon to reduce uncertainty.

There are opportunities to strengthen Ireland's policies and frameworks to build investor confidence and facilitate rapid deployment, based on a wealth of good practice examples from other markets. Key considerations are:

- Delivering a clear industrial policy for ORE, building on the recently published industrial strategy,[1] and methodologies for measuring and reporting on local content to maximise local economic benefit.
- Delivering clear, predictable and timely end-to-end frameworks for ORE deployment, which deliver for both investors and Irish citizens.
- Enabling timely investment in grid infrastructure, renewable hydrogen and interconnection to facilitate ambitious ORE deployment plans.

Supply chain and local economic benefit

Ireland has the opportunity to benefit significantly from the rollout of ORE. This report finds a gross value add (GVA) of between €8.8 billion and €53 billion to the Irish economy associated with domestic rollout of ORE, depending on the scenario. This equates to between 96,000 and 610,000 FTE years of employment for Irish workers. *Figure B* shows a comparison of overall GVA benefits associated with Irish deployment in each of the four scenarios. Employment benefits follow a similar trend.

Local content levels in fixed and floating offshore wind and wave projects are between 15 and 25%, depending on year, technology and deployment scenario.

This means that GVA and job opportunities are driven to a large extent by volume of deployment, rather than by increased local content levels.

Nevertheless, this report identifies a number of supply chain areas in which Ireland has the opportunity to capture inward investment, and therefore jobs and economic benefit. These include:
- Construction and marshalling ports (both fixed and floating).
- Tower manufacturing.
- Synthetic cable manufacturing.

With the expansion of its domestic offshore wind industry, Ireland has the potential to benefit significantly from export opportunities, especially if the above investments are captured. When export benefits are taken into account, GVA benefits to 2050 are between 16 and 36% higher than those delivered by the domestic pipeline alone. These benefits cover the export of goods and services associated with ORE deployment. They do not include the economic benefits of the export of hydrogen or electricity via interconnection, which have not been modelled. It is important to continue to evaluate the competitiveness of Irish electricity and hydrogen export within export markets, as the rollout of ORE progresses.

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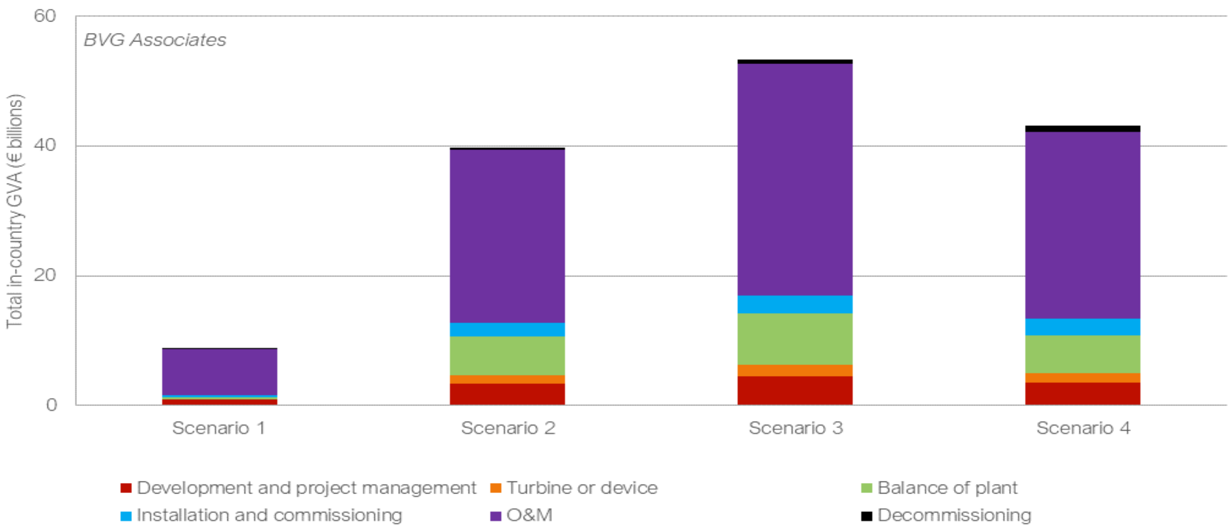
[1] Department of Enterprise, Trade and Employment, 2024, Powering Prosperity – Ireland's Offshore Wind Industrial Strategy, available at: https://enterprise.gov.ie/en/publications/powering-prosperity.html.

Figure B: Comparison of Irish GVA benefits of domestic deployment across scenarios, broken down by spend category



Key considerations in maximising local benefit are:

- Setting out ambitious long-term deployment targets.
- Establishing appropriate and targeted industrial strategy to identify and exploit investment opportunities.
- Providing investment incentives to build investor confidence and attract foreign direct investment within a competitive international context.
- Putting in place and continuing to refine clear, timely and predictable frameworks to support deployment, including for leasing, permitting, offtake and grid connection.
- Confirming the timing of future deployment opportunities, including clarifying a regular future pipeline of auctions with multi-year visibility.
- Ensuring appropriate mechanisms for community engagement and participation are built into frameworks, including, where proportionate, community benefit mechanisms to foster strong public support.
- Supporting research in areas of Irish opportunity and strength to derive a competitive advantage.

Research and research skills

Ireland already has a strong research base in ORE, in which a wide variety of Government agencies, academic institutions and research funding bodies participate. Strengthening this research ecosystem in line with ORE market growth helps ensure deployment and maximises local benefit within the supply chain.

Areas of specific focus should be:

- Generation technologies that are most likely to impact Ireland's future energy mix, so fixed and floating offshore wind and the best wave energy concepts.
- Greatest focus on floating offshore wind as it offers the best opportunity for the Irish research community to reduce consumer bills.
- Areas within these technologies where:
  - Skilled Irish research can provide additionality – there is little point following others who are further ahead
  - Significant benefit is available, regarding LCOE or market delivery (volume and / or speed) or enabling competitive local supply to Irish projects (and potentially exports), hence providing a route to market.
- A high degree of international awareness, industry engagement and where relevant, collaboration.
- A long-term framework for research support, but with flexibility to adapt to evolving market needs and research landscape.

The body of best practice examples from other markets shows that:

- Shared investment between industry and Government increases research value for money. This may involve strategic partnerships and co-funding.
- Prioritization is important, based on potential for impact and relevance to national needs.
- Continuity of funding in the route to market for worthwhile innovations is vital.
- Collaboration between industry and research institutions is key, leveraging existing knowledge and resources.
- International collaboration is often valuable, combining strengths to address key shared challenges.
- Data sharing repositories and standardization can be helpful to facilitate informed research and innovation.
- Long-term research visions and tangible goals are helpful in building areas of excellence.
- Coordination between funding bodies and streamlining of programmes helps bring clarity, but research, by nature, has an element of uncertainty and some overlap is inevitable.
- Rigorous stage-gate processes to limit later-stage funding only to viable solutions increases value for money.
- Signposting funding opportunities, providing challenge and business coaching helps innovators achieve commercial success.

Recommendations

On the basis of the above assessment, this report includes 50 recommendations for Ireland to drive forward deployment of ORE in line with the scenarios envisaged, maximising the domestic economic benefit of this effort and ensuring ORE deployment is supported by the Irish research and development sector.

Recommendations apply to all scenarios unless otherwise stated.

Energy strategy

1. DECC builds an ORE deployment strategy for Ireland primarily around fixed and floating offshore wind. These technologies offer the greatest certainty and return on investment for Ireland.
2. SEAI and DECC review on an ongoing basis whether other technologies, especially wave energy, should play a significant role in Ireland's energy mix, and monitor developments in most relevant technologies. Public support for technology development may be appropriate in some cases.
3. DECC delivers (and updates every 3 years) a decarbonised electricity system pathway, setting out Ireland's long-term ambitions for ORE technologies and their place within the wider energy system and addressing security of energy supply, cost-effective energy for consumers, local jobs and economic benefits, climate and environmental benefits and attracting foreign investment.
4. DECC integrates a firm vision for interconnection and alternative offtake solutions such as hydrogen or efuels into future pathway documents. This should include consideration of the international competitiveness of Irish interconnection, or alternative offtake, accounting for generation, production, storage and transmission costs, as well as optimisation of domestic usage.

Policy

5. DECC continues to ensure that industry participation and stakeholder consultation is built into future policy development, establishing a strong forum for ongoing dialogue with industry during policy and framework development and implementation.
6. DECC delivers timely clarity on the future framework for ORE and a policy statement outlining details of the future framework beyond ORESS 2 to provide forward certainty for developers.
7. If Ireland wishes to pursue significant deployment of other ORE technologies, DECC should consider setting a corresponding ambition. (Applies only to scenario 4.)

Frameworks to enable ORE delivery

8. DECC focusses on accelerating delivery through effective frameworks and by promoting the attractiveness of Ireland as a market for offshore wind.

9. DECC and The Department of Enterprise, Trade and Employment (DETE) consider how an appropriate balance can be achieved between delivering low cost deployment and driving investment in local supply chain, ensuring alignment between statements of policy and content of frameworks.

10. DECC ensures that frameworks allow sufficient time for necessary activities such as collection of site data, transmission network planning, supply chain planning and bid development between stages to minimise risk to investors and generate efficient outcomes for consumers.

Framework for marine spatial planning

11. DECC draws on developer feedback and industry expertise to ensure that state-run site surveys, assessments and selection activities meet the requirements of developers, whose preferences for data specification may vary.

12. DECC makes the data used to inform Designated Maritime Area Plan (DMAP) development available to industry to improve transparency and efficiency of the Maritime Area Consent (MAC) application and permitting processes.

13. DECC sets out a long-term plan for ORE-specific marine spatial planning on a national basis, including a plan for future DMAPs.

Framework for seabed occupancy and offtake[2]

14. DECC establishes a regular pattern of ORESS auctions or any successor schemes (for example every two years) with multi-round forward visibility for the market.

15. DECC fully describes the framework for upcoming offshore renewable offtake auctions at the earliest opportunity. If, in future schemes, the auction comes before MAC award and permitting, as in ORESS 2.1, bidders should have reasonable certainty they will receive a MAC and necessary permits, should they be successful, to reduce delivery risk and increase the attractiveness of the offshore renewable energy market.

16. MARA grants seabed exclusivity with respect to other ORE developments under MACs moving forward and maintains the 45-year rights period to give developers long-term certainty.

17. DECC clarifies policy for projects seeking to come to market via alternative offtake arrangements, such as corporate power purchase agreements (CPPAs), including MAC eligibility arrangements.

18. DECC maintains a suitable longstop date in future auction terms to ensure timely project delivery is incentivised while minimising risk to developers.

19. DECC considers whether to pursue auctions for other ORE generation technologies. (Applies to scenario 4 only.)

Framework for permitting

20. DECC and the Department of Housing, Local Government and Heritage (DHLGH) ensure both MARA and An Bord Pleanála respectively are appropriately resourced to deliver the desired volume of timely permitting decisions. The resourcing required will depend on the scale of Ireland's deployment plans.

21. DECC defines a full single point of contact (SPC) function to streamline the permitting process in line with *Renewable Energy Directive III* (RED III) requirements and implements the monitoring and enforcement elements of the SPC function.

Framework for export system and grid connection

22. DECC, the Commission for Regulation of Utilities (CRU) and EirGrid introduce:

- Measures to give early clarity of grid charging costs, grid connection dates and locations to reduce risk and cost to developers participating in future offtake auctions.

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[2] In the Irish context, seabed occupancy is analogous to what is termed seabed leasing in other markets

- Measures to incentivise both EirGrid and developers to ensure timely, aligned delivery of transmission infrastructure.

23. DECC, DETE and EirGrid consider adopting an integrated offshore hub model to reduce the number of connection assets required. The centralisation of responsibility for export system and grid connection under EirGrid in the plan-led model facilitates this type of strategic planning.
24. DECC clarifies EirGrid's long term role in design and build of transmission infrastructure beyond ORESS 2.1 and ensures that EirGrid is properly resourced to discharge its expanded responsibilities. The resourcing required will depend on the scale of Ireland's ORE deployment plans.
25. EirGrid develops a strategic roadmap for transmission network development to 2050, providing forward visibility of reinforcement plans and a commitment to updating it on a regular basis, informed by forthcoming marine spatial planning documents. This will increase investor certainty and facilitate future proofing of transmission network investments.
26. DHLGH considers how the planning regime could be changed to more easily facilitate delivery of new onshore export system and transmission network infrastructure.

Framework supporting wider energy system

27. DECC brings forward an updated regulatory regime for hydrogen, aligned with efforts at a European Union (EU) level to facilitate seamless trade. (Applies to scenarios 2, 3 and 4 only.)
28. DECC and DETE explore opportunities for Ireland to benefit from the development of local supply chains for renewable hydrogen. This should include consideration of Ireland's international competitiveness as a supplier of hydrogen. (Applies to scenarios 2, 3 and 4 only.)
29. EirGrid explores innovative technologies to support grid access for ORE.

Framework for health and safety

30. DETE and Health and Safety Authority (HSA) explore whether to bring forward updated offshore health and safety legislation which contains specific provision for the ORE industry and its working practices, and ensure the HSA is appropriately resourced to deliver a robust and transparent offshore health and safety framework.
31. DETE and the HSA develop Irish ORE wind health and safety guidance and and/or legislation with reference to best practice from global training bodies such as the Global Wind Organisation, G+ Offshore Wind Health and Safety Association, as well as examples of best practice in established markets.
32. DETE and the HSA, in consultation with SOLAS, review whether offshore-specific content should be incorporated in Safepass.

Framework for technology development and certification

33. The National Standards Authority of Ireland (NSAI) ensures that the Irish certification regime remains aligned with International Electrotechnical Commission (IEC) standards to ensure harmonisation and facilitate confidence in financing Irish projects, and that industry and investors have a strong voice in the development of new standards and certifications.
34. NSAI focusses where Irish site conditions are beyond the standard definition of site conditions, to ensure Ireland-specific risks are managed.
35. DECC and DETE undertake a feasibility assessment of regulatory sandboxes for ocean renewable technologies, allowing regulatory requirements to be altered on a limited basis for trial projects to test the effectiveness of new approaches.

ORE supply chain and skills development

36. DETE, the Department of Further and Higher Education, Research, Innovation and Science (DFHERIS), the Marine Institute, SEAI and Skillnet Ireland seek to maximise benefit in key areas of Irish advantage, including project development and operation and maintenance (O&M), through skills funding initiatives and support for research and development in adjacent subjects such as seabed surveying, LiDAR and remote monitoring technologies.

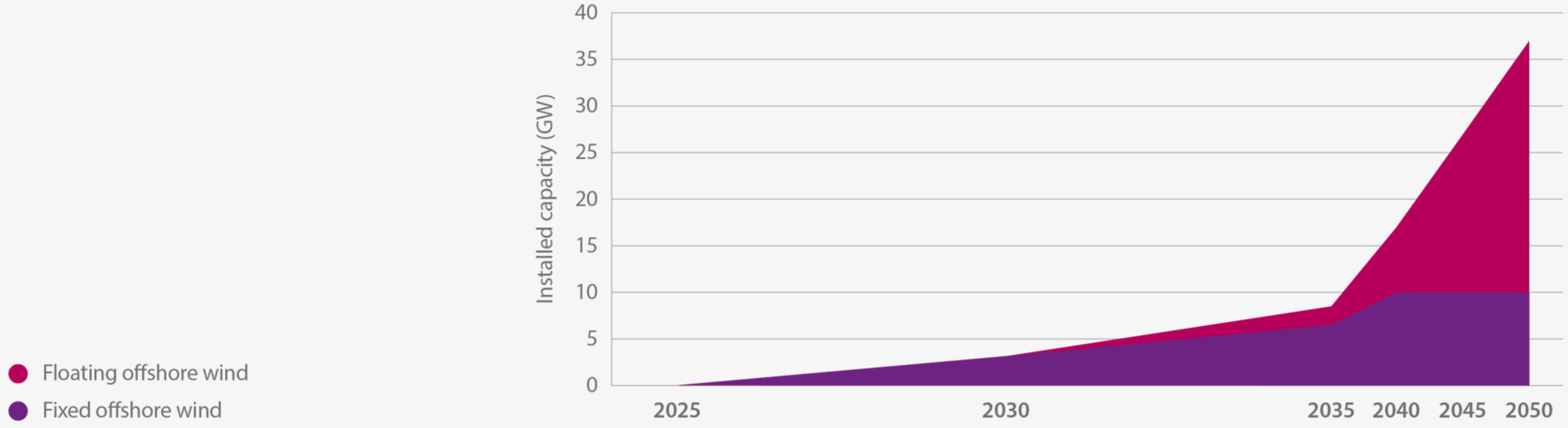
37. DECC adjusts the methodology for calculating Irish content within project delivery plan questionnaires to ensure calculated local content percentages reflect actual Irish value capture, in line with international best practice examples.
38. DETE establishes and implements a clear and targeted industrial strategy for offshore wind which targets investment in specific manufacturing facilities. (Applies to scenarios 2, 3 and 4 only.)
39. DETE, with collaboration from the Department of Finance, puts in place investment incentives specifically targeted at larger-scale manufacturing and infrastructure investments. Such incentives could include investment grants, tax incentives or preferential financing arrangements. (Applies to scenarios 2, 3 and 4 only.)
40. DoT establishes mechanisms to provide investment support for port infrastructure upgrades. (Applies to scenarios 2, 3 and 4 only.)
41. DETE facilitates the development of industrial clusters through supportive policies, funding for business networks, and other initiatives to encourage industry collaboration and investment, including regional development initiatives. (Applies to scenarios 2, 3 and 4 only.)
42. DFHERIS and SEAI support industrial clusters through targeted skills funding initiatives and support for research and development in areas relevant to targeted areas for Irish participation. This could include, for example, support for synthetic materials research to build Irish capability. (Applies to scenarios 2, 3 and 4 only.)
43. DETE considers whether an industrial strategy may be appropriate for wave energy, at a suitable time in the technology development pathway.
44. DECC and DETE continue to evaluate the competitiveness of Irish electricity and hydrogen export within export markets, as the rollout of ORE progresses, and use this to inform future deployment plans.

Research and development

45. SEAI develops a focussed ORE research and innovation strategy for Ireland with clear objectives, building on the content of this report, addressing any gaps in support and monitoring ongoing technology developments and innovations.
46. DETE and SEAI focus offshore wind research activity on:
    - Addressing the specific (often extreme) conditions seen in Irish waters:
    - For fixed offshore wind, project development and O&M, including AI, robotics, and sensing technologies to enable cost reduction in O&M
    - For floating offshore wind, foundations, including advanced manufacturing processes to enable cost reduction.
47. SEAI focuses wave energy research on lower-cost, lower-TRL activity, with robust stage gate in place before significant-scale sea trials. This will allow Ireland to support a wider array of innovations and assess which are likely to impact the market before progressing to more costly, large scale research.
48. DETE, SEAI and SFI maximise the value of research and innovation activities, where relevant, through business coaching, facilitating collaboration and wider enabling support for the ORE research and innovation community.
49. DETE, DFHERIS and SEAI collaborate in ensuring that the Government provides joined-up leadership in research and innovation in ORE.
50. DFHERIS works with research funding agencies to create a targeted research and development fund to support commercialisation of wave technology, including financial support for demonstrator-scale projects to support the development of Irish supply chain expertise. (Applies to scenario 4 only)

Figure C presents a timed roadmap of recommendations to deliver Scenario 2: Delivery of 37 GW ambition. This scenario is consistent with current Government policy, representing delivery of the target set by Ireland under North Seas Energy Cooperation (NSEC) and the *Policy Statement on the Framework for Phase Two Offshore Wind*. Some recommendations that are timed for implementation in a given period require ongoing action after this.

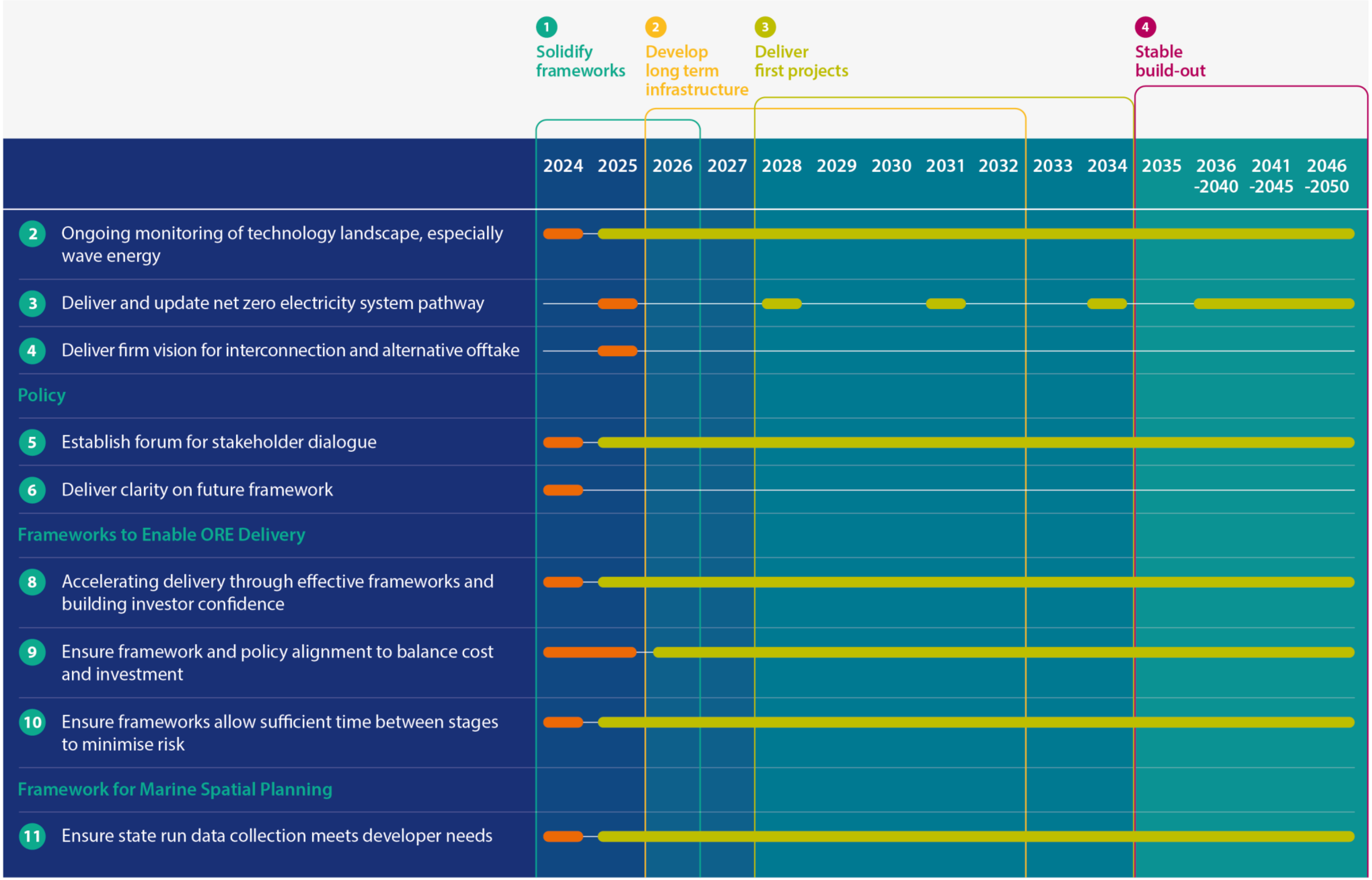
Figure C: Timed roadmap of recommendations to deliver the Government's current offshore wind ambitions



▬ Initial Deliverable
▬ Ongoing Delivery

① **Solidify frameworks**
② **Develop long term infrastructure**
③ **Deliver first projects**
④ **Stable build-out**

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036 -2040	2041 -2045	2046 -2050
Annual fixed and floating offshore wind installation rate (GW/yr)					.9	1.0	1.2	.8	1.0	1.1	1.1	1.4	1.7	2.0	2.0
Cumulative operating capacity (at end of year) (GW)	0.025	0.025	0.025	0.025	.9	1.9	3.2	4.0	4.9	6.0	7.1	8.5	17.0	27.0	37.0
Energy Strategy															
① Build ORE deployment strategy around fixed and floating offshore wind	▬														



2 Ongoing monitoring of technology landscape, especially wave energy

3 Deliver and update net zero electricity system pathway

4 Deliver firm vision for interconnection and alternative offtake

Policy

5 Establish forum for stakeholder dialogue

6 Deliver clarity on future framework

Frameworks to Enable ORE Delivery

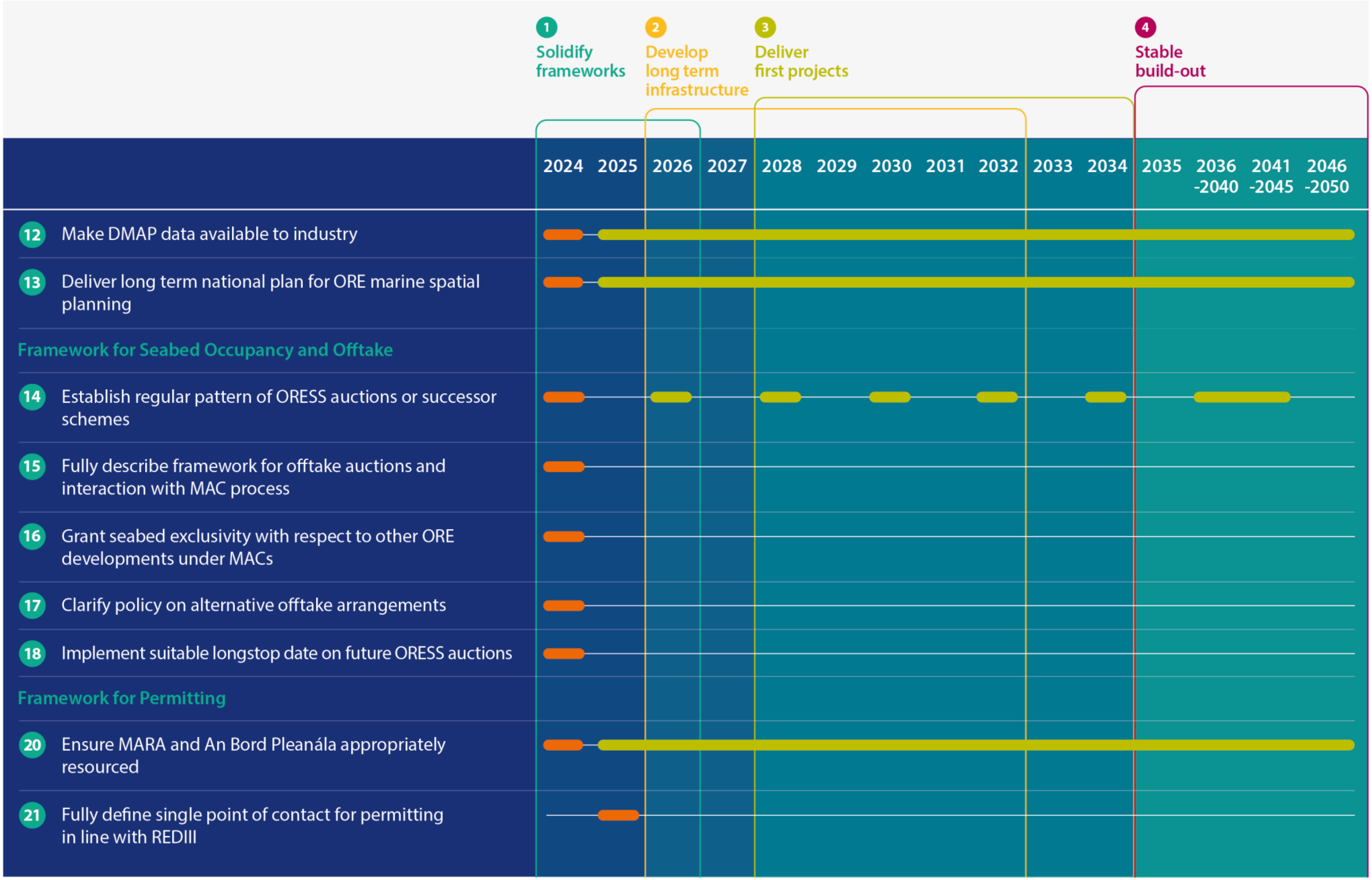
8 Accelerating delivery through effective frameworks and building investor confidence

9 Ensure framework and policy alignment to balance cost and investment

10 Ensure frameworks allow sufficient time between stages to minimise risk

Framework for Marine Spatial Planning

11 Ensure state run data collection meets developer needs



12 Make DMAP data available to industry

13 Deliver long term national plan for ORE marine spatial planning

Framework for Seabed Occupancy and Offtake

14 Establish regular pattern of ORESS auctions or successor schemes

15 Fully describe framework for offtake auctions and interaction with MAC process

16 Grant seabed exclusivity with respect to other ORE developments under MACs

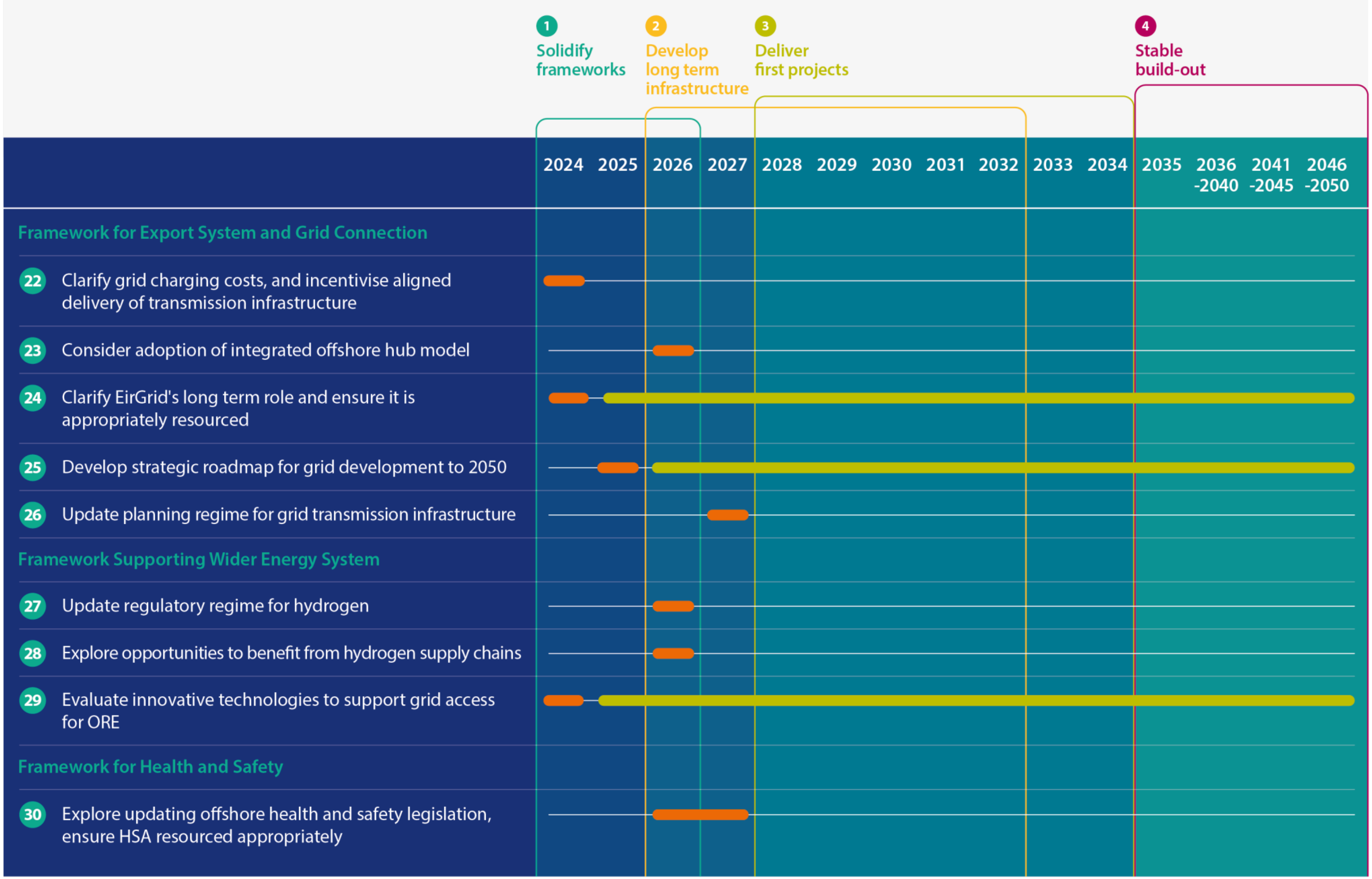
17 Clarify policy on alternative offtake arrangements

18 Implement suitable longstop date on future ORESS auctions

Framework for Permitting

20 Ensure MARA and An Bord Pleanála appropriately resourced

21 Fully define single point of contact for permitting in line with REDIII



Framework for Export System and Grid Connection

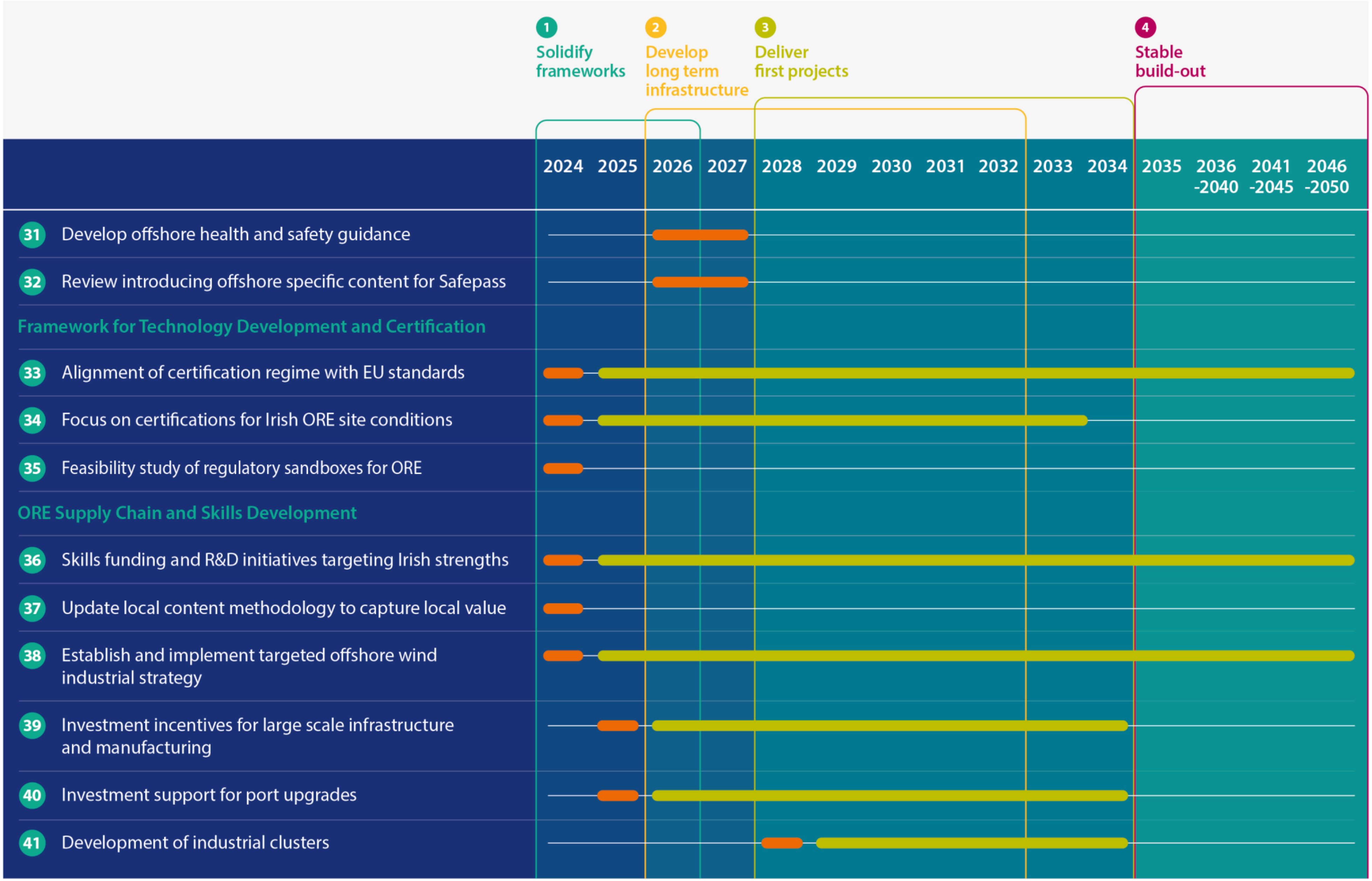
- 22 Clarify grid charging costs, and incentivise aligned delivery of transmission infrastructure
- 23 Consider adoption of integrated offshore hub model
- 24 Clarify EirGrid's long term role and ensure it is appropriately resourced
- 25 Develop strategic roadmap for grid development to 2050
- 26 Update planning regime for grid transmission infrastructure

Framework Supporting Wider Energy System

- 27 Update regulatory regime for hydrogen
- 28 Explore opportunities to benefit from hydrogen supply chains
- 29 Evaluate innovative technologies to support grid access for ORE

Framework for Health and Safety

- 30 Explore updating offshore health and safety legislation, ensure HSA resourced appropriately



31 Develop offshore health and safety guidance

32 Review introducing offshore specific content for Safepass

Framework for Technology Development and Certification

33 Alignment of certification regime with EU standards

34 Focus on certifications for Irish ORE site conditions

35 Feasibility study of regulatory sandboxes for ORE

ORE Supply Chain and Skills Development

36 Skills funding and R&D initiatives targeting Irish strengths

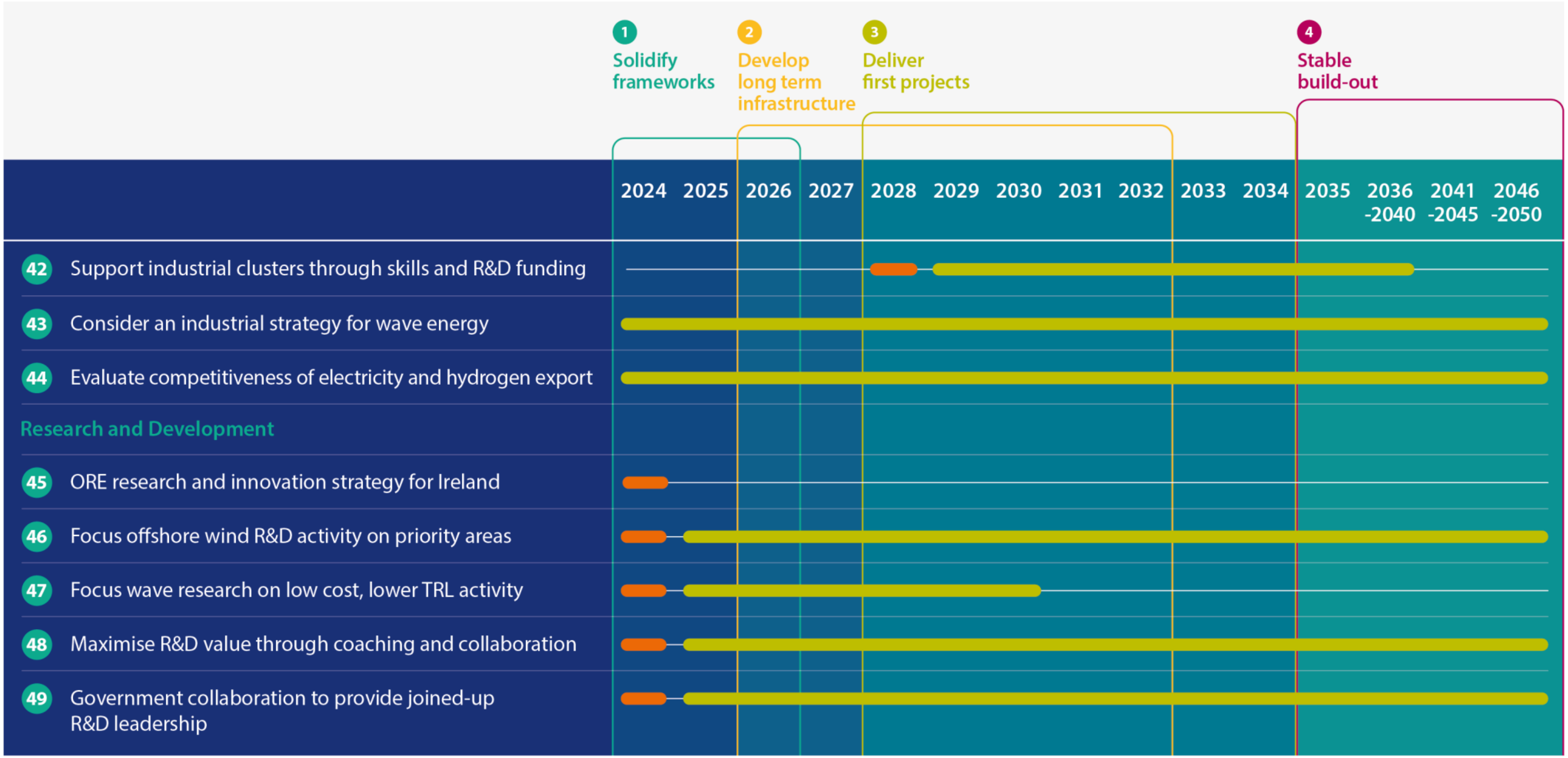
37 Update local content methodology to capture local value

38 Establish and implement targeted offshore wind industrial strategy

39 Investment incentives for large scale infrastructure and manufacturing

40 Investment support for port upgrades

41 Development of industrial clusters


① Solidify frameworks
② Develop long term infrastructure
③ Deliver first projects
④ Stable build-out
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036 -2040
2041 -2045
2046 -2050
42 Support industrial clusters through skills and R&D funding
43 Consider an industrial strategy for wave energy
44 Evaluate competitiveness of electricity and hydrogen export
Research and Development
45 ORE research and innovation strategy for Ireland
46 Focus offshore wind R&D activity on priority areas
47 Focus wave research on low cost, lower TRL activity
48 Maximise R&D value through coaching and collaboration
49 Government collaboration to provide joined-up R&D leadership

1. Introduction

1.1 View to 2050 and beyond

With a sea area seven times the size of its landmass, and with excellent wind and wave resource, Ireland is well positioned to benefit from clean, domestically produced power from ocean renewable energy (ORE) to enable its energy transition.

In the near term, Ireland has a target of having 80% of domestic electricity generated from renewable resources by 2030. This includes 5 GW coming from offshore wind, with an additional 2 GW in development, as set out in the *National Energy and Climate Plan 2021-2030*.[3] This capacity is expected to be delivered through upcoming rounds of the ORE support scheme (ORESS), the next of which, ORESS2.1, is expected to take place in 2024. In the March 2023 *Policy Statement on the Framework for Phase Two Offshore Wind*, the Ireland has established its intention to deliver ORE capacity through a centralised plan-led system, with a strategic approach to marine spatial planning. The purpose of this is to ensure strategic consideration of the impact of site selection on biodiversity, other uses of the marine environment and the electricity system as a whole at an early stage.[4]

Also in the *Policy Statement on the Framework for Phase Two Offshore Wind*, Ireland confirmed ambitious plans to deliver 37 GW of offshore wind in Irish waters by 2050. Relative to the expected progression of domestic electricity demand, these large volumes represent an opportunity for Ireland to become a significant energy exporter, in the medium to long-term, supporting the wider European energy transition.

Significant challenges must be overcome to realise Ireland's excellent ORE potential. Technology development is required to increase commercial readiness of relevant technologies, especially floating offshore wind and wave energy, and to adapt them to the particular challenges of deployment in Irish waters. There is a role for Ireland to play in driving this effort forward. Ireland has made strong progress in developing policy and frameworks to support its deployment ambitions, but further progress is required to unlock greater investment and maximise economic benefit.

This technology roadmap aims to inform the pathway to harnessing Ireland's ORE potential to drive decarbonisation of the Irish electricity system and unlock the associated economic benefits of ORE deployment. It sets out the key technologies which could play a part and the current state of technology readiness. It then outlines a series of indicative deployment pathways to 2050, and examines the necessary policy frameworks to enable them. It assesses the economic benefit associated with these pathways, and finally considers the research and research skills agenda.

1.2 Scope of the roadmap

The roadmap is structured in five further sections.

- **Section 2: Technology assessment.** This section describes the three main ORE technologies relevant to Ireland as well as a group of generation technologies either at earlier stages of technology development or less suited to deployment at scale in Irish waters. The assessment includes technology readiness, expected future development, levelized cost of energy, environmental considerations and system impacts.

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[3] Government of Ireland, (2020), *'Ireland's National Energy and Climate Plan 2021-2030'*. Available at: https://www.gov.ie/en/publication/0015c-irelands-national-energy-climate-plan-2021-2030/.

[4] Government of Ireland, (2023), *'Policy Statement on the Framework for Phase Two Offshore Wind'*. Available at: https://www.gov.ie/en/publication/f3bb6-policy-statement-on-the-framework-for-phase-two-offshore-wind/.

- **Section 3: Deployment scenarios.** This section builds on the technology assessment, presenting ORE deployment trajectories to 2050, along with required international interconnection and hydrogen production plant deployment volumes for each. Three scenarios consider the impact of increasing volumes of offshore wind, with 10 GW, 37 GW and 50 GW installed by the end of 2050, generally in line with thinking from the Department of the Environment, Climate and Communications. A fourth scenario has wave energy making a significant impact, reducing the volume of offshore wind installed by the end of 2050 by about 10%. It is not in the scope of this report to justify the viability of these scenarios, rather to use them in order to explore technology suitability, supply chain considerations and local economic benefit from local supply.
- **Section 4: Policy framework assessment.** This section considers energy strategy, policy, frameworks and delivery aspects. It starts with international practice and learning in each area, then considers the current status in Ireland and provides recommendations to support the deployment of the corresponding volumes of ORE in the different scenarios.
- **Section 5: Supply chain and local economic benefit**. This section provides gross value add and employment trajectories for Irish supply chain activities under each of the four scenarios. These are broken down by year, technology type and activity and consider the evolving opportunity for local content in each area, depending on anticipated volumes. This study does not consider wider economic impacts.
- **Section 6: Research and research skills assessment.** This section considers the current ORE research landscape in Ireland, including where there are gaps that may impact delivery of scenarios or local supply opportunities. It also provides input to an offshore renewable energy research strategy for Ireland.

At the end of Sections 2, 4, 5 and 6 are recommendations relating to the findings of that section. Each recommendation throughout the report is numbered sequentially and a full list can be found in the Executive Summary. Appendices provide background information including a summary of the technology parameters used in LCOE modelling, definitions of technology readiness and commercial readiness levels, and details of the economic assessment methodology.

1.3 The engagement process

The roadmap was developed by BVG Associates, with assistance from Beauchamps and in close collaboration with SEAI. Other stakeholders that were directly involved were:

- Commission for Regulation of Utilities (CRU)
- Department of the Environment, Climate and Communications (DECC)
- Department of Enterprise, Trade and Employment (DETE)
- Department of Housing, Local Government and Heritage (DHLGH)
- Department of Further and Higher Education, Research, Innovation and Science (DFHERIS)
- EirGrid
- Enterprise Ireland
- Foras Na Mara (The Marine Institute)
- Foreign Direct Investment Agency (IDA)
- Marine Renewables Industry Association (MRIA)
- University College Cork (UCC); and
- Wind Energy Ireland (WEI).

Key consultation points were:

- In September 2023, involving an online and in person meeting with the Offshore Wind Delivery Taskforce to present and receive feedback on the overall project scope and individual work package content.[5] A specific focus was on deployment scenarios.

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[5] The Offshore Wind Delivery Taskforce is convened by DECC and comprises senior officials from Government Departments and agencies with offshore wind related actions under the Climate Action Plan. For more information see https://www.gov.ie/en/publication/c8749-offshore-wind-delivery-taskforce/.

- In January 2024, involving a second online and in person meeting with the Offshore Wind Delivery Taskforce to present and receive feedback on findings across the work packages. A specific focus at this meeting was on key messages and recommendations.

Attendees at these meetings received pre-reads with material and provided feedback both in the meetings and verbally and in writing after the meeting. Input was then incorporated into the roadmap in consultation with SEAI.

2. Technology assessment

2.1 Introduction

This section describes the three main ocean renewable energy (ORE) technologies relevant to Ireland as well as a group of technologies either at earlier stages of technology development or less suited to deployment at scale in Irish waters as summarised in *Table 1*. These are considered in the context of the future decarbonisation scenarios described in Section 3.

Technology readiness level (TRL) and commercial readiness index (CRI) metrics provide a measure of the maturity of technology types. Recognised scales are summarised in Appendix B.

Levelized cost of energy (LCOE)[6] is a good way to compare the cost of a unit of energy produced by different technologies, although it does not account for issues such as intermittency and predictability which can impact overall value of a technology to the electricity system.

Sub-sections below consider each ORE technology listed, then key cross-cutting technology development themes relevant to all ORE technologies.

Table 1: Summary of ocean renewable energy technologies relevant to Ireland

	Fixed offshore wind	**Floating offshore wind**	**Wave**	**Other ocean renewable energy technologies**
Most modern technology under construction / in operation	• Commercial 1 GW+ projects • 13 MW turbines	• Demonstration 0.1 GW projects • 8 MW turbines	• Single product demonstrations • Up to 0.5 MW devices	• Tidal barrage is the most mature offshore technology (250 MW) • Inland floating solar has commercial 1 GW+ projects
Technical and commercial readiness level now	• TRL 9 (highest) CRI 6 (highest)	• TRL 9 (highest) CRI 2 (highest)	• TRL 9 (highest), most at TRL 5-7 CRI 2 (highest)	• Tidal barrage is at TRL 9, CRI 4 • Other technologies are at TRL 7-9, CRI 1-2

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[6] LCOE is the revenue required (from whatever source) to earn a rate of return on investment equal to the weighted average cost of capital (WACC) over the life of the wind farm. Tax and inflation are not modelled. In other words, it is the lifetime average cost for the energy produced, quoted in today's prices. LCOE is used to evaluate and compare the cost of electricity production from different technologies and at different locations.

	Fixed offshore wind	**Floating offshore wind**	**Wave**	**Other ocean renewable energy technologies**
Key future developments[7]	• Larger turbines • Increased turbine reliability and maintainability • More optimised foundations in deeper waters • Lower cost export system • More optimised offshore operations	As fixed offshore wind (bullets 1, 2, 4, 5), plus: • Refinement of concepts • Industrialisation of hull manufacturing • Improvements to dynamic cable systems • Improvements to mooring and anchoring systems • Development of new installation, operation and maintenance methods	• Concept convergence • Economies of device and project scale • Economies of industry scale • Design optimisation • Co-location with offshore wind	• Depends on technology, but generally the same as wave (1-4), except in the case of tidal barrage
Headline LCOE for a new project installed in Ireland in 2050	• €30 /MWh to €60 / MWh	• €35 /MWh to €70 / MWh	• €35 /MWh to €230 / MWh	• Wide range, with significant uncertainty
Main environmental considerations	• Avian (during operation) • Pelagic, cetacean and benthic (during installation) • Visual and landscape (during operation) • Pollution due to increased vessel traffic, risk of spillage • Coastal and onshore impact due to export cables and substation.	• Similar to fixed offshore wind, with variations due to different technical characteristics, suitable locations and installation methods.	• Marine life (during installation and operation) • Pollution due to increased vessel traffic, risk of spillage • Coastal and onshore impact due to export cables and substation.	• Depends on technology, with tidal barrages having the greatest potential impact

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[7] In addition to technology specific key future developments, cross cutting developments which apply across all technologies such as advanced manufacturing, big data, AI, robotics and internet of things are discussed in Section 2.6.

	Fixed offshore wind	**Floating offshore wind**	**Wave**	**Other ocean renewable energy technologies**
System impacts	• Average capacity factor up to about 60%, fairly predictable days ahead • Strong seasonal pattern; weak daily pattern, significant periods of low generation	• Similar to fixed offshore wind, but with potential for wider geographic spread and average capacity factor up to about 65%	• Similar to fixed offshore wind, but more predictable, slower to change, lower average capacity factor and greater seasonal variation	• Depends on technology, with tidal having the benefit of long-term predictability
Potential in Ireland	• Ireland enjoys excellent wind speeds but shallow water required for deployment of fixed offshore wind is somewhat limited.	• Ireland has excellent wind speeds and ample deep water deployment sites to deploy a large floating offshore wind fleet.	• Ireland has strong wave resource and numerous suitable sites. If costs can be driven down, wave could play a significant role in the energy mix.	• Airborne wind has best long-term potential in Ireland if technology develops. • Offshore floating solar, tidal stream and tidal barrage have limited suitable sites in Ireland. • Other technologies are unlikely to impact significantly.
Anticipated volume in Ireland 2050	• 26 TWh (scenario 1) to 43 TWh (scenarios 2 to 4)	• 15 TWh (scenario 1) to 193 TWh (scenario 4)	• 0.5 TWh (scenarios 1-3) to 14 TWh (scenario 4)	• Up to 0.3 TWh (scenario 4)

2.2 Fixed offshore wind

2.2.1 What is it?

Fixed offshore wind projects are those using wind turbines on monopile, jacket or gravity-base foundations fixed to the seabed. To date, fixed projects have been installed in water depths of up to 60 m, but maximum depths will likely continue to increase for at least the next decade, as discussed in Section 2.2.3. The first wind energy projects were installed in the 1990s with turbines designed for onshore use, but by the early 2010s, turbine suppliers were providing offshore-specific models.

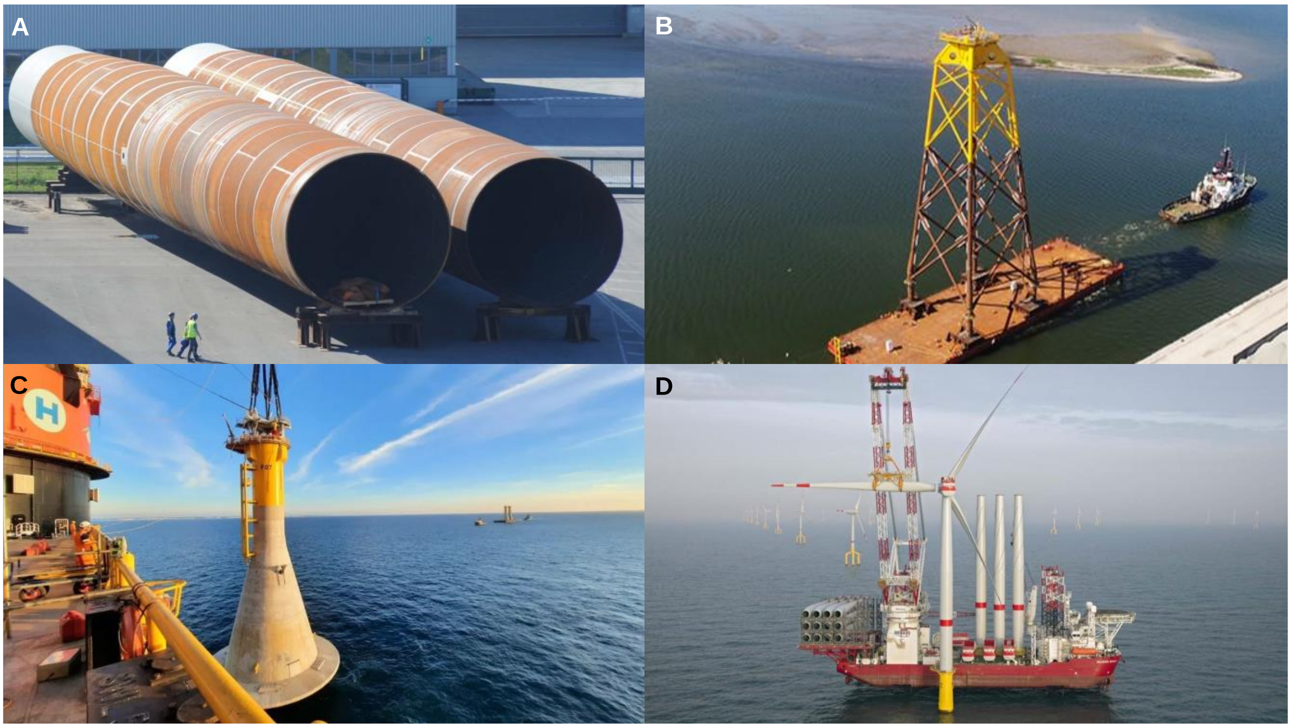
Table 2 summarises the characteristics of a typical fixed offshore wind project reaching operation between 2022 and 2024, considering the global market, based on weighted averages for each value from BVG Associates' market intelligence database.

Table 2: Characteristics of a typical fixed offshore wind project reaching operation between 2022 and 2024, considering global market

Parameter	Value
Water depth (m)	33
Mean wind speed (at 100 m height) (m/s)	9.1
Distance from shore[8] (km)	30
Turbine rating (MW)	8.5
Rotor diameter (m)	157
Project size (MW)	410
Project lifetime (years)	30

Figure 1 shows the three main foundation types for fixed offshore wind and a jack-up vessel used in wind turbine installation in fixed offshore wind.

Figure 1: Typical monopile (A), jacket (B) and concrete gravity base foundation (C) and turbine installation vessel (D). Courtesy of EEW SPC, Bladt Industries, Heerema Marine Contractors and Seajacks



The installation process varies for each project. The typical order of installation (with some overlap) is generally:

- Foundations

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[8] Most relevant is distance to construction / operation port / distance from grid, but such data is less available.

- Array cables
- Offshore and onshore substations
- Export cables; and
- Turbines.

More details of the full lifecycle of a fixed offshore wind project are available in the *Building Offshore Wind in Ireland* online tool.[9]

2.2.2 Readiness

The fixed offshore wind market is fully commercial. Worldwide, there is approximately 62 GW operational fixed offshore wind in about 250 projects operating in 16 national markets. A further 214 GW has been awarded exclusive rights for development.

In Ireland, the only project in operation is the 25 MW Arklow Bank phase 1 project, a small project of 7 turbines, installed in 2004. A further 3.1 GW offshore wind energy has been awarded an offtake agreement through ORESS 1.[10]

Fixed offshore wind has TRL 9 and CRI 6 in accordance with Appendix B.

There is a pipeline of technology innovations in fixed offshore wind at a range of TRLs and CRIs that are reducing LCOE. These are supported by public and private investment. Many innovations are relevant to all markets, though some are specific to a subset of markets, for instance increased typhoon or earthquake resistance.

Bottlenecks in the development of emerging markets for fixed offshore wind generally relate to market rather than technology considerations. Market considerations include establishing energy strategy, policy and frameworks for offshore wind development, including marine spatial planning, leasing, permitting and revenue mechanisms. In some areas, such as wind turbine installation vessels, the supply chain could limit growth as it may not keep up with current anticipated growth in demand. There is also a need for continued investment in new vessels, components and infrastructure capable of handling increasingly large turbines, which can also create supply chain bottlenecks.

Any such bottlenecks can impact nationally, regionally or globally (depending on market dynamics). For example, construction ports have to be relatively local to projects, so the market for construction ports is typically seen as national (though Irish east coast projects could use UK ports, like UK projects have used ports in Denmark and Netherlands for construction). At the other end of the scale, subsea cables are easily transportable so can be manufactured a long way from the project, meaning that there is a global supply for global demand. Market dynamics for subsea cables are also impacted by activity in other infrastructure sectors.

Industry recognises that countries with strong pipelines, frameworks attractive to project developers and local suppliers will be less impacted by supply chain bottlenecks, as limited supply is likely to be concentrated on such markets.

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[9] BVG Associates, Gavin and Doherty Geosolutions and Beauchamps on behalf of Green Tech Skillnet and Wind Energy Ireland, (2024). Available at: https://offshore-wind.ie/.

[10] EirGrid, (2023), *'Renewable Electricity Support Scheme'*. Available at: https://www.eirgridgroup.com/site-files/library/EirGrid/ORESS-1-Final-Auction-Results-(OR1FAR).pdf.

2.2.3 Expected future developments

Fixed offshore wind technology is by far the most mature of the technologies assessed. It has established a place in the current and future renewable energy mix, making up 11% of the new wind farm capacity installed globally in 2022.[11]

Over recent years, large fixed offshore wind projects have been progressed effectively 'subsidy free' in a range of established markets with good wind conditions.[12] LCOE has reduced to being lower than many onshore wind projects constrained in size by environmental and social considerations.

As markets consider their route to zero carbon energy systems, offshore wind is seen as attractive also due to the scale of development possible within exclusive economic zones, especially where onshore renewable energy opportunities are constrained.

The key drivers for fixed offshore wind are shallow-enough waters, coupled with strong wind resource. Projects in established markets so far have a mean wind speed of about 9 m/s at 100 m height, but some projects in emerging markets have mean wind speeds as low as about 7.5 m/s. This trend is in line with that seen previously in onshore wind, with projects with even lower mean wind speeds made viable due to the development of turbine models with relatively larger rotors which are optimised for such sites. This product trend is also likely in offshore wind as volumes increase. Ireland has above market average mean wind speeds, in the range 10 to 12 m/s.

Key areas of future technology development are:
- Larger turbines, including knock-on consequences elsewhere in the supply chain.
- Increased turbine reliability and maintainability.
- More optimised foundations in deeper waters.
- Lower cost export system and higher voltage array cables.
- More optimised offshore operations.

Each is explored further, below. Key cross-cutting technology development themes relevant to all ORE technologies are covered in Section 2.6.

Larger turbines

It was in the early 2010s that wind turbine suppliers started supplying turbines designed specifically for offshore wind, and since then there has been a growing gap between the typical scale of onshore and offshore wind turbines available on the market. Since then, there has been a rapid increase in average turbine rating installed, year-on-year, both in established and emerging markets, as shown in *Figure 2*. Annual variations in the trends are due to the characteristics of the projects installed in any given year.

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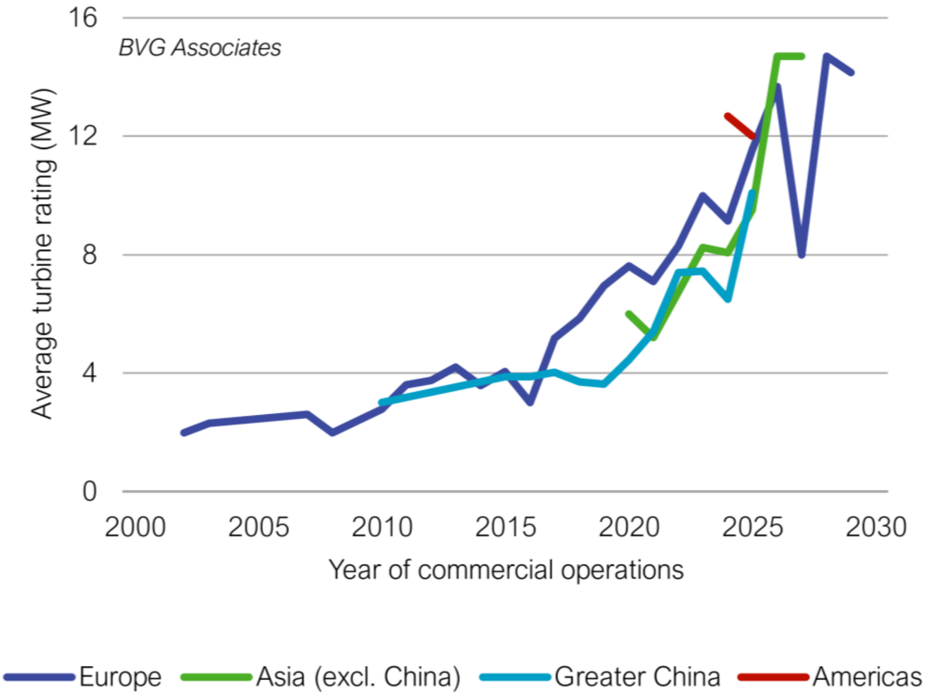
[11] Global Wind Energy Council, (2023), *'Global Wind Report'*. Available at: https://gwec.net/globalwindreport2023/.

[12] 'Subsidy free' meaning that power purchase contracts are at revenues no higher than anticipated wholesale power revenues.

Figure 2: Trend in average offshore wind turbine rating with year of commercial operations of projects



This trend is driven by a significant reduction in LCOE with increased turbine rating, driven mainly by:[13]

- Decreases in foundation and installation costs per MW.
- Decreases in operational cost per MW.
- Increases in hub height, driving increases in energy production per MW.

In line with long-term trends, the benefits of further significant increases in turbine scale are likely to be somewhat reduced and the challenges of scale-up increased. This means that at some point, smaller incremental development may replace the large steps in scale (for example, 30% increase in turbine rating) seen every few years, to date.[14] The key challenges relate to:

- New turbine product development costs, which could reach €1 billion for next generation products.
- Supply chain investment for the supply of such large components (including bearings, blades and castings, where the wind industry is already a leading purchaser and driver of scale).
- Supply chain investment for the installation and service of turbines and associated foundations (including very large, specialist jack-up vessels).

Increased turbine reliability and maintainability

Other key drivers of reducing LCOE are increasing reliability (fewer faults and failures) and increasing maintainability (easier inspections, repairs and replacements). Published statistics relating to reliability are limited, and the introduction of new products and technologies introduces new risks and uncertainties. The

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[13] A detailed discussion of drivers is provided in Section 6.3 of *Offshore wind cost reduction pathways: Technology work stream*, https://bvgassociates.com/download/1617/?tmstv=1689254339.

[14] A large step in turbine rated power is typically when a turbine supplier develops a new turbine platform (a new nacelle frame size that will be used for a number of turbine variants). This is typically in response to market competition and is expensive (including design, testing, demonstration and its own manufacturing scale-up needed). Turbine variants may involve small increases in rated power or rotor diameter, enabled by operational experience and technology development. At some point, the additional benefit of the next new turbine platforms is likely to decrease to the point where there is greater benefit to industry in staying with existing platforms and putting more available investment into scaling up supply volumes to meet global demand. The dynamics of this balance are complex, as they relate to individual suppliers' competitive positions within the industry, as well as the industry as a whole.

System Performance, Availability and Reliability Trend Analysis (SPARTA) collaboration releases annual reports relating to a subset of the UK offshore wind fleet, but the effects of continual updates to the portfolio of projects considered and the reluctance of turbine suppliers and project developers to release detailed data means that robust trends are difficult to extract.

More optimised foundations in deeper waters

Typically, fixed projects have been planned in waters of up to about 60 m but the trend in maximum water depth is increasing over time, as shown in *Figure* 3*,* as understanding about turbine and foundation loading, structure-soil interaction and overall turbine-foundation system dynamics and control continues to improve. In addition, innovations in manufacturing (for example electron beam welding) and installation (further increasing weather windows and process efficiency and decreasing noise) also enable cost effective fixed-foundation solutions in deeper water.[15] In time, fixed projects in water depths of 80 m or even more could be installed where shallower sites are not available or have other considerations that make them less attractive. Limits to the depths that fixed foundations can be used are economic, rather than technical. The oil and gas industry has installed over 100 jacket foundations in the UK North Sea in depths greater than 75 m, with some in depths over 150 m, but the economics of oil and gas activity is quite different to in offshore wind. In oil and gas, capital expenditure (CAPEX) is less of a driver of project economics than in offshore wind, where it dominates LCOE.

About 62% of fixed foundations installed to date have been monopiles, with this percentage expected to increase over the rest of this decade.[16] Monopiles are the simplest foundation structure and typically have the lowest installation cost in most good ground conditions. Jacket and gravity base structures each have 'sweet spots', (in terms of ground conditions, commodity costs and supply chain availability). Jacket foundations in particular may be suitable for use in Ireland at transitional depths of 60 to 80m where typically the most cost effective solution changes to from monopiles to jackets.

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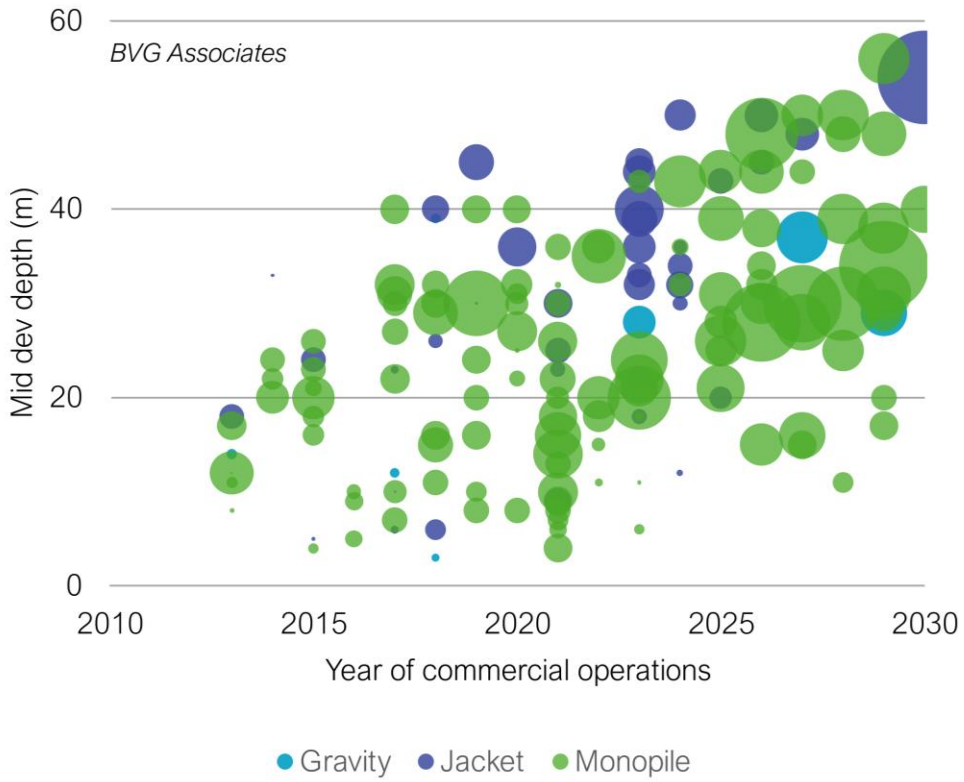
[15] 10 to 15 years ago, industry anticipated the use of monopiles to depths of only about 25 m, with jacket foundations used above this, Floating offshore wind was a distant possibility. As time has passed, the threshold depth between use of monopiles and jackets has increased significantly, based on economic considerations. At the same time, the threshold depth between the use of fixed and floating foundations has also increased. Such trends are typical in the wind industry, with significant effort spent advancing incumbent technology, typically offering lower risk and easier route to market. How far such trends go is hard to predict, as the economic balance can be quite fine and have many driving factors.

[16] Based on BVG Associates in-house database of existing and future planned projects.

Figure 3: Trend in known foundation type with year of commercial operations of projects. Bubble size indicates project size (GW)



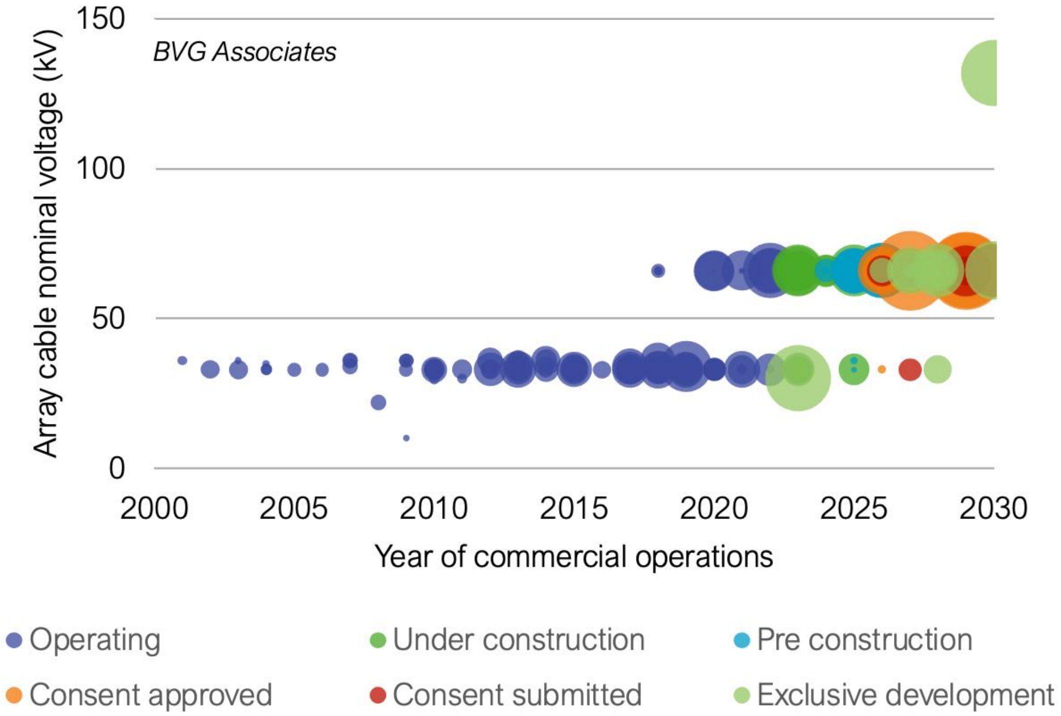
At one time, most foundations were installed using jack-up vessels, but now most are installed using floating vessels, reducing cycle time and cost in locations with suitable metocean conditions. Key areas of future innovation are in:

- Control of turbine-foundation system dynamics to reduce loads and hence structural mass.
- Design optimisation for specific locations, minimising unnecessary margins.
- Concept optimisation, especially relating to secondary steel (the move from separate transition pieces supporting access platforms, grouted into position to bolted or integrated arrangements).
- Manufacturing processes, including in automated welding of thick steel plates.
- Optimised installation, including with respect to minimising impact on biodiversity.

Lower cost export system and higher voltage array cables

The key changes in array cables between turbines in recent years have been driven by increased turbine scale and commodity prices. Turbines with increased rating drive up optimum voltage, resulting in a change of cable and switchgear rating from 33 kV to 66 kV in recent years, with a further step to 132 kV in development. *Figure 4* shows this trend in array cable voltage over time. The relative cost of copper and aluminium drives choices in cable design.

Figure 4: Trend in array cable voltage with year of commercial operations of projects. Bubble size indicates project size (GW)



Export cable design is driven by project power rating and export distance, with the dividing line between the optimum solution between high voltage alternating current (HVAC) and high voltage direct current (HVDC) influenced by a range of factors in recent years.[17] Eventually, the falling costs of HVDC converters, the development of larger projects and the increased ability to network HVDC systems will drive an increased use of HVDC export systems in a growing international mesh. The trend of use of HVAC and HVDC systems is shown in *Figure 5*.

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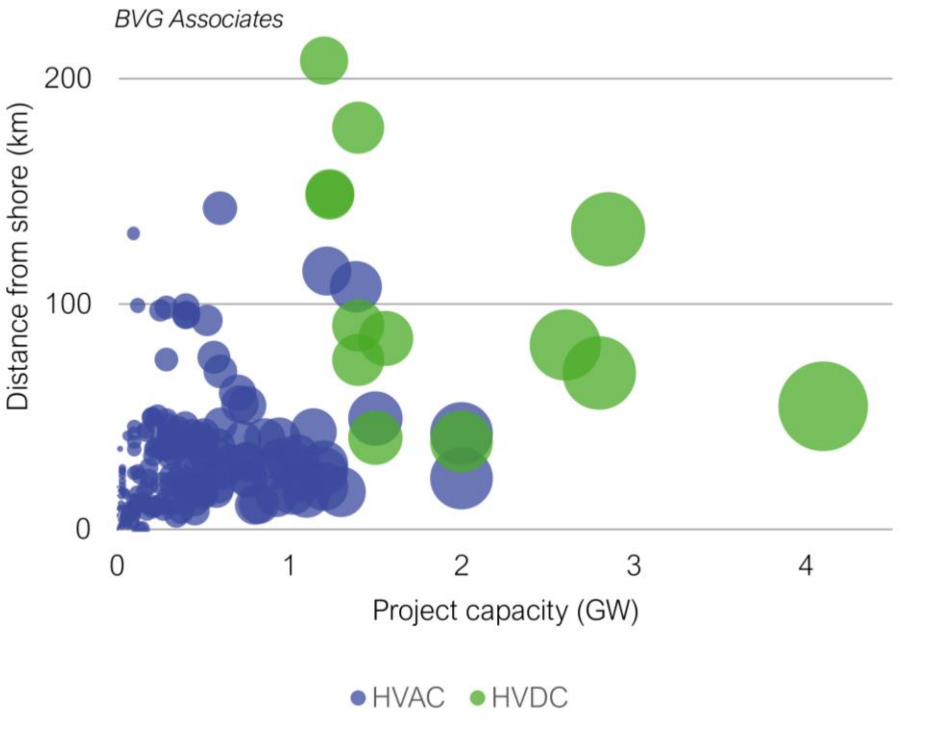
[17] As discussed with foundations, the wind industry has continued to find ways to address challenges with incumbent technology (in this case HVAC), increasing its envelope of use (to longer connections), rather than switching to alternatives. The economic balance is mainly between higher cost cables and grid stability challenges) for an HVAC system compared to higher cost substations at each end of an HVDC system. As the length of the grid connection increases, the optimum solution changes from HVAC to HVDC. This balance is impacted by innovation in either technology. An example of this for Hornsea 1 project was the use of a reactive power compensation station midway from the project to shore to decrease losses and improve grid stability of the HVAC system, making this more attractive. Another consideration for export systems is lead time for key components, as these can be on the critical path for a wind farm. HVAC components typically have lower lead time, including design, manufacture and testing. A future consideration will be the development of rare-earth high-temperature superconducting cables, with no losses apart from for auxiliary equipment to keep the at below 77 K (the boiling point of liquid nitrogen).

Figure 5: Trend in export system design with project capacity and distance from shore for fixed offshore wind projects. Bubble size also indicates project capacity (GW); existing and planned projects



More optimised offshore operations

Another key area of innovation is in wind farm operations – how the project is looked after during its operational life. Beyond the use of innovations covered in the future technology development themes relevant to many industries, key trends are in:

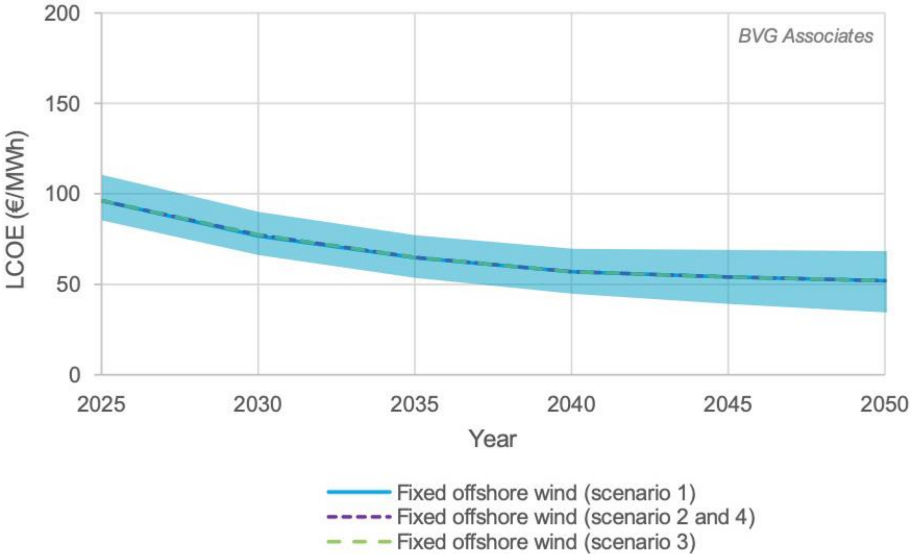
- Transition from use of crew transfer vessels (CTVs) travelling from port and requiring crew to jump/step across to turbines to service operation vessels (SOVs) staying at sea for weeks and with walk-to-work access systems. Although SOVs are more expensive to operate, they offer increased weather windows for accessing turbines, much reduced transit times for projects further from shore and a wider range of tools, consumables and spare parts than on CTVs.
- A gradual move from time-based (scheduled) maintenance to increased health monitoring / prognostics and risk-based maintenance. Wind turbines have significant health checking embedded in their control systems. Offshore turbines typically also have separate condition monitoring on main components in order to provide early warning of possible failure. This enables proactive service interventions, component exchange in low-wind times and times of reduced output operation to maximise revenue whilst waiting for spare parts.
- Innovations in digital operation and maintenance (O&M) methods and robotic maintenance to minimise the need for manned maintenance visits, improve the repeatability of work and reduce health and safety risks.
- A move to vessels powered by alternatives other than fuel oil, so hybrids with batteries, hydrogen or derivative e-fuels, thereby reducing local pollution and carbon footprint.

2.2.4 Levelized cost of energy

The projection for LCOE for fixed offshore wind in Ireland to 2050 is shown in *Figure 6* for typical site conditions in Ireland, summarised in Appendix A. The band indicates an uncertainty range regarding global technology and other industry progress, assuming consistent macroeconomic conditions. Assumptions in Section 5.3 regarding local content have been considered, along with the technology and supply chain drivers for LCOE reduction described in Section 2.2.3. The figure shows that in all scenarios, LCOE falls by just under 50% during the period 2025 to 2050 (by about one third from 2030 to 2050) on the back of high volumes of global activity. The size of the Irish market has negligible impact on the rate of change of LCOE, as differences in Irish content has little impact on LCOE. This is because levels of Irish content are relatively low and the alternative, to import from elsewhere in Europe, does not introduce a significant price difference.

LCOE estimates include approximate adjustments to account for the impact of relevant Irish metocean conditions on activities during installation and operation.

Figure 6: Trend in levelized cost of energy for fixed offshore wind with year of project commercial operation, under typical Irish conditions



2.2.5 Environmental considerations

The main environmental considerations for offshore wind:

- **Impact on birds:** Offshore wind farms can impact birds, both through collisions with turbines and disturbance of feeding grounds. This is also a concern for migratory birds with offshore wind farms in migration paths.
- **Impact on marine life:** Offshore wind farms can also impact marine life though noise and seabed disturbance during installation and then through noise and increased vessel movement during operation. Restrictions on seasons for installation can reduce the impact on fish spawning ground and cetacean (whale and dolphin) activity. In some projects, careful habitat management (including via artificial reefs) has led to local bio-positive impacts.[18] Various projects have now introduced bio-positive measures to improve local biodiversity, for example by careful design of scour protection materials to provide better quality artificial reefs than just through rock dumping, and the introduction of artificial reefs between turbines to help establish transit corridors for inhabitants. Noise disturbance can also be reduced through mitigation measures such as bubble curtains and vibro-piling.
- **Visual and landscape impact:** Offshore wind farms may be visible from the coast and can potentially impact the aesthetic value of coastal landscapes. Public perception of the visual impact is an important consideration, particularly in areas of high scenic value or where tourism is a significant economic driver. This can relate also to onshore works, such as substations. In some locations, visits to wind farms have become a tourist attraction.
- **Pollution:** Although offshore wind farms generate electricity with much lower carbon intensity than fossil fuels, they still contribute carbon dioxide to the atmosphere through use of fossil fuels in construction and operation. Pollution contribution, through the release of contaminants from seabed sediments, from

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[18] Ørsted, (2023), *'Uniting action on climate and biodiversity: How the green energy transition can address both crises'*. Available at: https://orsted.com/en/insights/white-papers/uniting-action-on-climate-and-biodiversity.

increased vessel traffic and risk of spillage of liquids (including oils and greases) also requires mitigation.[19]

- **Coastal and onshore impact:** The electrical export system for any ORE project typically has to come ashore and then connect to the transmission network via an onshore substation. Coastal areas are often important, dynamic habitats so careful route planning and sometimes underground horizonal directional drilling is required to manage local impact to flora and fauna. Social considerations relating to disruption due to cable installation and substation construction are also relevant to take into account.

Separate from these considerations are further social and technical considerations including navigation and shipping, fishing, aircraft and radar and military zones. In addition, special areas of conservation exist in Irish coastal areas which require special protection. The Maritime Area Planning Act, 2021 (MAP Act), and the National Marine Planning Framework require that these environmental, social and technical considerations be taken into account in the development of Designated Maritime Area Plans. [20] [21] In some cases, measures may be available to mitigate environmental or social impacts. Such measures are sometimes included as conditions of permits.

Fishing within fixed offshore wind installations is restricted in many jurisdictions, and there is evidence that offshore wind farms can act as safe havens, increasing biodiversity and improving stocks of certain species in the vicinity.[22] Multi-use arrangements, allowing fishing to take place have also been implemented, including in the UK. This shows that, depending on the form of fishing, continuation of fishing among wind farms is possible.[23]

2.2.6 System impacts

Energy production varies depending on mean wind speed and wind farm availability at the time. Availability is the fraction of time that individual turbines and the export system are fault-free, enabling generation and export of energy. This is impacted by the reliability of these technologies and the time to repair faults that occur. The greatest variation is due to mean wind speed, driving changes between successive years and in seasonal (and less so, daily) patterns. The larger the portfolio of projects and geographical spread, the lower the variation and the higher the predictability of energy production. It is anticipated that Ireland will develop mix of east, south and west coast fixed and floating offshore wind projects, separated by up to about 500 km due to the geography of Ireland.[24]

Studies of the system impact of offshore wind in Ireland are limited, and it is recognised that unless studies consider other source of supply and the dynamics of demand, looking ten to 20 years ahead to when volumes are significant, it is hard to derive useful results.

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[19] Fossil fuels release on average 500 metric tons of CO_2 per GWh of electricity generated. Offshore wind releases on average about 1-2% of this. Analysis has found that an offshore wind farm pays back the carbon produced during construction within 7.4 months of the start of operation. The life of an offshore wind farm is likely to be 30 years or more. For more details, see Section 7.1 of World Bank. 2022. *Offshore Wind Roadmap for the Philippines*. Washington, DC: World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/37429 License: CC BY 3.0 IGO.

[20] Government of Ireland, (2021), *'Maritime Area Planning Act 2021'*. Available at: https://www.irishstatutebook.ie/eli/2021/act/50/enacted/en/html.

[21] Official Journal of the European Union, (2014), *'Directive 2014/89/EU of the European Parliament and of The Council'*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014L0089.

[22] Hooper, T and Austen, M, (2014), 'The co-location of offshore windfarms and decapod fisheries in the UK: Constraints and opportunities', *Marine Policy*. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0308597X13001371.

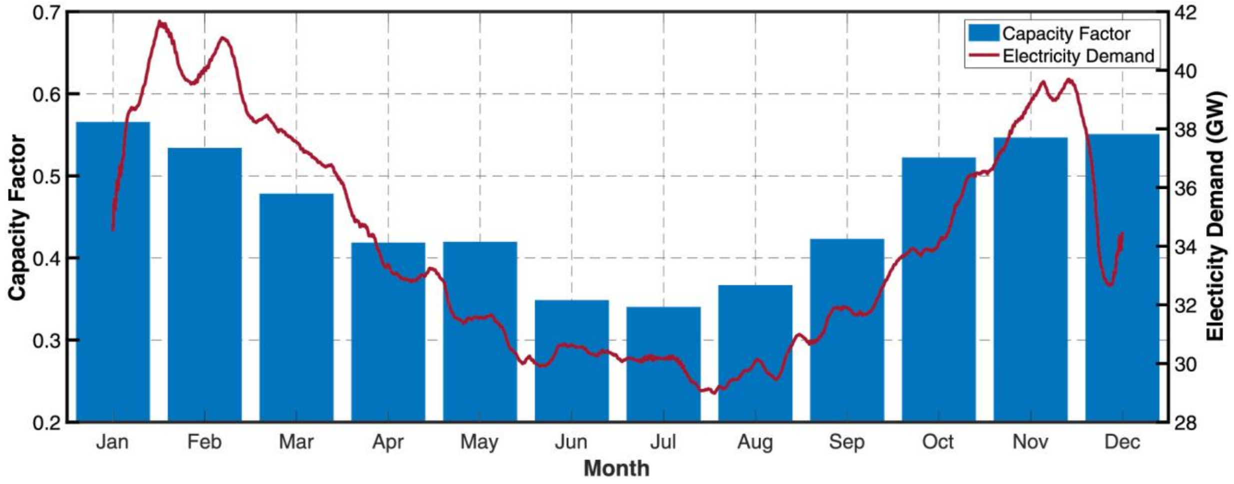
[23] NFFO on behalf of The Crown Estate, (2014), *'Changes to Fishing Practices Around the UK as a Result of the Development of Offshore Windfarms – Phase 1 (Revised)'*. Available at: https://www.thecrownestate.co.uk/media/2600/final-published-ow-fishing-revised-aug-2016-clean.pdf.

[24] There is logic to Ireland first building projects to the east and south, then moving to the deeper, harsher conditions in the Atlantic ocean to the west. By the time projects have been built in all these areas, there will be a fair geographical separation, smoothing energy production from offshore wind.

Looking at data available now, there has been much more analysis of variability of offshore wind energy production in UK, as the volume of offshore wind is so much greater. Due to the proximity of Ireland, insights can still be obtained in advance of more detailed system impact modelling in Ireland. Relevant considerations are:

- **Inter-annual variability.** Variations in annual generation due to differences in annual wind resource in UK are characterised by a standard deviation of 4 to 5%.[25,26] Variations due to reliability are less significant. In many markets, there are significant increases in generation each year due to new projects being installed.
- **Seasonal variability.** Variations in seasonal generation again are due to variations in wind resource. In the UK, there is a correlation between average monthly offshore wind output and demand, as shown in *Figure 7* (note axes do not start at zero). Energy production in the three summer months with lowest capacity factors is about 63% of that in the three winter months with the highest capacity factors. As capacity factors rise for future projects, this fraction is likely to increase slightly. Offshore wind generation therefore fits well in Ireland where power demand and prices currently tend to peak in the winter months.

Figure 7: Seasonal variation of offshore wind energy production compared to average UK electricity demand between 2011 and 2017[25]



- **Diurnal (daily) trends.** In Ireland and UK, these are less significant, but also less correlated with demand, as shown in
- ***Figure 8*** (note axes do not start at zero).

Figure 8: Diurnal variation of capacity factor by season compared to average UK electricity demand from 2011 to 2017 [25]

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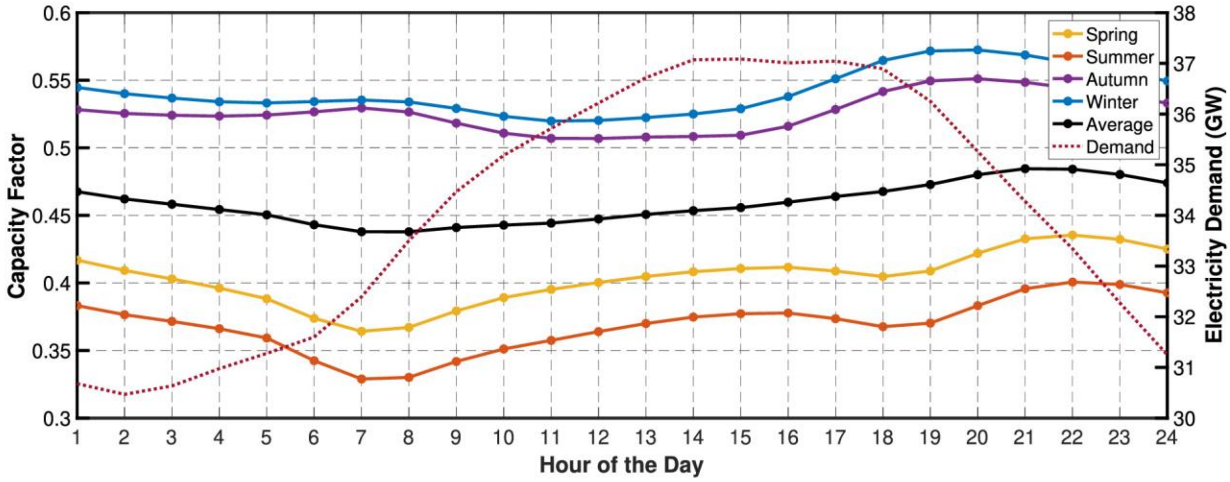
[25] Potisomporn, P and Vogel, C, (2021), 'Spatial and temporal variability characteristics of offshore wind energy in the United Kingdom', *Wind Energy*. Available at: https://onlinelibrary.wiley.com/doi/full/10.1002/we.2685.

[26] DNV on behalf of The Crown Estate, (2016), *'Study on UK offshore wind variability'*. Available at: https://www.thecrownestate.co.uk/media/1772/uk-offshore-wind-variability.pdf.



- **Low generation events.** For energy security of supply, it is important to consider how long a period of low (or no) generation could last, across a portfolio of projects. Any lengthy periods are due to low winds below the operating envelope (rather than high winds above the operating envelope). The likelihood of prolonged periods of reduced wind energy production depends on the selected capacity factor threshold. During the period 2000 to 2017, analysis shows that in the UK, 17% of day-long periods had average portfolio capacity factor below 20%. This drops to less than 1% of 16 day-long periods. [25] In other words, low wind periods can impact generation in the short run, but it is a rare to see a sustained period of low generation over a longer timeframe.

The challenge of variability and persistently low offshore wind production therefore is likely to be a significant factor when considering requirements for alternative generation and energy storage solutions in systems with high penetration of offshore wind in Ireland. Whilst many have anecdotal evidence about low- and high-wind periods, ultimately, a statistical approach is needed to design and implement any energy system with a combination of generating and storage technologies and demand management solutions. This is best achieved at the largest-scale system possible and will be an important consideration in defining future research priorities and designing policies and frameworks enabling a rapid but controlled build out of ORE in Ireland.

2.3 Floating offshore wind

2.3.1 What is it?

Floating wind projects use turbines mounted on floating hulls, attached to the seabed through mooring systems and anchors. So far, the same turbines as for fixed offshore wind have been used, except for changes in tower design and control systems to account for different loading patterns. Key hardware differentiators are the floating foundation on which the turbine is mounted, the mooring and anchoring systems used to tether the turbine to the seabed, and the dynamic array cables used to export power to the substation. Further differentiators are in approaches to transport, installation and operations and maintenance.

The key advantage of floating offshore wind over fixed is its ability to deploy in deeper waters, thereby increasing the opportunity for offshore wind. This enables access to areas of higher wind resource, for instance off the west coast of Ireland. The maximum economic water depth for fixed offshore wind is unlikely to significantly exceed 80 m (as discussed in Section 2.2), beyond which floating is likely to be preferred. Floating offshore wind can theoretically be deployed in water depths in excess of 1 km, though costs are likely to rise somewhat as water depth increases. Changes in cost due to depths such as 1 km are not yet well understood, as only one project using commercial-scale turbines and in water deeper than 140 m has progressed to construction so far. This is in 300 m water depth. Although the oil and gas industry has installed in deeper water, there are enough differences between applications for much uncertainty to remain.

Floating offshore wind technology is much less well established than fixed, having a total global installed capacity of less than 300 MW at the time of writing, compared to more than 50 GW of fixed bottom wind. Only a handful of small multi-turbine projects have been installed worldwide, and so the technology has yet to benefit from:

- Much innovation in terms of both hardware (especially floating hull, mooring and anchors) and process design (especially installation and large component exchange).
- The economies of scale and associated efficiency gains from industrialisation of the supply chain.
- The learning-by-doing which have helped fixed bottom LCOEs reach competitiveness with onshore renewables.

As a result, the LCOE of floating offshore wind projects is currently significantly greater than that of fixed offshore wind projects, though costs are expected to fall.

Given the extensive deep-water area in Ireland's maritime area with high wind resource, floating offshore wind provides a significant opportunity for the Irish energy sector. To grow the offshore wind industry beyond 10 GW in Ireland, floating offshore wind will need to be deployed off the Irish coasts. Three of the four scenarios modelled have floating offshore wind capacity exceeding that of fixed offshore wind, with fixed offshore wind being limited by the suitable shallow-water area likely to be available for offshore wind use. Only in floating offshore wind can Ireland develop a 2.8 GW per year industry, which could be over 10% of the global floating offshore wind market in 2050.[27]

Table 3 summarises the characteristics of a typical floating offshore wind project aiming to reach operation between 2025 and 2030, considering the global market, and based on weighted averages for each value from BVG Associates' market intelligence database.

Table 3: Characteristics of a typical floating offshore wind project reaching operation between 2022 and 2024, considering global market

Parameter	Value
Water depth (m)	185
Mean wind speed (at 100 m height) (m/s)	9.5
Distance from shore[28] (km)	69
Turbine rating (MW)	5.1
Rotor diameter (m)	114
Project size (MW)	20
Project lifetime (years)	30

The installation process for floating offshore wind has more onshore activity than for fixed offshore wind. The turbine is typically installed on the floating foundation at the quayside, before being towed to the project site where it is tethered to the seabed using mooring and anchoring systems. Other solutions are in development (also targeting savings in operational expenditure (OPEX)) and tension leg platforms require additional stability provision during installation.

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[27] DNV, (2023), *'Pathway to Net Zero Emissions report 2023'*. Available at: https://www.dnv.com/energy-transition-outlook/.

[28] Most relevant is distance to construction / operation port / distance from grid, but such data is less available.

More details of the full lifecycle of a floating offshore wind project are available in the *Building Offshore Wind in Ireland* online tool.[9]

2.3.2 Key concepts

Due to the early stage of technology development, there remain a range of concepts and specific designs for floating foundations. It is likely that over the next ten years or so, a small number of preferred solutions will establish, but the range of site conditions and logistics arrangements will mean that it is unlikely that one single concept will be used universally. Most designs can be categorised in one of four concepts:

- Semi-submersibles (semi-subs)
- Tension leg platforms (TLPs)
- Barges; and
- Spar buoys.

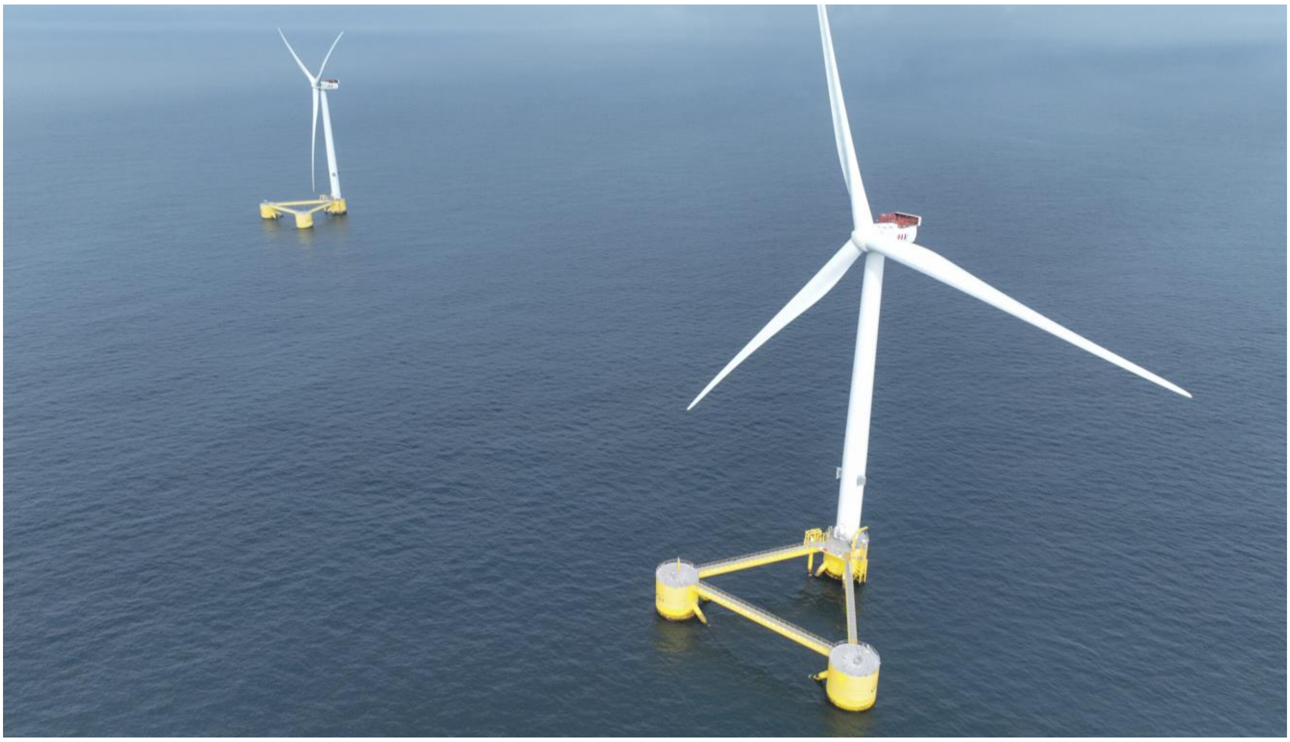
Each concept is described below. Within these concepts, designs may be predominantly steel or predominantly steel-reinforced concrete, depending on relative material costs for specific projects.

Most designs on the market currently are derived from structures which have been deployed effectively in the offshore oil and gas sector.

Semi submersibles

Semi-sub substructures typically consist of typically three or four connected floating elements. They are typically ballasted to provide additional stability. An example is shown in *Figure 9*.

Figure 9: Example of a semi-submersible floating substructure. Photo of the WindFloat Atlantic project courtesy of Principle Power/Ocean Winds



At present, Principle Power's WindFloat is the only semi-sub to have been installed at full scale. Semi-subs are suitable for water depths greater than 40 m, though are unlikely to be used at or close to 40 m unless more cost effective than fixed foundations. Design variables include: the number of columns, placement of tower (eccentric vs. central), construction material (steel vs. concrete) and ballast system (active vs. passive), with some designs opting to use a suspended submerged counterweight to lower the centre of gravity. This design can be used with a wide range of mooring and anchor configurations.

Semi-subs experience higher wave-induced motions than spars buoys, but lower motions than barges. They can experience large heave motions in extreme weather conditions when the wave period is close to their heave natural period. *Table 4* provides a summary of advantages and disadvantages of semi-submersible foundations.

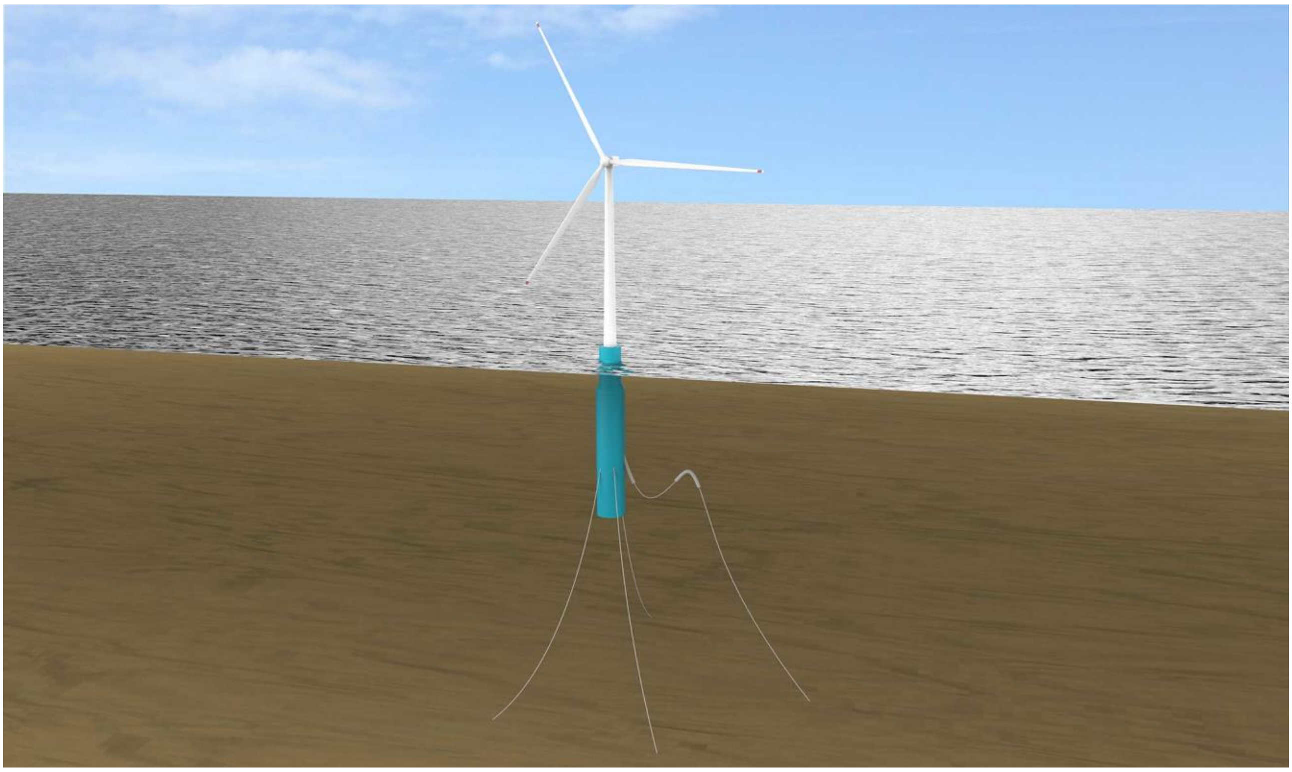
Table 4: Advantages and disadvantages of semi-submersible foundations

Advantages	Disadvantages
Typically, relatively shallow draft, enabling quayside integration of turbine	Typically, largest footprint of all concepts, in terms of length and width, meaning largest laydown and wet storage required for assembly and marshalling
Adjustable ballasting can make the complete structure stable for tow-out and installation, with no specialist offshore equipment or processes required	Typically, higher mass than tension leg platforms
Tugs and anchor-handling vessels (AHVs) can be used in broad weather windows, reducing the need for specialist vessels	

Spar buoys

Spar buoys use ballast-stabilised designs. They consist of a tall structure housing ballast in its lower part to lower the centre of gravity below the centre of buoyancy, creating a self-righting system. Spar buoys typically have a large draft and can be used with a wide range of mooring and anchor configurations. An example is shown in *Figure 10*.

Figure 10: A steel spar-buoy design. Image courtesy of ORE Catapult. All rights reserved



Spar buoys are suitable for water depths above 100 m and have been deployed by Equinor at Hywind Scotland and Hywind Tampen, using both concrete and steel-based designs.

Due to their high draft, spar buoy designs require deep water at the project site but also along the tow-out route and at the turbine integration location. Draft requirements are typically in the range 70 to 80 m. Due to this, integration is often completed in sheltered nearshore waters as few ports have the depth at quayside to accommodate them. It is unlikely the spar-buoy concept will be used in many markets because of this, unless an alternative integration and tow-out solution is developed that can be used in much shallower water. Ireland lacks the deep ports or fjord-like conditions required.[29] *Table 5* provides a summary of advantages and disadvantages of spar buoys.

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[29] Gavin and Doherty Geosolutions (GDG) on behalf of Wind Energy Ireland, (2022), *'National Port Study'*. Available at: https://windenergyireland.com/images/files/final-national-ports-study.pdf

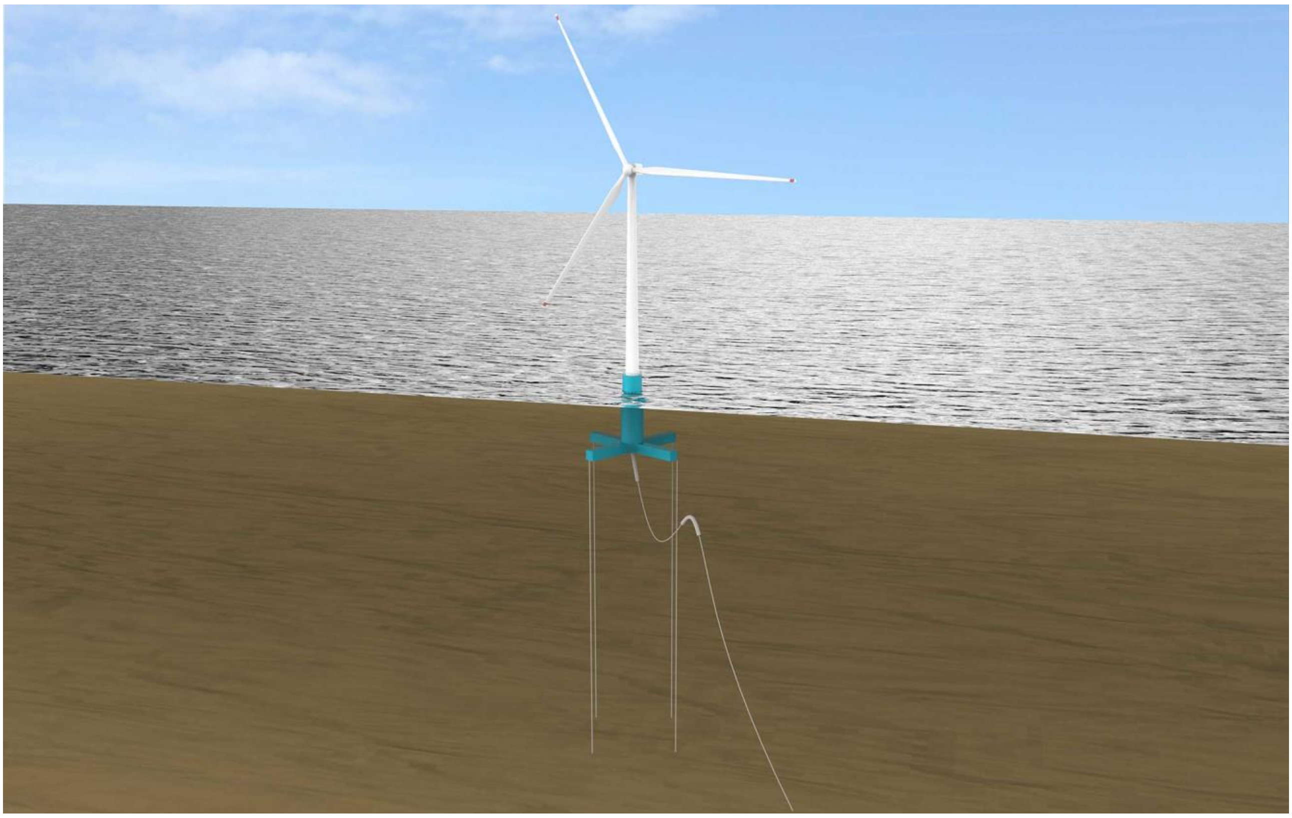
Table 5: Advantages and disadvantages of spar-buoys

Advantages	Disadvantages
Large draft and small waterplane area aid stability, meaning structure is less affected by wind, wave and current compared to other concepts	Largest draft of all concepts – needs sheltered deep water for turbine integration, tow-out and installation at the project site
	It has the highest tilt during normal operations of all foundation types and does not allow for active ballasting. This can make some maintenance activities more challenging, and has slight impact on turbine loading and performance.

Tension leg platforms

TLPs achieve stability through the predominantly vertical, tensioned mooring system. The upwards buoyancy force acting on the hull needs to be sufficient so that the tendons are continuously under tension across all operating cases. An example is shown in *Figure 11*.

Figure 11: A TLP design. Image courtesy of ORE Catapult. All rights reserved



TLPs are well established in the oil and gas industry but have not yet been demonstrated at commercial scale in offshore wind. Most designs use a multi-legged pontoon arrangement with minimal structure piercing the waterline. The first full-scale TLP demonstrator in offshore wind is expected to be SBM Offshore's design at Provence Grand Large, France, currently under construction. *Table 6* provides a summary of advantages and disadvantages of tension-leg platforms.

Table 6: Advantages and disadvantages of tension-leg platforms

Advantages	Disadvantages
Typically lowest mass of all concepts	Installation is complex compared to other concepts as the hull is less stable until installed, requiring either: • Turbine to be integrated on foundation on site, requiring a weather sensitive floating-to-floating lift, or • Turbine to be integrated in-port and transported then installed using a vessel providing sufficient stability This also potentially increases the complexity of major component exchange
Highest operational stability of all concepts, closest to that of fixed offshore wind	The mooring system and anchors are expected to be more expensive than for other concepts as they are subjected to higher loads and redundancy is required to counter the consequence of failure

Barges

Barge substructures have a single hull that pierces the waterline. They have a large surface area in contact with the water which provides stability, however this can make the structure more susceptible to wave loading, reducing stability in comparison with other concepts. An example is shown *in Figure 12*.

Figure 12: A concrete barge design, featuring a moonpool. Image courtesy of BW Ideol. All rights reserved

Barge concepts are suitable for water depths greater than 40 m. Barge substructures that have been installed to date are BW Ideol's Damping Pool (incorporating a moonpool to improve the stability of the structure) and Saitec Offshore Technologies' SATH.

Table 7 provides a summary of advantages and disadvantages of barge foundations.

Table 7: Advantages and disadvantages of barge foundations

Advantages	Disadvantages
Like semi-subs, the relatively shallow draft of barges enables integration of turbine at quayside.	The relatively shallow draft of barge foundations combined with large surface in contact with the water means this concept is less stable in rough conditions, impacting turbine performance and maintenance work.
Adjustable ballasting can make the complete structure stable for tow-out and installation, with no specialist offshore equipment or processes required.	
Tugs and anchor-handling vessels (AHVs) can be used in broad weather windows, reducing the need for specialist vessels.	
The overall dimensions typically are less than semi-subs, enabling installation from smaller ports and requiring smaller lay down and wet storage areas.	

Other concepts

Aside from the four key concepts discussed above, a variety of other concepts exist, none of which have yet been deployed at commercial scale. There remains the potential for one or more of these 'challenger' concepts to establish a market position. Given the significant LCOE reductions required to enable floating offshore wind to complete with fixed, there remains a need for such innovation. Many of these concepts have greater complexity, which introduces additional risk and uncertainty to in construction, performance, reliability and maintenance. Some listed are based on concepts above, but incorporate non-standard features.

Examples of other concepts include:

- Counterweight designs (hybrids of semi-subs and spar buoys) such as from Monobase Wind and Saipem's Hexafloat.
- Multiple-turbine designs such as Hexicon's TwinWind, which mounts two turbines on a single semi-sub foundation.
- Buoyant columns such as AWC's articulated wind column (part fixed).
- Vertical axis turbines such as SeaTwirl's S1 and S2.
- Single-point mooring solutions that yaw to face the wind, such as from X1 Wind.
- Combined wind and wave devices such as from Floating Power Plant.

2.3.3 Readiness

All key concepts are at TRL 8 or 9 and at CRI level 2 (ref. Appendix B), as shown in *Table 8*. Semi-sub and spar-buoy foundations have achieved level 9, having been deployed and proven at commercial scale in small projects such as the Kincardine array in the UK, which uses steel semi-subs, and the Hywind projects in UK and Norway, which use spar buoys. All variants now face the difficult challenge of scaling up to the next CRI level of scaled-up commercial deployment. Making this transition is challenging because the technology remains high cost in comparison to fixed offshore wind and other established technologies. Scaling up project size is critical to unlock the economies of scale and volume which will help drive down LCOE but scaling up projects entails greater spending on the project and infrastructure.

Table 8: TRL/CRI level of major foundation variants

Foundation concept	Technology Readiness Level (TRL) / Commercial Readiness Index (CRI)
Semi-sub	9/2
Spar buoy	9/2
TLP	8/2
Barge	8/2

Successful floating offshore wind also requires dynamic array and export cables. Dynamic array cables are similar to what has been used in the oil and gas sector. Dynamic export cables, larger diameter and at higher voltage, are in development but have not been used in volume so also remain at CRI 2. Dynamic cables are designed to allow and withstand repeat movement, as experienced in floating offshore wind. Floating substations may also be required. A floating substation has been demonstrated in Japan, though it is likely that many early floating projects in Ireland will opt for fixed substations using deep-water jacket foundations.

2.3.4 Expected future developments

Floating wind will benefit from many of the fixed offshore wind developments discussed in Section 2.2.3 as well as opportunities specific to floating offshore wind, as described below, and the key cross-cutting technology development themes relevant to all ORE technologies are covered in Section 2.6.

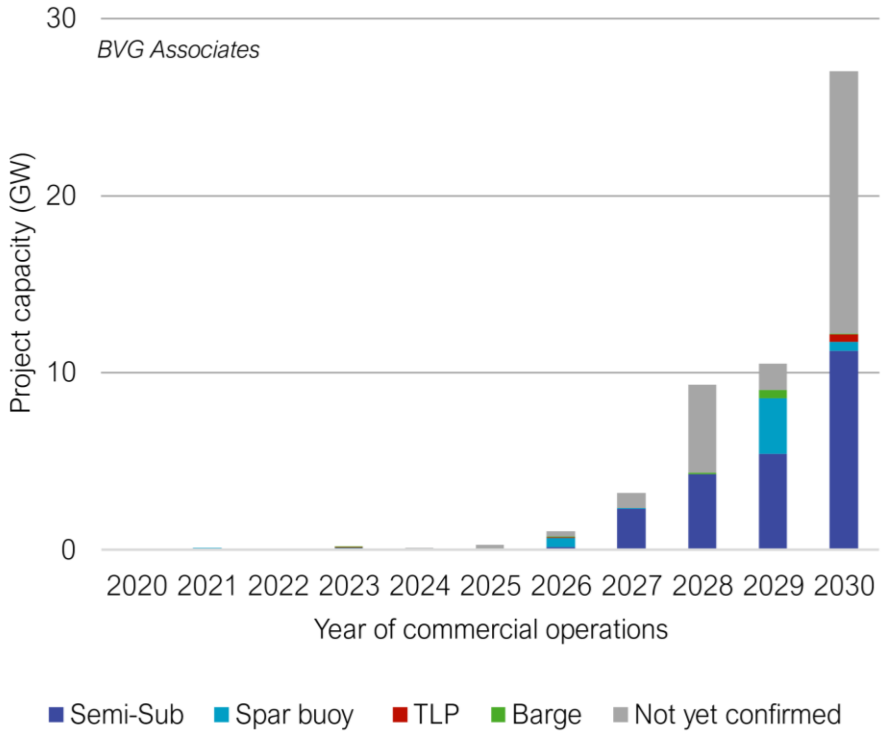
Refinement of concepts

There are a variety of floating foundation designs currently on the market, as discussed in Section 2.3.2. As the industry progresses, a rationalisation of designs is anticipated, meaning there is likely to be increased focus on the most economically attractive concepts.

Semi-subs are expected to be the dominant concept, as shown in *Figure 13* which represents current expectations of project developers, though this may change in time.

Refinement will also involve much work on interactions between wind and wave loading and the control of the turbine to account for different loading patterns compared to fixed offshore wind, manage whole-system dynamics and optimise loading and reliability.

Figure 13: Expected market share of different foundation types for known floating offshore wind projects deploying worldwide to 2030



Industrialisation of hull manufacturing

As floating offshore wind projects scale up to Gigawatt-scale and involve greater numbers of hulls, mooring lines and anchors, it can be expected that the industry will follow fixed offshore wind and will unlock learning-by-doing, innovation and investment in industrialising manufacture, driving LCOE reductions in many areas, especially floating hull manufacture through innovation in manufacturing methods, streamlining and speeding up production.

Over the long term, it is expected that steel foundations will move to modular construction where components are produced in specialised facilities before being shipped to facilities closer to projects for final manufacture and assembly. This is in line with the trajectory anticipated for jacket foundation manufacture, but is likely to occur in larger volumes.

Improvements to dynamic cabling systems

To date, almost all cables employed in fixed offshore wind projects have been static cables. Floating offshore wind uses dynamic cabling systems which are suspended in the water between the turbine and seabed.

Innovation to decrease the lifetime cost of such systems will be important in driving down the overall cost of floating offshore wind. Examples of such innovations include the development of:

- Innovative cable cores, sheaths and floatation systems to increase the durability and reliability of dynamic cables.
- Higher voltage cables that would enable the connection of more large turbines in each string connected to the substation.
- Specialised systems for connecting and disconnecting cables from turbines that would facilitate lower cost installation and ease of tow-to-port maintenance activities.
- Improved array cable "star" layout configurations using subsea hubs to minimise operational downtime whilst turbines are towed back to port for replacement of major components.

Improvements to mooring and anchoring systems

Mooring and anchoring systems which have been used to date in floating offshore wind projects generally cannot be considered new or innovative technologies as most have a record of successful application in the oil and gas industry. In floating offshore wind, loading patterns are different and the volumes required are larger than in oil and gas. This will drive significant innovation over time as the industry develops optimised mooring and anchoring solutions.

Examples of such innovations could include:

- A move from steel mooring chains to more lightweight synthetic ropes or cables.
- The development of detachable mooring systems which allow turbines to be untethered and retethered easily for tow-to-port maintenance.
- The optimisation of array layouts to reduce the overall length of mooring equipment required by sharing infrastructure between turbines within projects in deeper water.

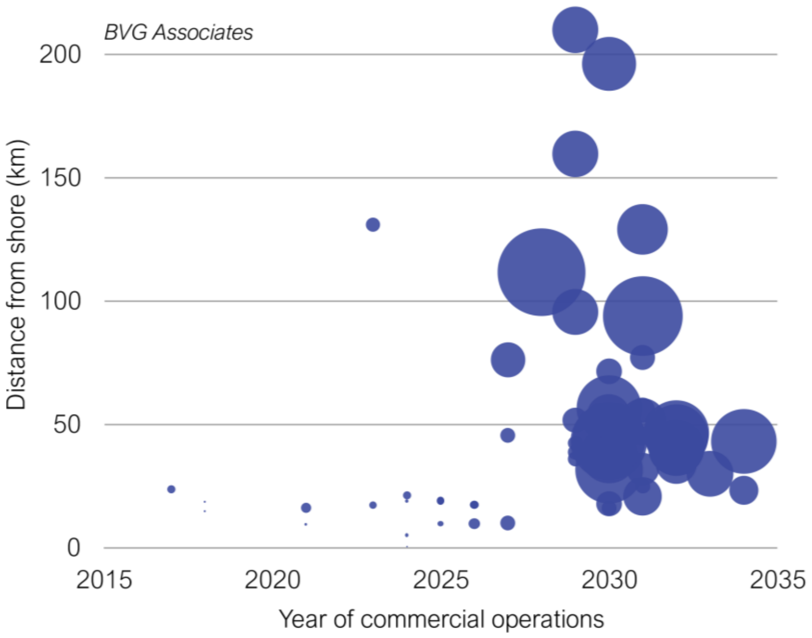
Development of new installation, operation and maintenance methods

Current volumes and rates of installation are low and will need to speed up considerably, through optimising tooling and processes and increasing weather windows (by developing solutions that can be implemented in harsher weather conditions). Opportunities for efficiency gains include the development of solutions that enable turbine integration at sea and innovations to facilitate the ease of hull component transport and assembly, such as the weld-free Stiesdal TetraSub, or the Bassoe D-Floater which facilitates stacking and transporting of multiple hulls together on a heavy-lift transport vessel.

In fixed offshore wind, major component exchange (such as changing a main bearing in the wind turbine nacelle at the top of the tower) uses a jack-up vessel that puts legs down to the seabed to provide a steady platform. Major component exchange has, in all floating projects installed to date, required the whole turbine system to be towed back to port. Such operations can only be completed in good weather windows (benign wind and wave conditions), which can be rare at some times of year, need deep-water ports with appropriate infrastructure and require spare turbine systems to be available, else may result in significant delays/lost generation time. Currently, all projects use tow-to-port methodologies as alternatives are not yet available. In time, tow-to-port methodologies are likely to become increasingly less viable the further from shore projects are located, as is the trend shown in *Figure 14*.

Although the Irish maritime area Is characterised by excellent wind conditions, metocean conditions can be challenging, with frequent storms and large wave swells. Adapting installation, operation and maintenance methods to the severe Irish sea conditions represents both a challenge and an opportunity for the Irish ORE and research sectors.

Figure 14: Project distance from shore for known floating offshore wind projects deploying in Northern Europe to 2035. Bubble size indicates project size (GW)



Aside from innovations in major component exchange methods, there are a number of challenges to be overcome in the day-to-day maintenance of floating systems. As in fixed wind, innovations in digital O&M methods, robotic maintenance and early fault detection systems to minimise the need for manned maintenance visits will be important to drive down costs.

In addition, routine at-sea maintenance of floating turbines presents particular challenges due to the pitch and yaw of floating turbines, especially in rougher weather conditions. The taller the turbine, the more movements at sea level are amplified in the nacelle, making it more difficult to carry out high-precision activities.

2.3.5 Levelized cost of energy

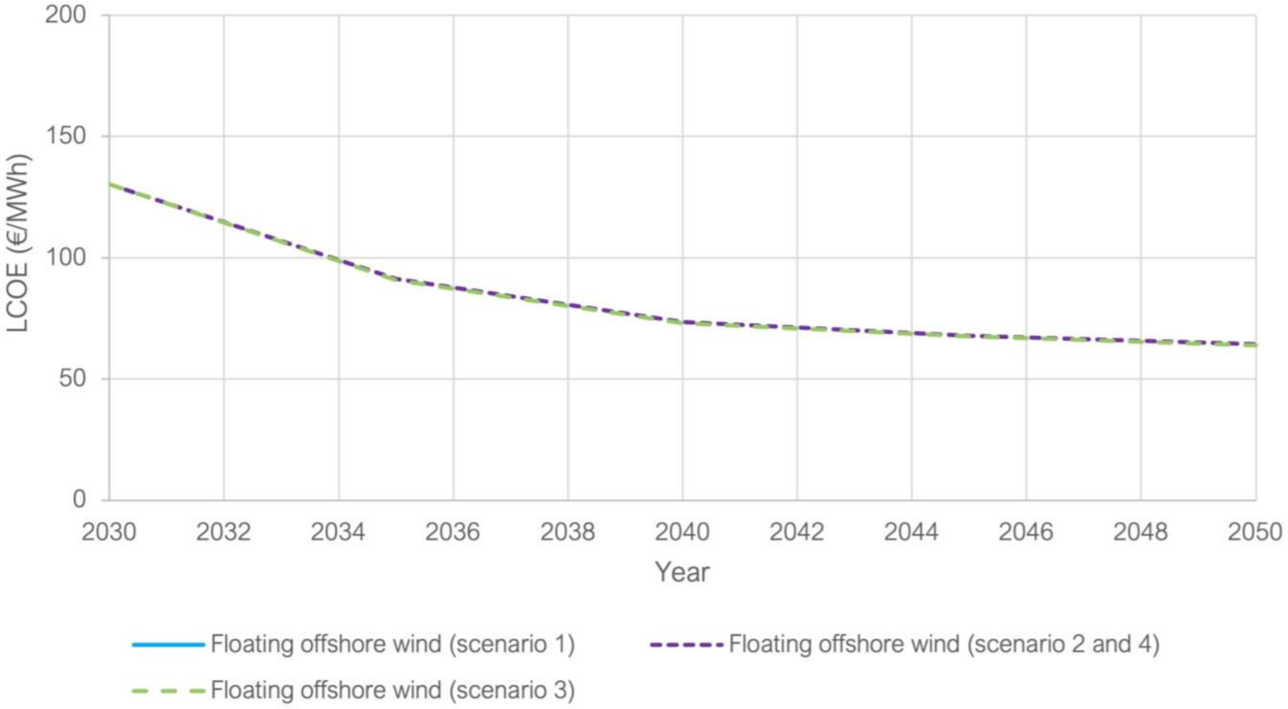
Floating offshore wind technology is much less well established than fixed, and foundation and various other costs are higher. As a result, the LCOE of floating offshore wind projects is currently around two to three times greater than that of fixed offshore wind projects. This gap will close over time, but by just how much and quickly is uncertain, as no commercial-scale floating offshore wind projects are yet in operation.

It is valuable to note, also, that in the early years of fixed offshore wind, between 2005 and 2010, many costs increased as suppliers started to fully understand the harsh complexities of repeat operations in harsh offshore conditions. It was only later that costs began to reduce as economies of scale impacted.

The projection for LCOE for floating offshore wind in Ireland to 2050 is shown in *Figure 15* for typical site conditions in Ireland, summarised in Appendix A. The band indicates an uncertainty range regarding global technology and other industry progress, assuming consistent macroeconomic conditions. Assumptions in Section 5.3 regarding local content have been considered, along with the technology and supply chain drivers for LCOE reduction described in Section 2.3.4. The figure shows that in all scenarios, LCOE falls by just over 50% during the period 2030 to 2050 on the back of increasing volumes of global activity. As explained for fixed offshore wind, the size of the Irish market has negligible impact on the rate of change of LCOE.

Figure 15 shows a decreasing premium for floating offshore wind of 75% in 2030, down to between 25 and 30% in 2050.

Figure 15: Trend in levelized cost of energy for floating offshore wind with year of project commercial operation, under typical Irish conditions



2.3.6 Environmental considerations

Many of the key environmental considerations associated with floating offshore wind are the same as those for fixed offshore wind, as discussed in Section 2.2.5, though some considerations are different.

- **Impact on birds:** Like fixed offshore wind projects, floating projects can impact birds, both through collisions with turbines and disturbance of feeding and breeding grounds.
- **Impact on marine life:** Floating offshore wind projects may have a smaller impact on marine life than fixed offshore wind projects, as the installation of anchors in deeper water is likely to be less impactful for the benthic ecosystem than piling activity in shallower water. Installation of mooring systems generates less noise than piling or other activities needed to install fixed foundations, which could lead to reduced impact on marine life.[30] More research is needed to understand the specific impacts of different floating mooring types on marine ecosystems, especially pelagic life and cetaceans.
- **Visual and landscape impact:** Like fixed offshore wind projects, floating projects may be visible from the coast and can potentially impact the aesthetic value of coastal landscapes, although floating offshore wind projects are less likely to be located within sight of shore as there are large areas in deeper Irish waters that are further from shore. Public perception of the visual impact is an important consideration, particularly in areas of high scenic value or where tourism is a significant economic driver. This can relate also to onshore works, such as substations. In some locations, visits to wind farms have become a tourist attraction.
- **Pollution:** Like fixed offshore wind, although floating offshore wind farms generate electricity with much lower carbon intensity than fossil fuels, they still contribute carbon and to pollution through increased vessel traffic and risk of spillage of liquids (including oils and greases). Release of contaminated seabed sediments are likely to be less of an issue due to less seabed disturbance during the installation of floating offshore wind anchoring systems compared to fixed foundations.

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[30] Maxwell, S, Kershaw, F, Locke, C C, Conners, G, Dawson, C, Aylesworth, S, Loomis, R, Johnson, A F (2022) 'Potential impacts of floating wind turbine technology for marine species and habitats', *Journal of Environmental Management,* available at: https://www.sciencedirect.com/science/article/pii/S0301479722001505.

As in the case of fixed offshore wind, there are also further social and technical considerations, including navigation and shipping, fishing, aircraft and radar and military zones. In some cases, measures may be available to mitigate environmental and social impacts. Such measures are sometimes included as conditions of permits.

The presence of mooring lines and dynamic cables suspended within the water column, lead to considerations beyond those of fixed offshore wind which require further investigation to understand their potential for coexistence with commercial fishing activity. Trials are currently ongoing to improve understanding of potential for fishing to take place among floating offshore wind farms.[31] Work is also underway in the UK through the Offshore Renewable Energy Catapult to identify relevant research needs to inform regulation in this regard.[32]

2.3.7 System impacts

From a system perspective, floating offshore wind offers largely the same benefits and challenges to fixed offshore wind. Floating offshore wind in Ireland, however, offers additional system value over fixed offshore wind:

- Smoothing supply, due to its potential for wider geographic distribution in Ireland, hence different projects experiencing different wind conditions at any time.
- Marginally increasing capacity factors, due to its ability to access better wind resource in areas of deeper water.

Although there have been limited studies in Ireland, UK studies have found deploying floating wind off the west coast compared to a fixed-dominated North Sea fleet could deliver 76% fewer 'very low power' events in the average year, and almost halve the maximum duration of such events.[33] It is recommended that more system modelling, including the impact of significant volumes of fixed and floating offshore wind, is prioritised in Ireland.

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[31] Offshore Renewable Energy Catapult, (2021), *'Floating Offshore Wind and Fishing Interaction Roadmap'*. Available at: https://tethys.pnnl.gov/sites/default/files/publications/FOW-and-Fishing-Interaction-Roadmap.pdf.

[32] Equinor, (2022), *'Equinor and Marine Scotland collaborate to trial safe fishing within floating wind farms'*. Available at: https://www.equinor.com/news/uk/collaboration-trial-safe-fishing-within-floating-wind-farms.

[33] Regen, (2022), *'Go West! An analysis of the energy system benefits and implications of a more geographically diverse offshore wind portfolio'*. Available at: https://www.regen.co.uk/wp-content/uploads/Regen-Go-West-Oct-2022.pdf.

2.4 Wave

2.4.1 What is it?

Wave energy technology captures the kinetic energy contained within ocean waves using wave energy converters (WECs). There is a vast global resource, with WECs best deployed in areas with significant and consistent wave patterns, for example open and exposed areas with long fetch and experiencing high wind speeds. Wind drives wave activity, wave energy resource at any time being a function of winds speeds over a broad area over recent days. This smoothing effect increases the ability to forecast energy production and decreases the rate of change of resource over time.

Ireland's large maritime area and strong wave resource mean it is well-placed to benefit from wave energy technology. At this stage, however, wave energy technology is pre-commercial, with much higher LCOE than established renewable energy technologies, both onshore and offshore. A key challenge to the commercialisation of WECs has been to maximise energy extraction efficiency whilst minimising device cost. This challenge is especially due to the impact of severe wave conditions, which can greatly increase the loads that devices must withstand.

2.4.2 Key concepts

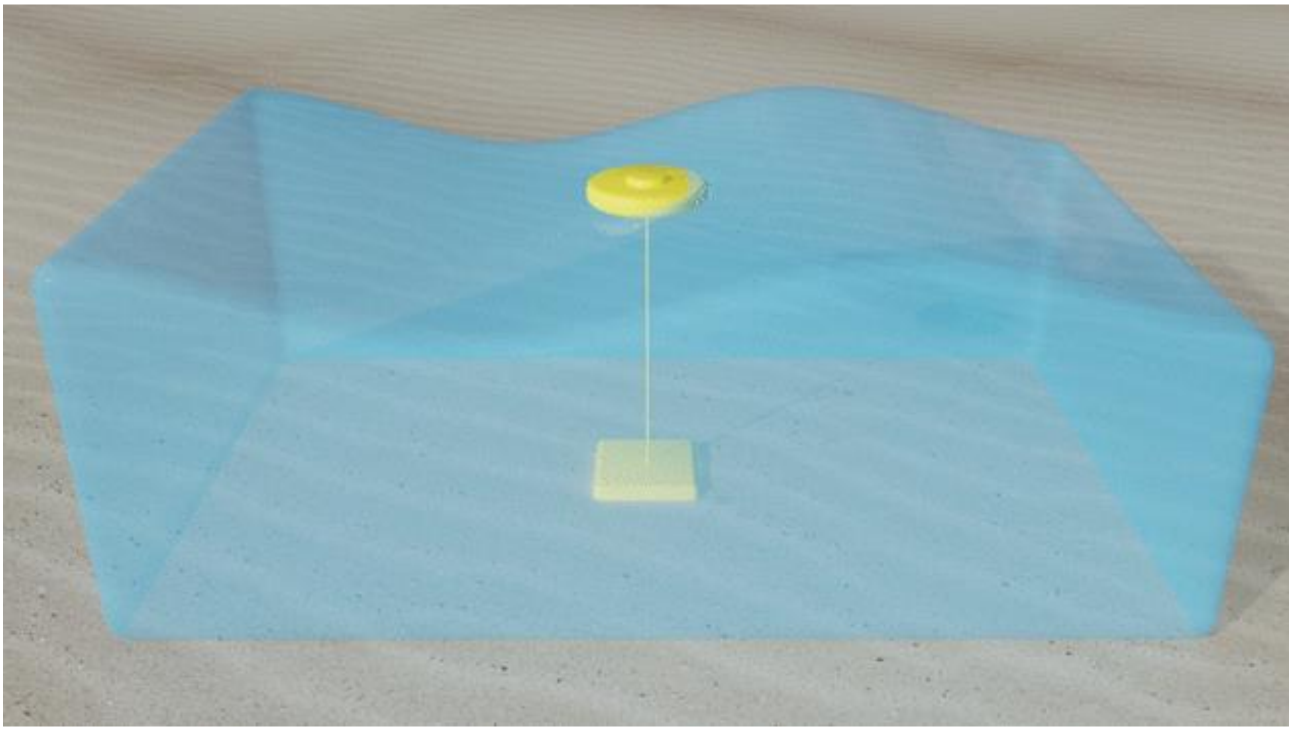
Unlike other more established renewable energy generation technologies, there is yet to be a convergence in the design of WECs, as discussed below.

Most current prototypes are point absorbers, attenuators or based on an oscillating water column or oscillating wave surge.

Point absorbers

These WECs consist of a buoyant, moving element linked to a power take-off system attached to a non-moving base. The moving element rises and falls with the motion of the waves and this movement drives an electrical generator (often a linear generator but sometimes a rotating generator, hydraulically, pneumatically or mechanically driven through a linkage), converting the kinetic energy in the waves to electricity. A schematic of an example point absorber is shown in *Figure 16*. Examples of point absorber device suppliers include AWS Ocean, Calwave, CorPower and Oscilla Power.

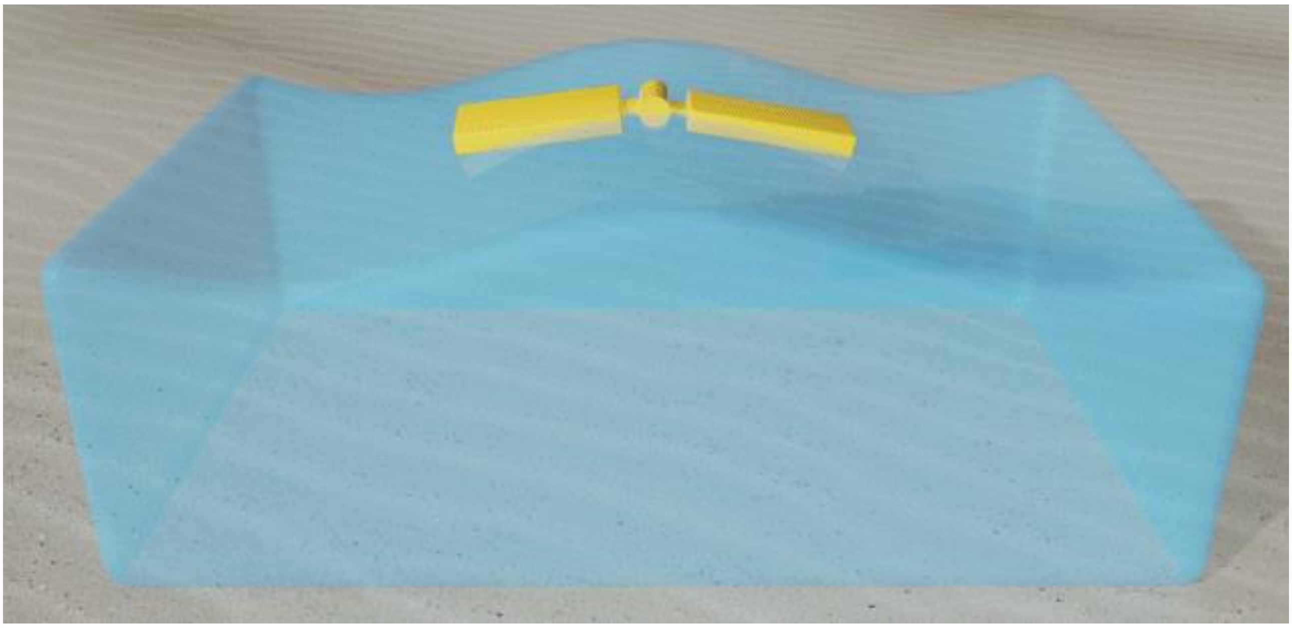
Figure 16: Example of a point absorber device. Sourced from openei.org



Attenuators

Rather than being anchored to the seabed, attenuators 'ride' the waves, floating at sea level and operating parallel to the wave direction. This type of WEC captures energy from the relative motion of two or more arms as waves pass by. A schematic of an example attenuator is shown in *Figure 17*. Examples of attenuator device suppliers include MOcean and Sharp Eagle.

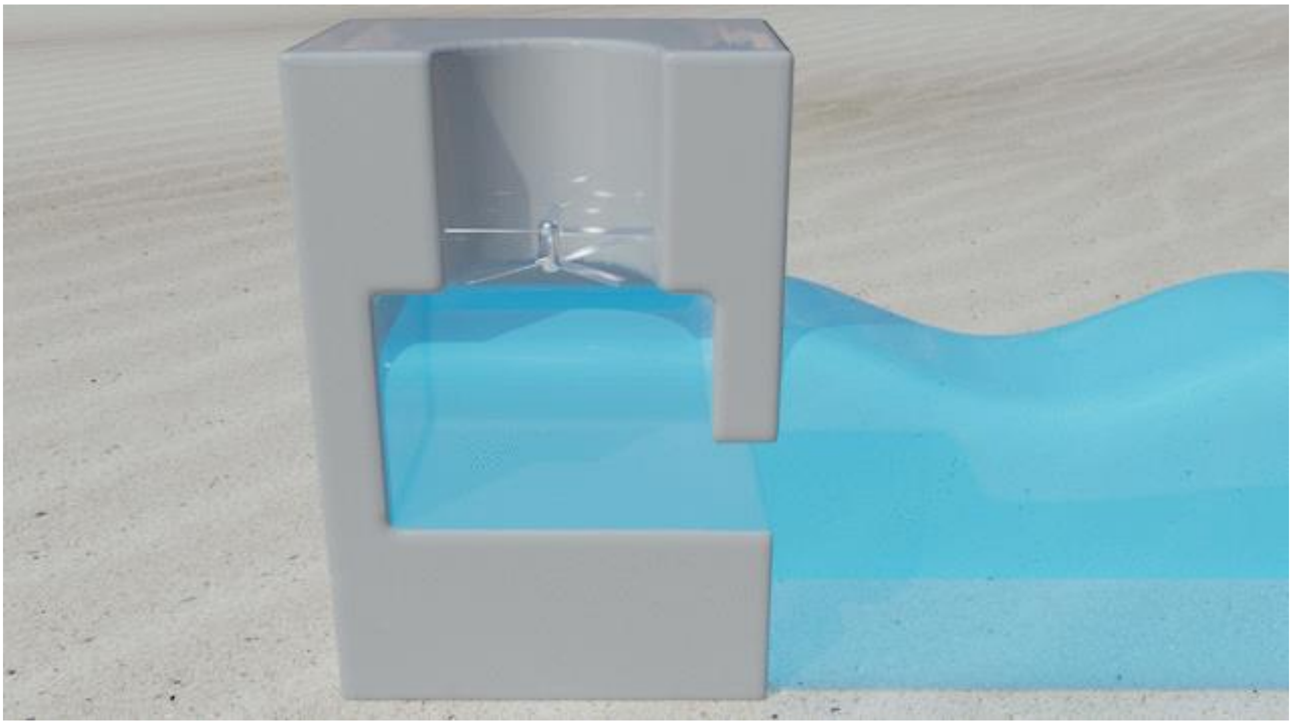
Figure 17: Example of an attenuator device. Sourced from openei.org



Oscillating water column devices

Oscillating water column devices are inspired by tidal blow holes, a naturally occurring feature common in limestone cliffs, whereby waves washing into a chamber forces air flow backwards and forwards through a turbine. A schematic of an example oscillating water column WEC is shown in *Figure 18*. Examples of suppliers of oscillating water column devices include Ocean Energy Buoy, Voith Siemens Hydro and Wave Swell Energy.

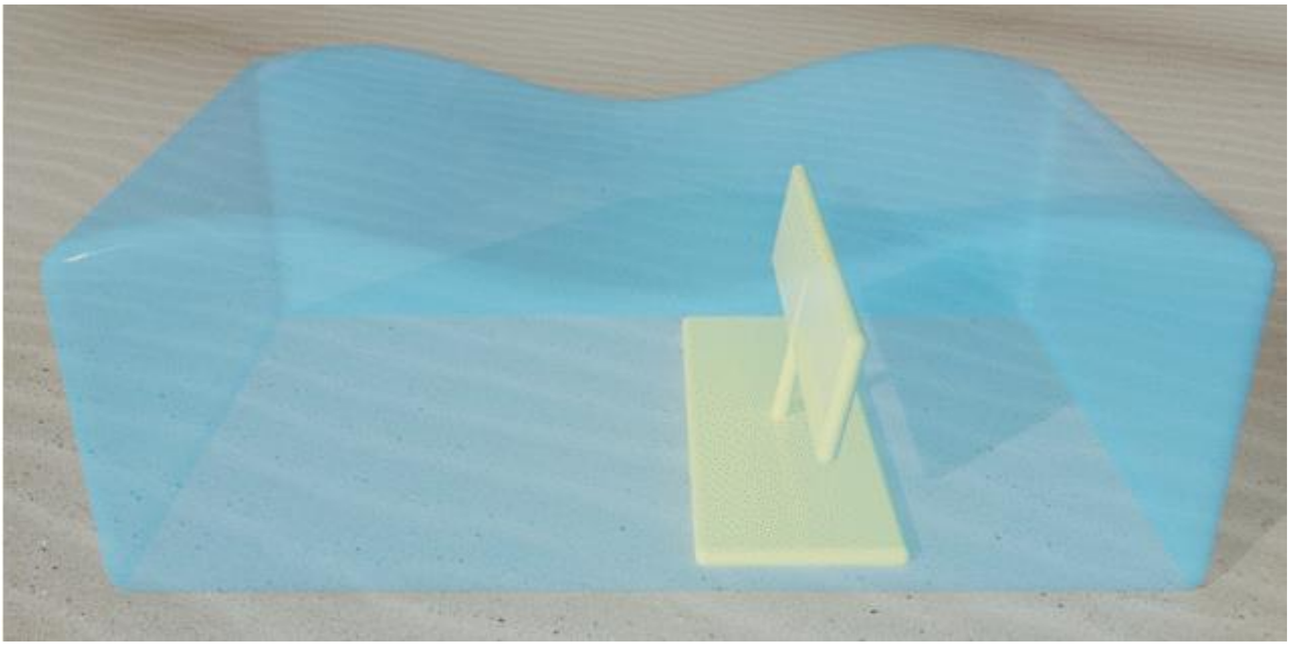
Figure 18: Example of an oscillating wave column device. Sourced from openei.org



Oscillating wave surge devices

Oscillating wave surge WECs typically take the form of a paddle or flap anchored to the seabed, which is moved back and forth, driven by the horizontal motion of the waves. The motion of part of the device is converted to electricity either with a generator at the hinge or by using the motion to pressure a fluid which drives a generator. A schematic of an example oscillating wave surge device is shown in *Figure 19*. Examples of suppliers of oscillating wave surge devices include Exowave, Slow Mill Sustainable Power, Wavepiston and Waveroller.

Figure 19: Example of an oscillating wave surge device. Sourced from openei.org



Current project characteristics

Table 9 summarises the characteristics of a typical pre-commercial wave project reaching operation between 2022 and 2024.

Table 9: Characteristics of a typical pre-commercial wave project reaching operation between 2022 and 2024

Parameter	Value
Water depth (m)	20
Annual average power density (kW/m)	50
Distance from shore (km)	1
Number of machines	1
Project size (MW)	0.5
Project lifetime (years)	10

2.4.3 Readiness

A large number of prototypes and small arrays were installed in the in 1990's and 2000's, driven by a mix of private and public investment. Although the industry made significant progress in understanding conditions and installing WECs, early players ran out of funding, with many devices unreliable, many not efficient enough and all too expensive compared to other renewable energy sources that were being installed in Gigawatt volumes. At the time, the industry did not convince public or private funders that the route to commercialisation was short or certain enough to invest in and technologies failed to pass through the mid-TRL 'valley of death'.

A second tranche of wave energy demonstration activity is now underway, taking learning and knowledge from the first. It is yet to be seen whether wave energy will become cost competitive with more established offshore energy technologies.

A non-exhaustive list of current devices taken from Ocean Energy System's *Wave Energy Development Highlights 2023* is provided in *Table 10:* Summary of projects highlighted in Ocean Energy System's *Wave Energy Development Highlights 2023*, with associated author TRL estimates.[34] Most devices are classified between TRL 5 and 7, though some are as high as level 9. The point absorber concept currently leads the market, for example with CorPower C4 undergoing pre-commercial testing at the HiWave-5 site in Portugal. In Ireland, Ocean Energy is developing its OE35 device, a 1 MW oscillating water column type WEC via the WEDUSEA project.

Table 10: Summary of projects highlighted in Ocean Energy System's *Wave Energy Development Highlights 2023*

Device name	Developer	Capacity (kW)	Commission-ing year	Location	WEC type	TRL
ISWEC 1:1 prototype	Wave for Energy and ENI	250	2023	Pantelleria, Italy	Point absorber	7

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[34] Ocean Energy Systems, (2023), *'Wave Energy Development Highlights'*. Available at: https://www.ocean-energy-systems.org/publications/oes-brochures/document/wave-energy-developments-highlights-2023/.

C4	CorPower	300	2022	Agucadoura, Portugal	Point absorber	7
UniWave200 demonstrator	Wave Swell Energy	200	2021	King Island, Australia	Oscillating water column	7
Sharp Eagle	Guangzhou Institute of Energy Conversion and others	500	2020	Zhuhai, China	Attenuator	7
Wavepiston 1:1 demonstrator	Wavepiston	200 (expected)	2020	Canary Islands, Spain	Oscillating wave surge	7
Yongsoo OWC Pilot Plant	Korea Institute of Maritime Science & Technology	500	2019	Jeju Island, South Korea	Oscillating water column	7
Mutriku Wave Power Plant	Mutriku Wave	296	2011	Mutriku, Spain	Oscillating water column	7
Archimedes Waveswing prototype	AWS Ocean	15-500	2022	Orkney, UK	Point absorber	6
Exowave WEC scale prototype	Exowave	–	2022	Ostend, Belgium	Oscillating wave surge	6
xWave	CalWave	100	2021	California, USA	Point absorber	6
Blue X scale prototype	MOcean	5-10	2021	Orkney, UK	Attenuator	6
DiKWE 1:4 prototype	Legendre Group, GEPS Techno, Ifremer	–	2022	Saint Anne du Portzic, France	Oscillating wave surge	5
Slow Mill 1:2.5 prototype	Slow Mill Sustainable projects	–	2022	Texel Island, Netherlands	Oscillating wave surge	5

2.4.4 Expected future developments

As wave energy technology is still at an early stage, there is a need for further technology development and demonstration before it becomes clear whether the technology can become cost competitive with more mature renewable energy technologies. With a vast global resource, and much opportunity for LCOE reduction, there remains a case for case for further public funding to help the sector to have a chance to become commercially investible at scale. There is an important continuing role for Ireland to play in this effort, alongside other governments and state-backed bodies who have established funding and support programmes in recent years aimed at the development of ORE technology, including wave. Examples include:

- **SEAI's Prototype Development Fund.** Between 2003 and 2018, SEAI funded 125 ocean projects; 113 of these were through the Prototype Development Fund. It awarded a total of €20 million to SMEs for industry-led projects in ORE, with just over half of this spend allocated to wave energy.[35]
- **EuropeWave stage-gate programme.** The EuropeWave programme is a €22.5 million stage-gate programme for wave energy technology that is intended to run from 2021 through 2025. Funding is

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[35] SEAI, (2020), *'Review of funding supports to the Ocean Energy Sector'*. Available at: https://www.seai.ie/publications/SEAI_OceanEnergyFundingReview.pdf.

sourced from Wave Energy Scotland and the Basque Energy Agency, whose grants are matched by the EU's Horizon 2020 programme.[36]

- **US Department of Energy (DoE) grant funding**. In 2022, the DoE allocated US$25 million to support the development of eight wave energy projects on the Oregon coast.[37]

Key future developments for the sector are likely to relate to:
- Concept convergence.
- Economies of device and project scale.
- Economies of industry scale.
- Design optimisation.
- Co-location with offshore wind.

Wave energy can also benefit from the key cross-cutting technology development themes relevant to all ORE technologies covered in Section 2.6.

Concept convergence

Due to the wide variety of WEC concepts currently in the market, research efforts are diluted across many different projects. In aggregate, this results in slower progress towards commercial viability for any single technology but does ensure that there is competition between concepts. Wave energy still has the potential to make significant improvements to economics through big technology steps, so it is important for the future of the sector that background research into promising opportunities continues.

At the same time, the commercialisation of wave energy needs convergence to fewer concepts and a focus on leading devices. This will enable the industrialisation of specific supply chains which will unlock economies of volume. This could be aided by more high-level evaluation of concepts (using available information and tools) and efficient application of capital on demonstrators to help bring concept convergence.

Economies of device and project scale

To-date, wave energy has only been deployed at small scale, with the largest devices currently of 1 MW-scale.[38] Scaling up to larger devices is likely to reduce LCOE, but the cost-drivers relating to device scale are not likely to be as powerful as in offshore wind.[39] Device suppliers will need to apply experience gained from smaller devices in order to design effective larger devices. The history in other more mature renewable energies shows that there are many lessons to learn on this journey, which typically cannot be avoided by taking much larger steps. As larger devices are developed, many design, materials, supply and process challenges will need to be addressed well in order to gain the anticipated economies of device scale. Locating WEC devices in much larger projects will also help drive down development, installation and operation costs per MWh. Trends to develop larger projects are typical as confidence in a new technology grows, reducing the risk of unexpected challenges during construction and failures / unreliability during operation.

Economies of industry scale

As demonstrated in many other industries, moving from one-off prototype production to serial manufacture can lead to significant cost savings. This arises through industrialisation of manufacture and installation and learning-by-doing benefits which increase efficiency through all stages of the project lifecycle.

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[36] EuropeWave. Available at: https://www.europewave.eu/.

[37] ENERGY.GOV, (2022), *'DOE Announces $25 Million for Cutting-edge Wave Energy Research'*. Available at: https://www.energy.gov/articles/doe-announces-25-million-cutting-edge-wave-energy-research.

[38] EMEC, (2023), *'OceanEnergy Sign Up to EMEC Wave Energy Test Berth'*. Available at: https://www.emec.org.uk/oceanenergy-sign-up-to-emec-wave-energy-test-berth/.

[39] Larger wind turbines operate higher above sea level, providing access to increased wind resource. This, along with the reduced per MW costs for many components and processes accounts for much of the LCOE saving achieved. In wave energy, scaling opportunities are much more dependent on the scale of waves and the physics of the different concepts.

For example, structural elements of WECs are usually composed of steel, reinforced concrete or composites. Designers weigh up the cost and mass of designs using different materials considering fatigue and extreme load resistance, supply chain, corrosion resistance, manufacturing processes, ability to repair and other relevant characteristics, based on the volumes in which they need materials. As device scale and industry volumes increase, and new materials and processes are developed for a range of industries, WEC designers will be able to access lower cost solutions.

Unlocking these benefits is dependent on achieving a degree of concept convergence and LCOE reduction to enable volumes to increase. Public support and a strong pipeline of projects then enables investment in the supply chain to deliver further economies of volume, and the cycle can continue.

Design optimisation

Beyond the above, there is much that needs to be optimised to progress a given concept, including device mechanical design, control and reliability as well as installation and maintenance methods and balance of plant. For a technology which has a lower CRI than its competitors, this optimisation is expected to continue over many years.

Co-location with offshore wind

As wind and wave energy benefit from similar offshore conditions, it has often been considered to co-locate devices. Studies have shown that co-location of wind and wave power projects can lead to cost savings in the following ways:

- **Shared development and management cost.** Development, permitting, operations management and learning can be shared over more capacity, reducing overall cost.
- **Sharing of electrical infrastructure.** Co-location of WECs and floating wind turbines allows especially for the sharing of electrical export systems.
- **Sharing of foundations / mooring systems.** Multi-use platforms are a possibility, however it is uncertain whether the additional complexity can be justified based on cost and risk considerations.
- **Combined installation and maintenance.** Transport vessels, installation equipment and maintenance teams can be shared between technologies, reducing operational costs. O&M crews can also be deployed across multiple tasks in both projects, allowing for optimal resource allocation.
- **Reduced environmental impact.** By deploying two technologies together, more energy can be extracted from the same area, reducing environmental overall impacts.
- **Diversification of energy production.** Wave energy will persist for some time even after wind speeds have reduced, offering an energy system benefit. System Impacts of wave energy are discussed in Section 2.4.7.

Although location of wave energy within an offshore wind project may reduce the LCOE of the wave energy technology, due to the high relative cost of wave energy, currently, it would be more commercially more advantageous to increase the size of the offshore wind project. Only with a significant change in relative LCOE would this balance change.

2.4.5 Levelized cost of energy

The wide range of concepts and early stage of the technology make it difficult to establish a robust LCOE trajectory. Current LCOE estimates put wave at an LCOE of greater than €317 /MWh.[40]

Ireland has some of the best wave resource in the world, which will help lower LCOE compared to other markets.

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[40] Guo, C, Sheng, W, De Silva, D G and Aggidis, G A, (2023), 'Review of the levelized cost of wave energy based on a techno-economic model', *Energies*. Available at: https://doi.org/10.3390/en16052144.

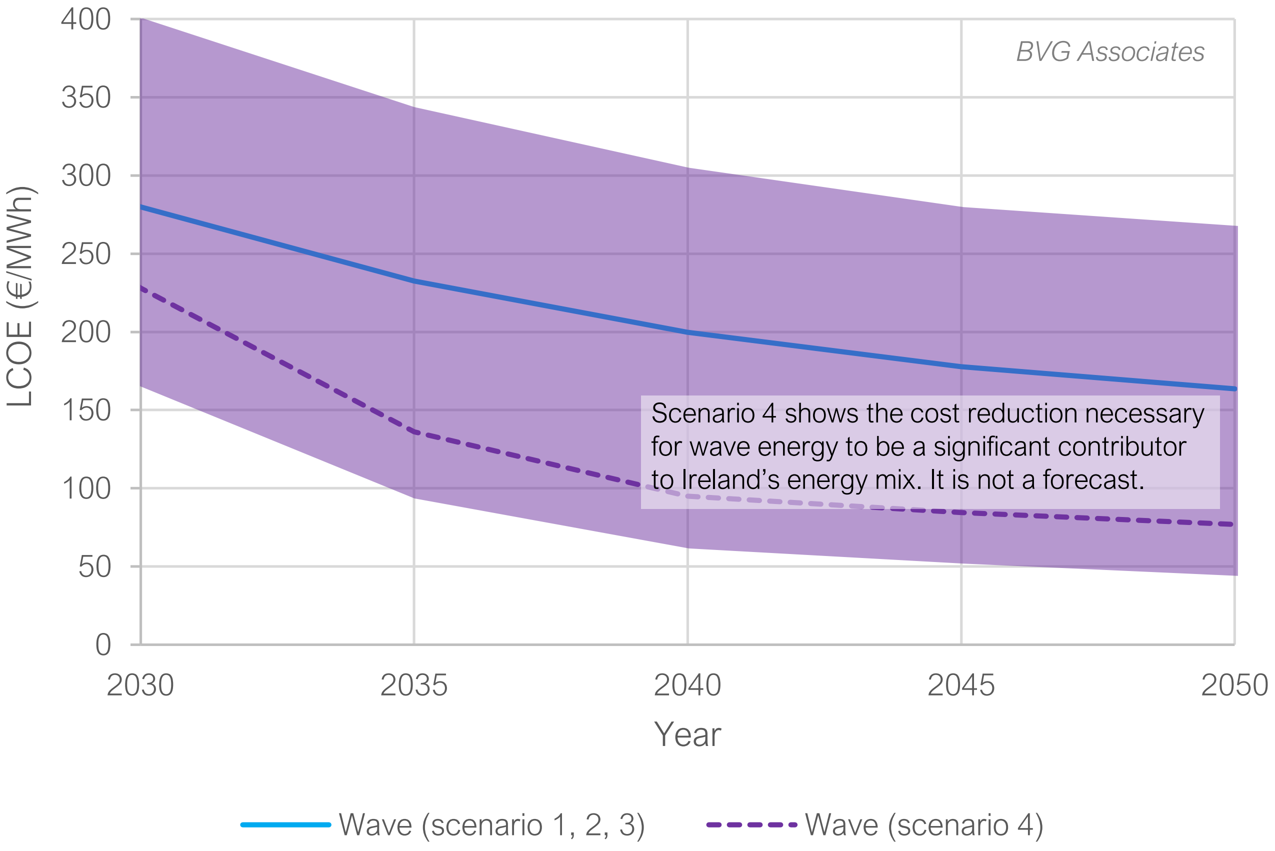
The projection for LCOE for wave energy in Ireland to 2050 is shown in *Figure 20* for typical site conditions in Ireland. The band indicates an uncertainty range regarding global technology and other industry progress, assuming consistent macroeconomic conditions:

- Scenario 1 shows a best estimate progression based on an extrapolation of current trends. This does not enable wave energy to play a significant role in Ireland.
- Scenario 4 shows the cost reduction pathway which would be necessary to see wave energy becoming a significant contributor to Ireland's energy mix by 2050. This shows wave energy LCOE with a decreasing premium over floating offshore wind of 50% in 2035, down to 20% in 2050. This is not a forecast, rather an estimate of the trajectory needed deliver scenario 4. For this to be achieved requires:
    - Efficient progress with the activities described in Section 2.4.4.
    - Through these activities, finding solutions that indeed reduce LCOE as much as shown, which is uncertain at this stage.

On current evidence, a cost reduction pathway for wave consistent with scenario 4 appears unlikely to be achieved.

It is recognised, however, that a range of technology developers, including SAOIRSE, have ambitions to drive down LCOE faster than this. The EU SET Plan's target for wave energy LCOE is €150 /MWh by 2030.[41] At this stage, there is insufficient evidence to give confidence that such savings will be achieved. Any future revisions of the report will however incorporate relevant new data.

Figure 20: Trends in levelized cost of energy for wave energy with year of project commercial operation, under typical Irish conditions



Scenario 4 shows the cost reduction necessary for wave energy to be a significant contributor to Ireland's energy mix. It is not a forecast.

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[41] Implementation Working Group Ocean Energy, (2021), 'SET-Plan, Ocean energy implementation plan'. Available at: https://setis.ec.europa.eu/system/files/2022-05/SET%20Plan%20OCEAN%20ENERGY%20Implementation%20plan.pdf.

2.4.6 Environmental considerations

In comparison with offshore wind, the environmental impact of wave energy is anticipated to be lower, but there is still much to learn:

- **Impact on marine life:** Installation of wave devices (and associated mooring systems) could impact marine life through noise and seabed disturbance during installation and then through noise, device movement, the presence of mooring lines and increased vessel movement during operation. WECs may also have a small effect on wave height or wave angle in the local area, potentially altering currents, water column structure and sediment transport, although further research is required on potential impacts of such effects on marine life with additional scale and number of devices.[42]
- **Impact on avian life:** WECs are likely to have negligible impact on avian life, due to their low profile and no large rotating surfaces.
- **Visual impact:** Although wave devices are not likely to have a significant visual impact, they still require onshore transmission assets that have a visual impact. Although not yet proven, it is likely that wave energy projects will be located within a few kilometres of shore, hence with little need for an offshore substation.
- **Pollution:** Although commercial-scale wave energy projects will generate electricity with much lower carbon intensity than fossil fuels, the manufacture and installation of WECs still contributes to carbon emissions and to pollution, through the release of contaminants from seabed sediments and from increased vessel traffic and risk of spillage of liquids (including oils and greases) from devices.
- **Coastal and onshore impact:** The electrical export system for any ORE project typically has to come ashore and then connect to the transmission network via an onshore substation. Coastal areas are often important, dynamic habitats so careful route planning and sometimes underground horizonal directional drilling is required to manage the local impact on flora and fauna. Social considerations relating to disruption due to cable installation and substation construction are also relevant.

As with any renewable energy technology, the rollout at scale of commercial WECs will need careful assessment of environmental, social and technical impacts, including navigation and shipping, fishing, aircraft and radar and military zones. In some cases, measures may be available to mitigate environmental and social impacts. Such measures are sometimes included as conditions of permits.

2.4.7 System impacts

In broad terms, the system impact of wave energy are similar to those of offshore wind. At a local level, wave energy generation is somewhat correlated with wind generation and not with solar generation. While waves are created and driven by wind activity and they persist after wind has died down.

Studies of the system impact of wave energy in Ireland are limited, and it is recognised that unless studies consider other source of supply and the dynamics of demand, it is hard to derive useful results. In scenario 4, by the time there is significant production from WECs, there will be much production from offshore wind. A 2020 study assessed the temporal and spatial correlation between wind and wave resources in Ireland using data collected over ten years. It showed that wave activity lagged wind activity by an average of five hours depending on the season, indicating smoothing potential in an energy system also using significant wind energy.[43]

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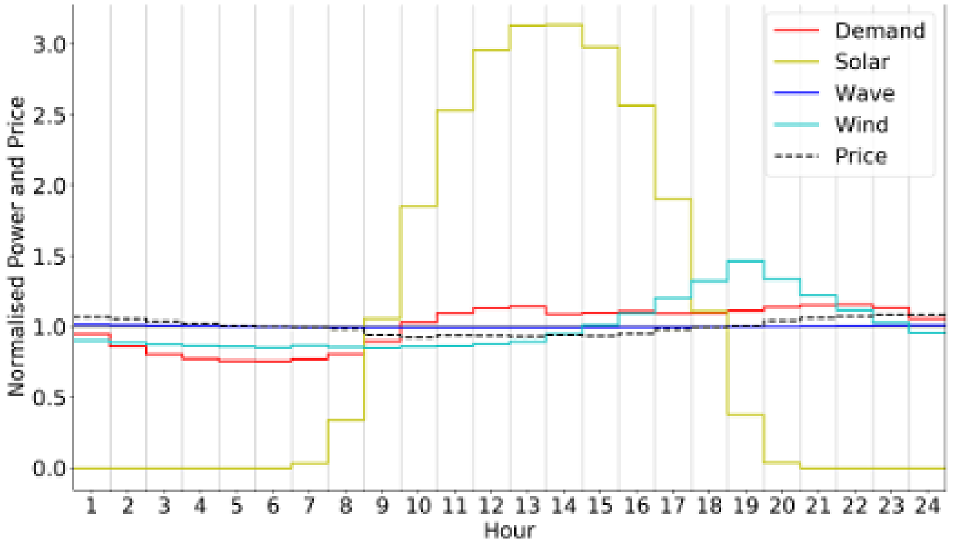
[42] Coast engineering Research Group, *'Waves, currents and sediment transport modelling at the Wave Hub site'*. Available at: https://www.plymouth.ac.uk/research/coast-engineering-research-group/waves-currents-and-sediment-transport-modelling-at-the-wave-hub-site.

[43] Gaughan, E and Fitzgerald, B, (2020), 'An assessment of the potential for co-located offshore wind and wave farms in Ireland', *Energy*. Available at: https://www.researchgate.net/profile/Breiffni-Fitzgerald/publication/340596153_An_assessment_of_the_potential_for_Co-located_offshore_wind_and_wave_farms_in_Ireland/links/5e970eafa6fdcca78918f69f/An-assessment-of-the-potential-for-Co-located-offshore-wind-and-wave-farms-in-Ireland.pdf.

A US-focussed study modelling combination of wave, wind and solar power showed that wave generation is somewhat less volatile than wind and solar on a short timeframe, generating a smoother and more predictable output.[44]

Figure 21 shows a comparison of diurnal generation. This is based on data from a Portuguese site, but it would be reasonable to expect Irish sites to follow a similar pattern. It shows a strong daily patterns for solar, but weak pattern for wind and weaker for wave.[45]

Figure 21: Portuguese diurnal pattern of wave generation with respect to wind and solar. From Vrana and Svendsen (2021), Quantifying the Market value of wave power compared to wind and solar – a case study



On a seasonal basis, wave energy shows large variation in generation between winter and summer months, with large swells driven by winter weather conditions. This pattern makes wave suitable to complement solar generation on the Irish grid, which has the opposite seasonal trend. Power demand and prices tend to peak in Ireland in the winter months, so wave energy fits well, providing systemic value by reducing price volatility.

Figure 22 shows a comparison of seasonal generation from the same Portuguese site, but it would be reasonable to expect Irish sites to follow a similar pattern. It shows a strong seasonal pattern for wave, weaker (and offset by 6 months) for solar and weakest for wind.

Figure 22: Portuguese – seasonal pattern of wave generation with respect to wind and solar. From Vrana and Svendsen (2021), Quantifying the Market value of wave power compared to wind and solar – a case study

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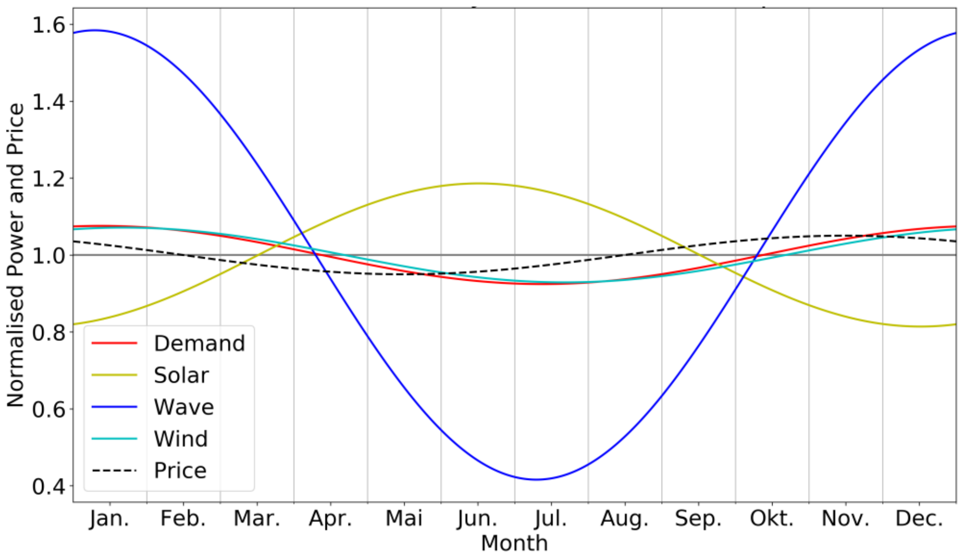
[44] Reikard, G, Robertson, B and Bidlot, J R, (2015), 'Combining wave energy with wind and solar: Short-term forecasting', *Renewable Energy*. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0960148115002141.

[45] Vrana, T K and Svendsen, H G, (2021), *'Quantifying the Market Value of Wave Power compared to Wind&Solar – a case study'*. Available at: https://sintef.brage.unit.no/sintef-xmlui/bitstream/handle/11250/2981188/Vrana2021qtm_akseptert.pdf?sequence=2.



A similar pattern for wave energy is shown in *Figure 23,* where to the west of Ireland the available resource in the three summer months is less than 25% of that in the three winter months.[46] This is supported by a more distinct picture in *Figure 24,* also for Ireland, where available resource in the summer is only 14% of that in the winter.[47] Though this cannot be directly compared with the ratio for energy production for offshore wind in Section 2.2.6, it shows a significant seasonal variation.

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[46] O'Connell, R, de Montera, L, Peters, J and Horion, S, (2020), 'An updated assessment of Ireland's wave energy resource using satellite data assimilation and a revised wave period ratio', *Renewable Energy*. Available at: https://www.researchgate.net/publication/343315063_An_updated_assessment_of_Ireland%27s_wave_energy_resource_using_satellite_data_assimilation_and_a_revised_wave_period_ratio

[47] ESB International on behalf of Marine Institute/Sustainable Energy Ireland, (2005), *'Accessible Wave Eenergy Resources Atlas: Ireland: 2005'*. Available at: https://www.marine.ie/sites/default/files/MIFiles/Docs/General/waveatlas.pdf.

Figure 23: Ireland's seasonal average wave power resource. From O'Connell et al. (2020), An updated assessment of Ireland's wave energy resource using satellite data assimilation and a revised wave period ratio

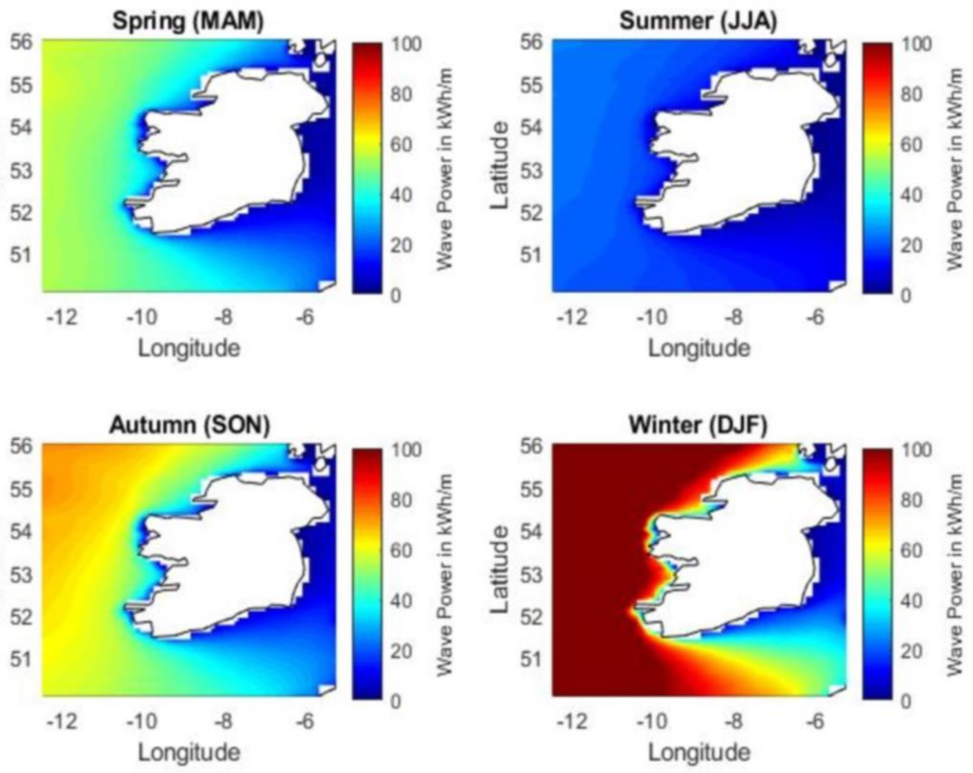
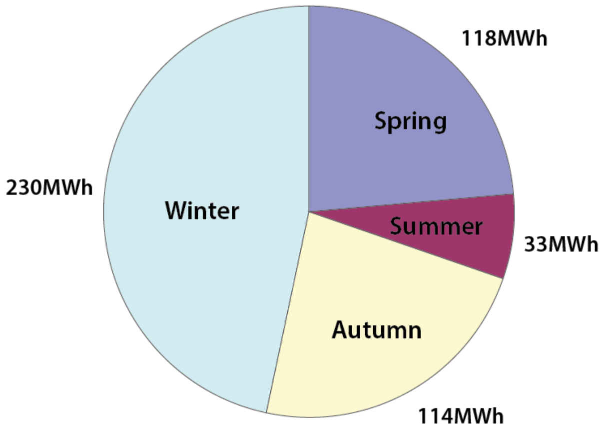


Figure 24: Seasonality of theoretical wave energy resource per metre. From Accessible Wave Energy Resource Atlas: Ireland (2005)



2.5 Other ocean renewable energy technologies

This section describes a range of other ORE technologies that could play a role in Ireland, but where technology is at an earlier stage and opportunities for impacting the energy system are lower. The technologies with a chance of playing a role in Ireland (should LCOEs reduce) are:

- Offshore airborne wind
- Offshore floating solar; and
- Tidal stream.

Technologies included for completeness but with a smaller chance of playing a role are:

- Tidal barrage

- Ocean thermal; and
- Ocean salinity gradient.

The section follows a similar but simplified pattern to sections above, without providing LCOE trajectories as these are so uncertain.

2.5.1 Offshore airborne wind

What is it?

Airborne wind energy (AWE) uses tethered airborne devices to generate electricity from the wind.

With an excellent wind resource, Ireland could be a significant market for AWE if it becomes competitive with conventional wind energy technology. It can be seen as a next step on from conventional fixed and floating offshore wind.

Two key concepts exist:

- **Ground-generating systems.** These typically generate electricity from the pulling action of the airborne device on its tether when in crosswind flying mode (like when flying a two-string kite in a figure-of-eight). The tether is allowed to extend, turning a generator. The airborne device is then set into a passive mode (like when a two-string kite just hovers) and the generator uses a fraction of the energy produced to pull the airborne device back towards the ground on its tether, before the cycle repeats.
- **Airborne-generating systems.** These generate electricity using small wind turbines on board an airborne device which is constantly in crosswind flying mode. In this case, the tether remains extended when generating and acts also as a conductor for electricity generated.

Some airborne devices are soft-wing (kites) and some are rigid-wing (gliders). Examples of the concepts are shown in *Figure 25* and *Figure 26*.

Optimum heights are likely to be not significantly greater than the heights at which conventional wind turbines operate (with maximum tip heights in the range (200 to 300 m for new projects). Both concepts have automatic take-off and recall modes to respond to changes in wind speeds and in the event of system faults.

Figure 25: The SkySails airborne wind energy system – an example of a soft-wing ground-generating device. From SkySails Group

Figure 26: The Makani drone – an example of a rigid-wing, airborne-generating device. From Google's X, The Moonshot Factory

Readiness

The airborne wind industry is still relatively new, with most devices being in the prototype stage. The industry is mainly based in Europe with the majority of devices in development being ground-generating. Onshore developments feature devices ranging from devices of 50 to 150 kW. The first commercial 150 kW AWE single kite system was supplied by SkySails in 2021, but larger devices could be developed for offshore use.

In 2019, Makani demonstrated a 600 kW offshore airborne wind device operating autonomously from a floating foundation.[48] Later, after a number of technical failures, its airborne programme was closed, but Google's X published much information about its journey and technical learning.[49]

As part of the MegaAWE project, in July 2022, RWE completed construction of an AWE test site in collaboration with Kitepower in County Mayo.[50, 51]

Airborne wind has TRL of 7-9 and CRI is 1.

Expected future developments

As for other renewable energy technologies, key future developments all relate to reducing LCOE through reducing CAPEX and OPEX and increasing energy production.

- **Long-term, autonomous operation.** A range of devices have demonstrated operation during limited test flights, but the number of completely autonomous operating hours, including starts and stops as the wind speed rises above a low-wind threshold then drops again, is limited, a key challenge being that a fault on in an airborne wind system can more easily have a larger consequence (the catastrophic loss of an airborne device via a crash, with possible risks to third parties) than a fault on a conventional wind turbine.
- **Concept and design optimisation.** Understanding how to optimise designs can only start with experience of manufacturing, installation and operation of early devices, and there is likely to be much to optimise in many areas. This is especially due to the risk of damage caused by a system fault, meaning there will continue to be a significant focus on improving the reliability of devices through high quality design, rigorous testing, comprehensive condition monitoring and efficient maintenance activities. Airborne wind offers more control options than other technologies, introducing increased opportunities to optimise energy production and structural loading.
  There is not a consensus as to the optimum device size, which must balance between the increasing mass per kW and the aim of reducing the cost per kW associated with the balance of plant and other components and processes.
  There is also an opportunity for increased energy production density (per square km of seabed) that could be realised by multiple devices being based on the same offshore foundation.
- **Industry and project scale-up.** Like other RE industries, as airborne wind finds technology innovations to reduce LCOE, it will also need to take advantage of increased volumes which can drive manufacturing installation and operational improvements to further reduce cost. Specific focus will be on high strength-to-mass materials, tethers and non-standard components. There are also opportunities for LCOE improvement as project sizes increase, due to volume-based efficiencies at each stage of the project lifecycle.

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[48] X, The Moonshot Factory, (2019), *'Makani's airborne wind power system takes flight offshore'*. Available at: https://x.company/blog/posts/makani%27s-airborne-wind-power-system-takes-flight-offshore/.

[49] X, The Moonshot Factory, *'Makani: Harnessing wind energy with kites to create renewable electricity'*. Available at: https://x.company/projects/makani/.

[50] RWE, (2023), *'RWE and Kitepower deliver new test site for Airborne Wind in Ireland'*. Available at: https://uk-ireland.rwe.com/press-and-news/2023-09-25-rwe-and-kitepower-deliver-new-test-site-for-airborne-wind-in-ireland/.

[51] Interreg North-West Europe, *'MegaAWE'*. Available at: https://vb.nweurope.eu/projects/project-search/megaawe-maturing-utility-scale-airborne-wind-energy-towards-commercialization/.

Levelized cost of energy

Trade body Airborne Wind Europe published a paper in 2022 setting out its vision for airborne wind energy, including why and how LCOE for airborne wind will transition from being two to three times higher to lower than for conventional onshore wind turbines by about 2037, as long as sufficient investment is secured. Of course this also depends on finding solutions that indeed reduce LCOE as much as predicted, which is uncertain at this stage. The paper also discusses different airborne wind concepts and the range of benefits it sees of airborne wind.[52]

Environmental considerations

Potential impacts on birds are less likely than with conventional wind turbines, however there is still potential for impact and the tether introduces another area of potential impact.

Airborne wind devices and their associated foundations use less material than conventional wind turbines and are easier to install and decommission. Therefore, they are likely to have less impact on marine life, and also less visual impact and less pollution during their project lifecycle.

However, the introduction of tethered, moving devices may increase aviation collision and radar interference risk, and in the event of system faults, devices and tethers may fall into the sea.

System impacts

System impacts are similar to those of offshore wind, with similar capacity factors and geographical distribution.

2.5.2 Offshore floating solar

What is it?

Floating solar consists of photovoltaic (PV) panels placed on structures floating on water.

Like onshore solar PV, offshore and inland floating solar can play a part in Ireland's future energy supply, but it is not likely to be significant, as Ireland has lower insolation than in many other European countries. Despite lower insolation, there has been significant growth in onshore solar PV in Ireland recently because it is well suited to domestic and small-scale projects. Offshore floating solar projects are likely to be at larger scale (50 MW and above) and require accessible, sheltered water without competing uses. There is a limited supply of such sites in Ireland.

Placing panels on water, as shown in *Figure 27* provides chemical efficiency benefits due to the lower ambient temperatures. Projects can be located on any calm water, including on reservoirs for hydroelectric dams, thereby using the availability of a local grid connection. To date, almost all projects have been on inland waters, but some have been in calm nearshore waters, typically tidal lagoons.

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[52] BVG Associates on behalf of Airborne Wind Europe, (2022), *'Getting airborne – the need to realise the benefits of airborne wind energy for net zero'*. Available at https://airbornewindeurope.org/studies-papers/white-paper-for-the-airborne-wind-energy-sector-by-bvg-associates-commissioned-by-airborne-wind-europe/.

Figure 27: Floating solar array. From SolarisFloat

Readiness

Land-based solar PV is an established technology, with the only difference between conventional solar and floating being the flotation system. As of 2021, the global installed inland floating solar PV capacity has exceeded 3 GW.[53] Inland floating solar is at TRL 9 and CRI 4, but offshore floating solar is at TRL 9 and CRI 2.

Expected future developments

Key future developments are:

- **Economies of scale.** Offshore floating solar projects are easily scalable, but with only marginal reductions in LCOE, in line with trends seen in land-based PV. This is because panels and power electronics, the largest cost elements, are highly modular and mass-produced and large projects just consist of many more of these.
- **PV technology development.** PV technology will continue to progress, driven by a huge global market for domestic and utility-scale projects. This will continue to drive cost reduction and increases in efficiency. For offshore floating solar, the key additional considerations relate to ensuring continued efficiency and reliability in offshore conditions, including the presence of salt water.
- **Floating structure optimisation.** An important opportunity for offshore floating solar is in the manufacturing and installation of modular floating structures that also enable efficient maintenance.

Levelized cost of energy

Land-based solar PV has achieved LCOE comparable to onshore wind in many markets and lower LCOE in markets with high insolation. While floating solar PV installations can use the same panels as land-based solar PV, the floating structures and less convenient access increases cost. This premium is likely to decrease over time as floating structures, installation and operational activities are optimised, though inland floating solar is likely to remain more attractive than offshore floating solar, due to lower salinity and typically less movement of water.

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[53] REN21, (2022), *'Global Status Report'*. Available at: https://www.ren21.net/wp-content/uploads/2019/05/GSR2022_Full_Report.pdf.

Environmental Considerations

Blockage of sunlight reduces evaporation and growth of aquatic plants and algae. This may be a benefit in some circumstances. Panels can reduce airflow over the water which restricts gas exchange between the air and water, affecting microbial communities and aquatic ecosystems.

Solar panels contain heavy metals that can be leached into the water over time. Buoys contain plastics which can degrade or abrade, increasing concentrations of microplastics in the water.

Electrical equipment always introduces the risk of fire, which could release toxic material into the water. Although relevant to other ORE technologies, it is most relevant to floating solar, with a large number of panels and connections located close to the water.

Floating solar projects also have a visual impact.

System Impacts

System impacts are similar to those of land-based solar PV, with the main considerations being intermittency and relatively low average capacity factors. Solar PV generation is highly variable during the day and across seasons, with maximum output in the middle of the day, whereas demand often peaks at other times, unless driven by air conditioning for cooling in some markets. Evidence suggests that solar systems may have complementary system balancing impacts when combined with wind generation, as they typically peak at different times and under different weather conditions.[54]

2.5.3 Tidal stream

What is it?

Tidal energy uses the kinetic energy of the free movement of water due to tides to generate electricity. Tides are driven by the relative movement of the earth, moon and sun and can be predicted years in advance. Tidal range (the difference between the largest and smallest tidal heights) is greatest during spring tides, and smallest during neap tides.
While Ireland has a high tidal range, up to 4.5 m during spring tides, depending on location[55], it is likely that tidal energy will not play a large role in Ireland's energy future due to limited suitable project locations where this translates into high flow speeds, relatively high LCOE and environmental concerns.

Most tidal energy converters (TECs) function similarly to wind turbines, capturing energy from water rather than air, though some designs act more like rigid-wing airborne wind devices. TECs are generally placed in areas with high flow speeds due to suitable bathymetry (such as tidal lagoons, estuaries or channels), though some designs are emerging that are optimised for lower flow speeds.

TECs are placed directly into the tidal current and may be fixed (with a range of different foundation types) or floating.

Readiness

Tidal stream technology has been in development for decades, but remains far from competitive, so still in need of much development. As of the end of 2022, over 80 GWh of energy has been generated from tidal stream sources in Europe.[56] The majority of this generation has come from the Meygen array, located

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[54] Hassan et al, 2023, A review of hybrid renewable energy systems: Solar and wind-powered solutions: Challenges, opportunities, and policy implications, *Results in Engineering*, Available at: https://www.sciencedirect.com/science/article/pii/S259012302300748X.

[55] Foras na Mara, *'Tidal flows around Ireland'*. Available at: http://www.marine.ie/site-area/data-services/real-time-observations/tidal-flows-around-ireland

[56] Ocean Energy Europe, *'Tidal current'*. Available at: https://www.oceanenergy-europe.eu/ocean-energy/tidal-energy/

between the Scottish Mainland and Orkney islands and developed by SIMEC Atlantis Energy. Tidal TRL is 7-9 and CRI is 1.

Expected future developments

Key future developments all relate to reducing LCOE through reducing CAPEX and OPEX and increasing energy production.

- **Concept and design optimisation.** As explained above for other generation technologies, understanding how to optimise designs can only start with experience of manufacturing, installation and operation of devices, and there is likely to be much to optimise in many areas.
    - TEC concepts focussed on high-flow areas lack the physical size scaling potential of wind turbines. Larger TECs have to be located in deeper water where there are lower mean flow speeds This is different to larger wind turbines which have greater hub heights, so access higher mean wind speeds. TECs also lack the market scaling (industrialisation) potential, as there are not so many locations, globally, that have high flow speeds.
    - Another route is for TEC concept to be focussed on areas of deeper water but lower mean flow speeds. There are many more areas (including in Irish waters) with such conditions. This allows the development of larger devices and rigid-wing devices that act like airborne wind devices. The challenge about this route is that lower mean flow speeds typically increase LCOE, making it harder for the technology to establish, even if eventually it could have a larger market.
    - The reliability and maintainability of subsea devices will need to improve in order for tidal energy concepts to establish themselves in the Irish market. This will require high quality design suited to the areas where there is sufficient tidal resource potential around the Irish coast, as well as rigorous device testing, comprehensive condition monitoring and efficient maintenance activities.
- **Industry and project scale-up.** As the industry finds technology innovations to reduce LCOE, it will also need to take advantage of increased volumes to drive manufacturing installation and operational improvements to further reduce cost. This could result in securing significant reduction in the main component costs of TECs and growing a supply chain with experience in the tidal stream application. Opportunities will also emerge as project sizes increase, due to volume-based efficiencies at each stage of the project lifecycle.

Levelized cost of energy

The main barrier to wider market adoption remains LCOE. In the UK, various tidal projects were awarded CfDs in the 2023 auction round, all with a strike price of £198 /MWh in 2012 terms, about four to five times higher than offshore and onshore wind and solar.[57]

The LCOE of tidal stream generation has been falling over time, but the gap compared to offshore wind has not closed significantly. ORE Catapult estimates that tidal stream can reach a LCOE of £80 /MWh after 2 GW of cumulative installed capacity, highlighting there is a strong potential for cost reduction with increased project size.[58] The challenge remains that this is still higher than other variable renewable energy technologies and the route to parity, at volume, is not clear.

Environmental considerations

Tidal stream projects focussed on high flow speeds are typically close to shore. This means that associated considerations relate to marine life, especially the potential for disturbance of / collision with cetaceans, and vessel movements, including for fishing activities.

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[57] Department for Energy Security and Net Zero, (2023), *'Contracts for Difference Allocation Round 5 results'*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1183230/cfd-ar5-results.pdf.

[58] Offshore Renewable Energy Catapult, (2018), *'Tidal Stream and Wave Energy Cost Reduction and Industrial Benefit'*. Available at: https://ore.catapult.org.uk/wp-content/uploads/2018/11/Tidal-Stream-and-Wave-Energy-Cost-Reduction-and-Industrial-Benefit.pdf.

System impacts

Tidal energy offers a highly predictable source of generation, though always cyclical, dropping to zero twice each day. Tides can be predicted years in advance but with no correlation with daily or seasonal demand. A geographical distribution of projects smooths output as high tides occur at different times in different locations. A 2013 study showed that it is possible to provide base load power to the Irish grid via tidal energy, specifically by geographically spreading installations to utilise the different phases of tidal stream velocity along the Irish coast.[59] Furthermore, a 2020 study modelling the impact of tidal energy on the Irish transmission system indicated that geographic spread of tidal sites in Ireland helps balance variability of wave energy.[60] Tidal stream generation can be constrained easily, as required.

2.5.4 Tidal barrage

What is it?

Generation using tidal barrages use turbines integrated directly into the barrage wall. As water flows in and out of an estuary, natural or man-made basin due to tidal activity, water will flow through the barrage, driving the turbines, similar to in hydroelectric dams, but with much reduced pressure head. The most well-known tidal barrage was completed in 1966 in La Rance, France (240 MW).

Tidal barrage generation is not likely to play a large role in the future of Ireland’s energy supply. Tidal barrages are most suited to be placed across rivers or tidal basins with high tidal ranges, without the need for regular vessel navigation, and in areas without sensitive coastal ecosystems that would be disrupted by changes in water level and reduced access through the barrage.

Readiness

Tidal barrage technology is mature and has been commercially exploited for decades. The Sihwa Lake tidal power station, constructed in 2011 in South Korea (254 MW) is the largest tidal barrage in operation. Various other commercial scale tidal barrage plants exist worldwide. While tidal barrage installations have been proven to be commercially viable, suitable locations are limited, limiting wider adoption. Tidal barrage technology TRL is 9 and CRI is 4.

Expected future developments

Tidal barrages will be able to take advantage of ongoing advances in large civil engineering infrastructure technologies and processes, as well as water turbine and generator technology. Key will also be development in understanding of environmental impact and mitigation, including with regard to coastal and riverine sediment.

Levelized cost of energy

LCOE is highly dependent on the parameters of each project, especially tidal range and the volume of water that can be stored. The Rance plant currently produces electricity cheaper than French nuclear plants.[61]

Environmental considerations

Tidal barrages have significant environmental impacts but can also provide additional river crossings for transport. Marine habitats are disrupted and up- or downstream movement of fish and other aquatic life are affected. Alterations in water level, quality, salinity and temperature affect the often rich biodiversity found in

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[59] Giorgi, S and Ringwood, J, (2013), ‘Can Tidal Current Energy Provide Base Load?’, *Energies*. Available at: https://www.mdpi.com/1996-1073/6/6/2840.

[60] Jónsdóttir, G M and Milano, F, (2020), *‘Stochastic Modelling of Tidal Generation for Transient Stability Analysis: A Case Study based on the All-Island Irish Transmission System’*. Available at: http://faraday1.ucd.ie/archive/papers/tideirish.pdf.

[61] Energy Monitor, (2022), *‘The mystery of the UK ’s untapped tidal power’*. Available at: https://www.energymonitor.ai/renewables/the-mystery-of-the-uks-untapped-tidal-power/?cf-view.

tidal ecosystems. Sediment transport and vessel traffic will also be affected. Much environmental monitoring of the Rance estuary was carried out in response to such concerns and by ten years after commissioning of the tidal barrage, the Rance estuary was considered again as richly diversified as before. A new biological equilibrium had been reached and aquatic life was flourishing again.[62]

System impacts

Similar to tidal stream, tidal barrage generation offers a highly predictable source of generation, though always cyclical, dropping to zero twice each day. Tides can be predicted years in advance but with no correlation with daily or seasonal demand. A geographical distribution of projects smooths output as high tides occur at different times in different locations. Tidal barrage generation can be constrained easily, which provides a short-term energy storage solution.

2.5.5 Ocean thermal

What is it?

Ocean thermal energy conversion (OTEC) systems harness the thermal gradient present between warmer surface waters and the colder waters deeper in oceans to generate electricity.

Ocean thermal energy conversion is unlikely to play a significant part of the future energy mix in Ireland. As with other generation technologies relying on the heat engine concept, thermodynamic efficiencies are greater when operated under large temperature differentials. The regions offering the greatest temperature differences between the surface and deep waters typically are tropical regions. OTEC projects further from the equator, such as Ireland, will not be as efficient.

Readiness

Most of the technology required to build an OTEC system is either readily available off-the-shelf or can be used without significant redesign. The main source of uncertainty is the scaling and maintenance of the large heat exchangers required, and this is an ongoing area of research and development effort.

Pilot and demonstrator-scale projects include the K-OTEC 1000 barge in South Korea (1 MW), the Makai Ocean Engineering demonstrator in Hawaii, USA (105 kW), a demonstrator on Kumejia Island in Japan (100 kW) and a demonstrator in Qingdao, China (15 kW).[63] No commercial or utility scale facilities currently exist. Ocean thermal energy TRL is 7 and CRI is 1.

Expected future developments

Key future developments again relate to cost reduction and revenue maximisation.

- **System scaling.** A study carried out in 2010 by the University of Hawaii indicated that the cost of electricity for a 10 MW OTEC system would be US$440 /MWh, with costs for a 100 MW system dropping to US$180 /MWh, indicating good opportunities for scaling.[64] Market scaling will also have a positive impact through design optimisation, learning-by-doing and manufacturing optimisation, especially of heat exchangers.
- **Obtaining additional value from byproducts.** This can be from:
    - Desalination (a 1 MW plant can produce approx. 4,500 cubic metres of desalinated water per day[65]).

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[62] Pacific Northwest National Laboratory, *'La Rance Tidal Barrage'*. Available at: https://tethys.pnnl.gov/project-sites/la-rance-tidal-barrage.

[63] IEA Ocean Energy Systems (OES), (2021), *'Ocean Thermal Energy Conversion'*. Available at: https://tethys-engineering.pnnl.gov/sites/default/files/publications/oes-white-paper-on-otec.pdf.

[64] Vega, L A, (2010), *'Economics of Ocean Thermal Energy Conversion (OTEC): An Update '*. Available at: https://onepetro.org/OTCONF/proceedings-abstract/10OTC/All-10OTC/OTC-21016-MS/36399.

[65] Herrera, J, Sierra, S, Ibeas, A, (2021), 'Ocean thermal energy conversion and other uses of deep sea water: A review', *Marine Science and Engineering*. Available at: https://tethys.pnnl.gov/sites/default/files/publications/jmse-09-00356-v2.pdf

- Use of pumped, colder water in air conditioning systems and chilled-soil agriculture (enabling crops normally grown in cooler climates or winter to be grown in warmer regions or out of season).
- Aquaculture (by circulating colder and nutrient rich deep-sea water to the surface).

Levelized cost of energy

LCOE depends greatly on available thermal differentials and obtaining additional value from byproducts. There remains significant uncertainty on the long-term trend for commercial-scale OTEC projects, and the technology is unlikely to be deployed in Ireland due to its limited resource potential and northerly location.

Environmental considerations

Open-cycle OTEC systems involve mixing of nutrient-rich, but oxygen-deficient, deepwater with surface seawater which may be beneficial but may also affect surface layer ecosystems, potentially causing excessive algae or plankton growth.[66] Closed-cycle OTEC systems use environmentally hazardous work fluids, with the risk of leakage to the environment. OTEC systems cause sub-surface noise during operation, due to large pumping systems.

System impacts

OTEC systems generate energy continuously, with high capacity factors. They are dispatchable.

2.5.6 Salinity gradient

What is it?

Salinity gradient power exploits the difference in salt concentration between seawater and freshwater. Installations are ideally located in areas where rivers discharge into oceans or seas. There are two main concepts currently under investigation:

- Pressure retarded osmosis (PRO), the more advanced; and
- Reverse electrodialysis (RED).

While Ireland has many rivers which discharge into the surrounding seas and ocean, giving it good salinity gradient power potential, it is unlikely that salinity gradient will play a significant part in Ireland’s future energy mix due to the quality of its offshore wind and wave resource. Pilot projects and studies have determined that, with current technology, salinity gradient is still a distance from being economically viable.[67]

Readiness

The technology is relatively simple, with the main technology barrier being the semi-permeable membrane. Other equipment such as pumps and pressure vessels are readily available. There have been a handful of small-scale pilot projects, such as the 10 kW Statkraft plant in Norway and the 50 kW Afsluitdijk REDstack plant in the Netherlands, but no commercial or utility scale plants currently exist. Salinity gradient TRL is 6 and CRI is 1.

Expected future developments

Key future developments relate to cost reduction and revenue maximisation.

- **System scaling.** Membrane technology is key in achieving market viability. There are currently only a small number of membrane manufacturers. Market scaling is needed for larger scale production of lower cost, more efficient membranes.

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[66] Rivera, G, Felix, A and Mendoza, E, (2020), ‘A review on environmental and social impacts of thermal gradient and tidal currents energy conversion and application to the case of Chiapas, Mexico’, *Environmental Research and Public Health*. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7663693/.

[67] Straube, A, Deshmukh, A and Elimelech, M, (2016), 'Pressure-retarded osmosis for power generation from salinity gradients: is it viable?', *Energy & Environmental Science*. Available at: https://pubs.rsc.org/en/content/articlehtml/2016/ee/c5ee02985f.

- **Hybrid applications.** Salinity gradient plants can be used in tandem with other processes such as desalination or other chemical processes that produce saline wastewater, generating energy from industrial wastewater while also converting it to less environmentally harmful brackish water. Hybrid application may be more economically viable than standalone operation.[68]

Levelized cost of energy

Salinity gradient power is only suitable in limited locations or for niche hybrid applications. Due to this, it is unlikely that economies of scale and cost reductions are realised.

Environmental considerations

Salinity gradient power does not consume salt or water and does not release environmentally harmful pollutants. It does not produce noise pollution.

Salinity gradient plants can cause turbulence in the directly surrounding area due to water intake and discharge, potentially impacting local ecosystems. This can be mitigated by proper plant configuration.

System impacts

Salinity gradient systems generate energy continuously, with high capacity factors. They are dispatchable.

2.6 Technology development themes relevant to all ocean renewable energy technologies

Sections above discuss future technology development in specific ORE technologies. This section considers future technology development relevant to industry more broadly, covering five themes:

- Materials development, additive and advanced manufacturing
- Big data, analytics and digital twins
- On-site robotics and autonomous technology
- Internet of things and sensing technology; and
- Artificial intelligence (AI) and machine learning (ML).

Each is relevant to all ORE technologies.

Also relevant, is the development of energy storage technologies and the development of new energy vectors such as hydrogen. These are an enabler of increased penetration of all variable renewable energy technologies.

In all cases, developments are being driven by organisations from small start-ups through to globally-active engineering businesses. These are expected to have an impact on ORE as a whole, though most early applications are focussed on offshore wind.

Unless otherwise stated, for each technology investment is relatively organic/stepwise, without any specific large steps requiring significant risks to be taken (like needing to construct a costly demonstrator). Organisations based in Ireland with expertise in these areas will have opportunities to impact the market in Ireland and beyond, typically through early-stage innovation then technology trials for project owners, turbine suppliers or service providers (depending on the technology).

Overall, based on industry studies and experience, anticipated impact on LCOE for offshore wind over the next 15 years is as shown in *Table 11*. Impacts on other technologies are likely to be similar. Individually,

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[68] IRENA, (2014), *'Salinity Gradient Energy: Technology Brief'*. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2014/Jun/Salinity_Energy_v4_WEB.pdf.

none of these impacts are game-changing, but together, they provide a valuable contribution to downward trends in LCOE.

Table 11: Anticipated impact of different technologies on LCOE for offshore wind over the next 15 years

	Anticipated impact on LCOE for offshore wind over the next 15 years	Main sources of saving
Materials development, additive and advanced manufacturing	3-4%	CAPEX
Big data, analytics and digital twins	2-3%	OPEX and energy production
Artificial intelligence and machine learning	2-3%	CAPEX, OPEX
On-site robotics and autonomous technology	1-2%	OPEX and energy production
Internet of things and sensing technology	1-2%	OPEX and energy production

2.6.1 Materials development, additive and advanced manufacturing

Innovation in materials, additive and advanced manufacturing[69] will continue to impact ORE projects. The main benefits relate to improved CAPEX. Examples of future impacts include:

1. Blade manufacture: Composites offer opportunities for all three main ORE technologies analysed in this report, especially in reducing the staffing needs and associated quality risks during manufacture. There are a range of offshore wind energy projects active in this field that will eventually come to market and similar advancements could also apply to wave energy in time.
2. Device component manufacture: To date, additive manufacture at any scale has not been sufficiently cost effective, but as design methods improve and costs reduce, applications are likely to appear.
3. Steel production. Steel is a large contributor to material use in most ORE technologies. During the next 15 years, there will be a transition from steel manufacture using high grade heat from coking coal to hydrogen, producing 'green steel'. As well as significantly reducing the carbon footprint of steel, it will enable refinement of the steel manufacturing processes, with resulting improvements in material properties, enabling more efficient structural material use.

Investments to incorporate these technologies into ORE projects are significant and as manufacturing of significant componentry and inputs in Ireland is unlikely, Irish opportunities are not likely to be significant. First volume production of green steel production is expected in 2025 or 2026, with a significant number of facilities operating by 2030 and much of the transition in Europe complete by 2040. Although Ireland is unlikely to benefit directly from green steel production, an emerging green steel industry in Europe will be a significant source of hydrogen demand and an export opportunity for renewable hydrogen produced from ORE in Ireland.

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[69] Additive manufacture is where components created by 3D printing, rather than more conventional moulding or machining. Advanced manufacturing involves the use of innovative technologies and methods to improve manufacturing, considering all aspects of the value chain.

2.6.2 Big data, analytics and digital twins

Developments in big data, analytics and digital twins[70] are highly relevant to ORE projects, typically with multiple similar devices operating remotely and in complex, varying conditions. Such technologies are also applied to installation processes and tooling and in many areas within the supply chain to improve the efficiency of activities.

The main benefits of the technology in ORE applications relate to reducing OPEX and increasing energy production through more precise understanding of operational conditions and their impact on devices. Examples of future impacts include:

- During construction: Much improved real-time monitoring and forecasting of weather conditions allows more efficient execution by better planning to maximise use of good weather conditions.
- During operation: More accurate digital twins of whole devices and sub-systems, coupled with use of advanced sensing enables earlier recognition of changes in device behaviour, highlighting early onset of failures, helping to minimise OPEX and downtime.

During operation: Analysis of spares usage across a whole fleet of devices in different conditions enables improved Intelligent sensors (for example, advanced acoustic emissions sensors and self-powered, wireless technology allowing the monitoring of critical large bearings) provide improved health monitoring and prognosis of failure, enabling proactive service operations in conditions that allow crew access to devices, reducing downtime and lost generation.

2.6.3 Artificial intelligence and machine learning

Developments in AI and ML[71] have already been applied to ORE projects. The main benefits relate to improved project design and operations. Examples of future impacts include:

- During project development: AI/ML will be increasingly used to derive reliable resource estimates from multiple big data sources. It will also be used to assess the environmental impact of ORE projects more comprehensively by analysing more data sources and simulations. AI/ML will also help to optimise device locations in arrays, using a growing range of data sets and cost models.
- During operation: As well as big data analytics, AI/ML will be increasingly used to find changes in device behaviour and hence prognose failure, enabling proactive repair or replacement and to improve forecasting of energy production, thereby improving the efficiency of grid integration. It will also be used in whole project control to optimise energy production and/or device lifetime based on real time data.

2.6.4 On-site robotics and autonomous technology

Future technology developments in on-site robotics and autonomous technology include the use of:

- Free-moving drones, surface vessels and underwater vehicles that can move between devices autonomously.
- Robots moving autonomously on a structure, having been placed there by service crews.

The main benefit is in reducing the cost of offshore operations (hence reducing LCOE) and reducing the need for workers to operate in challenging offshore environments. Examples of future impacts include:

- During site development: Technical and environmental surveys are likely to involve more autonomous activity.

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[70] Big data covers larger, more complex data sets that can be analysed to extract trends to help improve decision making. Analytics covers the complex analysis of such data sets. Digital twins are virtual models of physical objects that can be used to predict physical behaviour and monitor performance.

[71] AI is an umbrella term for computer software that mimics human cognition in order to perform complex tasks and learn from them. Machine learning (ML) is a subfield of AI that uses algorithms trained on data to produce adaptable models that can perform a variety of complex tasks.

- During operation: Autonomous drones, surface vessels and underwater vehicles can be deployed to collect data and assess the condition of equipment. This allows for early detection of issues, predictive maintenance planning, and improved system reliability.
- During operation: Remote-operated or autonomous robots can be used for maintenance and repair activities on ORE systems, especially accessing hard-to-reach areas to perform repairs, or to transfer spare parts to service crews.

2.6.5 Internet of things and sensing technology

Developments in the internet of things[72] and sensing technology include the use of more (and more advanced) sensors, including with built-in intelligence, in ORE devices and in their installation and operation.

The main benefits of the technology in ORE applications relate to reducing CAPEX and OPEX and increasing energy production through more precise device control and advanced health monitoring of operating systems. Examples of future impacts include:

- During construction: On-pile sensors enable more controlled and effective piling activities.
- During device operation: Technologies such as nacelle-mounted LIDAR enable advanced, proactive control, looking at the incoming flow field, rather than reacting to changes in loading.
- During operation: Intelligent sensors (for example, advanced acoustic emissions sensors and self-powered wireless technology allowing the monitoring of critical large bearings) provide improved health monitoring and prognosis of failure, enabling proactive service operations in conditions that allow crew access to devices, reducing downtime and lost generation.

Investment is likely to continue to flow into this field relatively readily, as the concept of the Internet of Things has already seen successful development in the consumer space with the advent of much "smart" technology. Innovation in cyber security will also be important to ensure these critical assets are not vulnerable to interference.

2.7 Recommendations

On the basis of the above assessment of the readiness of different ORE technologies to contribute to Ireland's generation mix, it is recommended that:

- DECC builds an ORE deployment strategy for Ireland primarily around fixed and floating offshore wind. These technologies offer the greatest certainty and return on investment for Ireland.
- SEAI and DECC review on an ongoing basis whether other technologies, especially wave energy, should play a significant role in Ireland's energy mix, and monitor developments in most relevant technologies. Public support for technology development may be appropriate in some cases.

More detailed systems modelling balancing research via EirGrid, in line with recommendation 29, will provide further clarity regarding the potential reduction in infrastructure cost from diversifying Ireland's generation fleet into other ORE technologies. Due to the significant gap in LCOEs currently between offshore wind and other technologies, such research is unlikely to significantly impact this report's overall finding that Ireland's ORE deployment strategy should be built primarily around fixed and floating offshore wind.

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[72] The internet of things is the network of ways of gathering and exchanging data easily over the internet in order to improve system understanding.

3. Scenarios for offshore renewable energy technologies in Ireland

This section establishes four volume scenarios for ORE technologies in Ireland, which are used as a basis for the LCOE modelling in Section 2. These scenarios are intended to provide four illustrative futures for the Irish ORE landscape to aid comparison and analysis of policy choices rather than representing predictions of the future.

Three of the four scenarios focus on an ORE landscape which is dominated by offshore wind, both fixed and floating. This reflects the significant challenges faced by other ORE technologies in reaching commercial readiness, as discussed in Section 2.5, which make it unlikely they will compete on price in the foreseeable future with offshore wind and other established onshore technologies to become an important part of Ireland's energy system. Scenarios 1-3 therefore include a very small quantity of wave energy and no other ORE generation.

The fourth scenario examines a world in which wave energy moves through the TRL/CRI scale and achieves the significant cost reductions necessary to play a significant role in Ireland's energy system. It also includes a small amount of other ORE technologies, likely tidal, though even in a world in which tidal energy makes significant cost savings its overall capacity to contribute to Ireland's ORE fleet is likely to be limited by a lack of ideal sites.

In each scenario, projections of domestic demand and onshore generation up to 2050 are based on the National Energy Projections 2022 (NEP). Deployment of ORE technologies up to 2030 are taken from the NEP, as there is limited opportunity to change deployment within the 2020s at this stage.

Where there is excess energy being generated above that which is being used domestically, it has been allocated evenly between export via interconnector and alternative offtake solutions such as conversion to hydrogen via electrolyser, either for onward export or domestic use. This choice is illustrative only, and the exact ratio of allocation of excess generation to either interconnector export, hydrogen electrolysis or other offtake solutions will depend on many factors including the relative cost per megawatt of each, global hydrogen market dynamics and wholesale electricity price differentials with nearby partner countries.

The scenarios do not consider potential increases in domestic demand beyond the National Energy Projections, which could be a third way of addressing the challenges of excess generation and capturing additional economic benefit. An excess of clean, affordable energy could offer opportunities for expansion of energy intensive industries such as data centres, steel making or aluminium making to name a handful.

For the purposes of this study, it has been assumed that any excess power generation which is not exported via interconnector goes to renewable hydrogen electrolysis, operating at a capacity factor of 70%, in keeping with higher performing contemporary giga-scale projects.[73]

3.1 Scenario 1: Decarbonising through offshore wind

In this scenario, shown in *Table 12* and *Figure 28,* ORE is overwhelmingly used to power the energy transition of the domestic economy. This is achieved using fixed and floating offshore wind combined with onshore generation technologies.

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[73] Poljak, J, (2021), *'Giga-scale green hydrogen: Developers are being unrealistic about levelized costs'*. Available at https://www.rechargenews.com/energy-transition/giga-scale-green-hydrogen-developers-are-being-unrealistic-about-levelised-costs/2-1-1046646.

Limited additional interconnection is built and there is no significant domestic hydrogen production from electrolysis. Ireland does not become a major exporter of energy, instead focussing only on meeting its own energy needs.

Table 12: Total capacity installed for different technologies in scenario 1

Technology	Total capacity installed by end 2030 (GW)	Total capacity installed by end 2040 (GW)	Total capacity installed by end 2050 (GW)
Fixed offshore wind	3.2	5.5	6
Floating offshore wind	0	1	3.3
Wave	0	0.01	0.15
Other ORE technologies	0	0	0
Interconnection	0.7	1.4	3.1
Hydrogen electrolysis	0	0	0

The ORE landscape is dominated by offshore wind, and more fixed offshore wind is built than floating offshore wind, as early fixed sites are likely to offer the lowest unit cost of energy. Wave and other ORE technologies are assumed to make a negligible contribution and remain uncompetitive with offshore wind, as today.

Any excess power is assumed exported by interconnector at a capacity factor of 25%.[74] This is consistent with an interconnector fleet geared towards both import and export, with flows often reversing to import power from other markets when needed.

By 2030, it is assumed that 3.2 GW fixed offshore wind will be in operation. This is broadly consistent with the deployment of known ORESS 1 projects by 2030. It is assumed that deployment from ORESS 2.1 and other future offtake auctions will not take place until after 2030. This assumption also applies to scenarios 2, 3 and 4.

The domestic decarbonisation pathway set out in this report differs from that set out in the recent analysis published alongside DECC's draft *Offshore Renewable Energy Future Framework Policy Statement* in January 2024.[75] This report envisages 9.3 GW fixed and floating offshore wind deployment by 2050, as opposed to 16 GW in the future framework analysis. This is due to the different input assumptions upon which the two scenarios were based. This report aligns ORE generation with the domestic demand projections set out in the NEP 2022, whereas the future framework analysis is aligned with EirGrid's 'self sustaining' scenario set out in EirGrid's *Tomorrow's Energy Scenarios* 2023 report.[76]

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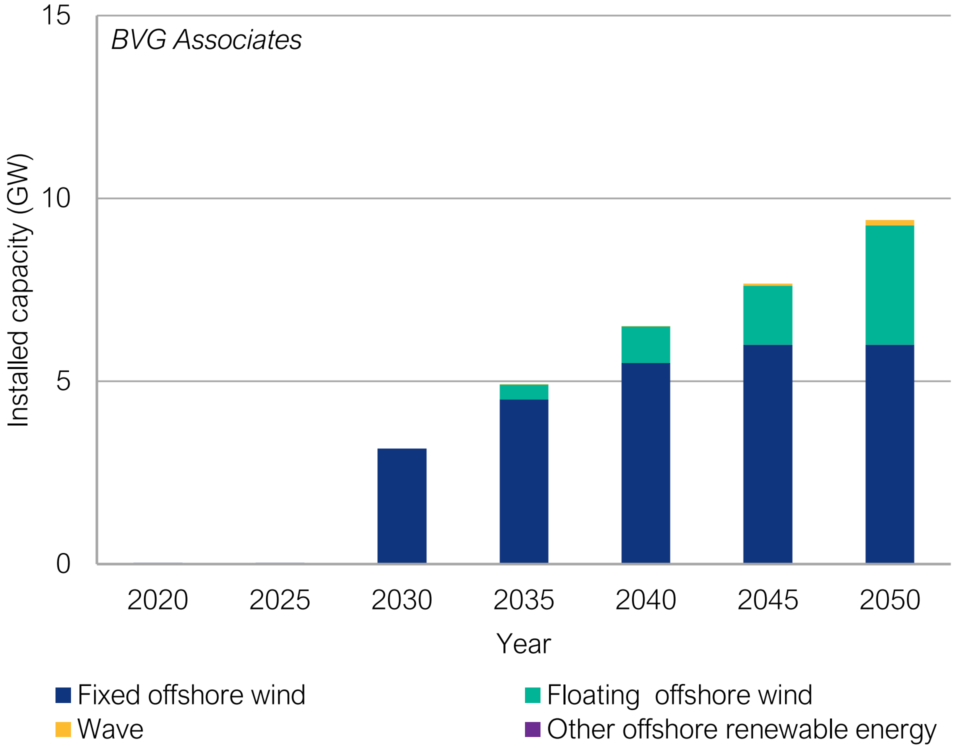
[74] Capacity factor represents the ratio of energy export to theoretical maximum export, were the interconnector to operate at full capacity and flow only in one direction for the entire period.

[75] Afry and BVG Associates (2024) *'Offshore renewable energy export potential for Ireland', Workstreams 1 to 5*, Available at https://www.gov.ie/en/consultation/747c7-consultation-on-the-offshore-renewable-energy-ore-future-framework-policy-statement/.

[76] EirGrid, 2023, *'Tomorrow's Energy Scenarios'*, Available at: https://www.eirgrid.ie/industry/tomorrows-energy-scenarios-tes/.

Figure 28: Scenario 1 ORE deployment profile



3.2 Scenario 2: Delivery of 37 GW ambition

In this scenario, shown in *Table 13* and *Figure 29*, Ireland pursues its stated ambition of 37 GW offshore wind by 2050. In so doing, Ireland becomes a significant net exporter of energy, generating about 250% of its domestic electricity demand by 2050.

Table 13: Total capacity installed for different technologies in scenario 2

Technology	Total capacity installed by end 2030 (GW)	Total capacity installed by end 2040 (GW)	Total capacity installed by end 2050 (GW)
Fixed offshore wind	3.2	10	10
Floating offshore wind	0	7	27
Wave	0	0.01	0.15
Other ORE technologies	0	0	0
Interconnection	0.7	4.7	13
Hydrogen Electrolysis	0	3.8	11

In scenario 2, the ORE landscape is dominated by offshore wind, with wave and other ORE technologies remaining uncompetitive. Fixed offshore wind deployment is capped at 10 GW. In addition, 27 GW of the 37 GW total offshore wind is floating offshore wind.

Although fixed offshore wind is likely to remain lower-cost than floating for the foreseeable future, this cap reflects the relatively limited shallow-water areas off the eastern and southern coasts which are suitable for fixed offshore wind deployment. Most of Ireland's extensive maritime area is comprised of deeper waters of depth 80 m and upwards, in which floating offshore wind is likely to be more economic.

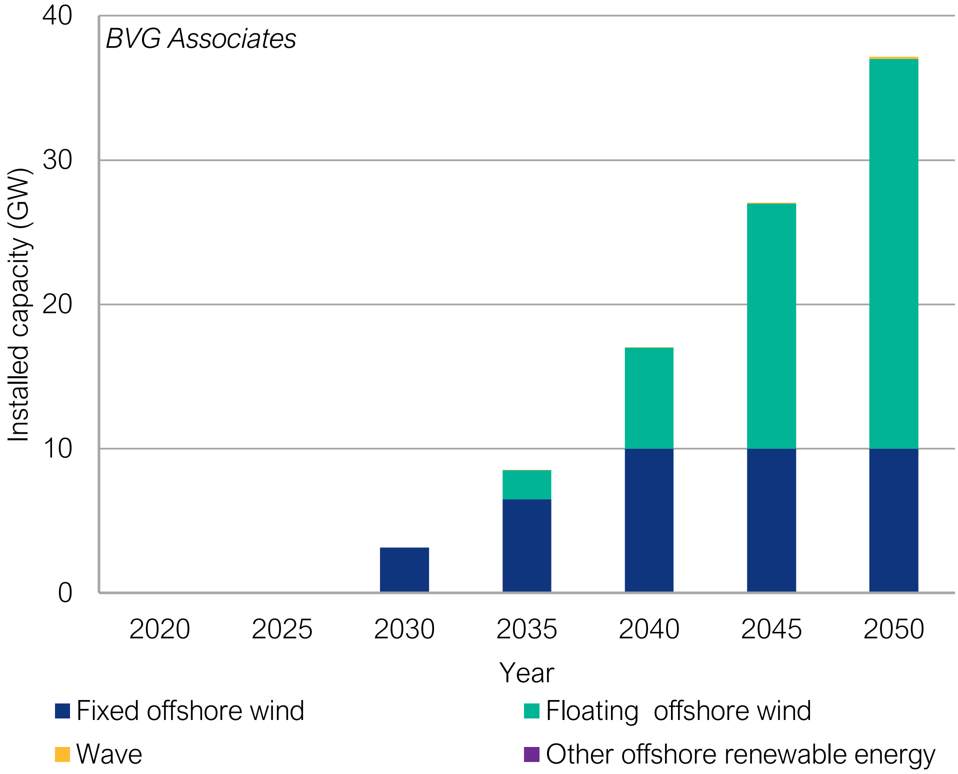
Ireland's technical potential for fixed offshore wind is likely to be significantly higher than 10 GW, however a higher technical potential is unlikely to be reached in practice. Experience in other markets has shown that as deployment zones become more crowded, cumulative environmental and social impact become more of a concern.

The extensive Irish territorial waters to the west and south-west offer excellent wind resource but are only suitable floating offshore wind. As limited deployment zones suitable for fixed offshore wind are used it is anticipated that most subsequent deployment will be floating offshore wind.

Due to uncertainty over political and economic limits on fixed deployment, the cap of 10 GW we have applied for the purposes of this study should be viewed as indicative only. Ireland's chosen pathway and division between fixed and floating deployment will be clarified through forthcoming marine area spatial plans, which will account for wider environmental and social considerations, and as fixed and floating offshore wind technologies progress, which may alter the water depth and wind speeds at which floating offshore wind becomes more economic than fixed. The trend towards fixed offshore wind in deeper waters, which could extend in future up to 80m, is discussed in more detail in Section 2.3.4.

Excess supply is split equally between interconnector export and renewable hydrogen production. Interconnectors operate at a capacity factor of 65%, higher than in scenario 1. This is consistent with an interconnector fleet geared mainly towards one-way transfer. Renewable hydrogen produced from electrolysis at a capacity factor of 70% is sold either for export or domestic use.

Figure 29: Scenario 2 ORE deployment profile



3.3 Scenario 3: Stretch wind target

In this scenario, shown in *Table 14* and *Figure 30,* Ireland is able to deploy 50 GW offshore wind by 2050, going beyond the Ireland's current stated ambition. This scenario sees Ireland generate more than 300% of domestic electricity demand, with corresponding increases in interconnection and hydrogen generation.

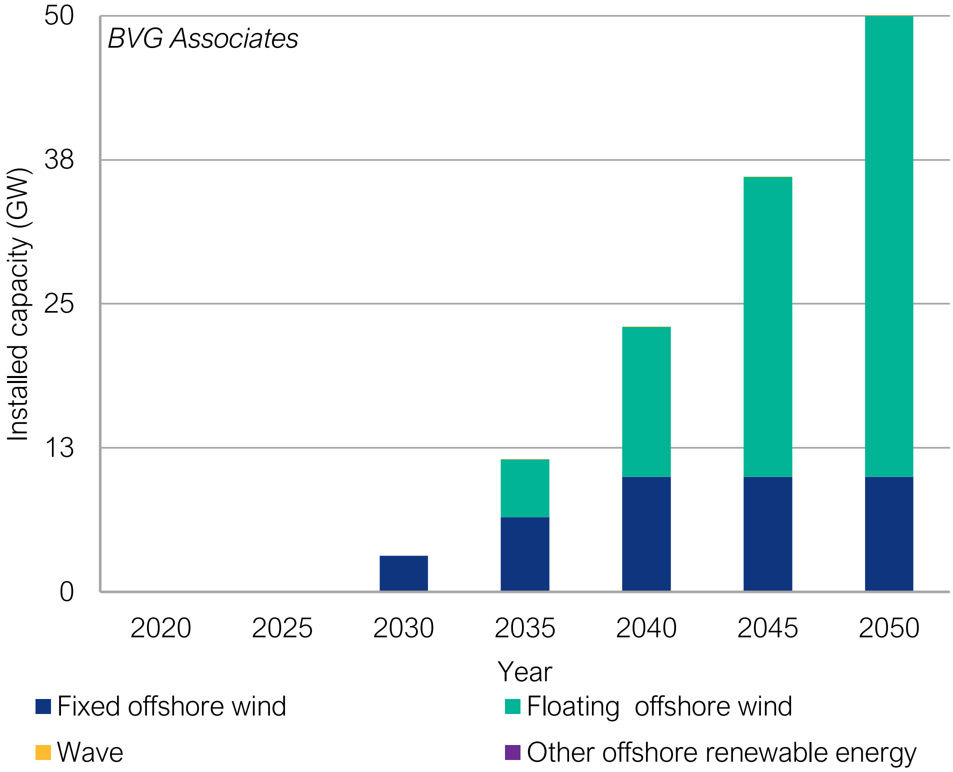
Table 14: Total capacity installed for different technologies in scenario 3

Technology	Total capacity installed by end 2030 (GW)	Total capacity installed by end 2040 (GW)	Total capacity installed by end 2050 (GW)
Fixed offshore wind	3.3	10	10
Floating offshore wind	0	13	40
Wave	0	0.01	0.15
Other ORE technologies	0	0	0
Interconnection	0.7	7.1	18
Hydrogen Electrolysis	0	6.1	16

As in scenarios 1 and 2, the ORE landscape is dominated by offshore wind, with wave and other ORE technologies remaining uncompetitive. 40 GW of the 50 GW total offshore wind is floating offshore wind, with fixed offshore wind remaining capped at 10 GW.

As in scenario 2, excess supply is split between interconnectors and renewable hydrogen production. Interconnectors operate at a capacity factor of 65% and hydrogen production at 70%.

Figure 30: Scenario 3 ORE deployment profile



3.4 Scenario 4: Meeting 37 GW ambition with wind and wave

This is the only scenario in which a technology other than fixed or floating offshore wind plays a significant part in Ireland's ORE generation mix. Total capacities installed are shown in *Table 15* and *Figure 31*. To enable this scenario, rapid progress is required in the development of wave technology, following an LCOE trajectory shown in *Figure 20*.

Despite wave's strong progress in this scenario, offshore wind still makes up the majority of Ireland's ORE fleet. As wave energy is starting from a lower base of technology and commercial readiness, it will take time to ramp up to gigawatt scale deployment, with total deployment in Ireland not reaching 1 GW until 2040, and building to 4 GW by 2050.

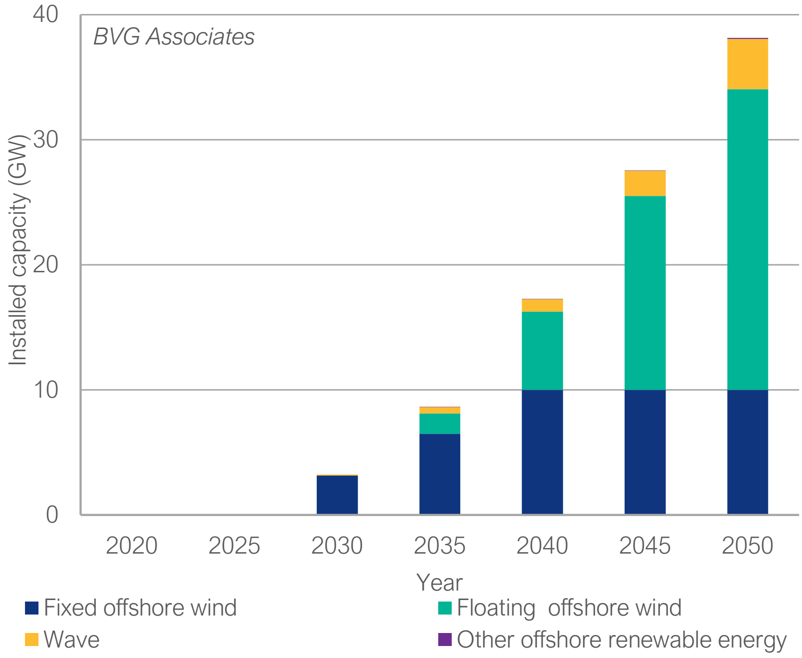
This scenario also sees some deployment of other ORE technologies, consistent with progress in commercialisation of the technologies. Overall deployment of such technologies remains severely constrained by higher costs and limited suitable sites for development.

In all other respects, this scenario is consistent with scenario 2, with the same total domestic supply, leading to the same excess generation and using the same interconnection and hydrogen infrastructure.

Table 15: Total capacity installed for different technologies in scenario 4

Technology	Total capacity installed by end 2030 (GW)	Total capacity installed by end 2040 (GW)	Total capacity installed by end 2050 (GW)
Fixed offshore wind	3.3	5.5	10.0
Floating offshore wind	0	6.3	24
Wave	0	1	4
Other ORE technologies	0	0.02	0.1
Interconnection	0.7	4.7	13
Hydrogen Electrolysis	0	3.8	11

Figure 31: Scenario 4 ORE deployment profile



4. Strategy, policies, frameworks and delivery

4.1 Introduction

Ireland has world-class Ocean Renewable Energy (ORE) resources relevant to its future, decarbonised energy system. This offers Ireland opportunities beyond those available to many countries. To evaluate and realise these opportunities requires analysis and decision making on a range of levels, regarding:

- Energy strategy, to establish what energy mix is best for Ireland.
- Policy considerations, to help Ireland achieve what it wants from its ORE resources.
- Frameworks, to manage and enable delivery of its strategy and policy objectives.
- Delivery, to facilitate deployment at the volumes sought.

Each of these is discussed in the sections below, building on content from the World Bank Group's report *Key Factors for Successful Development of Offshore Wind in Emerging Markets*, which provides further detail in all areas.[77]

In Sections 4.2 to 4.13, each of the above areas are considered and good practice and learning relevant to Ireland is summarised. The main markets considered are Denmark (DK), France (FR), Germany (DE), Netherlands (NL), Taiwan (TW), United Kingdom (UK) and United States of America (US) but relevant learning from other markets is also included. A full description of strategy, policies, frameworks and delivery in each market is not provided, rather a focus on where best learning applicable to Ireland is available. In each section, consideration of the current status in Ireland, including strengths and weaknesses, is provided. Section 4.14 provides recommendations to best facilitate deliver deployment scenarios.

As an introduction, *Table 16* summarises deployment to date and future outlook for key markets.

Table 16: Deployment to date and future outlook for key international comparator ORE markets

Market	Deployment to date	Future outlook (as stated by governments)
Denmark	• 2.3 GW fixed offshore wind operating in 15 projects • 2.6 GW offshore wind in exclusive development in 9 projects	• Targeting between 12.5 and 17.5 GW installed by the end of 2032, and 22 GW by the end of 2040
France	• 0.5 GW fixed offshore wind operating in 1 project • 0.002 GW floating offshore wind operating in 1 demonstration project • 4.2 GW offshore wind in exclusive development in 12 projects	• Targeting 18 GW installed by the end of 2035 and 40 GW by the end of 2050
Germany	• 8.5 GW fixed offshore wind operating in 30 projects • 5.6 GW offshore wind in exclusive development in 11 projects	• Targeting 30 GW installed by the end of 2030, 40 to 50 GW by the end of 2035 and 70 GW by the end of 2050

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[77] World Bank Group, (2021), *'Key Factors for Successful Development of Offshore Wind in Emerging Markets'*. Available at: https://documents1.worldbank.org/curated/en/343861632842395836/pdf/Key-Factors-for-Successful-Development-of-Offshore-Wind-in-Emerging-Markets.pdf. In this context, the Irish ORE market is considered emerging, despite its economy being advanced.

Market	Deployment to date	Future outlook (as stated by governments)
Netherlands	• 3 GW fixed offshore wind operating in 9 projects	• Targeting 21 GW installed by the end of 2031, 50 GW by the end of 2040 and 70 GW by the end of 2050
Taiwan	• 0.6 GW fixed offshore wind operating in 4 projects • 6.5 GW offshore wind in exclusive development in 17 projects	• Targeting 5.6 GW installed by the end of 2025 and 20.6 GW by the end of 2035
UK	• 13.6 GW fixed offshore wind operating in 40 projects • 0.08 GW floating offshore wind operating in 2 demonstration projects • 74 GW offshore wind in exclusive development in 74 projects	• Targeting up to 50 GW installed by the end of 2030, including up to 5 GW of floating offshore wind

4.2 Energy strategy

Energy strategy establishes a nation's long-term direction for providing energy for its people and businesses. Key considerations for markets that plan to establish ORE as part of a wider energy strategy include:

Security of energy supply:

- ORE can help meet increasing electricity demand and reduce reliance on imported fuels. This helps achieve the security of energy supply and energy independence.
- Offshore wind can already provide large-scale electricity generation, with higher capacity factors than onshore wind and solar projects.[78]
- As the proportion of variable renewable generating capacity on a system increases, the need to consider short- and mid-term energy balancing through interconnects, demand management and diversity of supply increases.
- In a decarbonised European market, important choices about source of supply and movement of energy will be needed.

Cost-effective energy for consumers:

- The cost of early ORE projects will decline over time as the Irish market develops and technology improves. It is important, therefore, that governments plan their long-term energy strategy based on future costs and work to reduce costs of early projects as much as possible, while establishing a sustainable long-term market.
- Floating offshore wind in deeper water is likely to become cost competitive with offshore wind on fixed foundations in shallower water by the early to mid-2030s.
- Markets that have clear policy and robust frameworks to nurture an ORE industry can rapidly and significantly reduce the cost of energy.

Local jobs and economic benefits:

- ORE generates economic benefits by creating jobs to support the development, manufacture, construction, and operation of projects. This is enabled by clear long-term targets and robust,

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[78] Capacity factor is the ratio of actual electricity produced over a period to the maximum possible electrical output over that period. Capacity factors of 40–50 percent are common in offshore wind and are mainly dependent on the wind resource. With Ireland's excellent wind resource, capacity factors of about 60% are achievable for some projects.

transparent and enduring policy frameworks, as well as supportive industrial policies focussed on what value can be added locally in an efficient and effective way.
- Markets with electricity generated by ORE can attract international companies that are seeking to decarbonize their supply chains.
- Markets with low-cost ORE can boost balance of trade through exporting energy.

Climate and environmental benefits:
- ORE can play a major role in reducing greenhouse gas emissions and decarbonizing energy systems.
- ORE directly contributes to reduced local air pollution and water savings.

Attracting foreign investment:
- Offshore wind is already viewed as an attractive investment opportunity, and with the correct frameworks in place to manage risks, there is a large pool of available capital to finance projects. The scale of investment required is such that much of this investment will be foreign direct investment (FDI).
- International financing for ORE requires environmentally and socially sustainable development.

Key practices underpinning successful energy strategies include:
- Providing clarity about long-term priorities.
- Conducting balanced and robust analysis.
- Securing buy-in from relevant stakeholders.

4.2.1 International best practice

Providing clarity about long-term priorities

EU countries are mandated to prepare ten year national energy and climate plans (NECPs) to outline how they intend to meet the EU energy and climate targets for 2030. This includes consideration of:
- Energy efficiency
- Renewables
- Greenhouse gas emissions reductions
- Interconnections; and
- Research and innovation.[79]

When large ORE projects frequently take longer than this to progress to completion, clarity on longer-term priorities is also required. Specific industries (like ORE) benefit from such strategies being across multiple industries, in order to give confidence of a robust, joined-up approach. EU countries are also mandated to provide long-term strategies to meet their Paris Agreement commitments and the energy union objectives, though these are broader and less focussed on energy.[80]

The UK Government's latest energy strategy, summarised in *Powering up Britain*, considers (in its words):
- Energy security: setting the UK on a path to greater energy independence.
- Consumer security: bringing bills down, and keeping them affordable, and making wholesale electricity prices among the cheapest in Europe.
- Climate security: supporting industry to move away from expensive and dirty fossil fuels.
- Economic security: playing our part in reducing inflation and boosting growth, delivering high skilled jobs for the future.[81]

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[79] European Commission, *'National energy and climate plans (NECPs)'*. Available at: https://energy.ec.europa.eu/topics/energy-strategy/national-energy-and-climate-plans-necps_en.

[80] European Commission, *'National long-term strategies'*. Available at: https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-long-term-strategies_en.

[81] Department for Energy Security and Net Zero, (2023), *'Powering Up Britain'*. Available at: https://www.gov.uk/government/publications/powering-up-britain.

The challenge about this strategy is that it does not have cross-party commitment, so is hard for industry to make long-term investments based upon it. To address such challenges, Denmark has a history of making Energy Agreements between political parties. These agreements are non-binding but commit parties to support the legislation necessary for implementing the content across changes of government. They have worked well in providing long-term continuity and in committing together to decisions that may prove unpopular in the shorter-term. As an example, Denmark committed to phase out electricity production from coal by 2030. The 2012 Energy Agreement set the framework for 2012-20, which was then extended in the 2018 Energy Agreement.

Conducting balanced and robust analysis

Underpinning any strategy needs to be balanced and robust analysis, considering the role of ORE in an energy system evolving to deliver strategic objectives in the areas described above. This analysis can be challenging owing to the uncertainties and assumptions that are required at the same time that different generation and energy management technologies are also progressing towards commercial readiness. It is also becoming more important to consider interconnected national energy systems, rather than just a single national system.

The Danish long-term strategy, in line with the EU mandate, is based on as robust analysis as is reasonable at this time.[82] Likewise, alongside the UK strategy mentioned above, the Government published chart, sources and methodology details, enabling interrogation of its analysis.[81]

Securing buy-in from relevant stakeholders

It is often complex to obtain stakeholder agreement due to the number of interested parties and the uncertainties underpinning energy strategy. Such agreement, however, is critical to the long-term success of energy strategy. Securing support from government and industry through early, transparent and fair consultation is therefore important. As outlined above, Denmark makes non-binding cross-party Energy Agreements to secure the buy-in of Government stakeholders required to implement long-term energy policy. In the UK, *Powering up Britain* was published after Government had received detailed and wide-ranging stakeholder feedback via an independent review of its 2020 Net Zero Strategy.[83, 84] The team leading the independent review engaged with stakeholders over an eight week period, obtaining input from stakeholders through a call for evidence and roundtable sessions. Over 1,800 responses to the call for evidence were received and the chair of the review toured the UK holding a total 52 roundtable events. This resulted in individuals, businesses, academic institutions and local government providing input into the strategy, making it one of the largest national engagement exercises on the future of net zero.

4.2.2 Energy strategy in Ireland

Ireland's energy strategy is the responsibility of the Department of the Environment, Climate and Communications (DECC). The primary document defining short-term energy strategy in Ireland is the *Climate Action Plan 2024* (CAP24), which outlines the country's objectives for energy and climate action to 2030. CAP24 sets out Ireland's ambition to meet 80% of electricity demand from renewable energy by 2030, including deployment of at least 5 GW of offshore wind, with an additional 2 GW, earmarked to support renewable hydrogen production.[85] This commitment is underlined by the *National Hydrogen Strategy*, published July 2023.[86]

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[82] European Commission, (2018), *'Denmark's Long-term Strategy'*. Available at: https://ec.europa.eu/clima/sites/lts/lts_dk_en.pdf.

[83] Department for Energy Security and Net Zero, (2022), *'Mission Zero: Independent Review of Net Zero'*. Available at: https://www.gov.uk/government/publications/review-of-net-zero

[84] Department for Energy Security and Net Zero, (2021), *'Net Zero Strategy: Build Back Greener'*. Available at https://www.gov.uk/government/publications/net-zero-strategy.

[85] Irish Department of the Environment, Climate and Communications, (2023), *'Climate Action Plan 2024'*. Available at: https://www.gov.ie/en/publication/79659-climate-action-plan-2024/.

[86] Irish Department of the Environment, Climate and Communications, (2023), *'National Hydrogen Strategy'*. Available at: https://www.gov.ie/en/publication/624ab-national-hydrogen-strategy/.

In accordance with the European Union's *Governance of the Energy Union and Climate Action Regulation* (The Governance Regulation), Ireland also has a *National Energy and Climate Plan* (NECP). Ireland is expected to publish an update to its NECP later in 2024. [87] The Governance Regulation requires each member state to develop and maintain an NECP, including publishing a progress report every two years.

The Governance Regulation also requires that each member state produces a national long-term strategy. Ireland has not yet fulfilled this requirement. In its Policy Statement *Framework for Phase Two Offshore Wind*, published in March 2023, Ireland committed to publishing a net zero electricity system pathway.[88]

In July 2023, DECC also published the National Policy Statement on *Electricity Interconnection*. This document outlines an ambition to increase Ireland's electricity interconnectivity, but does not set specific deployment targets.[89]

The strengths of Ireland's current energy strategy are:

- CAP24 and the NECP together represent a comprehensive and generally credible plan for delivering emissions reduction commitments up to 2030.
- The NECP contains a comprehensive assessment of energy security, emissions and economic impacts of planned policies and measures.
- Strong statements of ambition and robust political support across mainstream parties for renewable energy supports investor confidence in the ORE sector.

The weaknesses of the current strategy are:

- Current lack of clarity on long term strategy creates uncertainty over future policy direction and acts as a drag on investment.
- No specific ambitions have been established for energy export, including interconnection, hydrogen and efuels, which are a key enabler for large scale ORE deployment, particularly as Ireland's domestic demand is likely to remain limited in comparison with ORE generation in higher deployment scenarios.

4.3 Policy considerations

A policy environment establishes priorities regarding energy planning, consumer and other local economic benefit and the environment. Key policy considerations in establishing ORE markets include:

Overall considerations:

- To ensure successful market development, policy must provide a clear vision of the government's long-term plans. This can be stated through targets and commitments which, in turn, provide confidence in the market.
- Clear policy targets help drive the work of different parts of government and communicate to industry what government wants.
- Policies need to support the participation of experienced ORE project developers.
- Governments need to balance several, often competing priorities in determining their ORE policies.
- Collaboration with industry is key to successfully building and evolving policy.

Volume and timescales:

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[87] Irish Department of the Environment, Climate and Communications, (2020), *'Ireland's National Energy and Climate Plan 2021-2030'*. Available at: https://www.gov.ie/en/publication/0015c-irelands-national-energy-climate-plan-2021-2030/.

[88] Irish Department of the Environment, Climate and Communications, (2023), *'Accelerating Ireland's Offshore Energy Programme: Policy Statement on the Framework for Phase Two Offshore Wind'*. Available at: https://assets.gov.ie/249823/bbd8b13c-73cd-46d4-9902-533fbf03d7fe.pdf.

[89] Irish Department of the Environment, Climate and Communications, (2023), *'National Policy Statement on Electricity Interconnection 2023'*. Available at: https://www.gov.ie/en/publication/3d96f-national-policy-statement-on-electricity-connection-2023/.

- Clear, long-term targets for ORE deployment volume are helpful in supporting policy statements and building confidence. It is helpful for national and international long-term visions to align.
- To some extent, countries in the same area compete for project developer interest and limited supply chain capability.
- Enabling a larger pipeline of ORE projects typically helps with the balance between the cost of energy and local economic benefit.
- A steady rate of project delivery maximizes learning and delivery efficiency, helping the supply chain to invest and grow.

Cost of energy:
- In established markets, there has been a long-term trend in reducing cost of energy from offshore wind, though recent macroeconomic changes have slowed this impact.
- The cost of energy reduction is due mainly to the use of larger turbines, larger scale projects, increased competition, and reduced project risk.
- Government policy can accelerate cost reduction in new markets.

Local jobs and economic benefit:
- Key roles for governments are to help provide industry-level visibility and to put in place policies and frameworks that give suppliers confidence to invest and establish their own pipelines.
- It is important to balance requirements for local content with the benefits of long-term, low-cost electricity production.
- Most employment is during manufacturing and project construction, but important long-term sustainable jobs are also created during the operational life of projects.

Environmental and social sustainability:
- Setting the priorities for sectoral / multi-sector marine spatial planning (MSP) is important as there are a variety of competing interests in the marine environment, including ORE.
- Proactive citizen engagement by both government and industry is important for enhanced social acceptance.
- Learning and data sharing should be encouraged to build an evidence base relating to environmental and social impacts.

Key practices underpinning successful policies include:
- Providing clear, logical targets.
- Enabling industry and public engagement.

4.3.1 International best practice

Providing clear, logical targets

Beyond the EU, examples of clearly stated policy targets include New York's *New York State Offshore Wind Master Plan* and *Master Plan 2.0: Deepwater*, and Japan's *Offshore Wind Industry Vision.*[90, 91]. These policy targets were adopted into legislation, which reduces the risk of targets being removed by a future government.

Enabling industry engagement

The UK has used the Offshore Wind Industry Council as a forum for stakeholder discussion for around a decade, with its focus on delivery of policy through frameworks, rather than shaping policy. The Offshore

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[90] NYSERDA, *'Offshore Wind Master Plan'*. Available at: https://www.nyserda.ny.gov/All%20Programs/Programs/Offshore%20Wind/About%20Offshore%20Wind/Master%20Plan

[91] METI, (2020), *'Vision for Offshore Wind Power Industry'*. Available online at https://www.enecho.meti.go.jp/category/saving_and_new/saiene/yojo_furyoku/dl/vision/vision_first_en.pdf.

Wind Industry Council was a key negotiation partner in the Offshore Wind Sector Deal, announced in 2019. [92, 93]

In Japan, a government-industry forum, the Public-Private Council, was established for a similar purpose in 2020, but its membership, terms of reference and ongoing conflicts of interest have limited progress.

4.3.2 Policy in Ireland

Ireland has a target of having 80% of domestic electricity generated from renewable resources by 2030. This includes 5 GW coming from offshore wind, with an additional 2 GW in development. This ambition is set out in CAP24 and the NECP.

Ireland is a member of the North Seas Energy Cooperation (NSEC), a nine-country regional group aimed at promoting renewable energy. [94] In September 2022, the NSEC set a target for at least 260 GW of offshore wind collectively by 2050. As part of this, Ireland set out an ambition to grow its offshore wind fleet to 20 GW by 2040 and 37 GW by 2050. This was reconfirmed in the January 2024 *Offshore Renewable Energy Future Framework* draft policy statement. In November 2023, the NSEC published an indicative offshore wind roadmap which set out plans for a further 9.6 GW offshore wind capacity to be auctioned in Ireland up to 2030.[95]

At an EU level, ambitions for the deployment of ocean energy (wave and tidal) generation have been set, including 100 MW by 2027, 1 GW by 2030 and 50 GW by 2050.[96] Ireland does not have a specific target for the deployment of these, or of other non-offshore wind technologies, at a national level.

The *National Marine Planning Framework* (NMPF) sets out policy proposals for future development of ORE in Ireland. This includes an updated marine spatial planning approach (see Section 4.5.2), plans for a stakeholder and evidence led approach to spatial planning and a framework of environmental assessments to evaluate the impacts of developments in Irelands maritime area. [97] The Government has contracted a service provider for citizen engagement and creative communications services to support communications related to DMAPs in Ireland.

The draft *Future Framework Policy Statement* 2024 establishes public and stakeholder consultation as a key pillar of Ireland's ORE development framework, in line with the NMPF. Engagement with local coastal communities and other marine users is mandated in order to avoid, minimise or mitigate impacts of the development of ORE and associated infrastructure.[98] Government has established the Seafood-ORE working group to facilitate collaboration between the fishing and ORE industries and to develop best practice guidance for engagement.

Ireland has also published *Powering Prosperity, Irelands Offshore Wind Industrial Strategy*, which sets out a roadmap to ensure Ireland captures a significant portion of the economic benefits of ORE deployment.[99] The

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[92] Offshore Wind Industry Council. Available at: https://www.owic.org.uk/.

[93] Department for Energy Security and Net Zero, (2019), ' *Offshore Wind Sector Deal*'. Available at: https://www.gov.uk/government/publications/offshore-wind-sector-deal.

[94] European Commission, *'The North Seas Energy Cooperation'*. Available at: https://energy.ec.europa.eu/topics/infrastructure/high-level-groups/north-seas-energy-cooperation_en.

[95] North Seas Energy Cooperation (2023), 'NSEC Tender Planning - November 2023'. Available at: https://energy.ec.europa.eu/document/download/95a9abc5-aa53-41a3-8330-4aa70381b2ed_en?filename=231117%20NSEC%20tender%20planning%20-%20November%202023_0.pdf.

[96] European Commission, (2020), *'An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future '*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:741:FIN&qid=1605792629666.

[97] Department of Housing, Local Government and Heritage, (2018), *'National Marine Planning Framework'*. Available at: https://www.gov.ie/en/publication/a4a9a-national-marine-planning-framework/.

[98] DECC (2024), Draft Future Framework Policy Statement 2024, available online at https://www.gov.ie/en/consultation/747c7-consultation-on-the-offshore-renewable-energy-ore-future-framework-policy-statement/

[99] DETE, (2024), 'Powering Prosperity – Ireland's Offshore Wind Industrial Strategy'. Available at: https://enterprise.gov.ie/en/publications/powering-prosperity.html.

National Skills Council's Expert Group on Future Skills Needs published the *Skills for Zero Carbon* report in November 2021, and Green Tech Skillnet published *Building our potential: Ireland's Offshore Wind Skills and Talent Needs* in January 2024, both of which included recommendations on upskilling the Irish workforce to meet the needs of the ORE sector.[100] [101] Primary responsibility for delivery of interventions in skills lies with DFHERIS, who lead a skills workstream within the Government's Offshore Wind Delivery Taskforce.

The strengths of Ireland's current policies are:

- Robust targets set far into the future, on a multi-decade timeline, are helpful for building visibility of future pipeline to stimulate investment.
- Alignment with a strong regional pipeline via the NSEC supports investment through expanded opportunities for the Irish supply chain.
- The NMPF sets out a robust approach to environmental and social sustainability in future ORE deployment decisions, helping build community acceptance.
- A focus on stakeholder involvement throughout the policy and framework development lifecycle helps ensure effective spatial planning and management of the marine space by its various users.

The weaknesses of the current policies are:

- Limited delivery to date raises uncertainty over effectiveness of frameworks and the likely timeline for delivery of early projects.
- Ireland's offshore wind deployment targets are widely seen as highly ambitious, which could raise doubts about their credibility if deployment is not seen to accelerate accordingly.
- A lack of clear ambition for other ORE technologies could be seen as a signal that it does not intend to pursue development and deployment of these technologies.
- There is not yet a credible vision for the route to market for the output from 20 GW or 37 GW of offshore wind.

4.4 Frameworks to enable ORE delivery

A set of robust and transparent frameworks are required to provide the processes and rules that turn the policies into reality. Frameworks are needed to define the approach to:

- Marine spatial planning
- Seabed leasing/occupancy
- Permitting
- Offtake
- Export and grid connection
- Development of the wider energy system enabling ORE deployment, such as interconnection and alternative offtake solutions such as hydrogen.
- Health and safety; and
- Technology development and certification.

These need to be implemented through agencies with clear roles, well-defined mandates, and sufficient resources. Key considerations in establishing ORE frameworks include:

- In a competitive international market, leasing and offtake frameworks offer an opportunity for governments to ensure that their policies are being implemented, through use of additional requirements such as prequalification criteria and non-price factors.
- Significant collaboration between industry, government, and wider stakeholders is needed to develop and evolve robust, effective frameworks and build industry confidence.

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[100] The Expert Group on Future Skills Needs, (2021), *'Skills for Zero Carbon'*. Available at: https://skillsireland.ie/all-publications/2021/skills-for-zero-carbon.html.

[101] Green Tech Skillnet, (2024), '*Building our Potential: Ireland's Offshore Wind Skills and Talent Needs*'. Available at: https://windenergyireland.com/images/files/web-bvg-report-jan-2024.pdf.

- Different countries operate different timing of leasing and offtake competitions. The choice of model is important, but strong definition and capable implementation of the chosen model is likely to have a greater impact.
- Some governments have chosen that a single agency administers multiple frameworks; others have chosen that different agencies manage different frameworks.

Individual frameworks are covered in the sections below. This section considers the organisation of frameworks and key features common to successful frameworks, generally.

Key practices underpinning a successful framework include:
- Deciding on organisation of frameworks and who should administer.
- Ensuring fair, repeatable, robust and transparent frameworks.
- Engaging with industry during framework development.

4.4.1 International best practice

Deciding on the organisation of frameworks and who should administer

Countries have approached framework creation in different ways, including considering existing governance structures. For example, many countries have frameworks for the delivery of onshore wind which have been adapted for offshore wind. In some countries, such as Scotland and France, aspects such as permitting are devolved to regional or local governments because of the existing framework structure in each country.

Countries operate different timing of leasing and offtake competitions. Permitting, grid connection, and other considerations typically fit in with these two key stages.[102] The two key models are:
- One-competition model, where leasing and offtake are awarded simultaneously. This typically involves the government playing a more active role in early project development so that project developers have enough information to be able to bid knowledgeably for specific sites. This model has been pioneered in Denmark and Netherlands.
- Two-competition model, where leasing is awarded first and offtake is awarded later. This typically involves project developers playing a more active role in early project development, for example selecting sites and undertaking initial surveys. This model has been used in the UK and US.

Some countries, such as Denmark (with Danish Energy Agency, DEA) and Netherlands (with Netherlands Enterprise Agency, RVO) have chosen to use one organization to provide a “one stop shop”. Other countries have chosen to keep the administration of different frameworks separate, such as in the UK where leasing (The Crown Estate and Crown Estate Scotland), permitting (the Planning Inspectorate and Marine Scotland) and revenue support (Department for Energy Security and Net Zero) are all administered by different organizations. The benefit of a one stop shop is the ease of communication and good coordination between frameworks. This is especially suited to smaller nations with fewer interactions between different industries. A benefit of having different administrative bodies is that the role and intent of each can be better defined. Existing organizations that administer the use of the seabed for other industries, such as fisheries or hydrocarbon extraction, should be considered when setting frameworks for ORE. Typically, given the scale of ORE projects, the frameworks are best administered at a national level.

Whatever solutions are chosen, it is important that they are administered by well-resourced and trusted organisations to ensure timely and bankable progress.

Ensuring fair, repeatable, robust and transparent frameworks

Frameworks with these characteristics help deliver a pipeline of bankable projects:
- Fair: Not unduly favouring any organisation or type of organisation.
- Repeatable: Can be followed efficiently multiple times and without unexpected results.

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[102] The different models are discussed in Section 3 of *Key Factors for Successful Development of Offshore Wind in Emerging Markets*, along with key considerations in choosing a model. See footnote 77.

- Robust: With a high probability of delivering a constructive result without unexpected consequences.
- Transparent: Relevant parties understand the process well and there is no room for underhand practice.

Lessons have been learnt in France which launched its first offshore wind tender in 2011, followed by another round in 2012, both using existing frameworks which proved inadequate for offshore wind. It was only in 2019 that the first project successfully closed financing. Many factors contributed to this delay but the inadequacies of legal and permitting frameworks were key.[103,104]

Engaging with industry during framework development

Governments need to treat offshore wind in a different way to other forms of renewable generation because offshore wind projects are typically on a much larger scale, with longer development times and greater infrastructure. This requires greater levels of investment, so project bankability is of the utmost importance. This increases the importance of engaging with industry stakeholders to help build trust and put in place robust, effective frameworks that mitigate risks.

Creating or changing frameworks can take two years or more to develop new processes, enact legislation, and reach a stakeholder agreement. It is important for governments to facilitate good communication with industry and to plan and implement changes within agreed timescales. This is because any such changes are likely to introduce uncertainty and potentially delay the completion of offshore wind projects.

An example of a good transition between frameworks was when the UK government used the Final Investment Decision Enabling for Renewables (FIDER) program in 2013 to provide continuity for the offshore wind industry during the transition to an auction system where the winner secures a contract for difference (CfD).[105] The Offshore Wind Industry Council was set up to facilitate strong industry engagement.[92] The interim solution, a simplified competition process with a strike price set by government for a subset of suitable projects, enabled ongoing activity and investment, avoiding gaps in wind farm development and installation activity. The downside of this process was that the FIDER strike prices turned out to be overly generous to project developers due to the rapidly falling LCOE at the time.

4.4.2 Frameworks in Ireland

In ORESS 2.1, Ireland is expected to operate a one-competition model, in which offtake contracts for a given location are offered in a competitive auction, with developers then required to secure a seabed lease non-competitively within a strictly-time limited period. Although still under consultation, it is planned that these two aspects will be administered by two different independent authorities (DECC and the Maritime Area Regulatory Authority (MARA)).It is expected that the competitive auction will be largely price-led, though certain other non-price criteria may also apply.

The nature of the framework for future ORESS rounds beyond 2.1 or successor schemes is yet to be determined.

The strengths of the ORESS 2.1 model Ireland are:

- It gives more opportunity for the Government to plan efficiently where projects go and when they are installed, and allows for strategic planning of new grid infrastructure.
- It reduces project development risk for developers, if implemented well.
- The price led competitive model helps drive down costs and deliver value to the consumer.

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[103] Champy, J L, Fouqué, C, (2021), *'A new horizon for offshore wind energy in France'*. Available at: https://www.whitecase.com/publications/alert/new-horizon-offshore-wind-energy-france.

[104] Duboua-Lorsch, L, (2020), *'France's ambitious offshore strategy faces obstacles'*. Available at: https://www.euractiv.com/section/energy/news/frances-ambitious-offshore-strategy-faces-obstacles/.

[105] Department of Energy & Climate Change, (2013). Available at: https://www.gov.uk/government/publications/increasing-certainty-for-investors-in-renewable-electricity-final-investment-decision-enabling-for-renewables.

The weaknesses of the ORESS 2.1 model are:

- It does not use competition to find the best sites.
- It has higher risks and up-front cost to Government.

4.5 Framework for marine spatial planning

The sustainable use of marine resources is mandated by international agreements and captured in United Nations Sustainable Development Goals (UNSDG). As ORE projects form nationally important infrastructure, it is good practice for a strategic approach to be adopted when deciding where ORE can be deployed. Marine spatial planning (MSP) can make a significant contribution to the strategic deployment of ORE by enabling larger volumes of ORE to be sited in the most environmentally, socially, and commercially appropriate locations. MSP processes provide input into an effective leasing framework by defining the geographical limits of leasing rounds or lease awards for ORE projects. This reduces project risk by making the permitting process more predictable but does not replace the need for permitting.

Key practices underpinning a successful MSP framework include:

- Adopting a central planning system.
- Following good international industry practice (GIIP).[106]
- Sharing MSP data with stakeholders and project developers.

4.5.1 International best practice

Adopting a central planning system

A central MSP system that takes a holistic view of marine resources is important in minimising the spatial conflicts between multiple stakeholders seeking to use marine space and enabling confident progress in developing offshore wind projects in the most suitable locations. It allows data and stakeholder input from different industries to be gathered and analysed by a central body to identify the least constrained, most economically attractive areas to deploy ORE projects, considering environmental, social, and technical constraints. Governments are best placed to lead MSP since it enables them to be clear about how they prioritise the use of marine space within their Exclusive Economic Zone (EEZ).

In Denmark, the Danish Maritime Authority (DMA) is the government agency responsible for multi-sector MSP. The DMA published the country’s first marine spatial plan in 2021 that provides a complete marine planning framework for Denmark.[107] It sets out development zones for several marine industries, including renewable energy, so that licenses related to these industries can be granted in these areas. The Danish Energy Agency (DEA) defines project sites for ORE projects within the renewable energy areas identified in by the DMA. The central MSP process carried out by the DMA gathered data and stakeholder input from different stakeholders to build a holistic view of marine resources so that space was allocated efficiently and appropriately. This reduces the burden on the DEA to seek agreement with other government bodies and industry stakeholders for the use of marine areas, while also building an evidence base which can be used by the DEA to site ORE projects in the allocated areas. The lesson learnt in Denmark is that a central planning system is effective in ensuring cross-industry requirements are accounted for in the allocation of sea areas, while also improving the efficiency of the leasing process.

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[106] GIIP, as defined by International Finance Corporation Performance Standard 3 (PS3), is the exercise of professional skill, diligence, prudence, and foresight that would reasonably be expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances, globally or regionally.

[107] Danish Maritime Authority, (2021), *‘Denmark’s Marine Spatial Plan’*. Available at: https://havplan.dk/en/page/info.

Following good international industry practice

Proportionate and pragmatic processes should be used to define the geographical limits of leasing rounds or lease awards for ORE projects. These processes should follow GIIP. The Intergovernmental Oceanographic Commission (IOC) has provided well established guidelines for MSP, including a step-by-step approach.[108,109] Early-stage technical assessments and sensitivity mapping, using existing available spatial data sets and expert stakeholder input, can be helpful first steps in the spatial planning process. The development of a sensitivity map can highlight areas of relatively lower or higher risk, as well as areas of highest risk that are unsuitable for development and which should be avoided altogether. The World Bank is developing an environmental and social framework for offshore wind spatial planning, which describes how environmental and social issues can be considered within the context of strategic spatial planning.[110, 111] It is important that MSP considers export system cable routing and onshore elements of ORE projects, as well as generating assets. Spatial mapping should also consider the economic viability of sites for offshore wind. GIIP encourages countries to collaborate during MSP to ensure maritime activities that cross national boarders are accounted for.

The European Union (EU) has promoted the use of GIIP for MSP through its directives. The Marine Spatial Planning Directive (Directive 2014/89/EU) was adopted in 2014 and required all coastal EU member states to develop and implement MSPs by 2021.[112] The Directive includes a number of provisions that promote the use of GIIP, including the following:

- Cooperating with neighbouring countries on MSP. This includes consulting with international stakeholders and sharing information relevant to MSP with neighbouring countries.
- Use a participatory approach for MSP. This means consulting with stakeholders, such as maritime industries, environmental groups, and coastal communities.
- Use the best available data and information for MSP.
- Supporting the development of international standards and guidelines for MSP.

The EU has also promoted the use of GIIP for MSP through other directives, such as the Marine Strategy Framework Directive (Directive 2008/56/EC) and the Environmental Impact Assessment Directive (Directive 2011/92/EU). These directives require Member States to consider cumulative impacts and transboundary effects when making decisions about activities that may affect the marine environment.

Sharing marine spatial planning data with stakeholders and project developers

The MSP process should be collaborative and transparent to ensure the interests of relevant parties are accounted for and the best available data is used. This can be achieved by sharing MSP data with stakeholders, including project developers. By sharing data as part of the stakeholder engagement process, interested parties are able to be informed (and inform others) by in more quantitative ways. Where necessary, commercially sensitive data can be subject to confidentiality restrictions, allowing release only after an appropriate time has elapsed. Making MSP data available to project developers can improve the efficiency of project development by reducing the need for repeat data collection and site surveys.

In Germany, the Federal Maritime and Hydrographic Agency (BSH) is responsible for MSP in the German EEZ. BSH develops Site Development Plans (FEP) which identify offshore wind sites that will be auctioned through a competitive process. BSH carries out preliminary site surveys to determine the suitability of the offshore

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[108] UNESCO. Available at: https://www.ioc.unesco.org/.

[109] UNESCO, (2021), *'International Guide on Marine/ Maritime Spatial Planning'*. Available at: https://www.mspglobal2030.org/resources/key-msp-references/.

[110] Environmental and Social Sensitivity Mapping: Guidance for Early Offshore Wind Spatial Planning, unpublished, currently under development by the WBG Offshore Wind Development Program (via the Energy Sector Management Assistance Program, ESMAP).

[111] World Bank Group, *'Environmental and Social Standards (ESS)'*. Available at: https://www.worldbank.org/en/projects-operations/environmental-and-social-framework/brief/environmental-and-social-standards.

[112] European Commission, *'Maritime spatial planning'*. Available at: https://oceans-and-fisheries.ec.europa.eu/ocean/blue-economy/maritime-spatial-planning_en.

wind sites. Based on the data collected from the site surveys, BSH publishes an environmental report and a suitability examination document which state the suitability of the sites. If a site is deemed suitable, the data collected from the site surveys is published on an online portal to inform developers' bids in the auction process. The lesson learned in Germany is that by sharing data collected through the MSP process project developers do not need to separately collect site survey data for the prospective site which saves money and improves the efficiency of the leasing process.

4.5.2 Marine spatial planning in Ireland

DECC oversees marine spatial planning in the Irish maritime area. Ireland has a large maritime area with an area seven times its land mass. On the west coast where waters are deep and Irish waters extend furthest, floating offshore wind will likely be used, rather than fixed.

The State has engaged in significant reform of the Marine Planning system in Ireland in recent years, most notably replacing the 80 year old Foreshore Act with the Maritime Area Planning Act 2021 (MAP Act).The MAP act sets out the legislative basis for marine spatial planning in Ireland and a hierarchical forward planning structure which has the NMPF at its apex. The NMPF is developed in accordance with the EU Maritime Spatial Planning Directive. It sets an overarching roadmap for the fair use of Irish waters for all maritime-based activities until 2040. [113]

Ireland has announced a switch from a developer-led deployment model as used in ORESS1 to a plan-led model, to be used in the next competition. Under the plan-led model, the State rather than developers will identify the areas for development and facilitate onshore connection arrangements, in accordance with national marine spatial planning legislation. This remains subject to consultation but means that Irish offshore wind marine spatial planning is likely to require deeper work to define specific sites than in a developer-led model where a higher-level government assessment of broad areas is sufficient.

Under the NMPF, ORE spatial planning in Ireland will be through DMAPs, prepared in compliance with the MAP Act (as amended). DMAPs are sub-national, forward looking spatial plans focused on the development of specific geographic areas and/or sectoral areas. Under the MAP Act the relevant Minister may designate a public body to take responsibility for the development of a specific DMAP. The Minister for Environment, Climate and Communications has been designated as the competent authority for the development of DMAPs for the deployment of ORE. In August 2023, DECC launched a consultation on the first DMAP for the south coast.[114] The South Coast ORE DMAP is due to be published in 2024. Further DMAPs are planned in future.

The strengths of Ireland's current marine spatial planning framework are:
- The approach is in line with EU Directives and can build on a body of good practice being developed across the continent.
- The plan-led development model facilitates integrated strategic planning of the energy system, if properly integrated with a wider energy strategy.

The weaknesses of the current framework are:
- MARA is relatively newly established and its structure, processes and resources are not yet fully tested and experienced in delivery.
- The State has not yet progressed offshore wind spatial planning processes to completion, including defining specific sites, and could face capability challenges in doing so effectively if the correct skills and advice are not secured.

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[113] Department of Housing, Local Government and Heritage, (2018), *'National Marine Planning Framework'*. Available at: https://www.gov.ie/en/publication/a4a9a-national-marine-planning-framework/.

[114] DECC, (2023), 'South Coast Designated Maritime Area Plan (DMAP) Proposal, Available at: https://www.gov.ie/en/consultation/eb17b-south-coast-designated-maritime-area-plan-dmap-proposal/.

- The recent switch from developer-led to plan-led model will take time to take effect and be fully understood, creating investor uncertainty in the interim.
- Under the NMPF, DMAP designations must pass through a number of statutory processes, such as draft publication, public consultation, stakeholder engagement, finalisation and adoption via Oireachtas and Ministers. Due to this, these processes can take years, making the speed of DMAP issuance potentially a major bottleneck to deployment, if not properly planned and resourced.

4.6 Framework for seabed leasing/occupancy

Seabed leasing/occupancy provides project developers exclusive rights to survey sites on which to then construct and operate ORE projects. Though known as occupancy is an Irish context, internationally it is more commonly referred to as seabed leasing.

Key considerations regarding seabed leasing include:
- It is important that leases are only provided for areas where there is a good chance that ORE projects will be constructed.
- Markets benefit from a pipeline of projects at different stages, so it is helpful to have a leasing process which is repeated.
- The awarding of leases can take a range of different formats and no clearly preferable framework for awarding leases has yet emerged.
- Leases can be offered for specific sites, or project developers can be asked to propose their preferred sites within large areas.
- Leasing processes need to cover cable routing and any other relevant considerations.
- Governments need to ensure that local legislation contains provisions to allow the leasing of sea areas for offshore wind projects.
- Lease obligations should include decommissioning requirements.
- A leasing competition in established offshore wind markets typically takes two years from announcement to award.

Key practices underpinning a successful seabed leasing framework include:
- Establishing a clear leasing process.
- Granting exclusivity for a leased area over a certain period of time.
- Implementing competition and leasing terms that support policy objectives.

4.6.1 International best practice

Establishing a clear leasing process

A clear leasing process, with well-defined selection criteria, builds confidence and minimises the risk of legal challenges because it allows project developers to consider their chances of success and decide whether to invest in the process. The administering organization needs to proactively lead the leasing process to ensure clarity and build confidence. This includes:
- Providing all relevant competition information as early as possible, including clarity regarding objectives and selection criteria.
- Engaging early with key stakeholders to brief them and listen to their views.
- Ensuring that bidders have had a chance to ask questions about the process and understand the answers.
- Ensuring that bidders have had time to understand risks and opportunities sufficiently to put in positive bids.
- Managing a secure, robust, and fair assessment process.
- Administering the results process and follow-up activities with successful bidders.

A transparent and robust process allows for lease competitions to be repeated which is required to build a pipeline of projects and a sustainable ORE market. It is important to continue to monitor leasing to ensure processes are delivering suitable volumes of projects and are following evolving international good practice.

In US, the Bureau of Ocean Energy Management (BOEM) is responsible for managing the granting of leases, easements, and rights-of-way for orderly, safe, and environmentally responsible renewable energy development activities on the outer continental shelf (OCS), seaward of state coastal waters. Key mandates include safety, protection of the environment, coordination with affected state and local governments and federal agencies, fair return for use of OCS lands, and equitable sharing of revenue with states. It provides transparent guidelines and details of stakeholder engagement, along with the status of specific leasing competitions, which to date have been state by state. Full details are available via its website, including national and regional guidelines.[115, 116] The lesson learned in the US is that communicating clearly and administering robust processes with independence and due regard for stakeholders builds industry confidence.

Granting exclusivity for a leased area over a certain period of time

Certainty of tenure is important from an early stage. This means that the leasing process should give a developer, and any investor it involves, confidence that the area leased is likely to be suitable for the construction of an ORE project and no other party will be able to take over the site against its will. MSP should ensure that leases are only provided for areas where there is a good chance that projects can be constructed.

Granting exclusivity allows the developer to invest in developing the site without the risk of losing it to another party. The lease award can be staged, where exclusivity rights are solely for surveys and for project development, with further rights granted based on an agreed process, or the full lease can be granted immediately. It is important that the lease period reflects project development and operational timescales to optimise the value of the leased area and give developers certainty around the length of their tenure.

In England and Wales, The Crown Estate auctions Agreements for Lease through a competitive leasing process to grant development rights to ORE projects. An Agreement for Lease sets out the terms on which The Crown Estate will grant a lease if a developer succeeds in obtaining all the necessary permits. This gives the developer the confidence that they are the sole party able to obtain the lease before investing in obtaining those permits. Once an Agreement for Lease has been signed, a developer has five years to submit a consent application to the national planning body during which time they must undertake the appropriate site surveys to support their application. If all necessary permits are obtained, a developers will be able to exercise the lease option. Leases in England and Wales have been awarded with a lease term up to 80 years to allow for a second generation of offshore wind technology to be installed on the site. This enables a cost-effective future project on the same site that benefits from previous site knowledge and uses existing infrastructure. It is valuable to a project developer to have this option so that they can plan for project life extension or repowering beyond the operating life of offshore wind turbines. The lesson learned in the UK is that clear terms around exclusivity enables long-term investment in both the development and repowering of projects.

Implementing competition and leasing terms that support policy objectives

Competition and leasing terms need to be designed so that they support policy objectives, while not overburdening developers. Given that policy objectives are often reflected in installation targets, key is that lease terms need to encourage project developers to keep projects progressing to timely construction. Any award of rights needs to be timebound, with developers required to show progress through key milestones to preserve their rights. This avoids project developers holding sea bed area without progressing development, as this could slow down the growth of the industry. Leasing agreements also provide an

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[115] Bureau of Ocean Energy Management, *'Renewable Energy'*. Available at: https://www.boem.gov/renewable-energy.

[116] Bureau of Ocean Energy Management, (2019), *'National And Regional Guidelines For Renewable Energy Activities'*. Available at: https://www.boem.gov/renewable-energy/national-and-regional-guidelines-renewable-energy-activities.

opportunity to commit developers to activities that deliver wider policy objectives, for example relating to supply chain development or network stability.

In Germany, once an auction has taken place and the opportunity to secure development rights have been awarded, the developer must meet milestones to ensure the project is on schedule. Failure to meet milestones will result in the developer paying a financial penalty to the transmission system operator (TSO) or, in the event that certain milestones are missed, the Federal Network Agency (BNetzA) has the right to terminate the contract. The developer has to:

- Submit a project plan to BSH within one year of receiving the contract.
- Provide evidence to BNetzA of binding contracts for the construction of the projects no later than two years before the commercial operation date defined in the site development plan.
- Provide evidence to BNetzA that the construction of the ORE project has started no later than six months before the commercial operation date.
- Provide evidence to BNetzA that the ORE is technically operational by the commercial operation date.
- Provide evidence to BNetzA that at least 95% of the awarded capacity is operational within six months after the commercial operation date.

The lesson learned in Germany is that a few high-level key milestones are sufficient to achieving policy objectives regarding timely delivery.

4.6.2 Seabed occupancy in Ireland[117]

Ireland's seabed occupancy process was revised in 2021. The new regime is laid out in the MAP Act, which aims to simplify the process. The historical foreshore lease regime is replaced under the MAP Act with a requirement to hold a Maritime Area Consent (MAC) authorising the occupation of a specified part of the maritime area for a specified use. MACs are awarded and managed by MARA. For Phase 1 projects, MACs were awarded in December 2022 by the DECC Minister under special transitional arrangements set out in the MAP Act pending the establishment of MARA.

The MACs granted to the Phase 1 projects granted the holder the right to non-exclusive use and occupation of a specified area of the maritime area for the development and operation of the offshore wind project for a specified term. MACs do not permit the development associated with the proposed use, for which separate planning and environmental consent must be obtained following receipt of the MAC. These are covered by permits obtained later. The MACs in ORESS 1 awarded to the developers of the Phase 1 Projects awarded non-exclusive rights for 45 years. The duration and exclusivity arrangements for MACs in future rounds have not yet been confirmed.

In ORESS 1, projects were required to hold a MAC to participate. In ORESS 2.1, it is expected that the offtake auction will take place ahead of securing a MAC, which must subsequently be secured within a time limited window in a non-competitive process. MACs are awarded by MARA having regard to specified criteria set out in the MAP Act.[118] For ORESS 2.1, DECC has set out its expectation that MACs will be awarded within four months of the conclusion of the ORESS auction.[119]

The strengths of the seabed occupancy framework which Ireland is implementing are:

- Single point of contact in MARA with clear responsibility for awarding MACs
- The one competition model offers greater certainty to developers when applying for a MAC that there is a route for their project to progress. This additional certainty could lower delivery risk and make the Irish market more attractive. It could also deliver lower strike prices due to reduced risk premium.

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[117] In the Irish context, seabed occupancy is analogous to what is termed seabed leasing in other markets.

[118] Government of Ireland, (2021), *'Maritime Area Planning Act 2021'*. Available at: https://www.irishstatutebook.ie/eli/2021/act/50/enacted/en/html.

[119] Government of Ireland, *'ORESS 2.1 Indicative Roadmap'*. Available at: https://www.gov.ie/pdf/?file=https://assets.gov.ie/277705/e8b1ddf7-7692-477c-a9ed-3c70dd27fe1e.pdf#page=null.

- The MAP Act provides a clear legal framework granting access to use and occupy distinct parts of the maritime area for ORE, with clear accountability for administration of the process.
- The 45-year period over which a MACs were awarded to phase 1 projects provides an appropriate window for project development to take place before the 25 to 35 year lifetime of the offshore wind asset begins.

The weaknesses of the framework are:

- The new framework, though introduced, has not yet been fully applied.
- The one competition model means that clarity over who will develop which sites is secured late in the project development process, potentially holding back long-term supply chain planning and investment. This could result in more value being directed to established supply chain players elsewhere in northern Europe.
- The process for securing a MAC for future projects has not yet been fully clarified, adding risk for ORE project developers.
- The current MAC framework is geared towards ORESS, and there is a lack of clarity around the process for integrating developments coming forward under alternative routes to market, such as CPPAs.

4.7 Framework for permitting

The process of providing all permits to survey, construct, operate, and decommission is critical to project delivery. Different markets break down required permits differently, but typically, permits are required covering:

- Environmental and social considerations (including an appropriate period of baseline surveys)
- Technical considerations, such as interaction with defence ministry and civil aviation activity, shipping, fishing
- Project design integrity and safety; and
- Electrical interfaces.

The final stages of permitting are always led by the project developer, but earlier activities may be led by Government or the project developer. Government's role is to ensure that there are frameworks in place to enable fair, consistent, transparent and well-considered permitting decisions.

Key practices underpinning a successful permitting framework include:

- Establishing a one stop shop approach.
- Mandating stakeholder engagement and public consultation.
- Encouraging proportionate local community benefit.

4.7.1 International best practice

Establishing a one stop shop approach

Good practice in established markets has been to appoint a single agency for the project developer to communicate with, which coordinates timely input from stakeholders and decisions from responsible parties.[120] It is beneficial to allow for some flexibility in the permits awarded, to allow projects to use the latest technology when they reach financial close. This helps to reduce the cost of energy, can reduce environmental and social impacts and reduces the need for time-consuming applications for small changes in permitted activity.

In the UK, the permitting process is managed by the Planning Inspectorate (PINS), which is part of central Government. Developers submit all required documents to PINS when applying for a Development Consent Order, which includes a number of consents granting permission to construct and operate electricity generation facilities. PINS then examine the application over an 18-month period, according to a permitting

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[120] This agency needs to be well-resourced and trusted, with non-conflicted role and following clear, published processes.

timeline set out in legislation. The principle of the Rochdale Envelope allows projects to define a range of technical characteristics upon which the application is assessed so that the developer can secure the required permit without fixing the exact project design. At the end of the period, PINS makes a recommendation to the relevant Secretary of State, based on a published process and assessment criteria. The Secretary of State then has three months to make a decision.[121] Introducing PINS as a national one stop shop for permitting has improved the UK permitting process. This is because PINS has developed the internal knowledge to make rational decisions, simplified the permitting process by reducing the number of organisations developers have to engage with and communicated a clear, timely application process.

Mandating stakeholder engagement and public consultation

ORE development can impact upon a wide range of different stakeholders, including local communities and other users of the marine environment such as fisheries, shipping and tourist industries. It is important to identify and address stakeholder concerns to facilitate transparency, public acceptance, and balanced use of marine resources. Robust environmental and social impact assessments can help reduce local objections and experience in established offshore wind markets has shown that stakeholder engagement and public consultation is a key factor in the success of projects in securing the necessary permits to proceed. Engagement activities should take place early in the process, at a time where genuine adjustments to the project's approach are still feasible.

In the US, a developer must submit a Construction and Operation Plan (COP) to BOEM following the award of a commercial lease. The COP describes how the developer will construct and operate the project, and is supported by stakeholder engagement carried out by the developer. Once BOEM has deemed the COP complete and sufficient, there are opportunities for the public to comment on the proposed project. There is a public consultation period of 30 days following BEOM's announcement to prepare an Environmental Impact Statement (EIS) and a further public consultation period of 45 days once the draft EIS has been released. The EIS assesses the physical, biological and social impacts of the proposed project and makes a recommendation on the approval of the COP, including not building the project. The lesson learned from the US is that the permitting process benefits from allowing stakeholders to engage directly with the developer during preparation of the COP but also throughout the EIS process, since early, continuous and inclusive stakeholder engagement ensures the interests of all parties are considered in permitting decisions.

Encouraging proportionate local community benefit

Offshore energy developments can be controversial in nearby coastal communities. Although ORE development offers significant economic opportunities, the benefits aren't always felt directly by those living closest to ORE infrastructure. Even where projects are located miles offshore, the locations of onshore cable connections and substations can often be a source of local concern. Building in proportionate opportunities for affected communities to benefit directly from ORE development can help increase social acceptance and smooth the development process.

In the UK, Ørsted set up the Walney Extension Community Fund to support local groups and organisations close to the Walney Extension project. Each year, approximately £600,000 is made available for community projects. This is expected to be made available for the 25-year lifetime of the wind farm. The Walney Extension Community Fund has awarded around £4 million to 220 community projects in Cumbria and Lancashire since its launch in 2016. This has funded community projects, training courses, recreational facilities, conservation activities and medical support services. Alternatively, in Denmark, Middelgrunden was the world's largest offshore windfarm when opened in 2001. It consists of 20 2 MW turbines, with 50% of the wind farm owned by about 8,500 investors in the Middelgrunden Wind Turbine Cooperative and 50% by the project developer and operator, Hofor (formerly Copenhagen Energy). The project raised €23 million from

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[121] A comparison of permitting processes in the Netherlands, the UK (England and Wales) and the US is provided in Table 3.3 of *Key Factors for Successful Development of Offshore Wind in Emerging Markets*.[77]

community shareholders who have received a 7% return[122] The lesson learned from the UK and Denmark is that there are different forms of local community benefit that can be implemented to ensure the benefits of ORE projects are felt by local communities.

4.7.2 Permitting in Ireland

Once a developer has acquired a MAC, it must submit a planning application to An Bord Pleanála, Ireland's national independent planning body, to receive development consent. The developer is responsible for preparing a robust Environmental Impact Assessment Report (EIAR) to enable An Bord Pleanála to carry out an Environmental Impact Assessment (EIA). In November 2023, the Government published the Planning and Development Bill 2023 which will see An Bord Pleanála renamed as An Coimisiún Pleanála, and will also introduce mandatory consenting timelines. The bill proposes a mandatory decision-making timeline of 48 weeks for strategic infrastructure developments.

Where the developer needs to undertake environmental surveys or site investigations it will need to first obtain a marine licence from MARA. These additional licenses must be applied for and approved separately to the MAC and include licenses for:
- Marine Environmental surveys
- Geotechnical surveys and retrieval of core samples; and
- Placement of lidar and other monitoring systems.

In addition to the above, developers must obtain authorisation to construct a generating station and a licence to generate from the Commission for the Regulation of Utilities (CRU), in accordance with the requirements of the Electricity Regulation Act, 1999. These permits are required for all electricity generation activities taking place on or offshore in Ireland.

In ORESS 1, developers were required to apply for site investigation licenses to survey potential sites and conduct preliminary site assessments before they could apply for a MAC. For future phases however, it is expected that the State will have conducted preliminary site assessments prior to MAC award. ORESS 1 also requires developers to contribute least €2/MWh of electricity generated by the project to the community benefit fund during the operational life of the project.[123] Community benefit funds are expected to continue to be a feature of future phases.

The strengths of Ireland's current permitting framework are:
- An Bord Pleanála represents an experienced and trusted organisation to undertake the planning and environmental consent process. Plans to introduce mandatory timelines for decision making by An Coimisiún Pleanála under the Planning and Development Bill 2023 will be important for ensuring timely decisions and clarifying project development timelines.
- Provision for community benefit funds can help increase social acceptance of ORE development (though at a cost to the consumer).

The weaknesses of the current framework are:
- The process for obtaining marine licenses for survey work from MARA, although fully developed, is yet to be tested.
- An Bord Pleanála currently has a backlog of onshore cases requiring resolution. These resourcing issues could impact offshore consenting timelines if unaddressed.[124]

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[122] Rushton, S, (2019), *'Rebel Cities 26: These Community Wind Farms in Denmark and Scotland are Decentralising Power to the People'*. Available at: https://www.occupy.com/article/rebel-cities-26-these-community-wind-farms-denmark-and-scotland-are-decentralising-power#sthash.b6hDJgNI.dpbs.

[123] SEAI, *'Community Benefit Funds'*. Available at: https://www.seai.ie/community-energy/community-benefit-funds/.

[124] RTÉ, (2023), *'An Bord Pleanála dealing with one year backlog of cases as legal costs surge 30%'*. Available at: https://www.rte.ie/news/business/2023/1005/1409191-an-bord-pleanala-dealing-with-a-year-backlog-of-cases/.

- Ireland does not operate a one stop shop permitting process, which has been shown to enable clarity of process and timely decision making. Renewable Energy Directive II and III (RED II and RED III) includes an obligation on Member States to have a single point of contact (SPC) for applicants for renewable energy development but does not go as far as requiring a single permitting process. The SEAI is the SPC for guidance on the consenting system in Ireland. The monitoring and enforcement elements of the SPC function are yet to be assigned.

4.8 Framework for offtake

ORE projects are typically designed to operate for at least 25 years. To recoup their investments, developers, lenders and investors desire long-term visibility and certainty of the revenues a project will generate. Revenue certainty can be provided by long-term offtake agreements (PPAs) and/or government mechanisms to provide revenue support.[125] Key considerations include:

- Transitions between offtake arrangements need to be carefully managed, with industry consultation during the design helping to maximize the chance of a successful outcome.
- Offtake competitions provide a further opportunity to commit developers to activities that deliver wider policy objectives and benefit the wider industry, hence the introduction of non-price criteria into offtake auctions.
- To establish a new ORE market, a government will often need to provide a higher level of revenue support, to cover a cost premium for the first projects, as the industry gets to understand and manage local risks and supply options.
- The starting point for any country considering revenue support and offtake agreements for offshore wind should be to review the suitability of what it has used for other forms of variable renewables.
- Incentives can also be provided in the form of fiscal (typically tax) incentives.
- Projects in established markets with high wind speeds are on the cusp of selling power without revenue support, through securing a sequence of Corporate Power Purchase Agreements (CPPAs).
- As more confidence is gained in the offshore wind industry, CPPAs are being set up in advance of project construction.
- Transitions between revenue support agreements need to be carefully managed.

Key practices underpinning a successful offtake framework include:

- Carrying out industry consultation during the design of auctions.
- Using competitive auctions to award offtake agreements.
- Ensuring the offtake agreement terms and contracting organisation are robust.

4.8.1 International best practice

Carrying out industry consultation during the design of auctions

Experience in established markets has shown that industry consultation during the design of auctions helps to create a transparent offtake agreement award process. It allows project developers to understand the objectives of the process, ask questions and provide input regarding the auction requirements and assess the risks associated with submitting bids. This process aims to provide acceptable conditions for project developers to enter the auction, while creating a process that ensures successful development.[126]

In Türkiye, the first offshore wind auction was held in 2018. It identified specific sites, but it set a relatively low ceiling (maximum bid) price, included local content requirements and did not provide adequate site characterization data which developers require to form a competitive bid. This resulted in no bids being

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[125] Offtake agreements can take several forms, including Power Purchase Agreements (PPA), Feed-In Tariffs (FIT), Contracts for Difference (CFD) and bilateral agreements with corporate entities.

[126] A selection process will often have prequalification criteria to ensure that any project developer receiving an award has the capability to deliver the project.

submitted.[127] Similarly, in the UK, recent the CfD Auction Round 5 in 2023 resulted in no bids being submitted for offshore wind, due to a strike price ceiling which was widely recognised by industry as too low.[128] In both cases, more effective industry consultation would likely have highlighted these issues to the responsible organisation which could have then changed the parameters of the auction to achieve a successful outcome.

Using competitive auctions to award offtake agreements

Competitive auctions have the potential to reduce the cost of ORE and to support wider policy objectives. Auctions that use a price element to award offtake agreements drive cost reduction by driving direct competition throughout the supply chain. This requires a moderate oversupply of bidders seeking offtake agreements. It is also beneficial to have an oversupply of projects in development to allow for some attrition, as some projects may fail at some point during development or the final capacity may be lower than initially planned due to technical and permitting constraints. Competitive auctions can also include non-price elements to achieve wider policy objectives, such as infrastructure development, supply chain development or skills development.

In New York State, the 2019 and 2020 offtake agreement auctions (named solicitations) sought to balance reducing cost to consumers with development of the local supply chain. It awarded bidders 70% of marks for their per MWh price, 10% for viability (the likelihood that the project will be successful) and 20% for local economic benefits offered. As a result, the winning bidder offered to establish in-state facilities for the manufacturing of foundation components and towers, and port facilities for construction and operation. The lesson learned in New York is that the design of auction award criteria was successful in balancing downward cost pressure with creating increased local economic benefit.

Ensuring the offtake agreement terms and contracting organisation are robust

To attract international finance at an attractive cost, it is critical that the offtake agreement is considered bankable for that market. This means that the terms of the agreement must be structured in a way that minimises the risk to lenders. Key elements of a bankable offtake agreement are explored in the US Department of Energy report, *10 Important Features of Bankable Power Purchase Agreements for Renewable Energy Power Projects*.[129] One key consideration is the timing of project commissioning. Given the construction ORE projects can be difficult to forecast, offtake agreements should provide some flexibility. Projects are usually given commissioning windows rather than specific commissioning dates and, in case of delay, the projects risk a reduction in the revenue support period rather than liquidated damages. It is also important that the contracting agency is robust and creditworthy which often results in state-owned entities or major utility companies providing offtake agreements.

4.8.2 Offtake in Ireland

Ireland supports renewable energy projects though the Renewable Electricity Support Scheme (RESS). As noted in Section 4.9.2 it is planned that offtake for phase 2 will be offered to developers in an auction format, with seabed rights in the form of MACs to be secured subsequently by winning bidders, though this remains subject to change for future phases.

The support mechanism is a two-way CfD, giving the developer security by earning a flat rate on the energy it produces. The rate is index linked up until the start of construction, using a formula which includes

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[127] World Bank Group, (2019), *'Going Global: Expanding Offshore Wind to Emerging Markets'*. Available online at: https://documents1.worldbank.org/curated/en/716891572457609829/pdf/Going-Global-Expanding-Offshore-Wind-To-Emerging-Markets.pdf

[128] Thurston, A, (2023), *'Offshore wind chiefs slam government's AR5 Auction failure'*. Available online at: https://theenergyst.com/offshore-wind-chiefs-slam-governments-ar5-auction-failure/

[129] US Department of Energy, '*10 Important Features of Bankable Power Purchase Agreements for Renewable Energy Power Projects*'. Available at: https://www.eere.energy.gov/etiplaybook/pdfs/phase3-sample-10-important-features.pdf.

consideration of steel prices and the Harmonised Index of Consumer Prices (HICP), and during operation based on HICP.[130] The length of support under ORESS 1 was 20 years.

DECC oversees RESS offtake auctions, with the State-owned TSO EirGrid facilitating the process. DECC acts as the contracting agency.

Ireland's first offshore wind auction, ORESS 1, was held in May 2023. The Phase 1 Projects that had already received MACs under the special transitional arrangements under the MAP Act were eligible to participate. The average price of the winning bids was €86 /MWh, significantly lower than the maximum allowable bid price of €150 /MWh. Unsuccessful participants did not automatically lose their MACs but were afforded a further period of time to secure corporate power purchase agreements as an alternative route to market.

In ORESS 1, each applicant was required to provide an estimation of Irish local content in its project as part of its application. Contracting terms also included a longstop date of 31 December 2031, by which the project must have achieved commercial operation, which may be extended by a maximum of two years in the event of a judicial review to the project's permit application.

Further offshore auctions are planned to be held in the coming years, beginning with ORESS2.1, expected to take place in 2024. At present, it is expected that future auctions will focus on offshore wind, with no plans currently announced to bring forward other ORE technologies.

The strengths of Ireland's current offtake framework are:
- The CfD is a well-proven competitive support mechanism in line with international best practice, with a record of delivering deployment and value for money.
- CfDs provide a bankable revenue stream which helps developers secure finance at favourable terms and in turn delivers lower costs.
- The Government's practice of consulting on auction design helps create acceptable conditions for developers and maximises the chance of a successful outcome.
- DECC is a reliable contracting partner, enhancing the bankability of offtake agreements.

The weaknesses of the current framework are:
- As the framework for awarding CfDs remains subject to consultation, there is a lack of certainty, holding back developer preparations.
- No plans in place to hold auctions for non-wind technologies could hold back development of these technologies.

4.9 Frameworks for export system and grid connection

Enabling timely connection to the transmission network is crucial for each ORE project. Key considerations include:
- It can take many years before a connection to the transmission network is available, as this can involve local or wider upgrades, depending on the capacity the developer seeks to connect and the strength of the local transmission network. This means that grid connection dates are often on the critical path for project completion.
- Developers require a clear, bankable, framework to apply for a grid connection and confidence (backed by compensation) that it will be available when agreed.
- Grid connection costs should be reflective of network upgrade requirements, and use of system / wheeling charges need to be based on a clear framework.
- Well-defined rules for network access, along with mechanisms for curtailment compensation, help reduce developer risk.

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[130] Government of Ireland, (2023), *'Terms and Conditions for the First Offshore Wind RESS Competition'*. Available at: https://www.gov.ie/pdf/?file=https://assets.gov.ie/252215/7eacfb9c-6702-4e72-9499-5bea86aa9d96.pdf#page=null.

- A strategically defined offshore hub / network model can reduce the number of connection assets required. A plan-led site selection approach, as employed in Ireland, can facilitate this long term strategic planning.

Key practices underpinning a successful export system and grid connection framework include:

- Define the responsibilities for constructing, owning and operating the export system.
- Establish a well-defined grid connection application process.
- Ensuring the grid connection agreement terms are robust.

4.9.1 International best practice

Define the responsibilities for constructing, owning and operating the export system

It is important to clearly define the responsibilities for constructing, owning and operating the export system for ORE projects to ensure the associated risks and costs are accepted by each party. In allocating responsibilities, it is important to consider which party can best manage each role. In a state-build model, a government-delegated organisation designs and constructs the export system. This enables centralised transmission planning and the resulting potential for reduced costs through economies of scale but introduces project interfaces that need to align in terms of design and timing. The success of a state-build model is dependent on timely delivery of export systems to the right standard. Delivery of the export system may be challenging for a TSO in an emerging ORE market as it is unlikely to have experience delivering offshore construction projects. A developer-led build, drawing on international specialist expertise, can support quicker and more efficient deployment by parties with a proven ability to manage construction, costs and risks in this environment, though it can make strategic planning of network and generation assets more difficult. Whichever approach is chosen, stability, transparency and forward visibility is key to attracting investment. Export system ownership and operation can lie either with the government, transmission network owner, or private investors. The approach will be influenced by the approach taken to the export system design, the existing transmission network ownership model and any legal frameworks relating to unbundling of value chain ownership to ensure healthy competition in both generating and export assets.

In the UK, for many early offshore wind projects the developer was responsible for permitting, licensing, constructing, and operating all the export system assets. The government decided that this system was incapable of delivering cost-effective and timely connections for this scale of development in a manner that would ensure the integrity of the transmission system. In 2009, a new offshore transmission license regime was implemented, whereby the energy regulator, Ofgem, granted export system licenses based on a competitive tender process to offshore transmission owners (OFTOs). In this new regime the wind farm developer has the option to design and build the offshore export system themselves, or for this to be carried out by the OFTO. To date, no developers have chosen the OFTO-build route due to increased risk. Under the developer-build model, the completed export system is subsequently transferred to an OFTO. The OFTO receives a regulated revenue stream which is guaranteed for a fixed period (20 years initially and now 18.5 years). Developers recover the capital invested from proceeds of the OFTO tender process. Ofgem reports that this hybrid regime has been effective in providing value for money for consumers and driving competition in export systems, separate to generating assets. The lesson learned in the UK is that the roles for design, constructing and owning of the export system are defined based upon which party can best manage each role, resulting in an efficient and cost-effective delivery model.

Establish a well-defined grid connection application process

A well-defined grid connection application process is essential for promoting efficiency, cost-effectiveness, and investor confidence. A transparent application process provides developers with a better understanding of the timings, requirements and costs associated with securing a grid connection agreement. This allows developers and investors to understand the potential risks associated with securing a grid connection and to implement measures to mitigate these risks. This is crucial as multiple offshore wind projects may be competing for the same grid connection point, and a fair process helps in allocating dates when projects are offered connection to the transmission network. It also supports effective grid integration and capacity planning because it allows the grid operator to coordinate the connection of offshore wind projects with the transmission network, ensuring grid compliance and capacity management.

In France, Réseau de Transport d'Électricité (RTE) is responsible for providing grid connection agreements for offshore wind projects. The option to secure a grid connection agreement with RTE is awarded as part of the competitive tender process, which also awards the lease and power purchase agreement. RTE determine any costs required for the connection of the offshore wind project prior to tendering, allowing developers to submit informed bids. Following the tender process, the successful developer must apply for a technical and financial proposal from RTE in accordance with the conditions set out in the tender process. RTE must provide the technical and financial proposal within three months of the application, outlining the technical specifications of the grid connection and the estimated construction timeline. The developer has three months to accept the proposal, following which RTE will conduct technical studies and stakeholder consultation. RTE has six months from the acceptance of the technical and financial proposal to send the developer the grid connection agreement, which must be accepted within three months. This grid connection application process was introduced to simplify the connection process and facilitate efficient centralised planning of transmission infrastructure by RTE.

Ensuring the grid connection agreement terms are robust

Grid connection agreement terms need to be bankable to enable investment. The terms need to allocate risk between the delivery parties and the compensation that will be provided if the terms are breached. The timing of the grid connection is a key area of concern since the grid connection date is often on the critical path for project completion and export systems often have the longest lead times of any aspect of an offshore wind project. It is important for a developer to be given a firm grid connection date early in the project development lifecycle, which is aligned with policy targets, so that they can plan the rest of the project efficiently. A project developer suffers a significant financial impact if a project is installed and then must wait for a grid connection before exporting power because of delays completing the export system or upgrading the transmission network. In the event of delays, a robust compensation mechanism should be implemented. In addition, the connection or offtake agreement needs to define whether a connection is eligible for curtailment compensation and the level and conditions of any compensation.

In Germany, under the grid connection agreement, the export system is financed, constructed and operated by one of Germany's TSOs, TenneT (in the North Sea) or 50Hertz (in the Baltic Sea). The transmission network operator is liable for any damages or losses suffered by the developer if it does not meet the arranged deadlines for providing the grid connection. The TSO will publish a completion date by which it will complete the export system construction. The date can be amended up to 30 months before the published completion date, after which is becomes legally binding. The developer is compensated if the export system is not commissioned 90 days after the deadline (providing the wind farm is capable of being fully operational). The developer is also compensated if the export system is not available after commissioning. For unplanned interruptions, the developer is compensated after ten consecutive days of downtime or 18 cumulative days throughout the calendar year, after which compensation is received for 90 percent of the lost production. This arrangement is in place after early offshore wind projects in Germany suffered long delays before grid connections were completed and resulted in protracted negotiation to resolve compensation arrangements. It was then recognised that compensation agreements for late delivery and curtailment are critical to the bankability of the grid connection agreement and the ORE project itself.

4.9.2 Frameworks for export system and grid connection

EirGrid is responsible for facilitating grid connections for offshore wind projects. The details of the grid connection framework adopted for the Phase 1 Projects were issued in February 2022 by the CRU.[131]

EirGrid undertook a grid connection assessment (GCA) of the Phase 1 projects and issued GCAs to the Phase 1 projects in accordance with the process set out by the CRU. Eligibility to participate in ORESS 1 was contingent on the Phase 1 project holding a GCA. The GCA entitled the holder to a grid connection offer on production of a notice of award under ORESS 1.

All export system assets for Phase 1 projects will be built by the developer up to an agreed onshore connection point, with the assets transferred to EirGrid on completion. For future phases, it is intended that EirGrid will be responsible for developing, installing and operating export systems from an offshore substation to the onshore transmission system with the developers connecting their project at the offshore substation. The Grid Connection Agreement for Phase 1 is currently being developed by EirGrid, and a consultation is expected later this year.

In August 2023, the CRU published the *Offshore Grid-Connection Pathway for Phase 2* proposed decision.[132] This set out the CRU's intention to offer ORESS 2 projects priority access to the grid, subject to a MAC, ORESS notice of CfD award and planning consent from An Bord Pleanála. The Proposed Decision did acknowledge that there may be Phase 2 projects that have a viable route to market other that ORESS but this needs further consideration particularly given that ORESS 2 support will be a pre-requisite to obtaining a MAC.

The proposed structure for Phase 2 envisages EirGrid providing a grid feasibility scenario (GFS) for use by all potential bidders in the ORESS, to inform developers of likely grid connection solutions. The GFS has not yet been published for ORESS 2.1. Successful bidders will then be required to apply for a full grid connection offer (FCO). An applicant will be eligible for a FCO where they hold a MAC, planning permission for the associated development and an ORESS Notice of Award.

ORESS 1 included a compensation mechanism to address curtailment issues. It is assumed this will apply for future projects, though this is yet to be confirmed.

The strengths of Ireland's current export system and grid connection framework are:

- As TSO, EirGrid has strong technical capability and a reputation for sound management of grid infrastructure, with centralised responsibility for transmission network capacity planning.
- Offering priority grid access to ORESS projects helps decrease risk that a suitable connection cannot be secured.
- Mechanisms to compensate for curtailment offer projects confidence and help reduce bid prices.

The weaknesses of the current framework are:

- Current framework offers little certainty for future projects on grid connection dates, costs and connection locations. It also offers no mechanism to compensate developers for late delivery of grid connections. This increases delivery risk and may lead developers add risk premia to their bids, as well as to expend unnecessarily planning for multiple connection scenarios.
- Current investment in transmission network infrastructure is not sufficient to keep pace with projected demand increases as Ireland's economy transitions away from fossil fuels.
- Delivery of new onshore export system and transmission network infrastructure is difficult as obtaining the necessary permits within an acceptable timeframe is challenging.
- Placing responsibility for export system delivery with the EirGrid could lead to a bottleneck which could hold back deployment if it is not properly resourced to deliver this task.

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[131] CRU, (2022), *'Offshore Grid Connection Assessment – Phase 1 Projects'*. Available at: https://cruie-live-96ca64acab2247eca8a850a7e54b-5b34f62.divio-media.com/documents/CRU202214-Decision-Offshore-Grid-Connection-Assessment-Phase-1-Projects2.pdf.

[132] CRU, (2023), *'Offshore Grid Connection Pathway – Phase 2'*. Available at: https://cruie-live-96ca64acab2247eca8a850a7e54b-5b34f62.divio-media.com/documents/Offshore-Grid-Connection-Pathway-for-Phase-2-Proposed-Decsion.pdf.

4.10 Frameworks supporting the wider energy system

As the global energy transition continues, there will be far-reaching implications for the wider energy system.

Key considerations include:

- Variable renewable energy will supply a larger fraction of energy, requiring more careful system design and demand management (including through consumer billing).
- More ORE will be exported across national borders as energy systems become more integrated.
- ORE is likely to be used in the production of renewable hydrogen[133] and derivatives for use in industry and transportation.

Key practices underpinning successful support of the wider energy system include:

- Implementing market mechanisms to best manage energy security of supply.
- Implementing market frameworks to encourage investment in infrastructure for production, storage, transport and usage of hydrogen and derivatives.
- Establishing robust mechanisms for international trading of energy in the form of electricity and alternatives.

Implementing market mechanisms to best manage energy security of supply

As variable renewable energy technologies form a greater share of the electricity system, a given level of supply becomes less certain. This means that matching supply to demand to guarantee system integrity and security of supply will require more sophisticated balancing mechanisms and market frameworks to drive investment in solutions to this challenge. Key considerations include:

- Implementation of capacity markets for rapid dispatch power.
- Investment in both long and short term energy storage solutions such as batteries, hydrogen and its derivatives or pumped hydropower.
- Demand-side response measures, such as dynamic pricing, enabled by smart metering.

Implementing market frameworks to encourage investment in infrastructure for production, storage, transport and usage of hydrogen and derivatives

Hydrogen is likely to play a key role in a decarbonised global energy system, offering an emissions free alternative to provide power to hard-to-decarbonise sectors, such as high-heat industrial processes. Hydrogen and hydrogen derivates also offer a useful low-carbon vector to facilitate long term storage and movement of energy. As the scenarios show, renewable hydrogen produced via electrolysis is expected to play an important role in enabling more ambitious ORE deployment pathways, by enabling a productive use for surplus power produced which cannot be absorbed by domestic electricity demand.

The global clean hydrogen market is currently nascent, and the vast majority of hydrogen produced today comes from fossil fuel sources.[134] Hydrogen produced via electrolysis is currently not price competitive with so-called 'grey' hydrogen from steam methane reforming. To drive the uptake of hydrogen as a clean fuel, financial support is required to enable technology development and unlocking of economies of scale. Key considerations include:

- Implementation of measures to support the creation of a liquid market for hydrogen and derivatives. This means addressing both demand and supply of hydrogen to encourage investment both in clean production and infrastructure to provide offtake.

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[133] Hydrogen produced using electricity from renewable sources, such as offshore wind, is sometimes known as renewable or green hydrogen.

[134] European Commission, (2020), *'Communication from the commission to the European Parliament, the Council, The European Economic and Social Committee and The Committee of the Regions: A hydrogen strategy for a climate-neutral Europe'*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301.

- Support for research and development to drive down the cost of electrolytic hydrogen and associated transport and storage infrastructure and increasing the end-to-end efficiency of the electricity-to-hydrogen-to electricity cycle.

Establishing robust mechanisms for international trading of energy in the form of electricity and alternatives

Increased electricity interconnection is a key enabler for the construction of surplus renewable energy generation in Ireland, and an important tool in increasing security of supply. By linking electricity markets together, opportunities for price arbitrage emerge, reducing price volatility in individual markets.[135] Regulatory alignment between partner countries can help facilitate trade in electricity by reducing barriers to trading, enabling more efficient market arbitrage and better outcomes for the electricity system.[136]

Regulatory alignment to facilitate trade of hydrogen and efuels is also important. This should be sought on matters such as product standards and health and safety requirements. Measures such as trade liberalisation and streamlining of customs processes associated with trade in hydrogen and its derivatives can also help encourage trade and drive investment.

4.10.1 The wider energy system in Ireland

Ireland has limited specific regulatory framework at present governing the production, usage, transportation and storage of hydrogen.

The EU hydrogen strategy has established an ambition to implement regulations governing the deployment of hydrogen generation, and ensure access to liquid markets for hydrogen producers and customers.[137]Regulation is forthcoming in the form of the EU Hydrogen and Decarbonised gas package. In the *National Hydrogen Strategy*, published July 2023, the government set out an aim to adopt the outcomes of this package in a timely manner, as well as a commitment to define renewable and low carbon hydrogen in line with EU regulations.[138]

Ireland currently has electricity interconnection with Northern Ireland, via the single electricity market (SEM) and Great Britain, via the 500 MW HVDC East-West Interconnector. There are plans for a 700MW HVDC link to France, the Celtic Interconnector. Electricity export via interconnector is subject to EU single electricity market regulations such as Electricity Regulation (EC) No 714/2009 Electricity Regulation (EU) 2019/943. Both undersea interconnectors and the SEM are regulated by the CRU.

The strengths of Ireland's current frameworks supporting wider energy system are:

- Alignment with the EU's developing hydrogen regulation package offers a good route to alignment with a standard which is likely to be widely adopted, especially among nearby trading partners.
- Ireland's membership of the SEM and EU single electricity market make it well positioned for efficient cross-border trade in electricity with EU and UK partners.
- Electricity Regulation (EC) No 714/2009 requires that interconnectors are treated preferentially by EirGrid over other generation or demand grid connections. This makes grid access easier for interconnector projects.

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[135] University College London and the University of Cambridge on behalf of Ofgem, (2019), *'The value of international electricity trading'*. Available at: https://www.ucl.ac.uk/bartlett/sustainable/sites/bartlett/files/ucl_report_ofgem_20102019_final.pdf.

[136] MacIver, C, Bell, K, Adam, G and Xu, L, (2021), *'Electrical interconnectors: Market opportunities, regulatory issues, technology considerations and implications for the GB energy sector'*. Available at: https://www.sciencedirect.com/science/article/pii/S2211467X21001073.

[137] European Commission, (2020), 'Communication from the commission to The European Parliament, The Council, The European Economic and Social Committee and The Committee of The Regions: A hydrogen strategy for a climate-neutral Europe', *Energy Strategy Reviews*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301.

[138] Government of Ireland, (2023), *'National Hydrogen Strategy'*. Available at: https://assets.gov.ie/263248/f982c10f-eca6-4092-a305-90000e5213ed.pdf.

The weaknesses of the current frameworks are:

- Little regulatory framework currently in place to govern production, usage, transportation and storage of hydrogen.
- Preferential grid connection for interconnectors could negatively impact ORE by placing it at a disadvantage to interconnectors in securing connections.

4.11 Framework for health and safety

The ORE industry in each market needs effective health and safety practices and a culture that protects people and the environment. Workforce safety must be the industry's highest priority. Key considerations include:

- Countries typically build on existing, national health and safety regulations when considering ORE.
- Companies and workers often act internationally, so continuity across markets is beneficial. Global, specialised training bodies have developed best practice that can be used.
- It is important to improve health and safety culture (safety-focused behaviours and individual accountability) as well as imposing regulations to protect workers.

Key practices underpinning a successful health and safety framework include:

- Establishing clear and comprehensive health and safety policies and guidelines.
- Assessing the existing, national health and safety regulatory framework.

4.11.1 International best practice

Establishing clear and comprehensive health and safety policies and guidelines

Building a strong health and safety culture within an industry requires a concerted effort to instil a shared commitment to safety at all levels. This is primarily achieved through appointing a national health and safety authority for offshore wind to lead in establishing health and safety policies and guidelines. In terms of policy, legislation should be introduced to require safety-focused behaviours, such as incident reporting, to foster transparency and enable the industry to learn from its experiences. Existing legislation and safety training provisions should be updated where appropriate to include offshore wind.

The relevant authority should draw upon globally recognised health and safety standards and guidelines to inform good practices and procedures. For example, the World Bank Group provides a series of general and sector specific Environmental, Health, and Safety (EHS) Guidelines, G+ Offshore Wind Health and Safety Association provides offshore wind-specific good practice guidelines and the Global Wind Organisations (GWO) issues training standards and accredits training providers.[139, 140, 141] Regular communication of policies and guidelines through engagement and consultation ensure that health and safety is embraced by all stakeholders, ensuring a collective sense of responsibility among all industry participants.

In Taiwan, the Occupational Safety and Health Administration (OSHA) has been appointed Taiwan's safety regulator for ORE projects. OSHA signed a memorandum of understanding with the UK's Health and Safety Executive (HSE) to draw on international experiences and accepted best practice. It has also partnered with the G+ Offshore Wind Health and Safety Association, resulting in a G+ focal group being set up in Taiwan. This has helped create the guidelines and standards for establishing a strong health and safety culture in the ORE industry. For example, the Taiwan International Windpower Training Corporation has become a GWO-accredited training provider which ensures the workforce receives training on safety protocols emergency response and risk

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[139] International Finance Corporation, (2007), *'Environmental, Health and Safety General Guidelines'*. Available at: https://www.ifc.org/content/dam/ifc/doc/2023/ifc-general-ehs-guidelines.pdf.

[140] Global Wind Organisation, (2021), *'Basic Safety Training Standard'*. Available at: https://www.globalwindsafety.org/standards/basic-safety-training-standard.

[141] Global Offshore Wind Health and Safety Organisation, *'Good practice guidelines'*. Available at: https://www.gplusoffshorewind.com/work-programme/guidelines.

management to an internationally accepted standard. This will promote use of the highest EHS standards in the construction and operation of offshore wind projects.

Assessing the existing, national health and safety regulatory framework

It is key for health and safety frameworks to be relevant to the local context. Each market will have a unique environment to consider, with existing regulations, local risks, and local cultures. It is also important not to rely solely on frameworks developed for onshore renewable energy projects, as offshore requirements differ due to the harsher environment and increased risks. The existing, national health and safety regulatory framework should therefore be assessed for gaps when considering ORE.

4.11.2 Health and safety in Ireland

The Health and Safety Authority (HSA) is the primary regulatory body responsible for ensuring compliance with health and safety regulations in Ireland, including in the offshore wind industry.

Key legislation governing the health and safety of offshore workers include the Safety, Health, and Welfare at Work Act 2005, covering health and safety in all Irish workplaces, and the Safety, Health, and Welfare at Work (Offshore Installations) Regulations 1989, specific to offshore installations. [142, 143] These provide guidelines for managing risks, safety procedures, and accident reporting.

Other relevant legislation may apply to certain activities within the project lifecycle, for example the Safety, Health, and Welfare at Work (Chemical Agents) Regulations 2001, where chemicals are being handled, or the Safety, Health, and Welfare at Work (Construction) Regulations, 2013, where construction activity is taking place.[144, 145]

The SOLAS Safepass is a mandatory health and safety training requirement for working in the construction industry in Ireland. It does not currently contain any offshore specific content.

The strengths of Ireland's current health and safety framework are:

- A competent and effective regulatory body in the HSA.
- A well established and understood general health and safety regime with high standards.

The weaknesses of the current framework are:

- A lack of ORE-specific health and safety legislation.
- Lack of offshore content within mandatory health and safety training.
- Resource constraints within the HSA could be a barrier to development and maintenance of a robust ORE health and safety framework, if unaddressed.

4.12 Frameworks for technology development and certification

Component design, manufacture, installation, and operation following technical standards help to reduce project risk. Key considerations include:

- Wind turbines are type certificated to international standards which cover fixed and floating offshore wind design bases.
- Project finance often requires third-party project certification against standards.

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[142] Government of Ireland, (2005), *'Safety, Health and Welfare at Work Act 2005'*. Available at: https://www.irishstatutebook.ie/eli/2005/act/10/enacted/en/print.

[143] Government of Ireland, (1991), *'S.I. No. 13/1991 – Safety, Health and Welfare (Offshore Installations) (Installation Managers) Regulations, 1991'*. Available at: https://www.irishstatutebook.ie/eli/1991/si/13/made/en/print.

[144] Government of Ireland, (2001), *'S.I. No. 619/2001 – Safety, Health and Welfare At Work (Chemical Agents) Regulations, 2001'*. Available at: https://www.irishstatutebook.ie/eli/2001/si/619/made/en/print.

[145] Government of Ireland, (2013), *'S.I. No. 291/2013 – Safety, Health and Welfare at Work (Construction) Regulations 2013'*. Available at: https://www.irishstatutebook.ie/eli/2013/si/291/.

Key practices underpinning a successful health and certification framework include:

- Using international standards wherever possible.
- Allowing industry and investors to determine what type certification and project certification is required.

Using international standards wherever possible

Wind turbines are designed according to international standards including the well proven IEC61400 suite. Other components typically are designed in line with aspects of the IEC[146] 61400 suite or alternatives, along with DIN[147], EN[148], International Organization for Standardization (ISO) and other internationally recognized standards for design and manufacturing.

If a government imposes national requirements in addition to these, then this can:

- Add cost, as the supplier needs to verify designs against additional standards and potentially change the design, requiring re-certification to international standards as well as national.
- Reduce competition, should international suppliers choose not to do this extra work, especially if the national market is small.
- Add risk, if less-proven designs or suppliers are used.

It is therefore valuable for governments either to facilitate the use of components designed to relevant international standards or to harmonize between relevant international and national standards where relevant. This was carried out in 2014 by the British Standards Institute (BSI) for offshore renewables.[149]

Germany is an example of a country that imposes additional national requirements, especially around onshore and offshore wind turbine structural integrity, through Germany's central maritime authority, BSH.[150] Delivered carefully and with deep understanding, this can play a role in harmonizing ORE with other industries in any market.

In some cases, site conditions typical in a market might exceed those defined in design bases in international standards. In such conditions, it is relevant for a county to push for a change in the design basis. This might require work to assess the impact and either agree a global change or enable a variant certification. Such practice has been used for areas prone to extreme weather, for example typhoons, where an additional T-class certification basis has been established.

Allowing industry and investors to determine what type certification and project certification is required

IEC standards also cover project certification, increasing confidence that project-specific design and implementation is in line with standards and good practice. Some investors and project developers require third-party certification against such standards by an appropriately qualified organisation. Others choose to manage risks internally or based on their own understanding of best practice established through delivery of projects.

Industry risk management processes, including those used by underwriters, have helped find a reasonable balance between independent verification and supplier accountability, enabling ongoing innovation while

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[146] IEC: International Electrotechnical Commission.

[147] DIN: Deutsches Institut für Normung - or German Institute for Standardisation.

[148] EN: Europäische Norm - or European Norm. Usually referred to as European Standards.

[149] BSI Group on behalf of Innovate UK, (2014), *'Offshore renewable energy standardization review'*. Available at: https://www.bsigroup.com/LocalFiles/en-GB/standards/BSI-Offshore-renewable-energy-standardization-review-UK-EN.pdf.

[150] Das Bundesamt für Seeschifffahrt und Hydrographie, (2015), *'Standard Design'*. Available at: https://www.bsh.de/DE/PUBLIKATIONEN/_Anlagen/Downloads/Offshore/Standards/Standard-Design_en.html.

managing risk. Governments imposing further restrictions again risk adding complexity and cost, with little benefit.

4.12.1 Regulatory sandboxes for innovative renewable technologies

Regulatory sandboxes are controlled, real world environments which provide a structured context for direct testing of innovative technologies, products, services or approaches under regulatory supervision. Regulatory sandboxes typically include some degree of regulatory lenience in combination with certain safeguards. The *Net Zero Industry Act* sets out the concept of regulatory sandboxes for the renewable energy sector. Waivers of specific legal provisions within regulatory sandboxes can enhance innovation capacity whilst under the supervision of a competent authority.

Testing and validating products in regulatory sandboxes prior to wider market deployment has a number of benefits, particularly in innovation (e.g. prototype testing and refinement) and business growth. Additionally, the supervision of innovative technology testing can reduce regulatory risk for innovators by providing facilitators with supervisory understanding of emerging technologies, which can inform an adequate policy response. Demonstration projects in Ireland could serve as regulatory sandbox opportunities (for example AMETS, SAOIRSE).

DETE has identified regulatory sandboxes as an area for consideration within *Powering Prosperity, Ireland's Offshore Wind Industrial Strategy*.[99] The European Commission provided guidance for member states on regulatory sandboxes (including those specific to renewable energy) within the *New European Innovation Agenda*.[151] In considering the development of new regulatory sandboxes in ORE, it is important for designated departments to draw on the expertise of relevant regulatory bodies, for example MARA and CRU in Ireland.

4.12.2 Technology development and certification in Ireland

Component design, manufacture, installation, and operation following technical standards help to reduce project risk. Key considerations include:

- Well proven international wind industry standards (such as the IEC 61400 suite) are used by established suppliers active in a range of markets.
- National standards driving market-specific solutions add cost and barriers to competition.
- Project developers and investors are well placed to determine what type- and project certification is required to manage risk for a given project.

National Standards Authority of Ireland (NSAI) is the body responsible for developing and maintaining national standards and certifications, including within renewable energy.

NSAI is involved with the International Electrotechnical Commission (IEC) Technical Committees 88 and 114 are responsible for supporting the preparation of international technical specifications for offshore wind and marine energy systems (including wave and tidal) respectively.[152]

The strength of Ireland's current framework is:

- The NSAI is well integrated with the IEC to ensure that Irish Standards are in line with international standards, facilitating trade in generating devices and associated componentry, and ensuring that innovations for the Irish market are exportable.

The weakness of the current framework is:

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[151] European Commission, 2022, 'A new European Innovation Agenda', available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0332.

[152] This IEC is an international standards organization that prepares and publishes international standards for all electrical, electronic and related technologies, including ORE technologies. See https://www.iec.ch/homepage.

- No recent commercial projects have been constructed, meaning that alignment between Irish and international standards has not been recently tested.

4.13 Delivery

Beyond setting strategy and policy and enabling frameworks, to sustain a long-term deployment and industry, governments should consider how else to support successful ongoing delivery. Key considerations include:

- Establishing a pipeline of large ORE projects requires long-term collaboration and trust between government and industry.
- Government oversight in partnership with industry groups has proved successful in established markets.
- Key ingredients for successful long-term delivery of ORE are flexibility, continuous learning and improvement, and ongoing consultation with stakeholders.

The delivery of ORE projects relies on:

- Supply chain development
- Knowledge, skills, innovation and research
- Ports
- Transmission network; and
- Financing.

4.13.1 Supply chain development

ORE offers economic benefits within the supply chain and needs a level of local supply chain development for it to be successfully delivered. Key considerations include:

- Supply chain gap analyses, incubation programs and good communication of opportunities help suppliers.
- Measuring and reporting local content helps enable meaningful dialogue about local economic benefits.
- Encouraging competition and enabling LCOE reduction enable local supply chains to deliver at home and abroad.
- Facilitating the development of industrial clusters through supportive policies, funding for business networks, and other initiatives encourage industry collaboration and investment.
- Ensuring appropriate frameworks are in place with resources to support timely delivery of ambitions.

Key practices underpinning successful supply chain development include:

- Facilitating investment in manufacturing facilities and ports.
- Establishing supplier education and support initiatives.

Facilitating investment in manufacturing facilities and ports

ORE needs investment in new manufacturing facilities and port facilities, but individual suppliers and ports can often find it hard to justify without a pipeline of projects to generate sufficient return on investment. Development of local deep-water construction ports suitable for deploying floating offshore wind at scale will be particularly critical to enable large scale deployment of this technology, due to the challenges of transporting integrated floating turbines over long distances. Public funding to support private investment can enable decisions where there is insufficient visibility. Mechanisms include targeted competitions or tax incentives. Often investment mechanisms, combined with supportive development policies and other initiatives, aim to create industrial clusters where a business network of interrelated companies concentrate around a central hub. Ports often provide the hub around which ORE industrial clusters develop. Several notable port-centred ORE clusters have developed in Cuxhaven (Germany), Esbjerg (Denmark), Humber (UK), Ostend (Belgium) and Saint Nazaire (France).

Establishing supplier education and support initiatives

There are a range of supplier education and support initiative that can be led by governments, trade associations or membership organisation to enable supply chain development. Some of the key initiative include the following:

- Commissioning supply chain gap analyses to identify gaps in the supply chain and opportunities for in-country suppliers.
- Establishing incubation programs to help educate suppliers on how to win first contracts, grow and export their products and services. In the UK, the current flagship program is mainly industry funded, as a result of the last government-industry deal.[153]
- Communicating the benefits of ORE supply opportunities to new suppliers by sharing market information and publicising opportunities in the early stage of industry development.
- Developing a supply chain database which provides up to date, accurate and verified information on suppliers to help purchasers identify those with the capability to support ORE projects.
- Developing a prequalification database, which holds corporate information on suppliers that demonstrates that they are a viable option to contract with, to reduce the need for suppliers to submit the same information to each purchaser in different formats.
- Implementing a standardised methodology to measure and report local content to enable meaningful dialogue around local economic benefits. The UK industry and government collaborated to develop a standardized methodology for setting expectations and measuring and reporting percentage project lifetime local content, rather than defining fixed requirements in terms of local supply of certain components .[154]

4.13.2 Knowledge, skills, innovation and research

To maximise successful delivery and local benefit in new industries needs capability building and innovation. Key considerations include:

- Skills development programs have been used successfully in different markets to transition workers from related industries.
- Enabling learning from suppliers in established markets is an efficient way to improve local supply.
- Well-focussed publicly funded innovation programs can reduce LCOE and help increase the amount of local supply.
- Workshop test facilities and onshore and offshore test sites can also play important roles in the route to market for innovations and suppliers that are new to ORE.

Key practices underpinning successful knowledge and skills development, and innovation and research include:

- Sharing information across the industry.
- Investing in innovation programmes and test facilities.

Sharing information across the industry

Sharing information across the industry is critical to knowledge and skills development. This often begins with government's sharing local skills studies or career opportunity assessments with industry to define the skills needed to support ORE projects. Skills development programs or programmes aimed at retraining workers in related industries, such as offshore oil and gas, marine construction or military, can then be established to develop a competent workforce. It is also important for industry to share information to help improve decision-making within government and across the supply chain. This can be achieved by encouraging the sharing of project data in the public domain, organising industry knowledge exchange programmes and events and supporting joint ventures or joint industry project between experienced and inexperienced parties. For example, the Offshore Renewable Energy Catapult established the System

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[153] Offshore Wind Industry Council. Available at: https://owgp.org.uk.

[154] BVG Associates, (2015), *'Methodology for measuring the UK content of UK offshore wind farms'*. Available at https://cdn.ymaws.com/www.renewableuk.com/resource/resmgr/Publications/Guides/uk_content_methodology.pdf.

Performance, Availability and Reliability Trend Analysis (SPARTA) which is an initiative to share operational reliability data between project developers.[155]

Investing in innovation programmes and test facilities

Publicly funded innovation programs and test facilities can support the development of new technologies and reduce LOCE, while also increasing the amount of local supply by providing a route to market for local innovators. Innovation programmes can be provided through a combination of grants, loans, or incubation programs. Some countries have established publicly funded research and technology organizations (RTOs) to support local and international collaboration and focus on key areas of innovation, as well as publicising support opportunities. Onshore and offshore test sites also play important roles in development of new technologies. Workshop facilities enable key conditions to be simulated, while offshore test sites enable innovations to be demonstrated at part- or full scale in small volumes. Example facilities include those for drivetrains at Clemson University, blade bearings at Fraunhofer IWES, blades at ORE Catapult, and complete turbines at the Østerild Test Center of the Technical University of Denmark.[156, 157, 158] Each ORE market will have characteristics that demand innovation and local solutions. Governments in emerging markets should focus on supporting any local innovators or innovations needed to reduce LCOE for their specific market through innovation programs and test facilities since they act as an important entry point into the market.

4.13.3 Ports

Nearby ports are essential to enable the construction, operation, and maintenance of ORE projects. Key considerations include:

- Governments have a role to play in assessing and communicating the suitability of existing port facilities for ORE and enabling investments with wider local economic benefits.
- Port investments need to be future-proofed by being able to adapt to accommodate new technologies.

Key practices underpinning successful ports development include:

- Assessing existing port facilities to determine the need for upgrades or new ports, and
- Establish effective ownership, funding and tax models to enable necessary investment.

Assessing existing port facilities to determine the need for upgrades or new ports

Governments have an important role to ensure that the port infrastructure is suitable to support its ORE strategy. Governments should therefore assess and communicate the suitability of existing port facilities that could be used for construction or operation of ORE projects, and identify where capability gaps exist. Established and emerging offshore wind markets, such as the UK, the US, India, and Taiwan have published port infrastructure studies.[159,160,161,162] Wind Energy Ireland also published its *National Ports Study* in 2022 which provides an assessment of the current and planned port infrastructure in Ireland, the requirements of offshore wind projects and the suitability of Irish ports in supporting such projects.[29] This will help to

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[155] Offshore Renewable Energy Catapult, (2020). Available at: https://www.sparta-offshore.com/SpartaHome .

[156] Fraunhofer Institute for Wind Energy Systems. Available at: https://www.iwes.fraunhofer.de/de/download-center/pitch-bearing-testing-at-iwes.html.

[157] Offshore Renewable Energy Catapult, *'Testing & Validation'*. Available at: https://ore.catapult.org.uk/what-we-do/testing-validation/turbine-blade-test-facilities/.

[158] DTU WIND ENERGY. Available at: https://windenergy.dtu.dk/fejl/404?item=%2ftestcenters%2foesterild&user=extranet%5cAnonymous&site=vindenergi_nyUK.

[159] Arup on behalf of Crown Estate Scotland, (2020), *'Ports for offshore wind'*. Available at: https://www.arup.com/-/media/arup/files/publications/p/ports-for-offshore-wind-the-net-zero-opportunity-scotland-ces-arup.pdf.

[160] American Association of Port Authorities (AAPA), U.S Department of Transportation (USDOT) and Maritime Administration (MARAD), (2017), *'Port Planning & Investment Toolkit'*. Available at: https://www.cmts.gov/assets/uploads/documents/InfrastructureInvestmentToolkit.pdf.

[161] GWEC, (2016), *'Supply chain, port infrastructure and logistics study for offshore wind farm development in Gujarat and Tamil Nadu '*. Available at https://www.gwec.net/wp-content/uploads/vip/Fowind-study-report_29-06-2016_pages_JWG-update_v2.pdf.

[162] Offshoreenergy,dk and ITRI, (2016), *'Offshore Wind Port Feasibility Study of Taichung Harbor'*. Available at: https://www.twtpo.org.tw/tools/download.ashx?id=134.

determine any upgrade or new ports required. Suitable existing ports provide an advantage by reducing the risk of delays and costs incurred to early projects due to new infrastructure being built. To build a port, or to undertake major upgrades, can take between two and ten years, depending upon on permitting, and public funding is often a feature of major infrastructure investments of this kind. Governments, private ports, developers, and major manufacturers should plan for making any necessary port upgrades in good time.

Establish effective ownership and funding models to enable necessary investment

Effective ownership and financing are crucial for facilitating investments in ports. Ports can by fully owned by the government (public service ports), private business (private service port) or a hybrid mix of both (landlord port or tool port). Most large ports worldwide are organized according to the landlord model and increasingly operate as autonomous organizations with a commercial focus. However, public investment in the port sector is still common in many countries and ports can receive fiscal exemptions, subsidies, grants, or other forms of government support, such as freeport status. The investment payback for small port expansions are three to five years, for moderate scale developments ten to 15 years, and for new ports can be greater than 25 years. Therefore, ports need to have confidence in future demand for their services which will generate sufficient return on investment. Investment
risk mitigation can be achieved by the following:

- Early engagement with developers and stakeholders to understand the requirement and project pipeline.
- Commitment or co-investment from government or industry if large investments are required that would not otherwise be delivered via a purely private finance model.
- Designing multifunctional ports that host fabrication facilities as well as marshalling/assembly, helping to diversify revenue streams and improve risk profile.
- Diversification to serve multiple industries rather than relying solely on offshore wind.

4.13.4 Transmission network

A robust approach to transmission network planning and upgrades is required to give industry confidence that projects can be connected to a sufficiently strong transmission network. Key considerations include:

- As variable supply increases on a transmission network, the role of interconnectors, storage, and demand and supply management becomes increasingly important.
- It is important to consider the anticipated pipeline of ORE projects to plan for efficient integration into the onshore transmission network.
- Grid support capabilities[163] and sufficient transmission network capacity can be encouraged by policy incentives.

Key practices underpinning successful transmission network development include:

- Carrying out grid capacity and integration planning.
- Coordinating network upgrades with stakeholders.

Carrying out grid capacity and integration planning

It is important to carry out a regular, holistic assessment of the transmission network capacity required across the electricity system, considering new generating capacity and changing demand. This maximizes the benefits of strategic network investments and reduces the risk of stranded transmission network assets if individual projects are not progressed. Anticipated future grid connection availability can also help to inform spatial planning and the prioritization of different areas for leasing. In addition, as variable supply increases on the transmission network, the need for interconnectors, storage, and demand and supply management becomes increasingly important. Grid integration planning considering these elements can provide system

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[163] Grid support capabilities means the ancillary services provided by a generator to help maintain desired frequency and voltage for the transmission network.

flexibility that can help align renewable energy generation with demand. The *Offshore Transmission Network Review* is an example of the careful approach needed towards grid capacity and integration planning.[164]

Coordinating network upgrades with stakeholders

The efficient integration of ORE into the transmission network requires coordination across multiple Stakeholders, including developers, TSO and owners, energy regulators and government. For transmission network upgrades, clearly defined roles and responsibilities are needed so developers know how they are to engage with the process. The design of upgrades is an iterative process and can introduce uncertainty in the timing and capacity that will be available for ORE projects. A large strategic network upgrade therefore requires coordination between the TSOs and developers as part of long-term network planning.

4.13.5 Financing

ORE is highly capital-intensive, requiring significant participation from the banks and the capital markets. Key considerations in enabling financing include:

- The offshore wind industry has a strong record over the past decade, and the finance community has grown comfortable with the technology. This is yet to happen with other ORE technologies.
- Governments need to consider how policy decisions affect ORE access to finance while managing the risk exposure to the public sector.
- The experience of international financiers is vital in managing risk in new markets.

Key practices underpinning successful financing include:

- Considering the financing implications of offtake contract terms.
- Enabling an environment which gives investors access to insurance from international markets.

Considering the financing implications of offtake contract terms

Careful consideration of indexation and other protection is required to manage project owner risk in dynamic market environments. Inflation risk is a material consideration for developers prior to first generation, where significant commodity price shifts have been seen in recent years. It is also important during operational life, as it erodes earnings over time. Other protection regarding counterparty creditworthiness, exchange rate fluctuation and changes in government policy can be relevant in some markets.

Enabling an environment which gives investors access to insurance from international markets

It is important to enable an environment that gives investors access to insurance from the international insurance and reinsurance markets. Local risk factors can be addressed better through the collaboration of local and international insurance sectors. ORE insurance will be influenced by such local factors.

4.13.6 Delivery in Ireland

Ireland's ORE supply chain is limited at present. It has domestic strengths in project development, engineering and onshore construction. It also has a strong onshore wind sector with transferable capabilities, particularly in the operations and maintenance phase. Ireland has made moves to develop this capability with the publication of *Powering Prosperity*.[99] As a member of the EU and World Trade Organisation, Ireland's ability to promote supply chain growth through favouring local content is limited. There are opportunities, however, to develop industrial clusters to support ORE deployment through supportive policies, funding for business networks and other initiatives to encourage industry collaboration and investment. There are no plans in place to develop an industrial strategy for other ORE technologies. In ORESS 1, applicants were required to submit Project Delivery Plan Questionnaires which included estimates of local content at various milestones along the project development timeline.

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[164] UK Government, *'Offshore transmission network review'*. Available at: https://www.gov.uk/government/groups/offshore-transmission-network-review.

There is one port currently on the Island of Ireland which has the necessary attributes to service large scale offshore wind project, at Belfast's D1 harbour. There are no ports in the Republic of Ireland with current capability, and no ports anywhere in Ireland with the capability to support assembly, marshalling and integration of floating offshore wind turbines at scale. If unaddressed, a lack of suitable port infrastructure could prove a bottleneck to Ireland's deployment ambitions, especially for floating wind, where local construction ports to provide integration and marshalling services are critical to current commercial models. The April 2023 Wind Energy Ireland report *We can build them: Supporting Irish ports to build offshore wind farms* set out a number of recommendations to support Irish ports in entering the ORE sector.[165]

The *National Ports Policy* governs ports policy in Ireland.[166] It is currently under review, and the review will consider what policies, structures or other measures would best support ports to develop the infrastructure necessary for the facilitation of ORE. Within the EU's general block exemption regulation, exemptions exist to facilitate state support for strategic port infrastructure investments of this kind.

In all scenarios considered in this report, Ireland's transmission network will require significant strengthening to cope with the additional demand associated with Ireland's energy transition, and the additional onshore and offshore generating capacity this will entail. Grid expansion in Ireland is difficult currently, and the difficulty of obtaining planning consents for new onshore transmission assets is often cited as a particular issue. If unaddressed, this could act as a significant blocker to delivery of the volumes of ORE envisaged in this report, particularly in scenarios 2-4.

SEAI has a key role in R&D funding within the ORE sector, as established in the 2002 Sustainable Energy Act[167], and runs regular funding rounds to support this activity, such as the National Energy Research Funding Programme.[168] It also administers the European Commission's Innovation fund and Horizon Europe funding within Ireland.[169] [170]

The Marine Institute is responsible for marine research, technical development and innovation, providing a range of scientific, advisory and economic development services. The Marine Institute operates national marine research infrastructure that provides essential platforms for research and early technology development. These include laboratories, two research vessels and oceanographic equipment. It also supports a number of test and demonstration platforms.

Taighde Éireann - Research Ireland was announced in November 2023 as Ireland's new competitive funding agency for research and innovation. Research Ireland will amalgamate the activities and functions of the Irish Research Council (IRC) and Science Foundation Ireland (SFI) to create a new competitive funding agency for research and innovation. Any recommendations referring to SFI apply to Research Ireland once these organisations have been amalgamated.

Ireland has a strong and dynamic finance sector, regulated by the Central Bank of Ireland and subject to overarching EU single market regulations.

The strengths of Ireland's current delivery framework are:

- Sophisticated and well-regulated finance sector facilitates financing of ORE projects.

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[165] Wind Energy Ireland, (2023), *'We can build them: Supporting Irish ports to build offshore wind farms'*, available at https://www.gdgeo.com/wp-content/uploads/2023/04/Irish_Ports_Funding_Study.pdf.

[166] Department of Transport, (2019) 'National Ports Policy', available at https://www.gov.ie/en/publication/4aa3cc-national-ports-policy/

[167] Sustainable energy act, (2002), available at: https://www.irishstatutebook.ie/eli/2002/act/2/enacted/en/html.

[168] SEAI, *'Research Funding'*. Available at: https://www.seai.ie/grants/research-funding/.

[169] SEAI, *'Innovation Fund'*. Available at: https://www.seai.ie/grants/research-funding/innovation-fund/.

[170] SEAI, *'Horizon Europe'*. Available at: https://www.seai.ie/grants/research-funding/horizon-europe/.

- Existing Irish strengths in project development and onshore wind capability, which provide opportunities for participation in delivery.
- Project delivery plan questionnaires provide an effective mechanism to measure local content in Irish offshore projects.
- Well-funded ORE R&D support is available.

The weaknesses of the current framework are:
- Lack of suitable port infrastructure which could prove a barrier to deployment, particularly of floating offshore wind, if unaddressed.
- Receivers of R&D funding have not always returned good value for money to date.
- Ireland does not currently have a skills development programme to address future skills needs.
- The definition of 'Irish Content' employed in ORESS 1 project delivery plan questionnaires allows for contracts awarded to entities incorporated in Ireland to be designated as local content, even if the majority of contract value goes elsewhere. This could lead to overestimation of local economic benefits and does not drive intended behaviour.

4.14 Recommendations

The following recommendations are based on the above assessment and examples of best practice from other markets. They apply to all deployment scenarios unless stated. In general, urgency and the strength of recommendation increases for higher volume scenarios. Note also that further recommendations are listed in Sections 2, 5 and 6.

Energy Strategy

- DECC delivers (and updates every 3 years) a decarbonised electricity system pathway, setting out Ireland's long-term ambitions for ORE technologies and their place within the wider energy system and addressing security of energy supply, cost-effective energy for consumers, local jobs and economic benefits, climate and environmental benefits and attracting foreign investment.
- DECC integrates a firm vision for interconnection and alternative offtake solutions such as hydrogen or efuels into future pathway documents. This should include consideration of the international competitiveness of Irish interconnection or alternative offtake, accounting for generation, production, storage and transmission costs as well as optimisation of domestic usage.

Policy

- DECC ensures that industry participation and stakeholder consultation is built into future policy development, establishing a strong forum for ongoing dialogue with industry during policy and framework development and implementation.
- DECC delivers timely clarity on the future framework for ORE and a policy statement outlining details of the future framework beyond ORESS 2 to provide forward certainty for developers.
- If Ireland wishes to pursue significant deployment of other ORE technologies, DECC should consider setting a corresponding ambition. (Applies only to scenario 4.)

Frameworks to enable ORE delivery

- DECC focusses on accelerating delivery through effective frameworks and by promoting the attractiveness of Ireland as a market for offshore wind.
- DECC and DETE consider how an appropriate balance can be achieved between delivering low cost deployment and driving investment in local supply chain, ensuring alignment between statements of policy and content of frameworks.
- DECC ensures that frameworks allow sufficient time for necessary activities such as collection of site data, grid planning, supply chain planning and bid development between stages to minimise risk to investors and generate efficient outcomes for consumers.

Framework for marine spatial planning

- DECC draws on developer feedback and industry expertise to ensure that state-run site surveys, assessments and selection activities meet the requirements of developers, whose preferences for data specification may vary.
- DECC makes the data used to inform DMAP development available to industry to improve transparency and efficiency of the MAC application and permitting processes.
- DECC sets out a long term plan for ORE marine spatial planning on a national basis, including a forward plan for future DMAPs.

Framework for seabed occupancy and offtake

- DECC establishes a regular pattern of ORESS auctions or any successor schemes (for example every two years) with multi-round forward visibility for the market.
- DECC fully describes the framework for upcoming offshore renewable offtake at the earliest opportunity. If, in future schemes, the auction comes before MAC award and permitting, as in ORESS 2.1, bidders should have reasonable certainty they will receive a MAC and necessary permits, should they be successful, to reduce delivery risk and increase the attractiveness of the offshore renewable energy market.
- MARA grants seabed exclusivity with respect to ORE developments under MACs moving forward, and maintains the 45-year rights period to give developers long-term certainty when participating in offtake auctions.
- DECC clarifies policy for projects seeking to come to market via alternative offtake arrangements, such as CPPAs, including MAC eligibility arrangements.
- DECC maintains a suitable longstop date in future ORESS auction terms to ensure timely project delivery is incentivised while minimising risk to developers.
- DECC considers whether to pursue ORESS auctions for other ORE generation technologies. (Applies to scenario 4 only.)

Framework for permitting

- DECC and DHLGH ensure both MARA and An Bord Pleanála respectively are appropriately resourced to deliver the desired volume of timely permitting decisions. The resourcing required will depend on the scale of Ireland’s deployment plans.
- DECC defines a full single point of contact (SPC) function to streamline the permitting process in line with RED III requirements and implements the monitoring and enforcement elements of the SPC function.

Frameworks for export system and grid connection

- The Commission for Regulation of Utilities (CRU) and EirGrid introduce:
  - Measures to give early clarity of grid charging costs, grid connection dates and locations to reduce risk and cost to developers participating in future offtake auctions.
  - Measures to incentivise both EirGrid and developers to ensure timely, aligned delivery of transmission infrastructure.
- DECC, EirGrid and DETE consider adopting an integrated offshore hub model to reduce the number of connection assets required. The centralisation of responsibility for export system and grid connection under EirGrid in the plan-led model facilitates this type of strategic planning.
- DECC clarifies EirGrid’s long term role in design and build of transmission infrastructure beyond ORESS 2.1 and ensures that EirGrid is properly resourced to discharge its expanded responsibilities. The resourcing required will depend on the scale of Ireland’s ORE deployment plans.
- EirGrid develops a strategic roadmap for transmission network development to 2050, providing forward visibility of reinforcement plans and a commitment to updating it on a regular basis, informed by forthcoming marine spatial planning documents. This will increase investor certainty and facilitate future proofing of transmission network investments.
- DHLGH considers how the planning regime could be changed to more easily facilitate delivery of new onshore export system and transmission network infrastructure.

Frameworks supporting the wider energy system

- DECC brings forward an updated regulatory regime for hydrogen, aligned with efforts at an EU level to facilitate seamless trade. (Applies to scenarios 2, 3 and 4 only.)
- DECC and DETE explore opportunities for Ireland to benefit from the development of local supply chains for renewable hydrogen. This should include consideration of Ireland's international competitiveness as a supplier of hydrogen. (Applies to scenarios 2, 3 and 4 only.)
- EirGrid explores innovative technological solutions to support grid access for ORE.

Framework for health and safety

- DETE and Health and Safety Authority (HSA) explore whether to bring forward updated offshore health and safety legislation which contains specific provision for the ORE industry and its working practices, and ensure the HSA is appropriately resourced to deliver a robust and transparent offshore health and safety framework.
- DETE and the HSA develop Irish ORE wind health and safety guidance and legislation with reference to best practice from global training bodies such as the Global Wind Organisation, G+ Offshore Wind Health and Safety Association, as well as examples of best practice in established markets.
- DETE and the HSA, in consultation with SOLAS, to review whether offshore-specific content should be incorporated in Safepass.

Frameworks for technology development and certification

- NSAI Ensures that the Irish certification regime remains aligned with IEC standards to ensure harmonisation and facilitate confidence in financing Irish projects, and that industry and investors have a strong voice in the development of new standards and certifications.
- NSAI focusses where Irish site conditions are beyond the standard definition of site conditions, to ensure Ireland-specific risks are managed.
- DECC and DETE undertake a feasibility assessment of regulatory sandboxes for ocean renewable technologies, allowing regulatory requirements to be altered on a limited basis for trial projects to test the effectiveness of new approaches.

Delivery

Note that recommendations relating to supply chain and skills development can be found in Section 5.6 and recommendations relating to R&D can be found in Section 6.5.

5. Economic and supply chain assessment

5.1 Introduction

This section considers the impact on the Irish economy of each of the ORE technologies described in Section 2 under the scenarios described in Section 3. It focusses on local economic benefit in terms of:

- Gross value added (GVA) from supply of goods and services to ORE during the full lifecycle of Irish projects
- Direct and indirect jobs, expressed in terms of FTE-years of employment; and
- Export opportunities in the same areas.

It does not consider the additional benefits in terms of climate (reduction in global warming potential (GWP), mainly through reduction in production of carbon dioxide, reduced air pollution and water usage due to the avoidance of energy production from fossil fuels, or shared use of infrastructure and benefits to the economy of reduced energy costs.

These figures account only for jobs and investment, and exclude the benefits of reduced energy costs. The economic impact of more expensive technologies can appear greater on this basis, though they cost the energy consumer more. Appropriate care should therefore be taken when interpreting these figures.

5.2 Economic opportunity methodology

Three types of impact are considered:

- Global impacts from projects in Ireland
- Irish impacts from projects in Ireland; and
- Irish impacts from projects overseas.

Direct impacts are defined as those associated with project developers and their main contractors. Indirect impacts are defined as those associated with their sub-suppliers. The report considers:

- Global impacts from projects in Ireland – representing total global project GVA, regardless of spend location.
- Irish impacts from projects in Ireland – then considering value added in Ireland, based on supply chain readiness and competitiveness.
- Irish impacts from projects in Ireland and overseas – adding consideration of export from Ireland.

Details of the methodology are provided in Appendix C.

5.2.1 Global impacts from projects in Ireland

This report presents the total gross value added (GVA) by year created for each market scenario if there was 100% local content (that is, there is no import of materials, components, and services). Different cost breakdowns are assumed for each of the three main technologies.

Multipliers are used to convert expenditure to FTE years and GVA. These multipliers have been tuned for the Irish market based on relevant literature, datasets and evidence.

The impacts from a single 1 GW project installed in 2040 are calculated in scenario 2 for fixed and floating offshore wind, and scenario 4 for wave energy. The total impacts of the pipeline of projects are calculated for each scenario, considering the different amounts of localization for different years of installation and in different scenarios.

Charts are to 2050, recognizing that there is further economic benefit for the full lifetime of each project, with more operation, maintenance service (OMS) spend, followed by a one-year peak during decommissioning (not shown).

5.2.2 Irish impacts from projects in Ireland

This report presents the impacts in Ireland by considering the current and potential future capability of the supply chain in Ireland and assessed the likely percentage of local content for each scenario.

5.2.3 Irish impacts from projects in Ireland and overseas

This is the sum of the above and anticipated exports. The potential was estimated based on our understanding of the regional and global market alongside the supply chain in Ireland and how that will develop in each scenario.

5.3 Local content methodology

The below narrative describes the assumptions applied to derive estimates of local content. In all scenarios, it is assumed that individual facilities are futureproofed or incremental investments are made to maintain throughput numbers as turbines become larger over time.

In general, the approach reflects a reasonable probabilistic assessment of value add that is likely in Ireland under each scenario, based on assessments of current Irish capability, size of pipeline and potential for Irish supply. It should not be viewed as a ceiling on Irish ambition. The levels of Irish content here could be exceeded with successful industrial policy to secure appropriate investment, supported by skills and training initiatives and R&D funding to build Irish capability.

Summary tables of local content for each technology in each scenario can be found in Section 5.4.2. A comparison table across all technologies and scenarios can be found in Appendix D.

5.3.1 Fixed offshore wind

Scenario 1

Fixed offshore wind assumptions are held constant across all three scenarios. This is because capacity does not vary greatly across scenarios, namely at 6 GW in scenario 1 and 10 GW in scenarios 2, 3 and 4. The assumptions are:

- Ireland has a strong share of project development and O&M activities, but all major components are imported.
- The pre-existing construction port in Northern Ireland, Belfast D1, will deliver fixed Irish projects, with an assumed maximum throughput capability 100 turbines per year. This capability is split so that 40% of the port's output serves the Irish market, 40% the UK market and 20% is unused or serves other markets.
- If the pipeline exceeds 40 turbines per year, it is assumed that investment in Republic of Ireland ports will commence to serve additional installation requirements.[171] Once port upgrades are commenced, it is assumed that the pipeline is split 2 to 1 between Irish ports and Belfast up to Belfast's 40 turbine limit. Thereafter domestic ports will service all domestic installation.
- Ireland has a small share of installation and decommissioning work, which is expected to be carried out by existing specialist international contractors.

In Scenario 1, Ireland's limited offshore wind pipeline decreases the attractiveness of Ireland as a destination for supply chain investment, relative to other scenarios, leading to lower investment, less Irish content in projects and a lower level of economic benefit on a per-project basis. Calculated local content levels are summarised in Table 17.

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[171] GDG on behalf of Wind Energy Ireland, (2022), *'National Ports Study'*. Available at: https://windenergyireland.com/images/files/final-national-ports-study.pdf.

Scenario 2, 3, and 4

As scenario 1, except:

- A tower manufacturing facility is constructed that supplies both fixed and floating projects (as well as onshore wind projects) from the start of 2030.
- The facility's throughput is assumed at 150 towers per year, with scale-up investments as necessary to maintain this throughput as turbines, and therefore towers, become larger over time.
- Steel plate and flanges are imported.
- The facility is assumed to have a maximum two-third market share within Irish projects. Of the remaining third, 50% of any additional capacity is used for export; the rest is unused.

5.3.2 Floating offshore wind

Scenario 1

- As in fixed offshore wind, Ireland has a strong share of project development and O&M activities.
- All domestic floating offshore wind turbines are assembled on to floating foundations from jack up vessels in Irish ports or sheltered Irish waters, as limited pipeline does not justify investment in new facilities. Installation vessels and crew are highly specialist and internationally mobile. Ireland lacks current capability in this area, so vessels and crew are assumed to be non-Irish.

Scenario 2 and 4

As scenario 1, except:

- Ireland has a higher share of project development, O&M activities than in scenario 1.
- A synthetic rope and mooring line manufacturing facility is constructed that supplies from the start of 2035.
  - Facility throughput assumed at 160 km synthetic mooring line per year.[172]
  - Assume maximum two-third market share to Irish projects and 50% of any additional capacity is used for export; the rest is unused.
- Investment occurs in all three suitable ports for floating offshore wind construction/assembly, operational from the start of 2032. Two are dedicated construction ports and the third is dedicated to floating foundation assembly.

Scenario 3

As scenario 2 and 4, except:

- Synthetic rope and mooring line manufacturing facility moves forward so that first supply is at the start of 2032, as increased project pipeline delivers necessary investor confidence at an earlier stage.
- Investment occurs in all three suitable ports for floating wind construction and assembly, operational from the start of 2032. All ports are initially dedicated construction ports as all port capacity is required to serve the domestic pipeline.
- From the start of 2035, a fourth floating port comes online. This is dedicated to foundation assembly. Alternatively, one of the preexisting ports switches to foundation assembly, while the new port focusses on construction. In either case, this leaves Ireland with three construction ports and one foundation assembly facility.

Floating offshore wind port capability assumptions

There is strong logic for using local construction ports, due to the technical and economic challenges associated with towing integrated floating wind turbines in open seas. There are three ports in Ireland with plan to service this requirement and the required technical characteristics, with investment: Cork, Moneypoint and Shannon Foynes Island. There may be opportunity for a fourth port, for example in Bantry Bay. Any fourth port is at least 10 years away from operation as nothing is currently in development.

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[172] Lankhorst euronete Brasil exceeds 800km mooring ropes production, *Press release*, Lankhorst, 26 April 2018, available online at https://www.lankhorstoffshore.com/about-us/news-events/lankhorst-euronete-brasil-exceeds-800-km-mooring-ropes-production.

The assumed maximum throughput of each port is 35 turbines per year. This is approximately one turbine per week over an eight-month installation window.

If the delivery pipeline is greater than 30 turbines per year, then it is assumed that spare facilities not dedicated to construction can be used for foundation assembly, each with maximum throughput 50 foundations per year with any excess capacity exported. If the delivery pipeline less than 30 turbines per year, it is assumed that assembled foundations are imported from elsewhere.

In all scenarios, it is assumed that modular foundation components are manufactured elsewhere, before final assembly in Ireland. Ireland has little of the type of heavy manufacturing industries which would carry out this work, and there is no strong logic for local supply as components are designed to be transportable. For this reason, it is assumed Ireland will not be an investment location of choice for new facilities of this kind due to its comparative lack of existing capability, coupled with relatively high wages compared to European and global alternative production locations. This means that investment into modular foundation components will more likely flow to other markets.

5.3.3 Wave energy

The following assumptions regarding local content in wave energy have been used. These are subject to greater uncertainty due the early stage of technology development:

- Ireland will have a strong share of project development and operations and maintenance activities, similar to fixed and floating wind.
- Wave energy generating device components are manufactured and assembled elsewhere and imported.[173]
- Ireland has a higher share of wave energy installation and decommissioning activities relative to fixed and floating offshore wind. This is because currently wave concepts are less likely to rely on scarce specialist heavy lifting equipment than fixed or floating wind, with a greater focus on offshore logistics carried out by non-specialist vessels. This may provide opportunities for local supply chains to play a greater role in services supporting installation and decommissioning, especially in early-mover markets developing wave projects.

5.3.4 Export assumptions

In deriving estimates of the export opportunity for Ireland, the following assumptions have been used:

- Domestic development and project management services companies are assumed to sell services abroad at a rate of 50% of domestic revenues. As domestic project development activity begins to tail off from the mid-2040s in all scenarios, the maximum level of export benefit reached is assumed to be maintained to 2050 as Irish firms continue to sell services abroad despite falling domestic activity.
- Where facilities for manufactured goods exist, such as towers and synthetic mooring lines, these facilities are assumed to service domestic pipeline first, with a maximum domestic market share of two-thirds. Half of any excess capacity is exported, the rest is assumed unused due to periods of less-than-full capacity operation.
- Fixed and floating construction and assembly ports are assumed to serve the domestic market first, due to the benefits of proximity to overall cost. There is no limit on their market share and they are not expected to export. Where excess capacity exists in floating foundation assembly, any excess capacity may be exported.

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[173] As in offshore wind, import of devices is assumed due to relatively high wages and service-based nature of the Irish economy, with few existing heavy industries which would carry out this kind of manufacturing relative to other European markets. Much of device value is in the manufacture of components and materials used. Final assembly, if that was to take place in Ireland, would not change results presented significantly.

- There is assumed to be some export of operations and maintenance related services. This could include monitoring software, maintenance and safety equipment or advisory services. Irish firms are assumed to export at a rate of 10% of domestic revenues.
- Export benefits encompass the export of goods and services associated with ORE deployment. They do not include the economic benefits of the export of hydrogen or electricity via interconnection, which have not been modelled. It is important to continue to evaluate the competitiveness of Irish electricity and hydrogen export within export markets, as the rollout of ORE progresses.

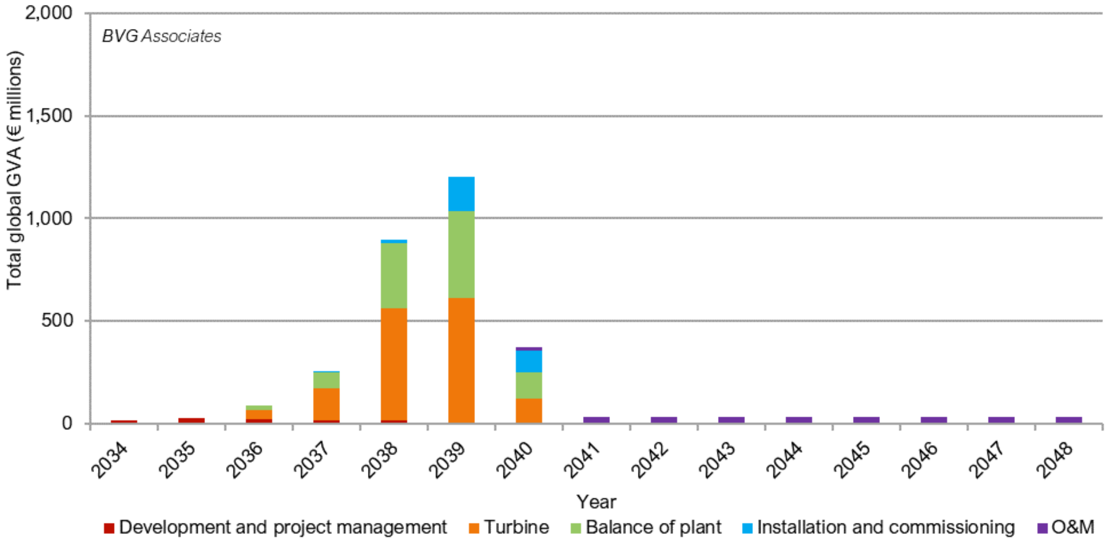
5.4 Results

5.4.1 Global impacts from projects in Ireland

Global impacts from projects in Ireland: single fixed offshore wind project

Figure 32 shows the gross value added (GVA) generated by a single 1 GW fixed offshore wind project installed in 2040 in scenarios 2 and 4. The majority of project spend occurs in the years leading up to installation. The peak annual GVA in 2039 is about €1.2 billion. After installation, there is a long, steady period of O&M spend. Note that only the early years of O&M are shown. O&M spend continues steadily for the full project life and is followed by decommissioning. The total GVA over the lifetime of the project is about €4.1 billion.

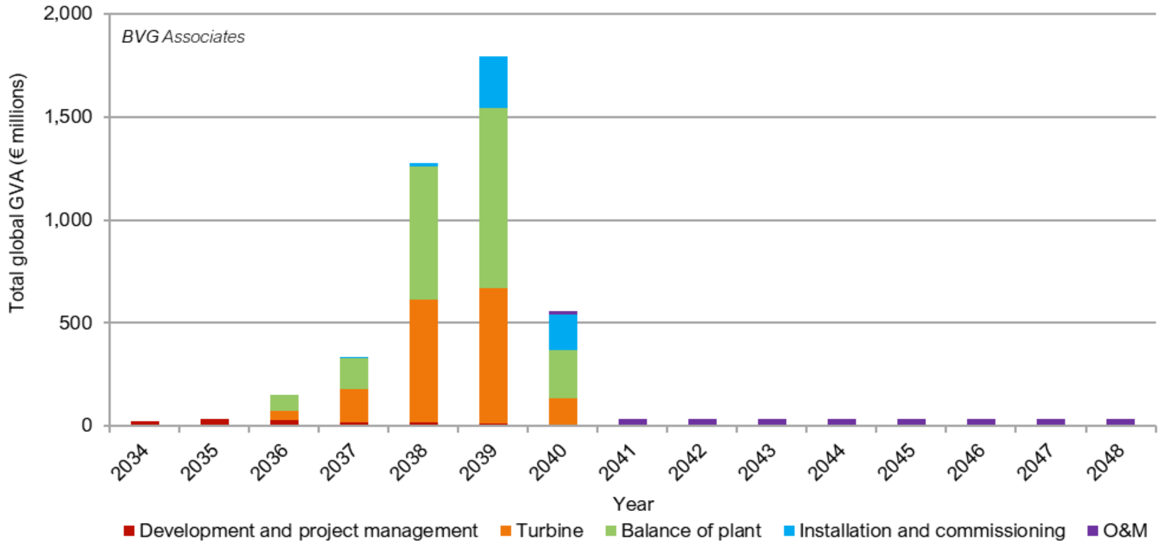
Figure 32: Global gross value added for a single 1 GW fixed offshore wind project installed in 2040, split by cost element



Global impacts from projects in Ireland: single floating offshore wind project

Figure 33 shows GVA generated by a single 1 GW floating offshore wind project installed in 2040 in scenario 2. The peak annual GVA in 2039 is about €1.8 billion. The total GVA over the lifetime of the project is about €5.6 billion, 36% higher than a comparable fixed offshore wind project.

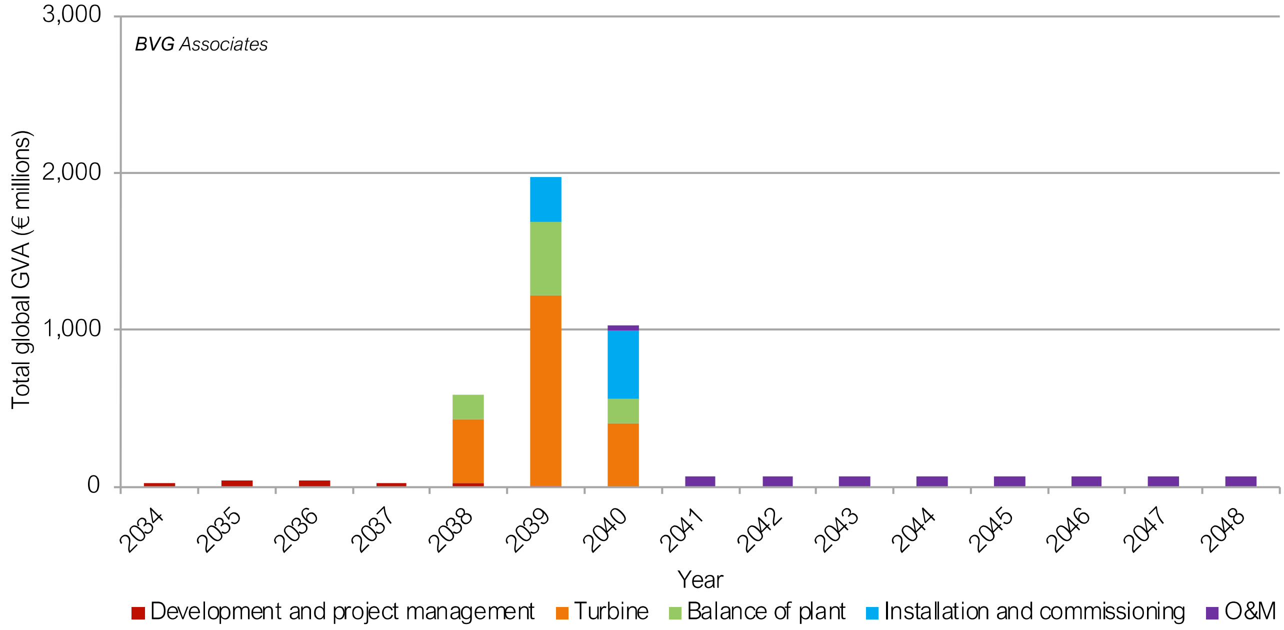
Figure 33: Global gross value added for a single 1 GW floating offshore wind project installed in 2040, split by cost element



Global impacts from projects in Ireland: single wave energy project

Figure 34 shows GVA generated by a single 1 GW wave energy project installed in 2040 in scenario 4. The peak GVA in 2039 is about €2 billion. The total GVA over the lifetime of the project is about €6 billion, 7% higher than a comparable floating offshore wind project. The wave project is assumed to be installed over a shorter window than a comparable fixed or floating project, two years as opposed to three. This is due to an assumed lower level of engineering complexity in the installation phase, as wave energy has no requirement for seabed piling as in fixed offshore wind. The marshalling, transportation and mooring of wave devices is assumed to be more straightforward due to the lesser height and draft of a typical wave device. There is significant uncertainty around this assumption however, due to an evidence gap concerning what form a commercial scale wave device would take and how exactly it would be installed.

Figure 34: Global gross value added for a single 1 GW wave energy project installed in 2040, split by cost element



Global impacts from projects in Ireland: comparison of single projects

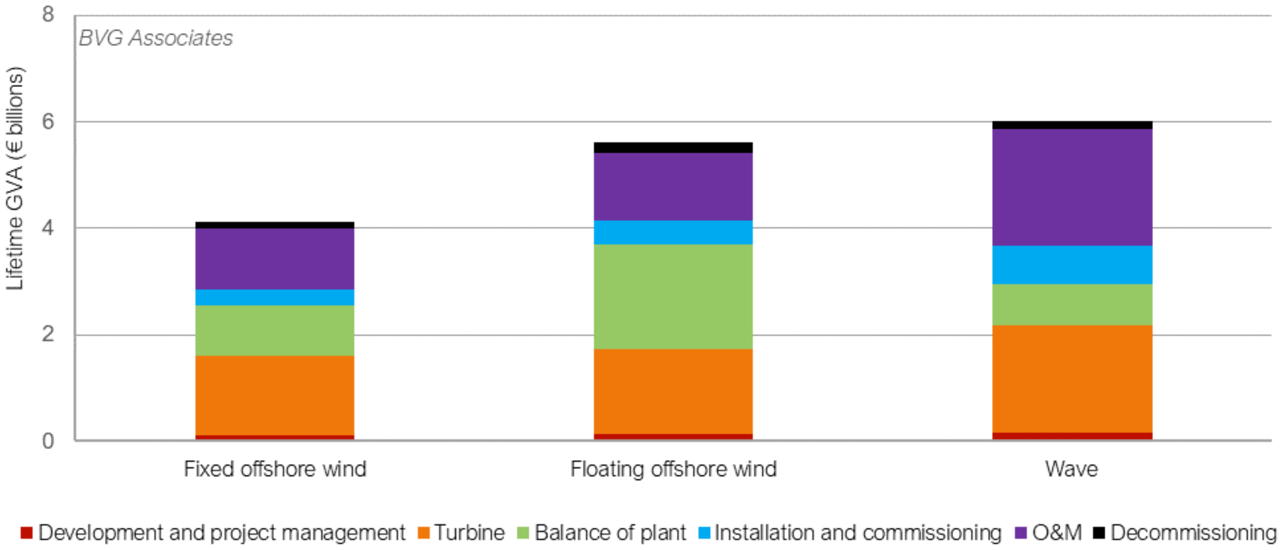
The GVA profile associated with each technology show various similarities. Each technology-specific GVA profile has a large peak of manufacturing and installation activity in the two to three years leading up to commissioning, and a long tail of O&M activity which continues for the project lifetime.

Key differences are:

- The fixed offshore wind GVA is notably smaller than other technologies. While indicative of lower investment potential, it is also representative of lower cost.
- Balance of plant spending plays a prominent role in the floating offshore wind profile. This reflects the significance of the manufacture and assembly of the floating foundations in the overall cost profile.
- The wave GVA profile contains a greater proportion of O&M spend than other technologies. This is reflective of the additional O&M required to maintain devices which are particularly exposed to the force of ocean swells. The actual balance of spend is uncertain, as it depends on the choice of technology design and the success of project implementation.

Figure 35 shows a global lifetime GVA comparison across the three technology types, for a 1 GW reference project deployed in 2040 as described above.

Figure 35: Comparison of global GVA for a 1 GW fixed offshore wind, floating offshore wind and wave energy project installing in 2040



5.4.2 Irish impacts from projects in Ireland

Table 17 to *Table 19* show how the local content (the percentage of spend within each cost category which is captured by the Irish economy)[174] changes over time as investments are made. In each scenario, the assumed local content percentage in 2025, 2030, 2040 and 2050 is presented based on the narrative provided in Section 5.3.

Across scenarios and technologies, the assumptions applied to Irish content as outlined in Section 5.3 lead to local content levels which fall in a relatively narrow range, between 16 and 26%. This means that differences in jobs and GVA outcomes between scenarios are almost completely driven by differences in deployment volumes, rather than differences in Irish content levels on a per-project basis.

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[174] For more detail on the principles used in the local content calculation methodology, see BVGA, (2015), '*Methodology for measuring the UK content of UK offshore wind farms*'. UK industry and Government agreed to use as part of formal processes in the UK for projects installed from the start of 2015 and it has been the basis of guidance in a range of other offshore wind markets, since. Available at: www.renewableuk.com/resource/resmgr/Publications/Guides/uk_content_methodology.pdf

Fixed offshore wind

Table 17 shows anticipated local content for fixed offshore wind based on the narrative given in Section 5.3. The share of local content in scenarios 2, 3, and 4 is identical as the pipeline and assumptions are identical across these scenarios. Ireland has a strong share of project development and O&M activity in all four scenarios, which rises slightly in higher deployment scenarios to reflect the additional strengthening of Irish expertise afforded by greater ORE deployment. This is due to the strong logic for local supply of O&M services, which benefit from project proximity.

In scenario 1, all components are imported and Ireland does not capture value in turbine manufacturing. In scenarios, 2, 3 and 4, Ireland is expected to secure investment in a tower manufacturing facility, which sees it capture approximately 2% of this value through development of a tower manufacturing facility.

In all scenarios, there is domestic balance of plant spend associated with onshore substation construction, which requires civil engineering capability, an area of domestic strength.

In all scenarios, Ireland captures some value in the installation and commissioning phase from onshore substation installation, port logistics and onshore export cable installation. This reflects Ireland's strength in onshore civil engineering, and the logic for using geographically proximate ports to support installation activities. The bulk of offshore engineering work is expected to be carried out by well-established specialist foreign contractors which currently dominate offshore installation work.

In decommissioning, as in installation, the majority of value is expected to be captured by specialist foreign contractors, though in all scenarios Ireland captures some value from the provision of ports and associated local services.

Realising the full extent of the local content opportunity outlined here will require investment in the supply chain to be delivered – most notably in construction ports and the tower factory envisaged in scenarios 2, 3 and 4. Additional investment will also be required throughout the supply chain including in skills development to ensure Ireland maximises the domestic value of its ORE rollout. To create the right environment for such investment to occur, government should:

- Set out ambitious long-term deployment targets.
- Put in place and continue to refine a clear, timely and predictable framework for deployment to occur, including mechanisms for seabed occupancy, permitting, offtake and grid connection to provide industry with confidence these targets will be achieved.
- Confirm the timing of future deployment opportunities, including clarifying a regular future pipeline of auctions with multi-year forward visibility.
- Ensure appropriate mechanisms for community engagement and participation are built into frameworks, including, where proportionate, community benefit mechanisms to foster strong public support.

Table 17: Local content for fixed offshore wind projects in Ireland completed in 2030, 2040 and 2050

	Scenario 1			Scenario 2, 3 and 4		
Year	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Project development	66%	66%	66%	67%	69%	71%
Turbine	0%	0%	0%	2%	2%	2%
Balance of plant	3%	4%	4%	4%	4%	4%
Installation and commissioning	8%	9%	11%	8%	10%	11%
O&M	51%	51%	51%	52%	56%	59%

Decommissioning	5%	5%	5%	5%	5%	5%
Overall local content	**20%**	**18%**	**18%**	**21%**	**20%**	**21%**

Floating offshore wind

Ireland's anticipated share of local content in floating offshore wind bears many similarities to its share of fixed offshore wind content. Local content shares in scenarios 2, 3, and 4 differ in this case due to differences in the size of pipeline, relative to the assumed throughput capability of Irish ports and manufacturing facilities, as outlined in Section 5.3.2.

The same considerations apply as in fixed offshore wind, with a number of differences:

- In scenarios 2, 3, and 4, Ireland's share of balance of plant spend is higher than in scenario 1 and in fixed bottom deployment. This is due to the emergence of Irish ports to service assembly of floating offshore wind foundations, alongside the emergence of a synthetic cable manufacturing facility Together, these see Ireland's share of balance of plant spend rise from less than 2% in scenario 1 to between 10 and 13% in scenarios 2, 3 and 4.
- Ireland's share of installation and commissioning spend also rises in scenarios 2, 3 and 4, to around 14%. This reflects the emergence of Irish ports to service floating offshore wind construction. The proportion of spend captured is higher than in comparable fixed bottom project due to the higher proportion of project spend which is captured by the construction port in floating offshore wind projects relative to fixed.

As in fixed offshore wind, it will be critical for government to create the right environment for supply chain investment to occur to realise the full extent of economic benefits. The same recommendations as outlined above also apply to floating offshore wind.

Table 18: Local content for floating offshore wind projects in Ireland completed in 2030, 2040 and 2050

	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
Year	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Project development	66%	66%	66%	67%	69%	71%	67%	69%	71%	67%	69%	71%
Turbine	0%	0%	0%	3%	2%	2%	3%	2%	2%	3%	3%	2%
Balance of plant	1%	2%	2%	2%	13%	10%	2%	10%	9%	2%	13%	12%
Installation and commissioning	10%	10%	11%	12%	14%	14%	12%	14%	14%	10%	15%	15%
O&M	51%	51%	51%	53%	56%	60%	53%	56%	60%	53%	56%	59%
Decommissioning	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Overall local content	**17%**	**16%**	**15%**	**18%**	**21%**	**21%**	**18%**	**20%**	**20%**	**18%**	**21%**	**21%**

Wave energy

Due to the high degree of uncertainty over the nature and cost breakdown of commercial scale wave devices, high level assumptions have been applied to estimate Irish content, which are held steady across scenarios.

As in offshore wind, Ireland is assumed to capture a strong share of project development and O&M spend. Ireland captures only a small portion of device and balance of plant spend, as devices are assumed to be imported, reflecting the weak logic for geographical proximity of supply and Ireland's limited heavy manufacturing base.

The key difference between wave and offshore wind is that Ireland is assumed to capture a higher proportion of installation and decommissioning spend, as such activities are less likely to rely on scarce specialist heavy lift equipment than fixed or floating wind, offering potential for new entrants and less specialised marine contractors to participate, particularly in early mover markets, and there will be less competition for services from overseas companies.

Recommendations to promote supply chain investment as outlined for fixed offshore wind also apply here.

Table 19: Local content for wave energy projects in Ireland completed in 2030, 2040 and 2050

	All scenarios		
Year	**2030**	**2040**	**2050**
Project development	60%	60%	60%
Device	5%	5%	5%
Balance of plant	5%	5%	5%
Installation and commissioning	28%	27%	27%
O&M	50%	50%	50%
Decommissioning	80%	80%	80%
Total local content	**26%**	**25%**	**25%**

Irish impacts from projects in Ireland: single fixed offshore wind project

Figure 36 shows the GVA generated by this single project. The peak annual GVA in 2039 is about €51 million. The total GVA over the lifetime of the project is about €820 million. Of the lifetime GVA, 45% is direct project spend.

Figure 37 shows the total FTE years employment created annually for a single 1 GW fixed offshore wind project installed in 2040 in scenario 2 and 4. It shows that annual employment peaks in 2039 at about 650 FTE years, when there is significant component manufacture as well as installation. Total employment for the project is about 9,000 FTE years over the lifetime of the project, 77% of this in O&M. Of the lifetime employment created, 45% are direct jobs.

Figure 36: Irish gross value added for a single 1 GW fixed offshore wind project installed in 2040, split by cost element

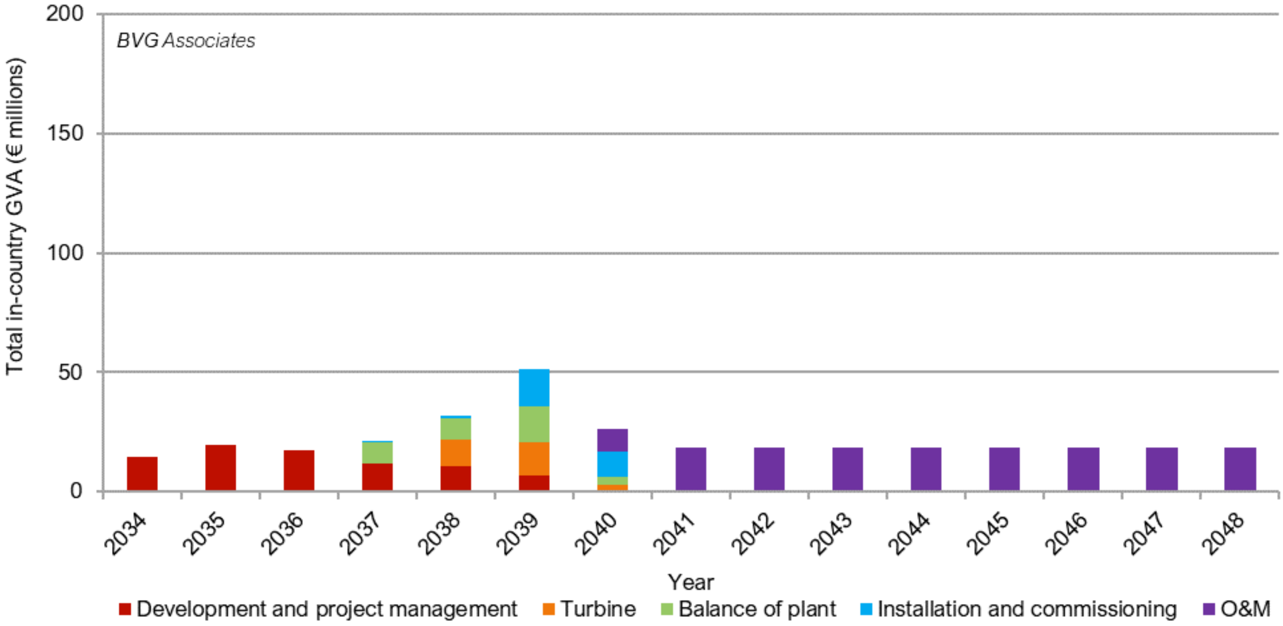
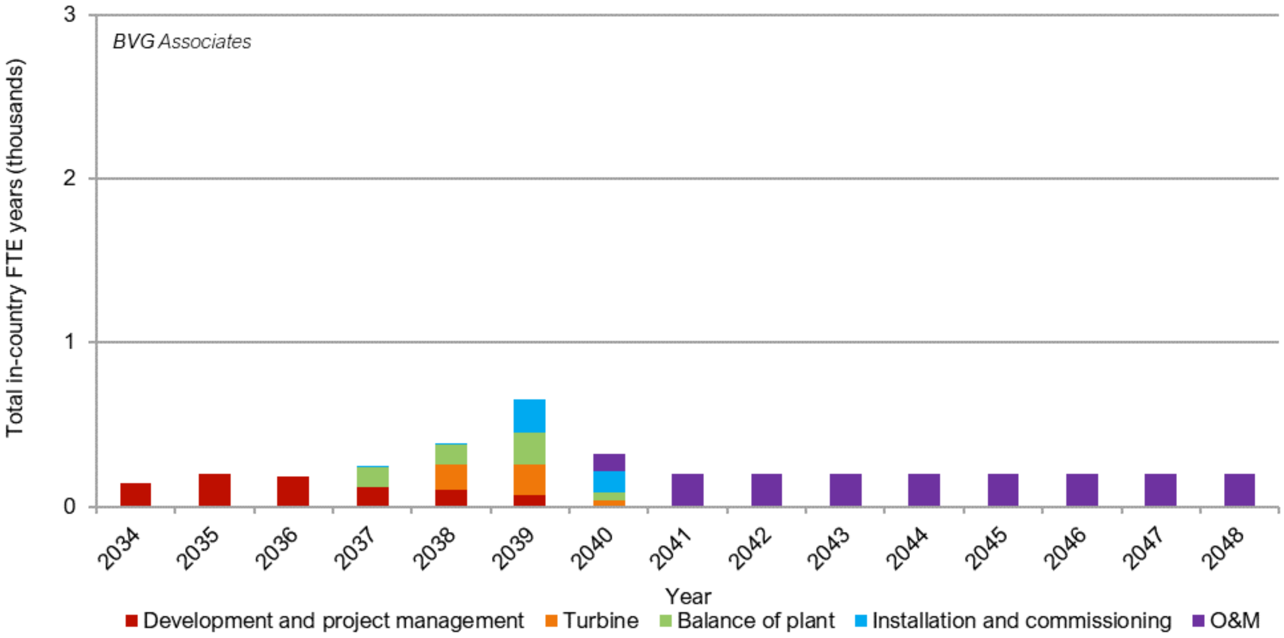


Figure 37: Irish annual FTE years employment for a single 1 GW fixed offshore wind project installed

in 2040, split by cost element



Irish impacts from projects in Ireland: single floating offshore wind project

Figure 38 shows the GVA generated by this single project. The peak GVA in 2039 is about €180 million. The total GVA over the lifetime of the project is about €1.2 billion. Of the lifetime GVA, 50% is direct project spend.

Figure 39 shows the total FTE years employment created annually for a single 1 GW floating offshore wind project installed in 2040 in scenario 2. It shows that annual employment peaks in 2039 at about 2,400 FTE years, when there is significant component manufacture as well as installation. Total employment for the project is about 14,000 FTE years over the lifetime of the project, 66% of this in in O&M. Of the lifetime employment created, 50% are direct jobs.

Figure 38: Irish gross value added for a single 1 GW floating offshore wind project installed in 2040, split by cost element

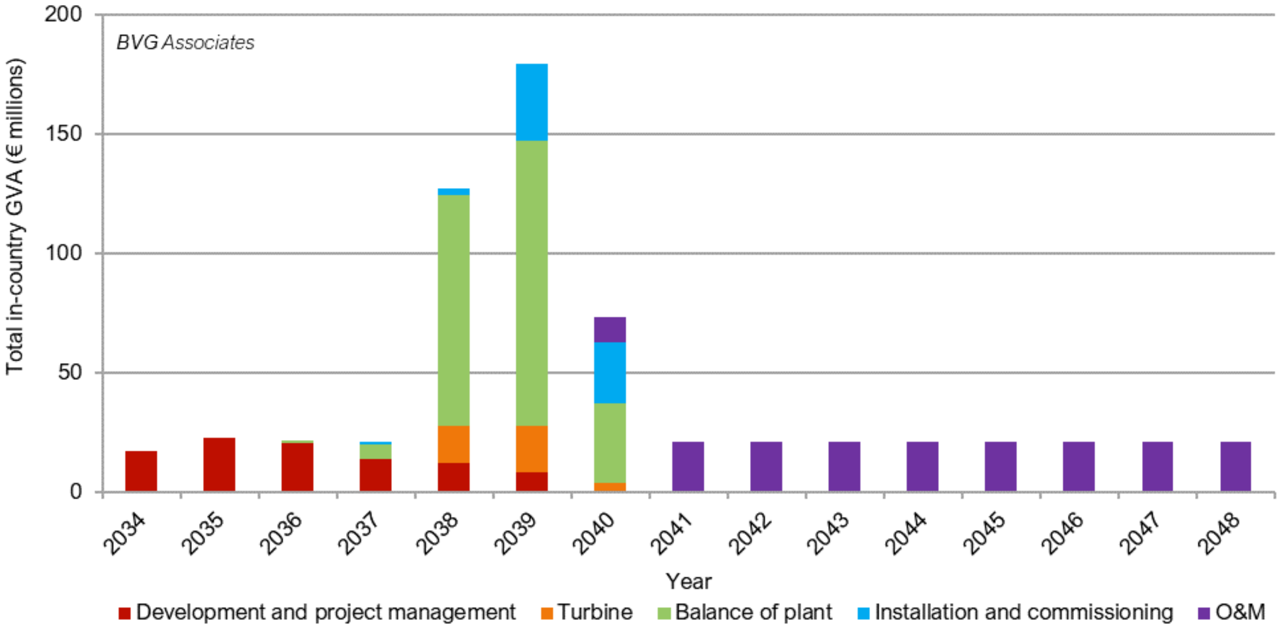
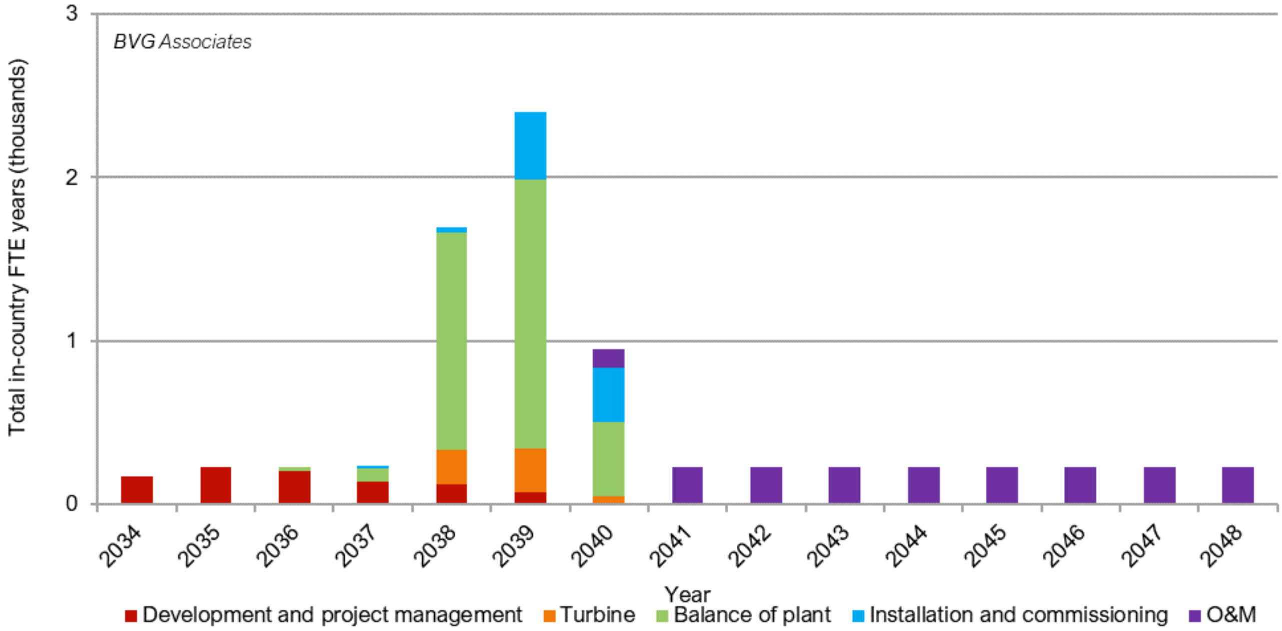


Figure 39: Irish annual FTE years employment for a single 1 GW floating offshore wind project installed in 2040, split by cost element



Irish impacts from projects in Ireland: single wave energy project

Figure 40 shows the GVA generated by this single project. The peak annual GVA in 2039 is about €170 million. The total GVA over the lifetime of the project is about €1.6 billion. Of the lifetime GVA, 67% is direct project spend.

Figure 41 shows the total FTE years employment created annually for a single 1 GW wave energy project installed in 2040 in scenario 4. It shows that annual employment peaks in 2039 at about 2,200 FTE years, when there is significant component manufacture as well as installation. Total employment for the project is about 19,000 FTE years over the lifetime of the project, 64% of this in in O&M. Of the lifetime employment created, 65% are direct jobs.

Figure 40: Irish gross value added for a single 1 GW wave energy project installed in 2040, split by cost element

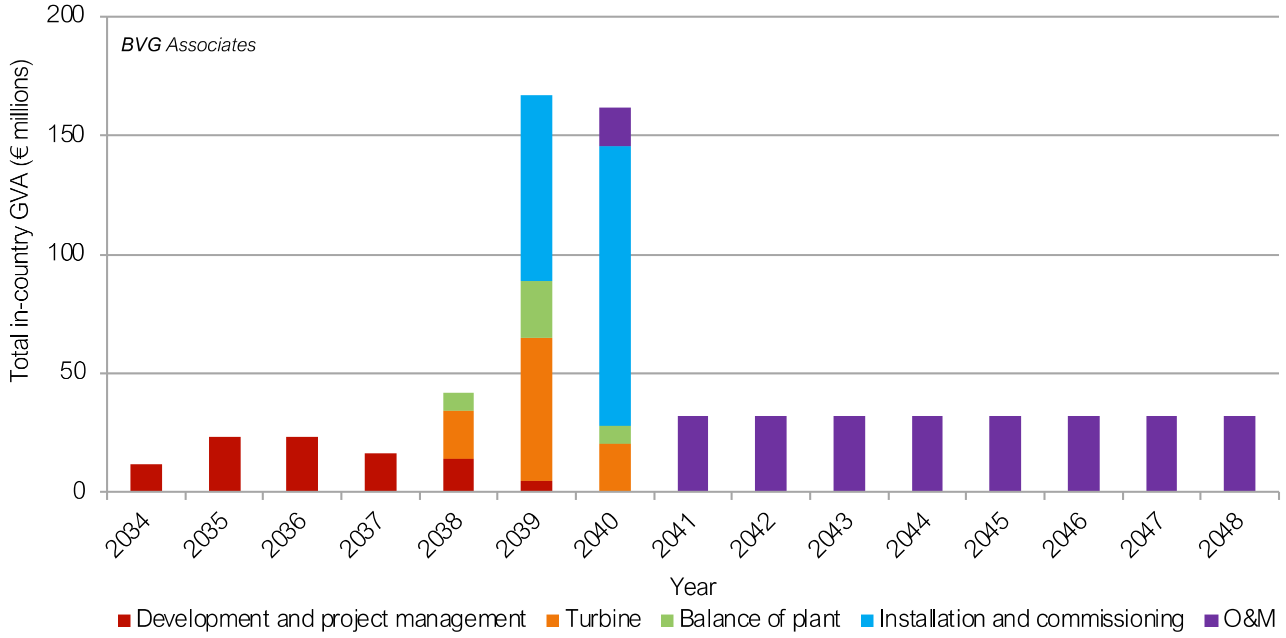
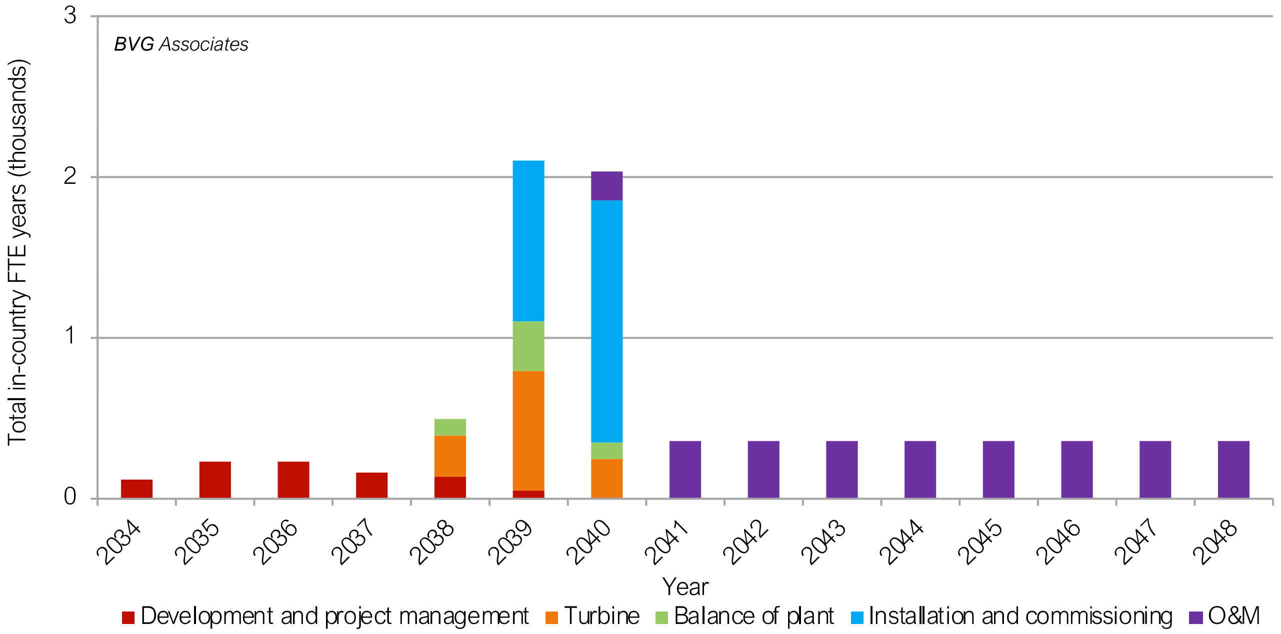


Figure 41: Irish annual FTE years employment for a single 1 GW wave energy project installed in 2040, split by cost element



Irish impacts from projects in Ireland: comparison of single projects

The GVA and jobs profiles associated with each technology are similar in many ways. Each has a large peak of manufacturing and installation activity in the two to three years leading up to commissioning, and a long period of O&M activity which continues for the project lifetime. Key differences are:

- Wave generation technologies have yet to converge, but currently concepts are less likely to rely on scarce specialist heavy lift equipment than fixed or floating wind, with a greater focus on offshore logistics carried out by non-specialist vessels. This may provide opportunities for local supply chains to play a greater role in services supporting installation and decommissioning, especially in early mover markets developing wave projects. Our modelling reflects this potential, however, given the nascence of the technology there is considerable uncertainty, and high local content capture for installation activities is not assured.

Figure 42 shows a global lifetime GVA comparison across the three technology types, for a reference project deployed in 2040 as described above. *Figure 43* shows the same comparison in terms of lifetime FTE years.

Figure 42: Comparison of lifetime Irish GVA for fixed offshore wind, floating offshore wind and wave technologies

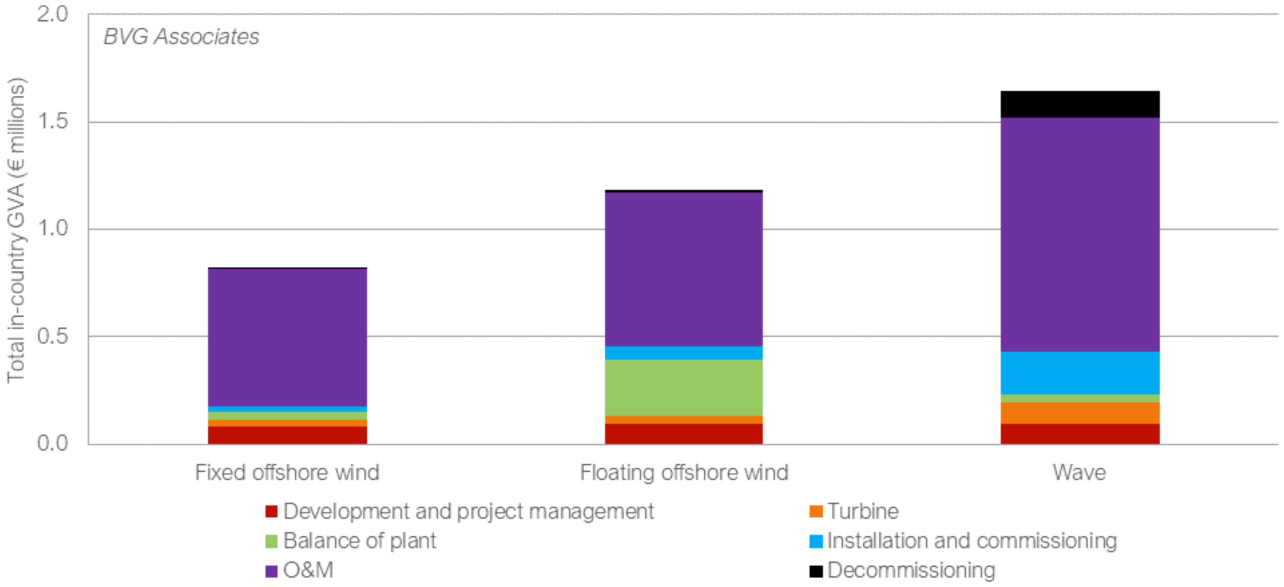
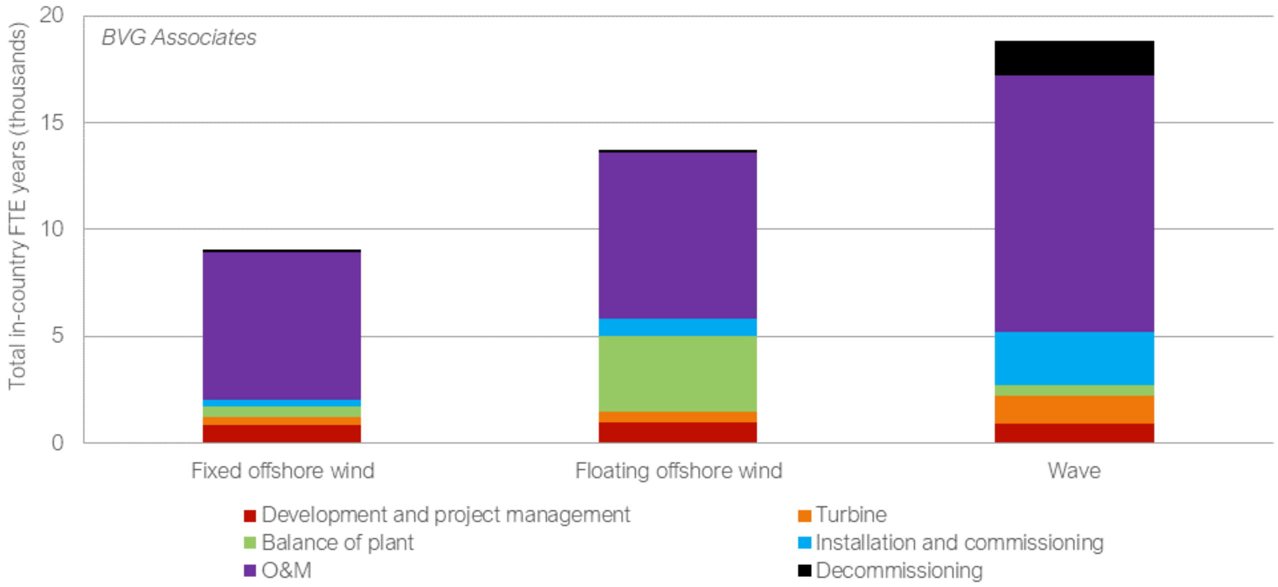


Figure 43: Comparison of lifetime Irish FTE years employment for the three technologies



Irish impacts from projects in Ireland: scenario 1

Figure 44 and *Figure 45* show annual GVA reaching a peak of about €240 million in 2048. Over the lifetime of the projects €8.8 billion GVA is generated in Ireland, about 18% of the total generated globally from these projects. 64% of this is in fixed offshore wind, 32% in floating offshore wind and 3% in wave energy. The relatively high share of wave GVA relative to its share of generation capacity reflects the assumed higher cost of wave in this scenario, consistent with the higher LCOE curve depicted in *Figure 20.*

The distribution of local annual employment in FTE years follows the same shape as GVA. The number of annual FTE years peaks at about 2,600 in 2048. Over the lifetime of the projects 96,000 FTE years of employment are created in Ireland, about 16% of the total created globally by the pipeline of projects in Ireland. 64% of this is in fixed offshore wind, 32% in floating offshore wind and 4% in wave.

Figure 44: Annual local gross value added in scenario 1, split by cost element

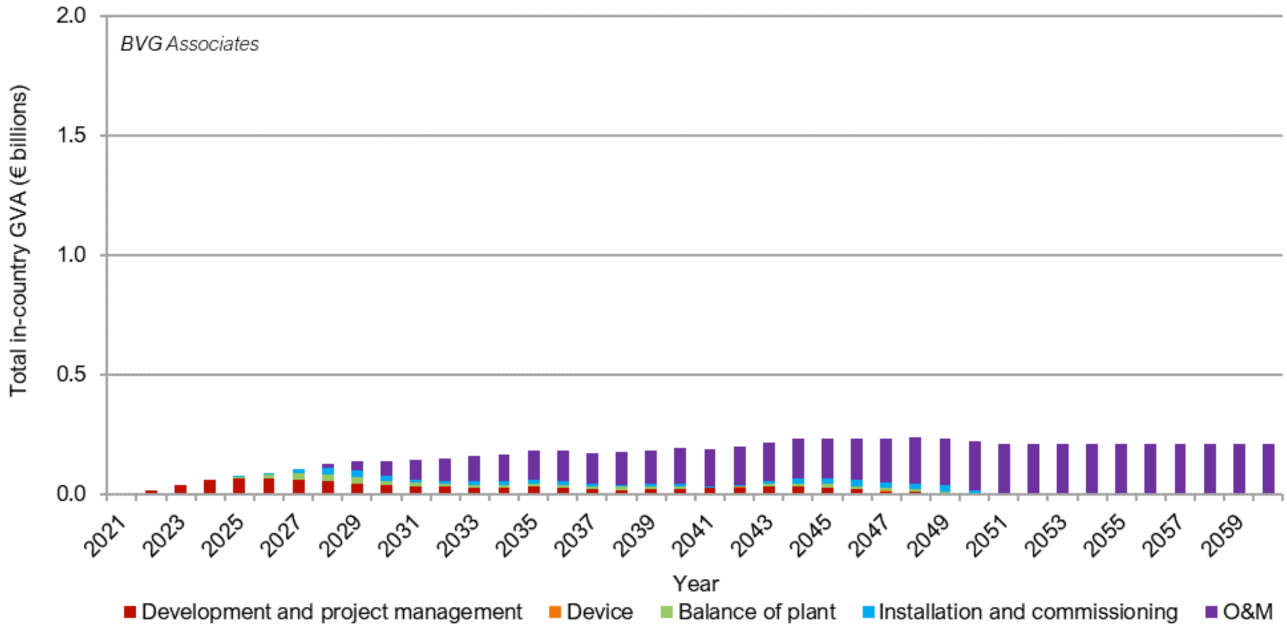
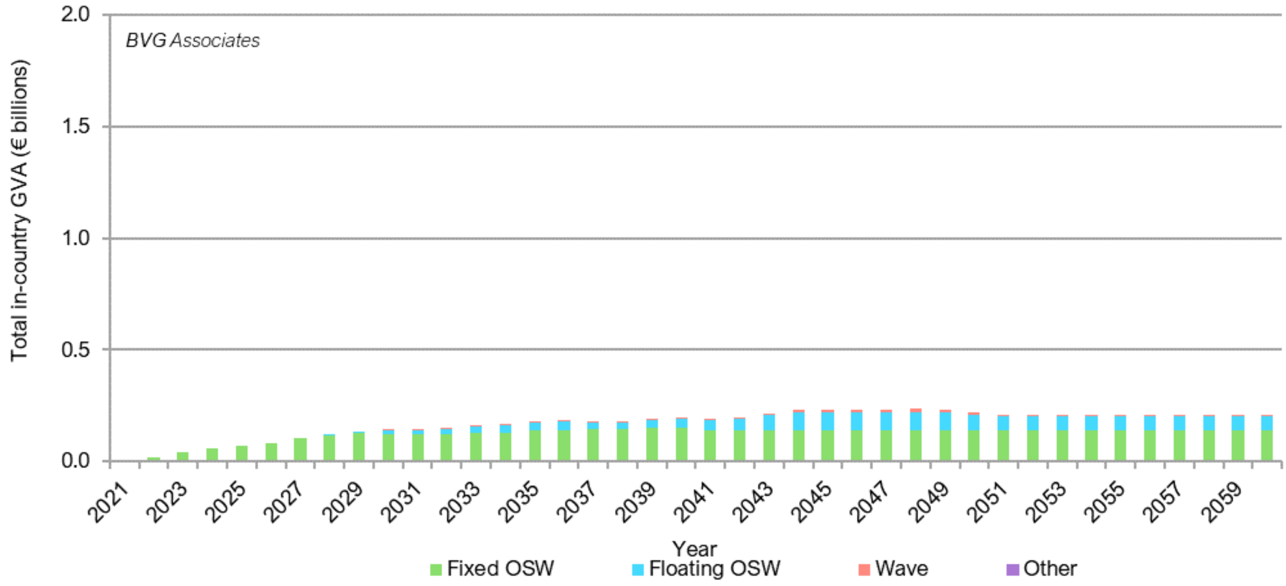


Figure 45: Annual local gross value added in scenario 1, split by technology



Irish impacts from projects in Ireland: scenario 2

Figure 46 and *Figure 47* show annual GVA reaching a peak of about €1.3 billion in 2045. Over the lifetime of the projects €40 billion GVA is generated in Ireland, about 20% of the total generated globally from these projects. 24% of this is in fixed offshore wind, 76% in floating offshore wind and 1% in wave energy.

The distribution of local annual employment in FTE years follows the same shape as GVA. The annual number of FTE years peaks at about 15,000 during the late 2040s. Over the lifetime of the projects 450,000 FTE years of employment are created in Ireland, about 18% of the total created globally by the pipeline of projects in Ireland. 23% of this is in fixed offshore wind, 76% in floating offshore wind and 1% in wave energy.

Figure 46: Annual local gross value added in scenario 2, split by cost element

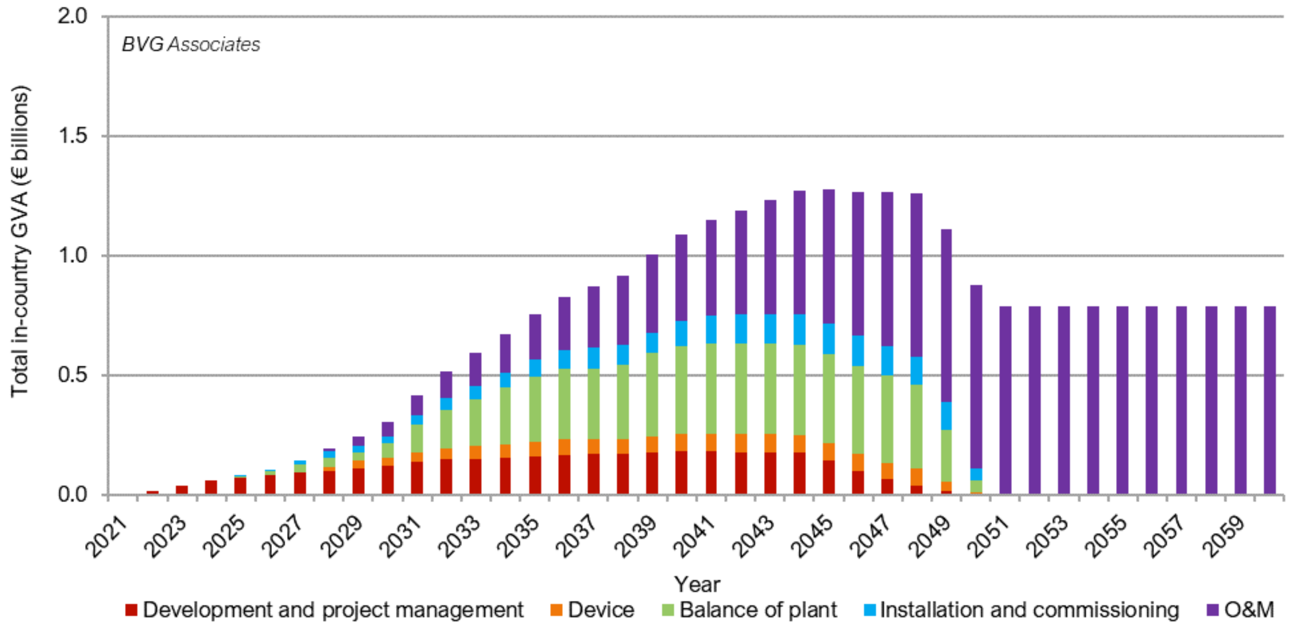
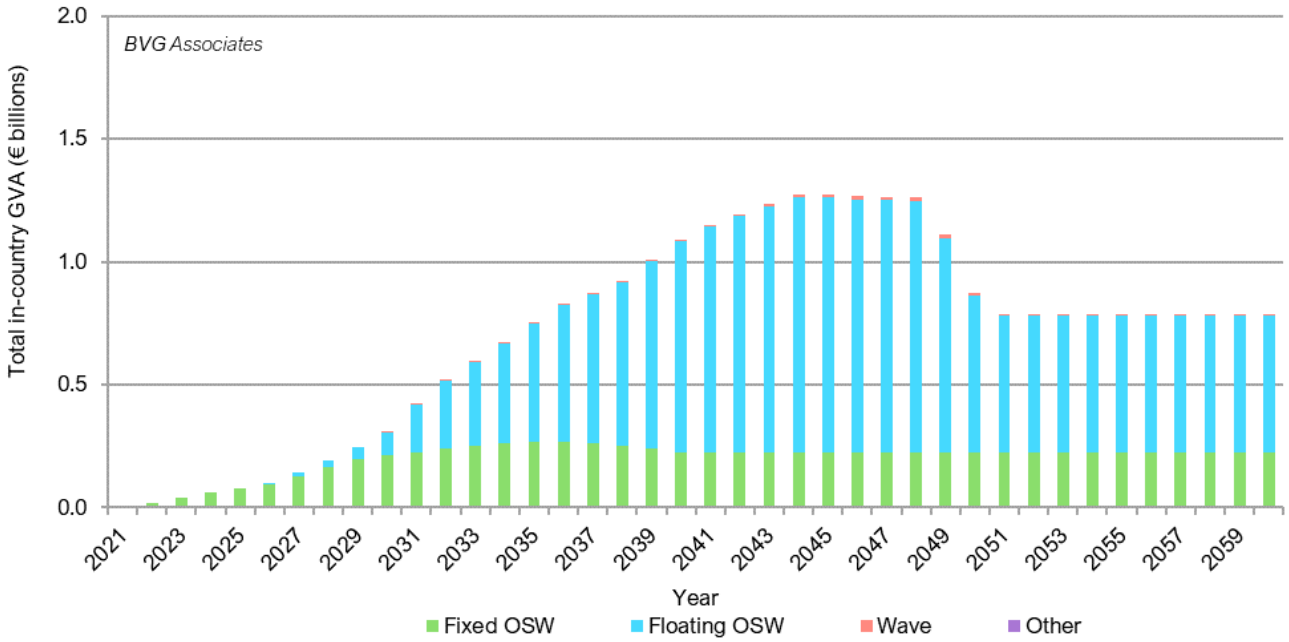


Figure 47: Annual local gross value added in scenario 2, split by technology



Irish impacts from projects in Ireland: scenario 3

Figure 48 and *Figure 49* show annual GVA reaching a peak of about €1.6 billion in 2045. Over the lifetime of the projects €53 billion GVA is generated in Ireland, about 20% of the total generated globally from these projects. 18% of this is in fixed offshore wind, 81% in floating offshore wind and 1% in wave energy.

The distribution of local annual employment in FTE years follows the same shape as GVA. The number of annual FTE years peaks at about 19,000 in 2045. Over the lifetime of the projects 610,000 FTE years of employment are created in Ireland, about 18% of the total created globally by the pipeline of projects in Ireland. 17% of this is in fixed offshore wind, 82% in floating offshore wind and 1% in wave energy.

Figure 48 Annual local gross value added in scenario 3, split by cost element

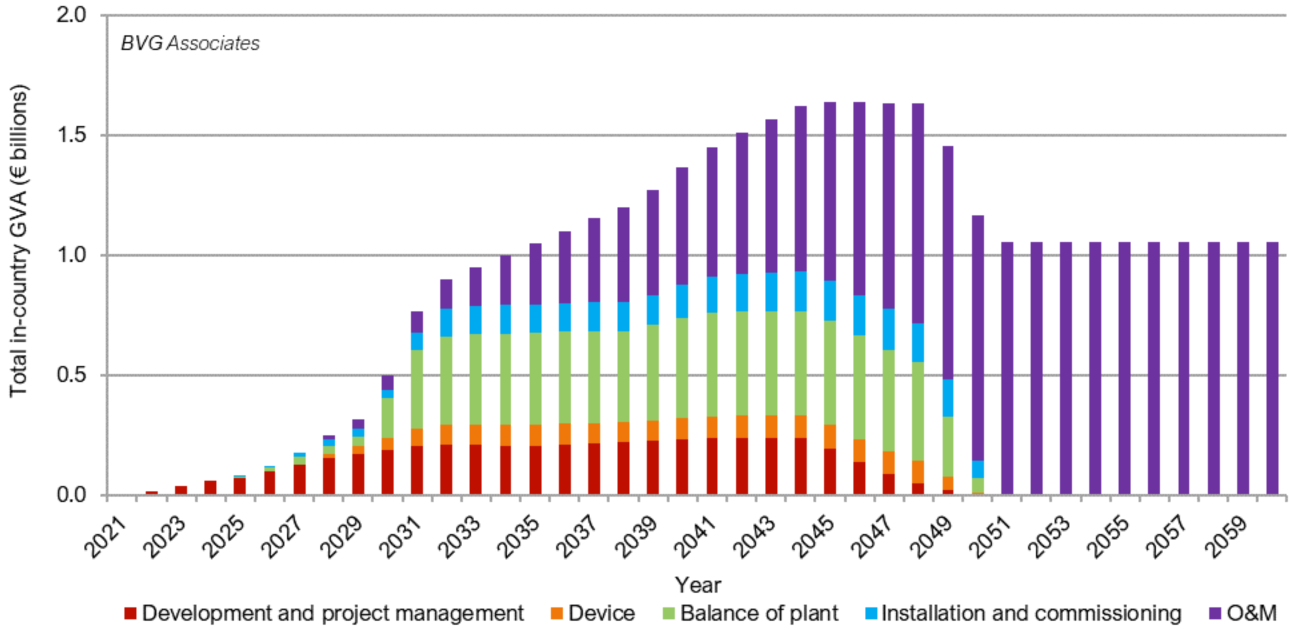
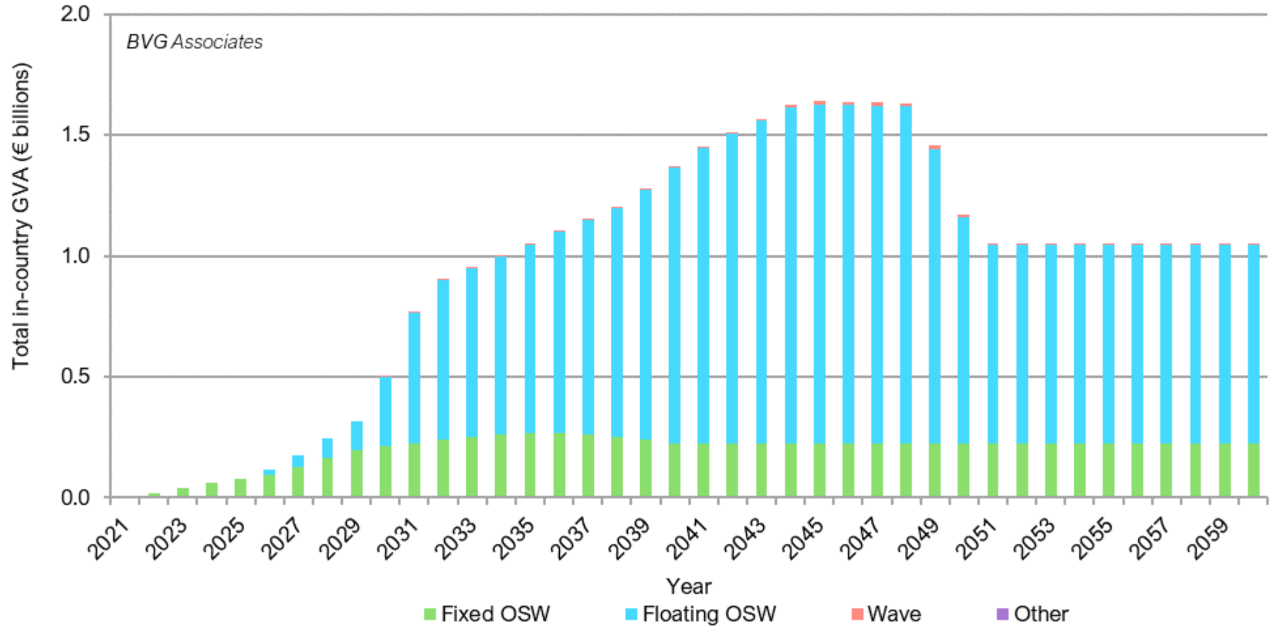


Figure 49: Annual local gross value added in scenario 3, split by technology



Irish impacts from projects in Ireland: scenario 4

Figure 50 and *Figure 51* show annual GVA reaching a peak of about €1.4 billion in 2047. Over the lifetime of the projects €43 billion GVA is generated in Ireland, about 21% of the total generated globally from these projects. 22% of this is in fixed offshore wind, 63% in floating offshore wind and 15% in wave energy.

The distribution of local annual employment in FTE years follows the same shape as GVA. The number of FTE years peaks at about 17,000 in 2047. Over the lifetime of the projects 490,000 FTE years of employment are created in Ireland, about 19% of the total created globally by the pipeline of projects in Ireland. 21% of this is in fixed offshore wind, 63% in floating offshore wind and 15% in wave energy.

Figure 50: Annual local gross value added in scenario 4, split by cost element

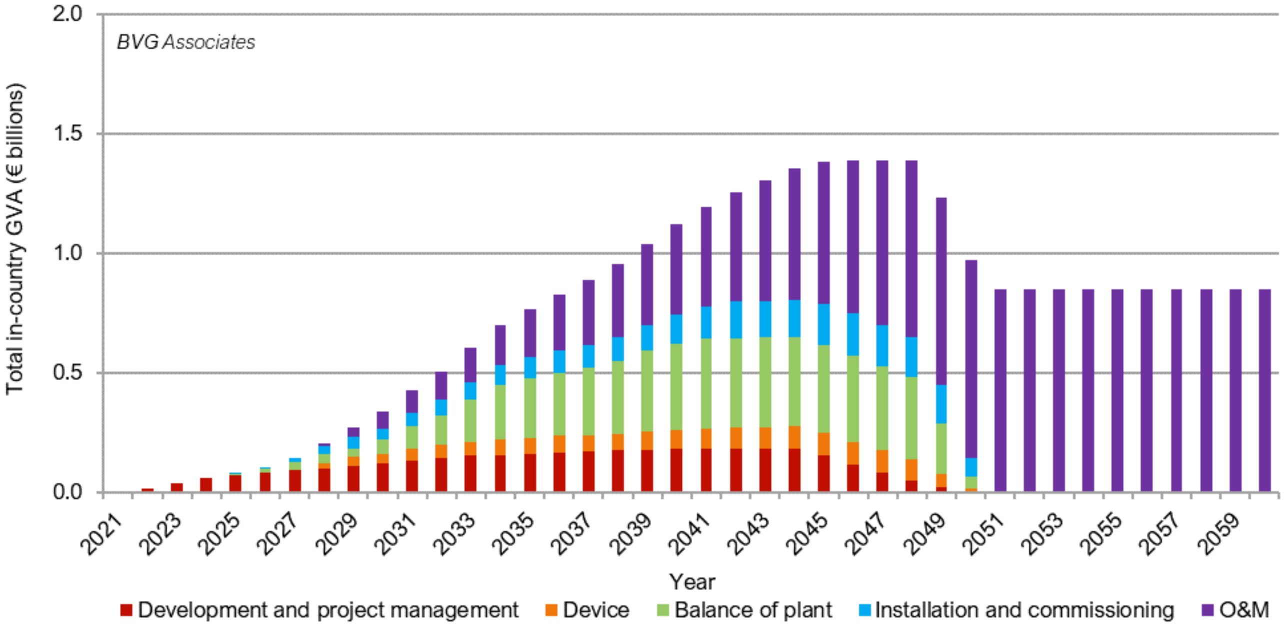
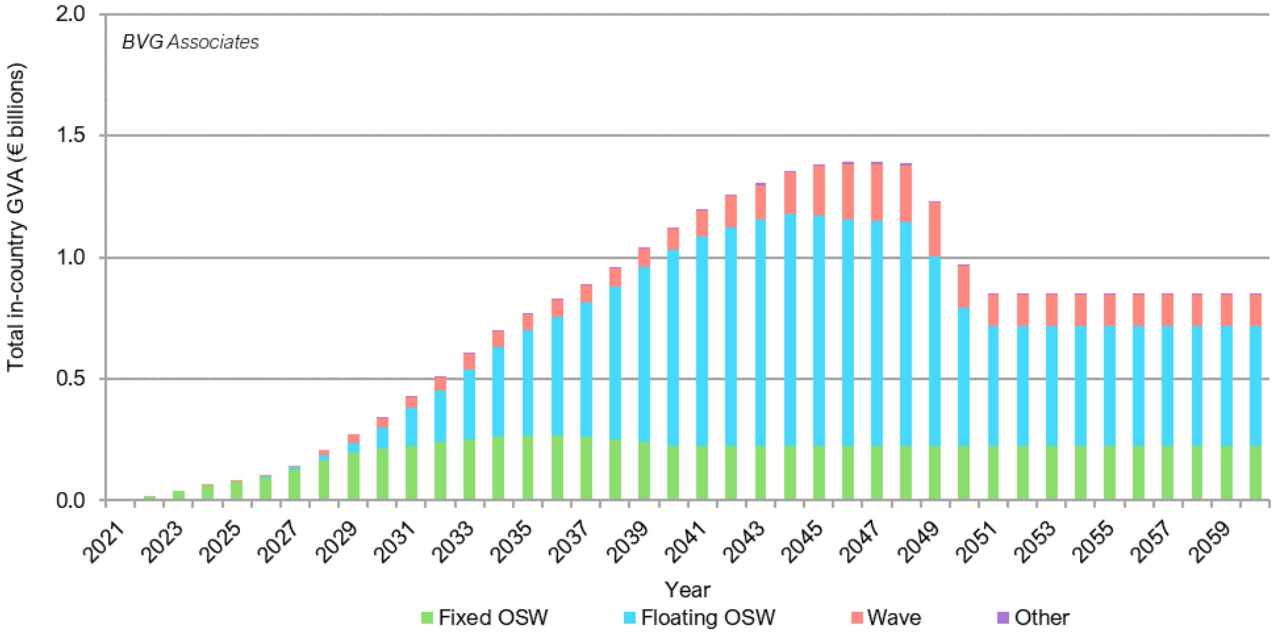


Figure 51: Annual local gross value added in scenario 4, split by technology



Irish impacts from projects in Ireland: comparison of scenarios

In all scenarios, O&M spending provides the greatest contribution to domestic GVA and jobs benefits. This is due to the strong Irish content within this area, coupled with the relatively high proportion of project spend in O&M, as O&M activities continue for the duration of the project lifecycle, whereas other activities are time bound within a shorter window.

The majority of differences between scenarios can be explained by differences in deployment volumes, rather than local content shares. Key differences are:

- In contrast to scenario 1, which sees no domestic value in the turbine or device and balance of plant stages, scenarios 2,3,4 see Ireland capture some value from these spend categories. This is due to the capture of investment in manufacturing facilities and floating offshore wind assembly ports as described in Section 5.3.
- Scenarios with greater floating wind deployment see a relatively higher Irish share of GVA and jobs especially in the balance of plant spend category. This is due to the jobs and GVA opportunity associated with assembly of floating foundations and manufacture of mooring lines.
- Scenario 4 sees a higher share of decommissioning activity captured by Ireland relative to other scenarios, though still a small proportion of the overall opportunity. This is due to an assumed higher share of Irish content in wave energy decommissioning, as described in Section 5.3.3.

Figure 52 shows a global lifetime GVA comparison across the four scenarios, broken down by spend category.
Figure 53 shows the same comparison in terms of lifetime FTE years.

Figure 52: Comparison of lifetime GVA in the four scenarios

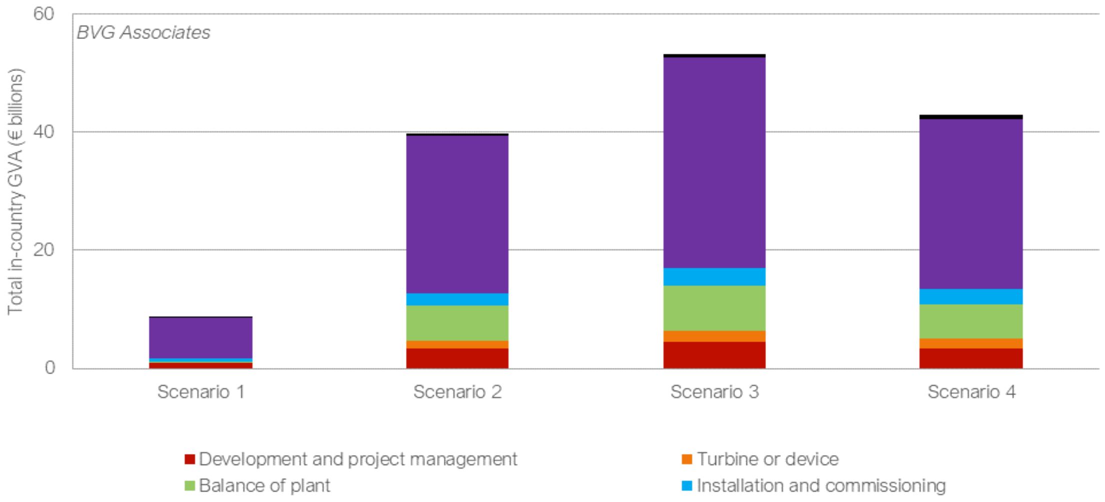
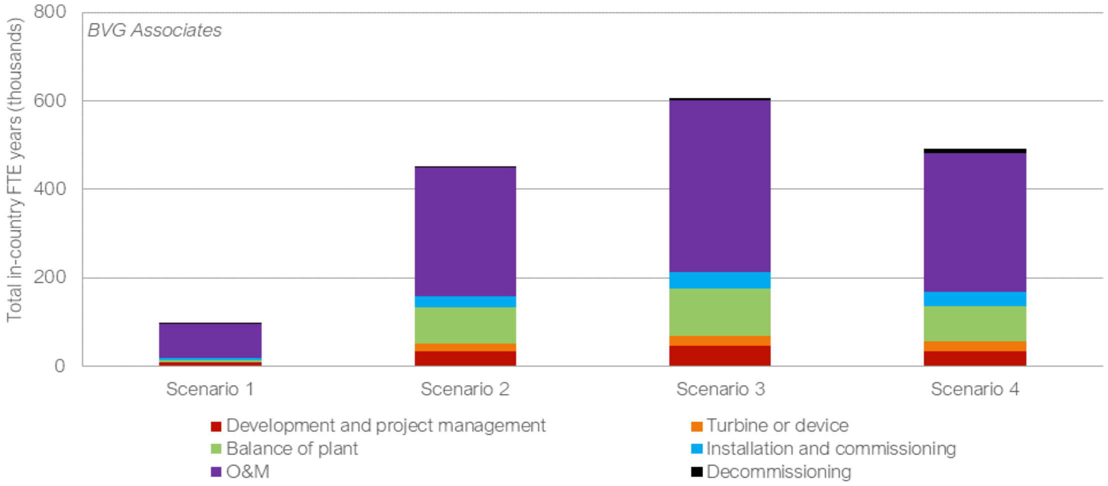


Figure 53: Comparison of lifetime FTE years in the four scenarios



5.4.3 Irish impacts from projects in Ireland and overseas

Irish impacts from projects in Ireland and overseas: scenario 1

In scenario 1, exports create an additional €0.8 billion in GVA. *Figure 54* shows annual GVA reaching a peak of about €0.3 billion in 2048. Up to 2050, €5.5 billion GVA is generated, about 16% higher than that of an exclusively Irish pipeline of projects.

Figure 55 shows a breakdown of export activity by cost element. 60% of comes from development and project management services and 40% from operational phase supply. This shows only the value captured domestically from servicing foreign projects, and does not include supply to Irish projects.

Figure 54: Annual local gross value added by Irish and overseas projects in scenario 1, split by domestic and export spend

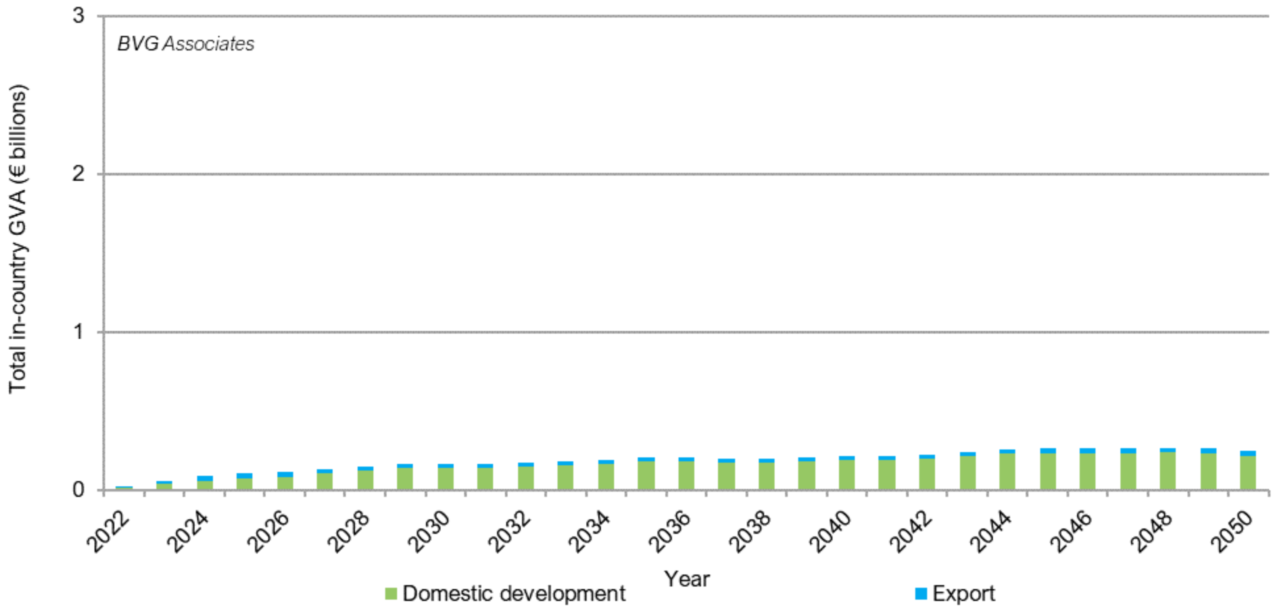
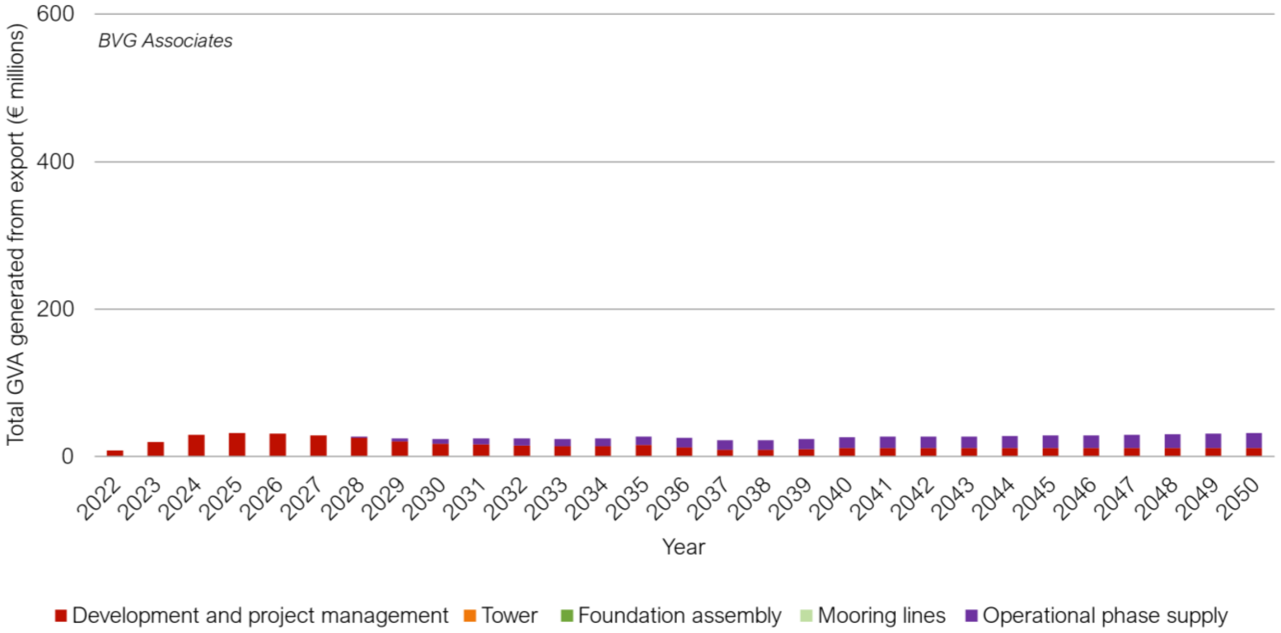


Figure 55: Annual local gross value added by overseas projects in scenario 1, split by cost element



Irish impacts from projects in Ireland and overseas: scenario 2

In scenario 2, exports create an additional €7.7 billion in GVA. *Figure 56* shows annual GVA reaching a peak of about €1.7 billion in 2048. Up to 2050, €28 billion GVA is generated, about 36% higher than from just the pipeline of projects in Ireland.

Figure 57 shows a breakdown of export activity. 27% of this comes from development and project management services, 20% from tower manufacturing, 88% from floating foundation assembly, 34% from mooring line manufacture and 11% from operational phase supply. This shows only the value captured domestically from servicing foreign projects. It does not include supply to Irish projects. This shows some export of floating foundations through the 2030s, which tails off later in the decade. This is because as the pace of Irish floating offshore wind deployment grows, the domestic pipeline increasingly takes up all the capacity of domestic assembly facilities until there is no additional capacity for export.

Figure 56: Annual local gross value added by Irish and overseas projects in scenario 2, split by domestic and export spend

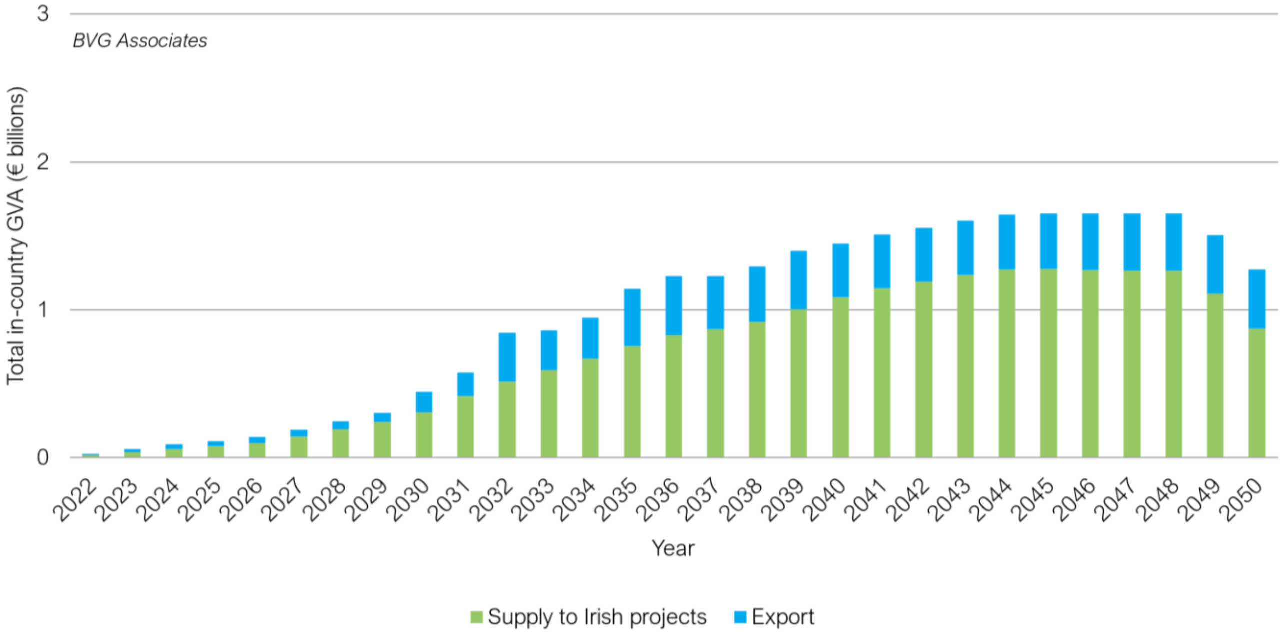
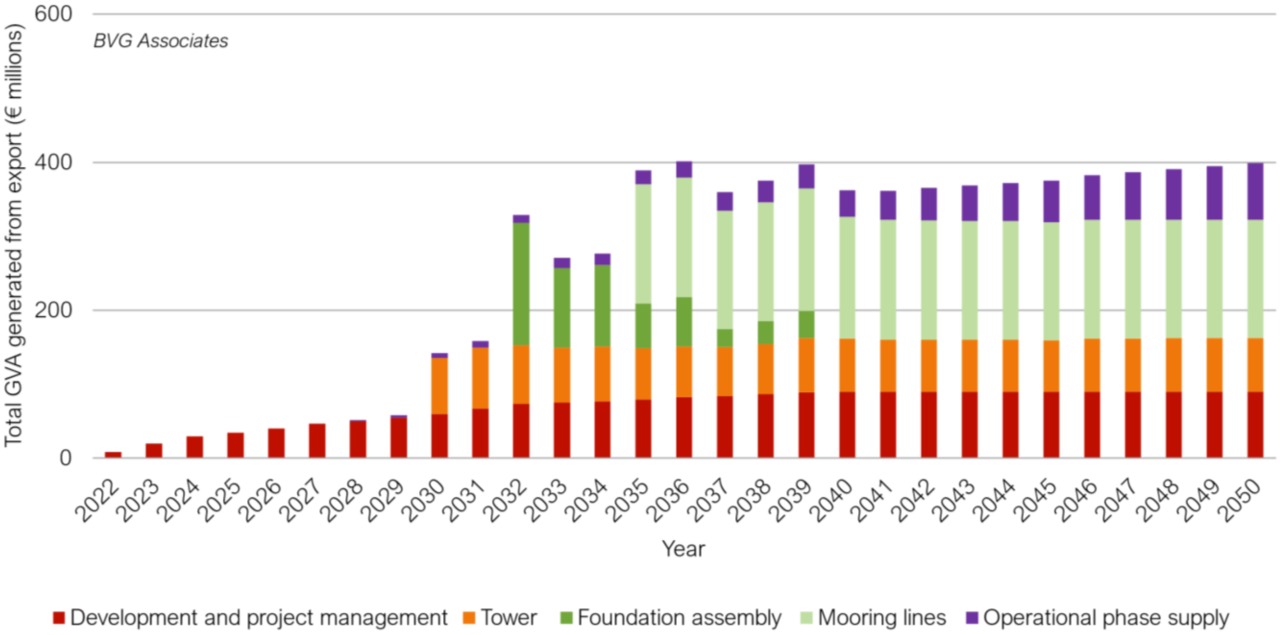


Figure 57: Annual local gross value added by overseas projects in scenario 2, split by cost element



Irish impacts from projects in Ireland and overseas: scenario 3

In scenario 3, exports create an additional €7.9 billion in GVA. *Figure 58* shows annual GVA reaching a peak of about €2 billion in 2048. Up to 2050, €36 billion GVA is generated, about 29% higher than from just the pipeline of projects in Ireland.

Figure 59 shows a breakdown of export activity. 34% of this comes from development and project management services, 16% from tower manufacturing, 37% from mooring line manufacture and 14% from operational phase supply. This shows only the value captured domestically from servicing foreign projects. It does not include supply to Irish projects.

Figure 58: Annual local gross value added by Irish and overseas projects in scenario 3, split by domestic and export spend

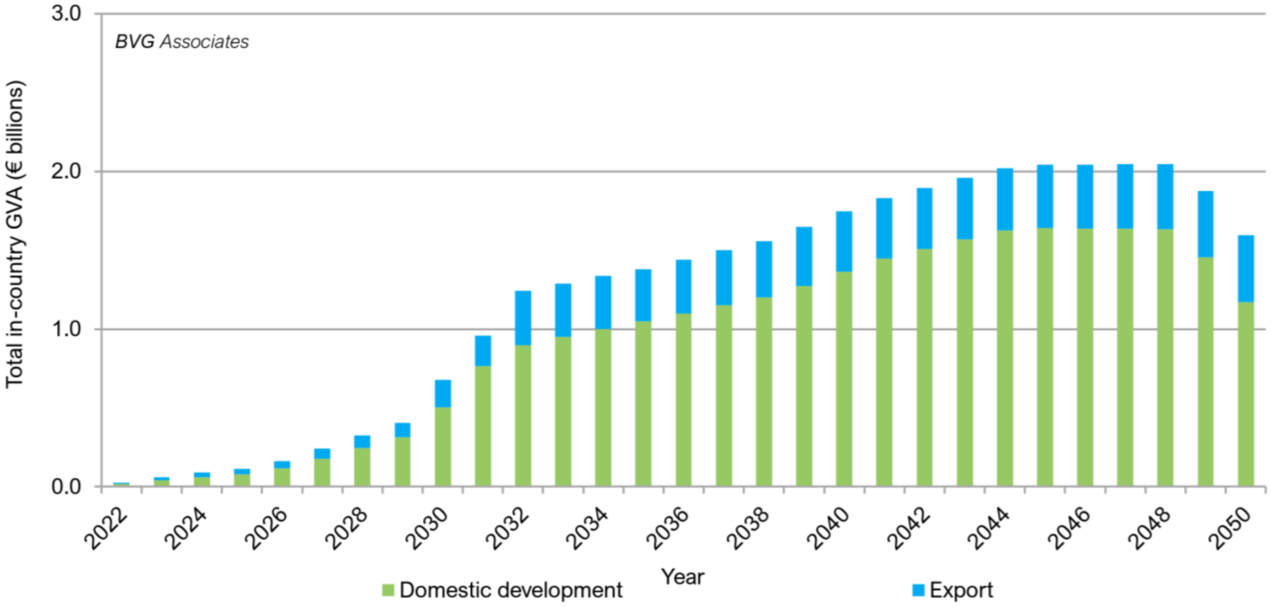
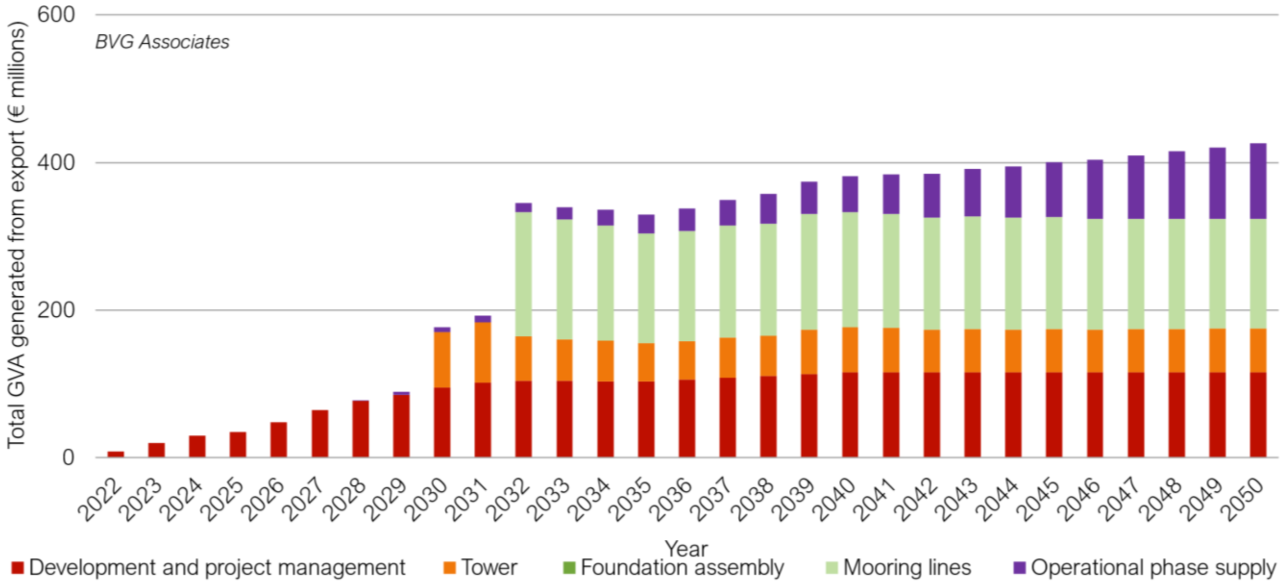


Figure 59: Annual local gross value added by overseas projects in scenario 3, split by cost element



Irish impacts from projects in Ireland and overseas: scenario 4

In scenario 4, exports create an additional €7.9 billion in GVA. *Figure 60* shows annual GVA reaching a peak of about €1.8 billion in 2047. Up to 2050, €30 billion GVA is generated, about 36% higher than from just the pipeline of projects in Ireland.

Figure 61 shows a breakdown of activity. 26% of this comes from development and project management services, 20% from tower manufacturing, 10% from floating foundation assembly, 33% from mooring line manufacture and 11% from operational phase supply. This shows only the value captured domestically from servicing foreign projects. It does not include supply to Irish projects.

Figure 60: Annual local gross value added by Irish and overseas projects in scenario 4, split by domestic and export spend

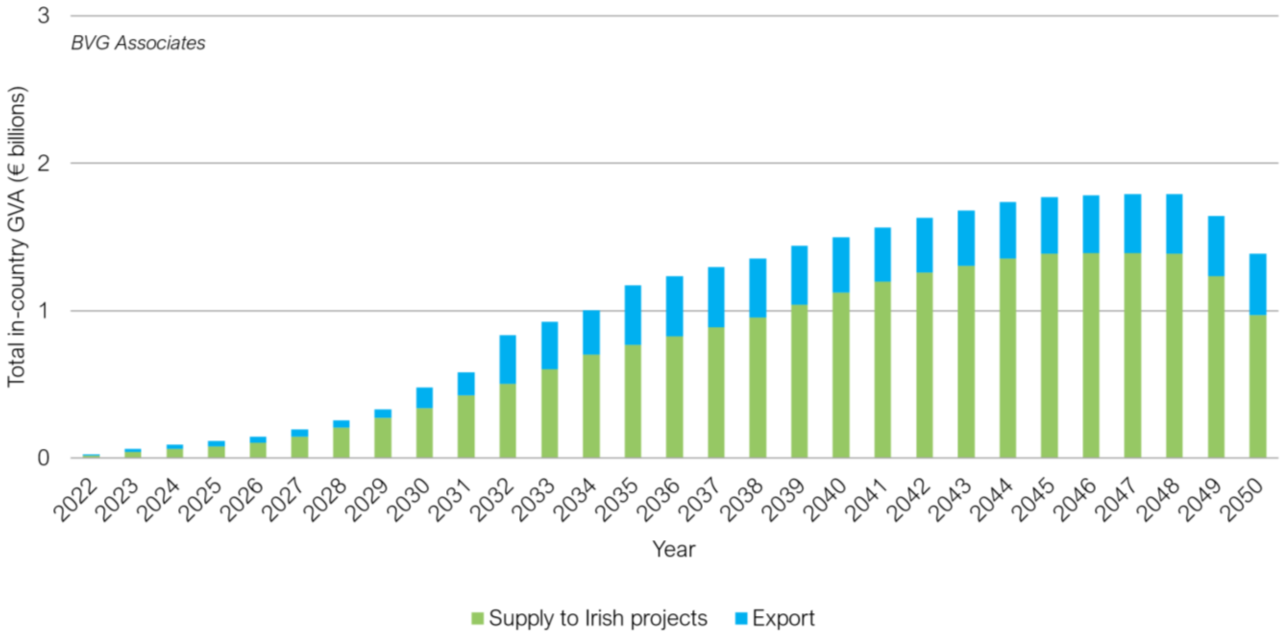
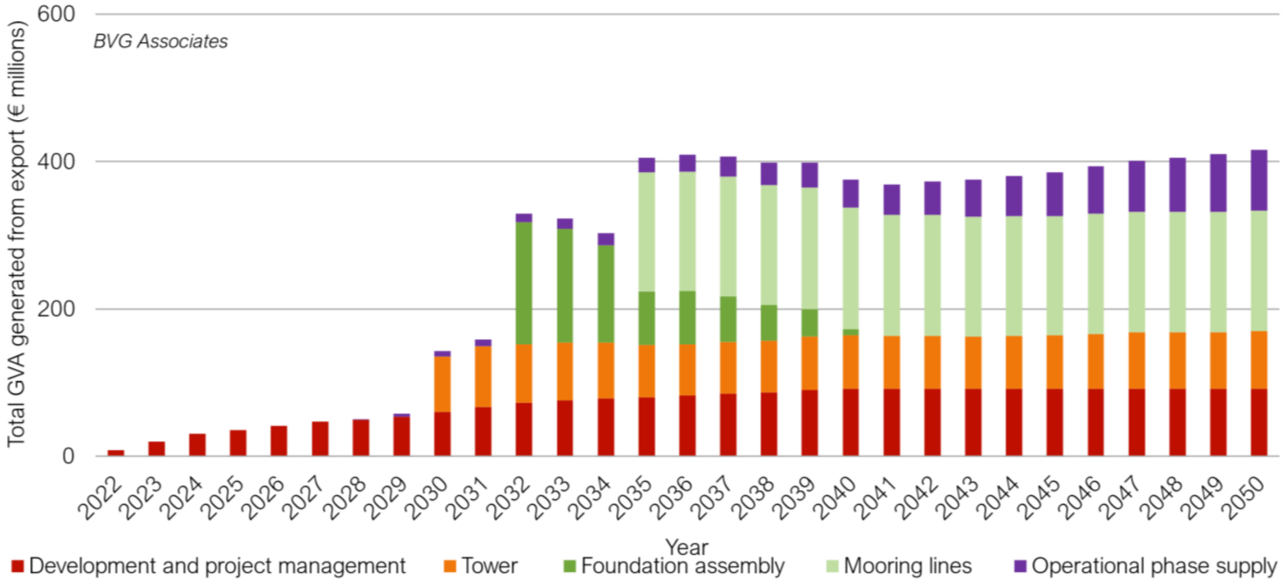


Figure 61: Annual local gross value added by overseas projects in scenario 4, split by cost element



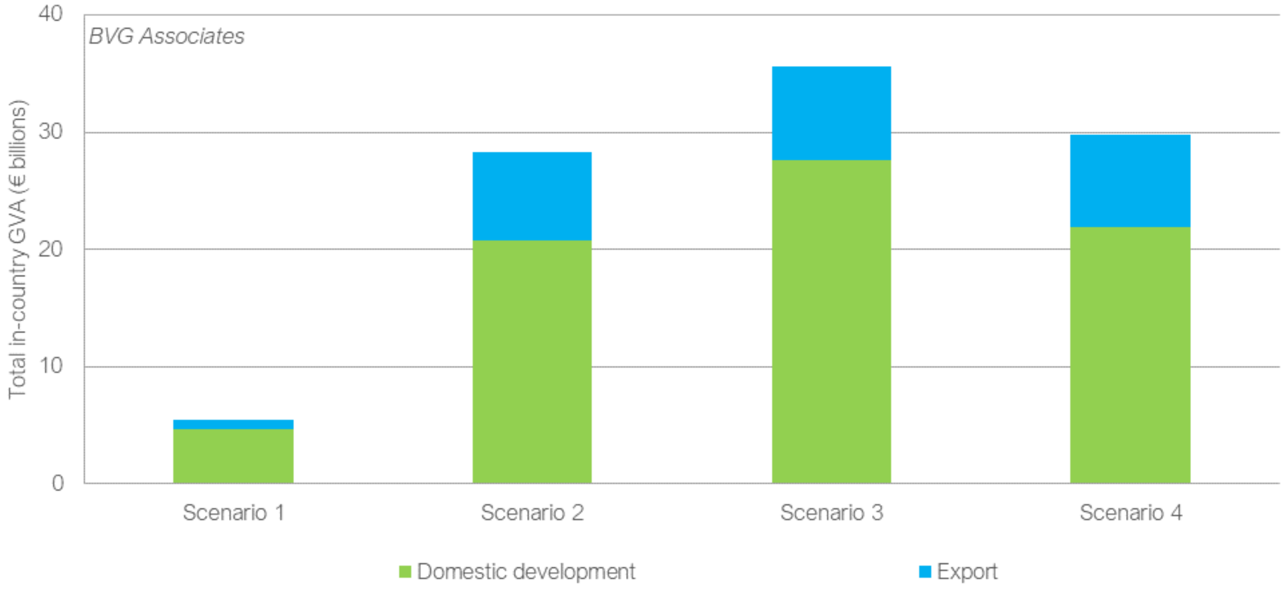
Irish impacts from projects in Ireland and overseas: comparison of scenarios

Figure 62 shows the total GVA created by Irish and non-Irish projects up to 2050. Overall figures GVA figures are lower than the figures presented in Section 5.4.2 as exports have been modelled only to 2050, rather than for the entire project lifetime.

The export potential in scenarios 2, 3 and 4 is significantly higher than in scenario 1 both in real terms and as proportion of domestic GVA. This is due to additional supply chain investments envisaged in higher scenarios which facilitate export of manufactured goods.

Differences between levels of export as a proportion of domestic GVA between the higher deployment scenarios are small. Differences between scenarios are mostly driven by the size of project pipeline.

Figure 62: Comparison of GVA to 2050 created by Irish and overseas projects in the four scenarios



5.5 Regional economic opportunities

This analysis considers Ireland as a whole. It is anticipated that the majority of fixed offshore wind projects will be located in the shallower waters off the south and east coast, whilst floating offshore wind projects will likely be located in deeper waters off the west and south coasts.

In all scenarios, economic benefits associated with O&M services are expected to be concentrated in proximity to project sites. O&M activities are usually clustered around the O&M port, which is often the closest viable port to the project site to minimise travel time. O&M ports require less investment and specialised capability than construction ports, and a range of Irish ports can be expected to participate.

Project development and engineering benefits are likely to be concentrated to some extent in proximity to the project site, as it is common industry practice to locate a project office in an urban centre near to the project site. Urban centres such as Cork, Dublin, Galway and Limerick are likely to be beneficiaries of such activity. Much project development and engineering spend is subcontracted to specialist contractors. The benefits of such activities are likely to be widely distributed across the country.

In the turbine manufacturing, benefits will be concentrated in manufacturing facilities. In all scenarios, such facilities are limited in Ireland, with the exception of the tower manufacturing facility in scenarios 2, 3 and 4. If such a facility is secured, its location is uncertain but it will be located adjacent to a port with sufficient heavy lift capability to facilitate load-out of manufactured products, and in proximity to an urban centre for access to labour and skills.

In the balance of plant, value is again likely to be concentrated around specific manufacturing sites, in particular assembly ports for floating foundation and synthetic cable manufacturing facilities. The benefits of onshore substation fabrication are likely to be more evenly spread around Ireland, depending on which local civil engineering contractors take part and their regional footprint.

Noting the small number of suitable ports with plans for foundation assembly, it is likely these benefits will be concentrated in Cork or the Shannon region, depending on where investment occurs. In scenario 3, this may include Bantry Bay or another as-yet unidentified site. Regional collaboration and development initiatives such as the Shannon Estuary Economic Taskforce can play an important role in convening stakeholders to drive investment.

There are fewer constraints on location of a synthetic cable manufacturing facility due to the lighter weight and lower volume of products, which make logistics less challenging. It is likely however that such a facility would be located close to a city with a good labour supply and in proximity to port facilities for access to international export markets.

Like O&M activities, many of the local economic benefits of installation work will be concentrated around fixed and floating construction ports.

A range of ports in Ireland have plans to develop capability to service fixed and floating installation.[175] For fixed offshore wind, benefits are expected to accrue depending on where enabling investments are made.

For floating offshore wind installation, infrastructure requirements are similar to those required for foundation assembly work. The same regions as identified above are therefore expected to benefit from this activity, subject to the necessary investments being made.

In scenarios 2 and 4, all three potential floating assembly or construction ports are established at Cork, Moneypoint and Shannon Foynes Island, resulting in benefits to these regions. In scenario 4, a fourth port at Bantry Bay or elsewhere is also developed, bringing further benefit, likely to the West or South coast.

In onshore substation installation and cable laying works, the participation of national civil engineering contractors will see benefits more widely dispersed within Ireland, as in onshore substation fabrication.

In decommissioning, benefit is likely to be concentrated around ports providing logistical support for specialist contractors. These ports are likely to be the same as those which supported activity at the installation phase.

5.6 Recommendations

To deliver the local jobs and GVA opportunities set out in this report, a range of prerequisites should be in place to create the right environment for necessary investment to occur. Recommendations to create the correct conditions for supply chain growth are described in Section 4.14. The recommendations below relate to actions to maximise Irish economic benefit through supply chain and skills development.

It is recommended that:

- DETE, DFHERIS, The Marine Institute, SEAI and Skillnet Ireland seek to maximise benefit in key areas of Irish advantage, including project development and O&M, through skills funding initiatives and support for research and development in adjacent subjects such as seabed surveying, LiDAR and remote monitoring technologies.
- DECC adjusts the methodology for calculating Irish content within project delivery plan questionnaires to ensure calculated local content percentages reflect actual Irish value capture, in line with international best practice examples.[176] [174].[174]
- DETE establishes and implements a clear and targeted industrial strategy for offshore wind which targets investment in specific manufacturing facilities as outlined in this report. (Applies to scenarios 2, 3 and 4 only.)

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[175] Gavin and Doherty Geosolutions on behalf of Wind Energy Ireland, (2022), '*National Port Study*'. Available at: https://windenergyireland.com/images/files/final-national-ports-study.pdf.

[176] For a best practice example from the UK, see BVGA, (2015), '*Methodology for measuring the UK content of UK offshore wind farms*'. Available at: www.renewableuk.com/resource/resmgr/Publications/Guides/uk_content_methodology.pdf

- DETE, with collaboration from the Department of Finance, puts in place investment incentives specifically targeted at larger-scale manufacturing and infrastructure investments. Such incentives could include investment grants, tax incentives or preferential financing arrangements. (Applies to scenarios 2, 3 and 4 only.)
- DoT establishes mechanisms to provide investment support for port infrastructure upgrades. (Applies to scenarios 2, 3 and 4 only.)
- DETE facilitates the development of industrial clusters through supportive policies, funding for business networks, and other initiatives to encourage industry collaboration and investment, including regional development initiatives. (Applies to scenarios 2, 3 and 4 only.)
- DFHERIS and SEAI support industrial clusters through targeted skills funding initiatives and support for research and development in areas relevant to targeted areas for Irish participation. This could include, for example, support for synthetic materials research to build Irish capability. (Applies to scenarios 2, 3 and 4 only.)
- DETE considers whether an industrial strategy may be appropriate for wave energy, at a suitable time in the technology development pathway.
- DECC and DETE continue to evaluate the competitiveness of Irish electricity and hydrogen export within export markets, as the rollout of ORE progresses, and use this to inform future deployment plans.

6. Research and research skills assessment

6.1 Introduction

This section considers the research environment and research skills development required in support of the ORE technologies described in Section 2 under the scenarios described in Section 3. It covers:

- The current ORE research landscape in Ireland.
- A research skills assessment, with associated recommendations.
- Input to an ORE research strategy for Ireland.

Research relevant to ORE in Ireland also includes activities to maximise net positive environmental and social impact through:

- Better understanding of impacts of ORE projects.
- Technology development relevant to ORE technologies.
- Market development relevant to ORE technologies.

For offshore wind, the majority of research leading to levelized cost of energy (LCOE) reduction, increased deployment and/or other benefits is likely to happen outside of Ireland. Research in Ireland may not have a significant impact on deployment in Ireland, but it can have an important impact on increasing the value of the local value of that deployment. The Irish research community has a good understanding of its strengths and focus, especially relating to floating offshore wind and addressing the harsh conditions in Irish waters.

For wave energy and other relevant ORE technologies, Irish research will have a proportionately larger impact, as the sector is much smaller and less developed, with fewer countries investing less in research. An important caveat is that wave energy and other ORE technologies are emerging technologies. As such it is uncertain at this stage whether research in these technologies will eventually lead to competitive technologies that are installed in volume and create local economic benefit.

Demonstration facilities which enable the testing of offshore renewable technologies at a range of scales continue to play an important role in the development of technology capabilities and commercialisation. Existing demonstration facilities (Lír National Ocean Test Facility and SmartBay) remain crucial to the validity testing of offshore renewable energy devices, components, sub-systems and moorings. The development of full scale demonstration projects (AMETS & Saoirse) are anticipated to play a significant role in the Irish offshore renewables landscape.

To achieve scale up and full-scale commercialisation, testing will be required. Offshore installations will cover thousands of kilometres of ocean space in the coming years, the EU has committed to increase targets from 28 GW to 300 GW in 2050 – which will require tens of thousands of devices to meet these targets. Devices and their components will require vast testing. Ireland could have a unique role in developing this industry via real testing at sea for both devices and components at various TRLs.

The analysis does not include research related to the wider energy system, including system modelling, energy storage, hydrogen and interconnection. It is assumed that technical research includes activities up to TRL 4 (see Appendix B) and that other research is non- or pre-commercial. It also includes enabling innovation to higher TRLs, recognising that it is important to address the gap between technology tested in a representative form and market sales.

It is anticipated that system balancing research and dispatch modelling underway via EirGrid and SEAI’s decarbonised electricity study will provide increased clarity regarding the potential reduction in infrastructure cost from diversifying Ireland's generation fleet.

6.2 Current offshore renewable energy research landscape in Ireland

6.2.1 Organisations, programmes and test facilities

Table 20 considers the main research organisations and programmes (including funding streams) relating to ORE in Ireland. All have relevance to fixed and floating offshore wind and wave energy. Beyond the national universities shown, there are also a number of technological universities that provide education and research. The focus of this report concerns ORE technologies, but it recognises significant environmental and social research on the marine environment and blue economy. This table includes only organisations directly funding research. There are a variety of other organisations who are involved in research activities in Ireland but are not listed in this table.

Table 20: Main offshore renewable energy research organisations, programmes and test facilities in Ireland

Name	Type / role	TRL range	Typical activity
Organisations			
Atlantic Technological University	Research		Runs various MScs in marine conservation and research and hosts various ORE-related collaborative research projects
Centre for Marine and Renewable Energy Ireland (MaREI)[177]	Research	1-5	SFI research centre co-ordinated by the Environmental Research Institute (ERI), with 250+ researchers covering the energy transition, climate action, and the blue economy. Includes research in device design, testing and evaluation – currently contributing to a wide range of research projects, many with international partnerships including many focussed directly on offshore wind and wave/other ORE technologies, as well as many on environmental and social considerations.
Dundalk Institute of Technology	Education, research		Runs MSc in Renewable Energy Systems (1 year, full time)
Munster Technological University	Education		Runs BEng (Hon) Sustainable Energy Engineering (four years, full-time)
Technological University Dublin	Education, research		Runs BEng(Hons) in Sustainable Energy Engineering (four years, full-time) and MEng in Sustainable Electrical Energy Systems (three years, full-time)
Technological University of the Shannon	Education, research		Runs BEng (Hons) in Mechanical Engineering with Energy (three years, full-time)

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[177] MaREI. Available at: https://www.marei.ie/.

Name	Type / role	TRL range	Typical activity
Trinity College Dublin	Education, research		Runs postgraduate course in Engineering (Environmental / Structural and Geotechnical / Transport/ Sustainable Energy) (one year, full-time) and P.Grad. Dip in Sustainable Energy and the Environment (one year, part-time)
University College Cork	Education, research		• Co-ordinates Centre for Marine and Renewable Energy Ireland (MaREI) (see below) • Offers PGCert in Offshore Renewable Energy (one year, part-time) and MEngSc in Engineering - Sustainable Energy (one year, full-time)
University College Dublin	Education, research		• Energy Institute, delivering various research projects in power systems and renewable energy enabling • Runs MSc in Sustainable Finance (one year, full-time)
University of Galway	Education, research		Leading TIDAL-GES project, decarbonising and just transition through use of tidal energy
Programmes			
Department of Enterprise, Trade and Employment (DETE) / Enterprise Ireland (under DETE)	Government department, Government agency	3-9	Disruptive Technologies Innovation Fund support industry to exploit disruptive technologies by de-risking collaborative projects.
Department of the Environment, Climate and Communications, Geological Survey Ireland and Foras Na Mara (The Marine Institute)	Government department, Government agencies		Integrated Mapping for the Sustainable Development of Ireland's Marine Resource (INFOMAR) is a 20 year programme to map Ireland's seabed.[178]
Enterprise Ireland	Government agency	4-7	The Innovation Partnership Programme supports industry-academic research partnerships.[179]

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[178] INFOMAR, available at: https://www.infomar.ie/.

[179] Enterprise Ireland, *'Innovation Partnership Programme'*. Available at: https://www.enterprise-ireland.com/en/funding-supports/company/esetablish-sme-funding/innovation-partnerships.html.

Name	Type / role	TRL range	Typical activity
Enterprise Ireland	Government agency		The Technology Gateway Programme supports 16 Technology Gateways, including the CREDIT Gateway (focussed on renewables and energy technology). Other gateways are in areas of relevance to ORE, such as coatings innovation and engineered materials.
Enterprise Ireland, IDA Ireland	Government agency, autonomous statutory agency	5-8	The Technology Centre Programme supports 9 Technology Centres and associated research partners. Again, although not focussed on ORE, many have research teams that could contribute, for example through artificial intelligence, construction and manufacturing technology.
Irish Research Council (under Department of Further and Higher Education, Research, Innovation and Science (DFHERIS))	Government agency	3-5	The Enterprise Partnership Scheme enables postgraduate researchers in higher education to collaborate with industry.[180]
Science Foundation Ireland (under DFHERIS)	Statutory body	1-3	• The Research Centres Programme supports 15 research centres beyond MaREI.[181] iCrag and NexSys also have a focus on offshore wind and many have research teams that could contribute, for example through artificial intelligence and software research. • The Strategic Partnership Programme enables academic researchers to build strategic collaborations with key stakeholders by supporting stand-alone research initiatives of scale.[182] • The Spokes Programme enables new industrial and academic partners and projects connect to existing SFI Research Centres.[183]
Sustainable Energy Authority of Ireland (SEAI)	Government agency		National Energy Research Funding Programme, which supports arrange of industry-academic partnerships including in ORE. [184]

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[180] Irish Research Council, *'Enterprise Partnership Scheme (Postgraduate)'*. Available at: https://research.ie/funding/eps-postgrad/.

[181] Science Foundation Ireland, *'SFI Research Centres'*. Available at: https://www.sfi.ie/sfi-research-centres/.

[182] Science Foundation Ireland, *'SFI Strategic Partnership Programme'*. Available at: https://www.sfi.ie/funding/funding-calls/sfi-strategic-partnership/.

[183] Science Foundation Ireland, *'SFI Research Centres – Spokes'*. Available at: https://www.sfi.ie/funding/funding-calls/sfi-research-centres-spokes/.

[184] SEAI, *'SEAI National Energy Research Funding Programme'*. Available at: https://www.seai.ie/grants/research-funding/research-development-and-demonstration-fund/.

Name	Type / role	TRL range	Typical activity
University College Dublin	Education, research		Next Generation Energy Systems (NexSys) is an all-island, multidisciplinary energy research programme in partnership with a range of other research organisations with 50+ research staff and 50+ PhD students.[185]
University of Limerick	Education, research		With ESB, Shannon Foynes Port Company and Clare County Council, stakeholder in the Dutch Irish research project HybridLabs, to help accelerate the deployment of ORE technologies for both electricity and hydrogen production.[186]
Test facilities			
Atlantic Marine Energy Test Site (AMETS) (SEAI)[187]	Test facility	7-9	Ireland's national marine test site in off the north west coast, County Mayo, with test facilities 6 km from shore in 50 m water depth and 16 km from shore in 100 m water depth. Suitable for full-scale offshore wind testing (pending permitting).
Lír National Ocean Test Facility (University College Cork)[188] (SEAI and UCC)	Test facility	1-4	Four wave tanks plus electrical rigs for use scale-testing ORE technologies, plus experienced testing and modelling team.
SmartBay (Foras Na Mara (The Marine Institute) and SEAI)[189]	Test facility	4-6	Ireland's national marine test site in Galway Bay, midway up the west coast, with test facility 1.5 km from shore in 20-25 m water depth, a data buoy, and subsea-cabled observatory and multidisciplinary support team. Suitable for 14 MW-scale offshore wind turbine testing.

Government has established a series of working groups bringing together key government and industry bodies to support Ireland's ORE research effort, including:

- The Offshore Wind Industry Forum (OWIF), comprising representatives from MRIA, WEI and a panel of company representatives from the offshore wind supply chain.
- The DETE Offshore Wind Interdepartmental Group, comprising DECC, DETE, DFHERIS, DHLGH, Enterprise Ireland, IDA, MARA, NDP Delivery and Reform, SEAI the Department of Public Expenditure, the Department of Finance, the Department of the Taoiseach and the Department of Transport.
- The DETE Offshore Wind RD&I Subgroup, established in 2023 under the main Interdepartmental Group, with the participation of EI, IDA, SEAI, and SFI.

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[185] NexSys. Available at: https://www.nexsys-energy.ie/.

[186] University of Limerick, (2023), *'HybridLabs: University of Limerick to participate in unique offshore renewables project'*. Available at: https://www.ul.ie/sustainability/news/hybridlabs-university-of-limerick-to-participate-in-unique-offshore-renewables.

[187] SEAI, *'Atlantic Marine Energy Test Site (Full Scale)'*. Available at: https://www.oceanenergyireland.com/test-facilities/atlantic-marine-energy-test-site/index.xml.

[188] MaREI, *'Lír National Ocean TF'*. Available at: https://www.marei.ie/infrastructure/lir-national-ocean-tf/.

[189] SmartBay. Available at: https://www.smartbay.ie/.

- The OWDT Workstream 8 (Skills) and the Expert Advisory Group, led by DFHERIS.

Sustainable Energy Authority of Ireland

SEAI plays a key role in supporting ORE test facilities in Ireland. The Lír National Ocean Test Facility provides a simulated testing environment for small scale TRL 1-4 devices, whilst Smart Bay offers testing for TRL4-6 technologies in in a shallow, nearshore environment. SEAI is currently developing an additional test facility, The Atlantic Marine Energy Test Site (AMETS), for full scale testing of TRL 7-9 technologies in the Atlantic ocean.

AMETS will provide a grid connected national test facility, at which full scale technologies can be tested in real sea conditions during their final stages of pre-commercial development at TRL 7–9. AMETS has a valuable test site offering; a harsh environment, high resource location, suitable for multiple technology types, for testing simultaneously while producing electricity to the national grid. A key aspect to significant multi-GW large scale floating wind in the Irish market will be proving O&M activities in harsh / exposed wave climates. AMETS is anticipated to play a key role in testing these.

Deployment at AMETS is expected also to accelerate the deployment of ocean energy in Irish waters by providing data for certification of technology and performance data, as well as real-world experience in installation and operation and maintenance, in advance of commercial deployment. With uncertain changes to climate, testing at AMETS reduces doubt over survivability of freak weather occurrences in other parts of the world. Accelerated testing offers investors a reduced risk, consequently speeding up the development timeline.

6.2.2 Documents and data

Key documents and data relating to the ORE research landscape in Ireland are summarised in *Table 21*. All have relevance to fixed and floating offshore wind and wave energy unless stated.

Table 21: Key documents and data relating to the offshore renewable energy research landscape in Ireland

Document, authoring organisation and year	Description
A proposal for Testing Floating Offshore Wind at the Atlantic Marine Energy Test Site (AMETS), SEAI, 2022[190]	Summary of testing proposition for floating offshore wind at Wind at the AMETS test site
Accelerating Ireland's Offshore Energy Programme *Policy Statement on the Framework for Phase Two Offshore Wind*, DECC, 2023[191]	Long-term vision and planning for offshore renewable energy in Ireland
Climate action plans 2021: Securing Our Future, DECC, 2021[192]	Long-term vision and planning for Ireland's energy transition

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[190] SEAI, *'A Proposal for: Testing Floating Offshore Wind at the Atlantic Marine Energy Test Site (AMETS)'*. Available at: https://www.seai.ie/publications/SEAI-AMETS-Booklet.pdf.

[191] Government of Ireland, (2023), *'Accelerating Ireland's Offshore Energy Programme: Policy Statement on the Framework for Phase Two Offshore Wind'*. Available at: https://assets.gov.ie/249823/bbd8b13c-73cd-46d4-9902-533fbf03d7fe.pdf.

[192] Government of Ireland, (2021), *'Climate Action Plan 2021: Securing Our Future'*. Available at: https://assets.gov.ie/224574/be2fecb2-2fb7-450e-9f5f-24204c9c9fbf.pdf.

Document, authoring organisation and year	Description
Impact 2030: Ireland's Research and Innovation Strategy, DFHERIS, 2022[193]	Wider national R&D strategy to 2030
Marine Renewable Energy Research Infrastructure programme (MARINERG-i) (Coordinated by MaREI, 2016-19)[194]	• Facilitated national and international collaboration in ORE with a common research agenda focused on the development of innovative, investable ORE technologies. • Published reports on intellectual property, funding streams and science plan. • Relevant to all ORE technologies.
National Hydrogen Strategy, DECC, 2023[195]	Long-term vision and planning for hydrogen production, transport and use in Ireland
National Marine Research Database and *Summary of marine research investments 2017-2021,* Foras Na Mara (The Marine Institute) [196, 197]	Provide detail and analysis of research projects funded / active during the period of the National Marine Research & Innovation Strategy 2017-2021
National Marine Research & Innovation Strategy, Foras Na Mara (The Marine Institute), 2017[198]	National strategy for ORE research and innovation to 2021
National Policy Statement: Electricity Interconnection, DECC, 2023[199]	Long-term vision and planning for electricity interconnection from Ireland
Review of funding supports to the Ocean Energy Sector, SEAI, 2020[200]	Summary of grants made in ORE and lessons learned

6.2.3 Research funding sources

Key research funding sources relating to the ORE in Ireland are summarised in *Table 22*. All have relevance to fixed and floating offshore wind and wave energy.

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[193] Government of Ireland, (2022), *'Impact 2030: Ireland's Research and Innovation Strategy'*. Available at: https://www.gov.ie/ga/foilsiuchan/27c78-impact-2030-irelands-new-research-and-innovation-strategy/.

[194] MARINERG-I. Available at: http://www.marinerg-i.eu/.

[195] Government of Ireland, (2023), *'National Hydrogen Strategy'*. Available at: https://assets.gov.ie/263248/f982c10f-eca6-4092-a305-90000e5213ed.pdf.

[196] Foras na Mara, *'National Marine Research Database'*. Available at: https://www.marine.ie/site-area/research-funding/marine-research-ireland/national-marine-research-database

[197] Foras na Mara, *'Summary of Marine Research Investments 2017-2022'*. Available at: https://app.powerbi.com/view?r=eyJrIjoiYTYyZTE3MTMtMjZkNi00MTFhLWJiNDktZmYxMWU5MWRhMWY2IiwidCI6IjEyY2I3YTM2LTFmMDktNDRhNC1iNjE0LWIzZWFjYWZmYjcxOCIsImMiOjh9&pageName=ReportSection1e03c8b2d0acbbbee19e

[198] Foras na Mara, *'National Marine Research & Innovation Strategy'*. Available at: https://www.marine.ie/site-area/research-funding/national-marine-research-strategy/national-marine-research-innovation

[199] Government of Ireland, (2023), *'National Policy Statement: Electricity Interconnection'*. Available at: https://assets.gov.ie/265251/7b3080d8-fa48-4011-9a77-1580abf8a9ff.pdf.

[200] SEAI, (2020), *'Review of funding supports to the Ocean Energy Sector'*. Available at: https://www.seai.ie/publications/SEAI_OceanEnergyFundingReview.pdf.

Table 22: Key research funding sources relating offshore renewable energy in Ireland

Programme (Funder)	TRL range	Scope
Irish programmes		
Climate Action Fund[201]	5-9	Supports projects which help Ireland achieve its climate and energy targets – current themes less directly relevant to ORE research
Enterprise Partnership Scheme (Irish Research Council)[180]	1-5	Supports postgraduate researchers in higher education to collaborate with industry
Environmental Protection Agency[202]	1-5	Focussed on addressing climate change evidence needs, facilitating a green and circular economy, delivering a healthy environment and protecting and restoring the natural environment.
Foras Na Mara (The Marine Institute)[203]	1-5	Focussed on marine research and innovation
Geological Survey Ireland[204]	1-5	Research funding for geoscientists
Innovation Partnership Programme (Enterprise Ireland)[179]	1-5	Supports industry-academic research partnerships
National Energy Research Funding Programme (SEAI)[184]	3-6	Innovative energy RD&D projects which contribute to Ireland's transition to a clean and secure energy future
Research, Development and Innovation (Enterprise Ireland)[205]	1-9	Support for Irish businesses through a range of programmes

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[201] Government of Ireland, (2020), *'Climate Action Fund'*. Available at: https://www.gov.ie/en/publication/de5d3-climate-action-fund/.

[202] Irish Environmental Protection Agency, *'EPA Research funding'*. Available at: https://www.epa.ie/our-services/research/epa--research-funding/.

[203] Foras na Mara, *'Research & Funding'*. Available at: https://www.marine.ie/site-area/research-funding/research-funding.

[204] Geological Survey Ireland, *'Funding'*. Available at: https://www.gsi.ie/en-ie/research/funding/Pages/default.aspx.

[205] Enterprise Ireland, *'Research, Development & Innovation Fund'*. Available at: https://www.enterprise-ireland.com/en/research-innovation/companies/r-d-funding/funding-for-independant-and-collaborative-r-d.html.

Programme (Funder)	TRL range	Scope
Science Foundation Ireland[206]	1-7	Supports wide range of scientific and engineering research
European programmes		
European Innovation Council (European Commission)[207]	3-6	EU’s flagship innovation programme to identify, develop and scale up breakthrough technologies and game changing innovations – Transition and Accelerator programmes most relevant
Horizon Europe Cluster 5 (European Commission)[208]	1-5	EU's key funding programme for research and innovation - Cluster 5 covers climate, energy and mobility. Energy covers ORE
Innovation Fund (European Commission)[209]	6-9	EU’s funding for climate policy, with focus on energy and industry – providing support for demonstration of innovative low-carbon technologies
LIFE Programme (European Commission)[210]	4-8	EU’s funding for the environment and climate action.

6.2.4 Strength and weaknesses, opportunities and threats

In considering the research landscape and associated opportunities, this report considers the supply chain landscape, as described in Section 3, as well as numerous other reports.

The greatest opportunities for Irish content in the offshore wind supply chain are in the project development and operations and maintenance project phases, as these are the areas in which existing domestic capability combines with a strong logic for local supply to generate economic opportunity.

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[206] Science Foundation Ireland, *‘Funding’*. Available at: https://www.sfi.ie/funding/.
[207] European Innovation Council. Available at: https://eic.ec.europa.eu/index_en.
[208] European Commission, *‘Cluster 5: Climate, Energy and Mobility’*. Available at: https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/cluster-5-climate-energy-and-mobility_en.
[209] European Commission, *‘Innovation Fund’*. Available at: https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund_en.
[210] European Commission, *‘Clean Energy Transition’*. Available at: https://cinea.ec.europa.eu/programmes/life/clean-energy-transition_en.

It is likely that there will be limited Irish content in component manufacturing, installation and decommissioning activities, though there may be opportunities in construction ports for both fixed and floating offshore wind, tower manufacturing and mooring lines for floating offshore wind. Capturing such opportunities will require active industrial policy from different levels of government, as there is significant international competition to capture these types of activities.

Bearing in mind Ireland's likely supply chain strengths, coupled with the wider economic and research landscape, the most fruitful areas of research for Ireland to host include:

- Technologies to enable remote O&M, including sensing technologies, robotics, monitoring software.
- Innovation in materials, including composites.
- Health and safety equipment and procedures.
- Environmental and social research into the impacts and benefits of ORE.

Table 23 summarises the strength and weaknesses of the ORE research landscape in Ireland and the related opportunities and threats, in the context of delivering the ORE scenarios described in Section 3. Where a given entry relates to scenario n, this is indicated "[n]". The opportunities section includes areas where there is significant potential for research in the future that will impact given scenarios and / or value creation in Ireland.

Table 23: Strengths, weaknesses, opportunities and threats (SWOT) analysis for offshore renewable energy research in Ireland in the context of delivering the four ORE scenarios

Strengths	Weaknesses
Environmental and social impacts and the wider blue economy	Limited local supply of major components
Test capability in harsh offshore conditions	Lower offshore wind technology understanding and design experience than many (as only one small project operating and few suppliers active)
Wave energy technology understanding and design experience	Currently no test facilities for large offshore wind components, though AMETS test site offers full-system test capability for up to a 10 MW floating offshore wind turbine – see *Table 20*.
Skills strengths in parallel sectors with synergies such as aerospace (composites, sensing, reliability), Information and communications technology (ICT) and software	
Opportunities	**Threats**
Understanding local conditions (some of which are extreme, hence will drive innovation and new hardware and processes across the lifecycle of ORE projects)	Research which is relevant to Ireland may be carried out elsewhere
Partnering with offshore wind technology leaders to develop solutions to Irish project needs due to local conditions	Overseas supply chain takes benefit of Irish-based research and findings

If wave energy establishes as a viable contributor to the energy mix, it could offer a significant home market and export opportunity for technology and services	Wave energy does not establish as a viable contributor to the energy mix

6.3 Research skills assessment

This section considers the skills needed, key skills gaps and potential sources of training. Recommendations about how gaps should be addressed and by who is provided in Section 6.4.

6.3.1 Research skills need and key skills gaps

The research skills need and Irish research capability (including gaps that could limit delivery of scenarios and/or local economic benefit) are shown in *Table 24*. These are based on the assumptions regarding local content in Section 5.3 and research and engagement with a range of key organisations of those listed in Section 6.2.1. Needs and capability are for all scenarios unless stated.

When considering limiting delivery of scenarios, this refers to the impact local skills gaps could have in slowing down progress or increasing project costs, thereby making the industry less attractive. When discussing limiting local economic benefit, this refers to the impact local skills gaps could have in hindering local supply. This is in addition to any reduction in economic benefit due to reduced installation due to skills gaps limiting delivery of scenarios.

Eight rows considered of most relevance to Ireland based on need, capability and impact of gaps are highlighted.

Table 24: Research skills need and capabilities

Broad area of ORE technology delivery	Detailed area of ORE technology delivery	Research need (relevant to Ireland)	Key Irish research capability Low / Medium / High (plus range of response)	Gaps will limit delivery of scenarios?	Gaps will limit local economic benefit?
Technology development	Devices	Concepts, control and design detail for wave and other technologies (in scenario 4)	Medium (range Low to High)	No (possibly in scenario 4)	No (yes in scenario 4)
Technology development	Foundations	• Concepts and design detail for wave and other technologies (in scenario 4) • Concepts and design detail for harsh Irish conditions for deep water fixed and floating offshore wind	Medium (range Low/Medium to High)	Possibly	Possibly
Technology development	Export systems	Concepts and design detail for wave and other technologies (in scenario 4)	Medium (range Low to High)	No (possibly in scenario 4)	No
Technology development	Installation	• Concepts and design detail for wave and other technologies (in scenario 4) • Concepts and design detail for harsh Irish conditions for deep water fixed and floating offshore wind	Medium (range Low to Medium)	Possibly	No
Technology development	Operation, maintenance and service[211]	As above	Medium	No (possibly in scenario 4)	Possibly

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[211] Operation covers the management and monitoring of the site. Maintenance covers planned, routine inspection and consumables and component replacement activities. Service covers unscheduled activities in response to failures (or prognosis of failure).

Broad area of ORE technology delivery	Detailed area of ORE technology delivery	Research need (relevant to Ireland)	Key Irish research capability Low / Medium / High (plus range of response)	Gaps will limit delivery of scenarios?	Gaps will limit local economic benefit?
Project development	Permitting	- Understanding of environmental and social impacts for wave and other technologies (in scenario 4) - Understanding of environmental and social impacts specific to Irish projects including public engagement, community involvement/ownership	High (range Medium to High)	Yes	No
	Technical characterisation	Understanding of conditions specific to Irish projects	High (range Medium to High)	Possibly	Possibly
	Design	Solutions to address conditions and environmental and social considerations specific to Irish projects	Medium (range Low/Medium to Medium)	Possibly	Yes
	Management	Optimum management of industrial megaprojects	Medium (range Low to Medium)	No	No
Device supply	Major component supply	Manufacturing process optimisation for components manufactured in Ireland	Low (except Medium in composites)	No (possibly in scenario 4)	Possibly
	Minor component supply	Innovation in design and manufacturing process optimisation for components manufactured in Ireland	Medium	No (possibly in scenario 4)	Possibly
	Assembly	Concepts and design detail for wave and other technologies (in scenario 4)	Medium (range Low to High)	Possibly (in scenario 4)	Possibly (in scenario 4)

Broad area of ORE technology delivery	Detailed area of ORE technology delivery	Research need (relevant to Ireland)	Key Irish research capability Low / Medium / High (plus range of response)	Gaps will limit delivery of scenarios?	Gaps will limit local economic benefit?
Balance of plant supply	Foundations major component supply	Manufacturing process optimisation for components manufactured in Ireland	Low	No	Yes
	Foundations minor component supply	Innovation in design and manufacturing process optimisation for components manufactured in Ireland including: • Materials development • Additive and advanced manufacturing	Medium	No	Yes
	Subsea cables supply	Minimal	Low	No	No
	Substation major electrical components supply	HVAC and HVDC topology , materials and component-level innovation	Low	No	No
	Substation minor component supply	Innovation in design and manufacturing process optimisation for components manufactured in Ireland	Medium	No	Yes
Installation and commissioning	Major vessel activity	Optimisation of use of limited port space (in scenarios 2-4)	Medium (range Low to Medium)	Possibly (in scenarios 2-4)	No
	Minor vessel activity	Minimal	Medium	No	No
	Management	Optimum management of industrial megaprojects	Medium	No	No
Operations, maintenance and service	Operations management	Concepts and design detail for wave and other technologies (in scenario 4)	Medium (range Low to High)	Possibly in scenario 4	No

Broad area of ORE technology delivery	Detailed area of ORE technology delivery	Research need (relevant to Ireland)	Key Irish research capability Low / Medium / High (plus range of response)	Gaps will limit delivery of scenarios?	Gaps will limit local economic benefit?
	Routine monitoring, inspections minor vessel activity	Concepts and design detail for wave and other technologies (in scenario 4) Artificial intelligence and remote operation solutions including: • AI and machine learning • IoT and sensing technology • On-site robotics and autonomous technology • Remotely operated vehicles and robotics • Software solutions, big data, analytics and digital twins (applicable also to ORE in other markets)	Medium (range Low to Medium)	No	Yes
	Major vessel activity	• Concepts and design detail for wave and other technologies (in scenario 4) • Solutions to major component replacement in-situ for floating offshore wind	Low	No	No
	Spares Supply	Repair, remanufacturing, recycling and opportunities in the circular economy	Low	No	Yes
Decommis-sioning	Major vessel activity	Minimal at this stage	Medium (range Low to Medium)	No	No
	Recycling	Reuse, recycling and opportunities in the circular economy	Medium (range Low to Medium)	No	Yes

Broad area of ORE technology delivery	Detailed area of ORE technology delivery	Research need (relevant to Ireland)	Key Irish research capability Low / Medium / High (plus range of response)	Gaps will limit delivery of scenarios?	Gaps will limit local economic benefit?
Policy, regulatory frameworks implementation	Project assessment and stakeholder approval	• Understanding of environmental and social impacts for wave and other technologies (in scenario 4) • Understanding of environmental and social impacts specific to Irish projects	Medium	Yes	Yes
Other	Training	Minimal	Medium (range Low to High)	No	No
	Securing workforce	Workforce trends and motivations	Low	No	Yes
	Financing	Minimal	Low	No	No

6.3.2 Potential sources of training

Upskilling for research will be mainly through academic institutions and in the workplace. Key providers (or types of providers) are listed in *Table 25*.

Table 25: Potential sources of training

Provider (or type of provider)	Focus
Academic institutions	
Graduate course providers	Core skills development and basic industry education to prepare people for professional careers
Postgraduate course providers	Specialist skills development and deeper industry education to prepare people for advanced careers which may be in research
Practical apprenticeships providers	Hands-on learning and skills development to prepare people for practical jobs
Workplace	
Component suppliers	Design and manufacturing process experience and practical understanding of real-world applications
Services suppliers	Design and process experience and practical understanding of real-world applications
Project developers	Design and process experience and practical understanding of real-world applications
Enabling organisations (including governments / agencies)	Market structure and basic industry, and technology knowledge

6.4 Input to an offshore renewable energy research strategy for Ireland

This section presents:

- Data relevant to a research strategy; and
- Recommendations to establish and support a research strategy.

6.4.1 Data relevant to a research strategy

Table 26 lists documents from other markets relating to offshore renewable energy research strategies.

Table 26: Key documents from other markets relating to offshore renewable energy research strategies

Document, authoring organisation and year	TRL range	Description	Technology relevant to
Blue skills of the future and ocean literacy and Marine renewable energy pillars (Atlantic Maritime Strategy, European Commission)[212,213]	n/a	Pillars of Atlantic action plan 2.0[214] defining goals to develop quality training and lifelong learning, ocean literacy, knowledge sharing and making use of best practices in ORE	Offshore wind, wave, other technologies
Ecological consequences of offshore wind (ECOWind) research programme (UKRI)[215] Marine wave and tidal research programme (UKRI)[216]	1-3	UKTI manages many other themed research programmes, including themes relevant across many industries, such as AI and data science for engineering, health and government, circular economy and control engineering	Offshore wind, wave, other technologies

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[212] European Commission, *'Pillar II: Blue Skills of the future and ocean literacy'*. Available at: https://atlantic-maritime-strategy.ec.europa.eu/sites/default/files/sites/default/files/infographic_pillar_ii_0.pdf.

[213] European Commission, *'Pillar III: Marine Renewable Energy'*. Available at: https://atlantic-maritime-strategy.ec.europa.eu/sites/default/files/sites/default/files/atlantico-infografico-3_0.pdf.

[214] European Commission, (2020), *'Communication from the commission to The European Parliament, The Council, The European Economic and Social Committee and The Committee of The Regions'*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0329&rid=1.

[215] UK Research and Innovation, *'Ecological consequences of offshore wind (ECOWind)'*. Available at: https://www.ukri.org/what-we-do/our-main-funds-and-areas-of-support/browse-our-areas-of-investment-and-support/ecological-consequences-of-offshore-wind-ecowind/.

[216] UK Research and Innovation, *'Marine wave and tidal'*. Available at: https://www.ukri.org/what-we-do/our-main-funds-and-areas-of-support/browse-our-areas-of-investment-and-support/marine-wave-and-tidal/.

Document, authoring organisation and year	TRL range	Description	Technology relevant to
Energy innovation needs assessment: offshore wind (Department for Business, Energy & Industrial Strategy (BEIS), 2019)[217]	4-8	• Discusses innovation opportunities in offshore wind, including associated economic benefit and barriers to innovation • BEIS also published similar assessments for tidal stream[218] and hydrogen	Offshore wind, other technologies
Innovation focus (Offshore Wind Industry Council, 2023)[219]	4-8	Discusses sector priorities broadly and derives technology and other innovation gaps.	Offshore wind
Last Stop to 2025 – A 2022 Action Plan to deliver on the Offshore Strategy's Ocean Energy Target (Ocean Energy Europe, 2022) [220]	7-9	Discussion of what needed to accelerate short-term activity to meet 2025 targets.	Wave, other technologies
Marine Renewable Energy Research Infrastructure (MARINERG-i) (Coordinated by MaREI, 2016-19)[221]	1	• Facilitated national and international collaboration in ORE with a common research agenda focused on the development of innovative, investable ORE technologies • Published reports on intellectual property, funding streams and science plan	Wave, other technologies
New partnership in Offshore Wind[222]	1-5	3 UK universities with multi-year research programme partnering Ørsted and Siemens	Offshore wind

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[217] Vivid Economics, (2019), *'Energy Innovation Needs Assessment – Sub-theme report: Offshore wind'*. Available at: https://assets.publishing.service.gov.uk/media/5dc588bee5274a4ec1b88794/energy-innovation-needs-assessment-offshore-wind.pdf.

[218] Vivid Economics, (2019), *'Energy Innovation Needs Assessment – Sub-tehem report: Tidal stream'*. Available at: https://assets.publishing.service.gov.uk/media/5dc58a24ed915d395410b758/energy-innovation-needs-assessment-tidal-stream.pdf.

[219] Offshore Wind Industry Council, (2023), *'Innovation Focus: An assessment of innovation priorities to accelerate the offshore wind sector in the UK'*. Available at: https://www.owic.org.uk/_files/ugd/1c0521_c6a41852027e4cff9c033fa63eb9ed12.pdf.

[220] Ocean Energy Europe, (2022), *'Last Stop to 2025: A 2022 Action Plan to deliver on the Offshore Strategy's Ocean Energy Target'*. Available at: https://www.oceanenergy-europe.eu/wp-content/uploads/2022/06/Last-Stop-to-2025.pdf.

[221] MARINERG-i. Available at: http://www.marinerg-i.eu/.

[222] New Partnership in Offshore Wind. Available at: https://npow.org.uk/.

Document, authoring organisation and year	TRL range	Description	Technology relevant to
Offshore wind innovation hub website (Offshore Renewable Energy Catapult)[223]	4-8	Hosts innovation roadmaps for floating offshore wind, turbines, foundations, export systems and operation maintenance and service. In each, considers key innovation opportunities for UK, documenting what the innovation is and what type of organisation the enabler and beneficiary is, UK benefit, potential to reduce LCOE, case for intervention and health and safety impact.	Offshore wind
Scaling up investments in ocean energy technologies (Ocean Energy Europe and IRENA, 2023)[224]	1-9	Discussion of route from early research to commercial impact for ORE, including examples of grant funding and recommended good practice for enablers	Wave, other technologies
Strategic Research and Innovation Agenda for Ocean Energy (European Technology & Innovation Platform for Ocean Energy, 2020)[225]	1-9	Discussion of research and innovation priorities for the years ahead, also guiding policymakers on the best ways to support.	Wave, other technologies
Supergen Offshore Renewable Energy (Engineering and Physical Sciences Research Council (EPSRC)), [226] including Research landscape[227] and 2023 summary[228]	1-6	National multi-year research programme in ORE, including coordination with industry and upkeep of a research landscape listing past and present research	Offshore wind, wave, other technologies

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[223] Offshore Wind Innovation Hub. Available at: https://offshorewindinnovationhub.com/.

[224] International Renewable Energy Agency and Ocean Energy Europe, (2023), *'Scaling Up Investments in Ocean Energy Technologies'*. Available at: https://www.oceanenergy-europe.eu/wp-content/uploads/2023/03/IRENA_OEE_Scaling_up_investment_ocean_energy_2023.pdf.

[225] ETIP Ocean, (2020), *'Strategic Research and Innovation Agenda for Ocean Energy'*. Available at: https://www.etipocean.eu/knowledge_hub/strategic-research-innovation-agenda-for-ocean-energy/.

[226] Offshore Renewable Energy. Available at: https://supergen-ore.net/.

[227] Offshore Renewable Energy, *'Supergen ORE Hub Research Landscape'*. Available at: https://supergen-ore.net/research-landscape.

[228] The University of Edinburgh on behalf of Offshore Renewable Energy, (2023), *'Research and Innovation for Wave and Tidal Stream in the UK and EU: A 2023 Summary'*. Available at: https://www.policyandinnovationedinburgh.org/uploads/3/1/4/1/31417803/research_and_innovation_for_wave_and_tidal_stream_-_a_2023_review.pdf

Document, authoring organisation and year	TRL range	Description	Technology relevant to
Tidal stream Industry energiser project (TIGER) (2019-23)[229]	1-7	EU funded collaboration between England and France to develop, test and demonstrate new tidal stream technologies. Has published reports including *Cost reduction pathway of tidal stream energy in the UK and France*[230], Tidal Stream Volume Manufacturing Roadmap [231] and *Role and Value of Tidal Stream Generation in the Future UK Energy System*[232]	Other technologies

Key learning

Key learning from review of this material and experience is:

1. Shared investment between industry and Government increases research value for money. This may involve strategic partnerships and co-funding.
2. Prioritization is important, based on potential for impact and relevance to national needs.
3. Continuity of funding in the route to market for worthwhile innovations is vital.
4. Collaboration between industry and research institutions is key, leveraging existing knowledge and resources.
5. International collaboration is often valuable, combining strengths to address key shared challenges.
6. Data sharing repositories and standardization can be helpful in facilitating informed research and innovation.
7. Long-term research visions and tangible goals are helpful in building areas of excellence.
8. Coordination between funding bodies and streamlining of programmes helps bring clarity, but research, by nature, has an element of uncertainty and some overlap is inevitable.
9. Rigorous stage-gate processes to limit later-stage funding only to viable solutions increases value for money.
10. Signposting funding opportunities, providing challenge and business coaching helps innovators achieve commercial success.

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[229] Interreg France (Channel) England TIGER. Available at: https://interregtiger.com/.

[230] ORE Catapult on behalf of Interreg France (Channel) England TIGER, (2022), *'Cost reduction pathway of tidal stream energy in the UK and France'*. Available at: https://ore.catapult.org.uk/wp-content/uploads/2022/10/Tidal-stream-cost-reduction-report-T3.4.1-v1.0-for-ICOE.pdf.

[231] ORE Catapult on behalf of Interreg France (Channel) England TIGER, (2022), *'Tidal Stream Volume Manufacturing Roadmap'*. Available at: https://ore.catapult.org.uk/wp-content/uploads/2023/03/EN-Volume-manufacture-roadmap-1.pdf.

[232] Imperial College London on behalf of ORE Catapult, (2022), *'Role and Value of Tidal Stream Generation in the Future UK Energy System'*. Available at: https://ore.catapult.org.uk/wp-content/uploads/2023/03/20220531-WP3-4-1-Role-and-value-of-tidal-stream-v3-clean-1.pdf.

6.5 Recommendations

Based on the above and dialogue with relevant stakeholders, to establish and support a research strategy this report recommends:

- Robust, clear focus on:
    - Generation technologies that are most likely to impact Ireland's future energy mix, so fixed and floating offshore wind and the best wave energy concepts.
    - Greatest focus on floating offshore wind as it offers the best opportunity for the Irish research community to reduce consumer bills
- Areas within these technologies where:
    - Skilled Irish research can provide additionality – there is little point following others who are further ahead
    - Significant benefit is available, regarding LCOE or market delivery (volume and / or speed) or enabling competitive local supply to Irish projects (any maybe potentially exports), hence providing a route to market
- A high degree of international awareness, industry engagement and (where relevant, collaboration)
- A long-term framework for research support, but with flexibility to adapt to evolving market needs and research landscape.

Building on these principles, the following specific actions are recommended:

- SEAI develop a focussed ORE research and innovation strategy for Ireland with clear objectives, building on the content of this report, addressing any gaps in support and monitoring ongoing technology developments and innovations.
- DETE and SEAI focus offshore wind activity on:
    - Addressing the specific (often extreme) conditions seen in Irish waters.
    - For fixed offshore wind, project development and O&M, including AI, robotics, and sensing technologies to enable cost reduction in O&M
    - For floating offshore wind, foundations, including advanced manufacturing processes to enable cost reduction.
- SEAI and SFI focus wave energy research on lower-cost, lower-TRL activity, with robust stage gate in place before significant-scale sea trials. This will allow Ireland to support a wider array of innovations and assess which are likely to impact the market before progressing to more costly, large scale research.
- DETE, SEAI and SFI maximise the value of research and innovation activities, where relevant, through business coaching, facilitating collaboration and wider enabling support for the ORE research and innovation community.
- DETE, DFHERIS and SEAI collaborate in ensuring that the Government provides joined-up leadership in research and innovation in ORE.
- DFHERIS works with research funding agencies to create a targeted research and development fund to support commercialisation of wave technology, including financial support for demonstrator-scale projects to support the development of Irish supply chain expertise. (Applies to scenario 4 only)

Appendix A. Summary of technology parameters used in levelized cost of energy modelling

Parameters used in LCOE modelling are summarised in *Table 27* and *Table 28*.

Table 27: Summary of technology parameters used in LCOE modelling. For fixed offshore wind in Ireland

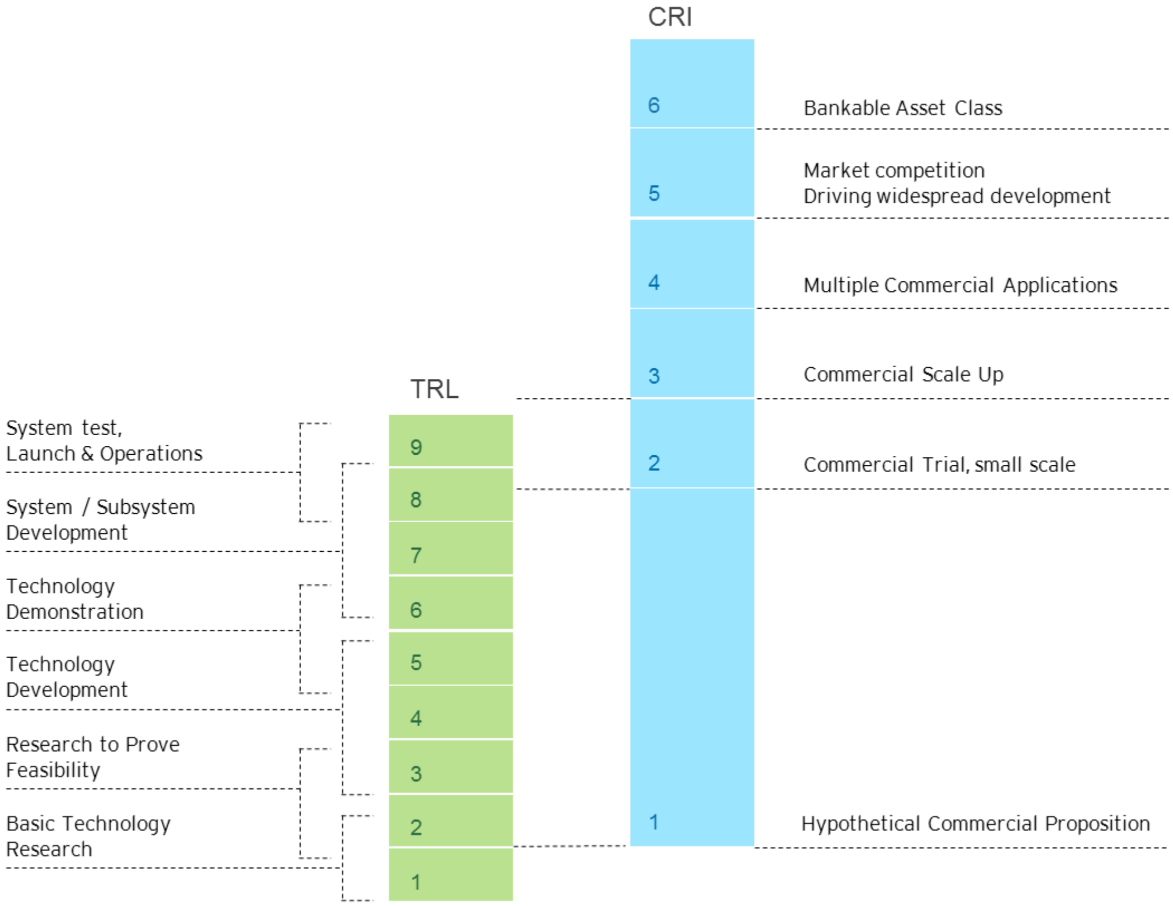
Year COD	2025	2030	2035	2040	2045	2050
Turbine rating (MW)	13	17	21	25	27.5	29
Project capacity (MW)	800	1,000	1,250	1,400	1,500	1,600
Mean wind speed at 150 m height(m/s)	10.5	10.5	10.5	10.5	10.5	10.5
Lifetime (years)	30.6	32.3	34	34.7	35.4	36.1
Water depth (m)	40	40	40	40	40	40
Foundation type	Monopile	Monopile	Monopile	Monopile	Monopile	Monopile
Distance to construction port (km)	100	100	100	100	100	100
Distance to OMS port (km)	70	70	70	70	70	70
O&M vessel strategy	SOV	SOV	SOV	SOV	SOV	SOV
Offshore export distance (km)	50	50	50	50	50	50
Onshore export distance (km)	10	10	10	10	10	10
Transmission type	HVAC	HVAC	HVAC	HVAC	HVAC	HVAC
Number of offshore substations	2	2	3	3	3	3

Table 28: Summary of technology parameters used in LCOE modelling. For floating offshore wind in Ireland

Year COD	2030	2035	2040	2045	2050
Turbine rating (MW)	17	21	25	27.5	29
Project capacity (MW)	600	1,100	1,400	1,500	1,600
Mean wind speed at 150 m height (m/s)	11.1	11.1	11.1	11.1	11.1
Lifetime (years)	32.3	34	34.7	35.4	36.1
Water depth (m)	130	130	130	130	130
Foundation type					Steel semi-sub
Mooring type					Hybrid steel chain / polyester
Anchor type					Drag embedment
Distance to construction port (km)	150	150	150	150	150
Distance to OMS port (km)	150	150	150	150	150
O&M vessel strategy	SOV	SOV	SOV	SOV	SOV
Offshore export distance (km)	120	120	120	120	120
Onshore export distance (km)	30	30	30	30	30
Transmission type	HVAC	HVDC	HVDC	HVDC	HVDC
Number of offshore substations	2	3	3	3	3

Appendix B. Definitions of technology readiness levels and commercial readiness index

The following technology readiness level (TRL) and commercial readiness index (CRI) scales are taken from paper *Commercial Readiness Index for Renewable Energy Sectors* by the Australian Renewable Energy Agency.[233]



The TRL scale is interpreted for whole ORE technologies in *Table 29*.

Table 29: Technology readiness level interpreted for ocean renewable energy technologies

TRL	Description
9	**Technology used on commercial ORE projects** operating offshore under relevant conditions, offshore. Series-production models field-proven through installation using series methods and during a full season of operation.
8	**A pre-production model** demonstrated at full scale and under relevant conditions, offshore.
7	**A Prototype version** has been demonstrated at full scale and under the relevant conditions, offshore.
6	**Developed technology, demonstrated in a representative environment**, but not yet demonstrated at both full scale and under the full set of operational conditions.
5	**The technology has been tested under relevant conditions**, in an integrated form to simulate what can be expected in the offshore environment.
4	The **technology tested in a form representative of its intended application**, through basic physical validation (likely in a laboratory or workshop).

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[233] See https://arena.gov.au/assets/2014/02/Commercial-Readiness-Index.pdf.

3	The **basic function of the technology proven**, through physical validation, for instance within a laboratory. It has not been integrated into a full system and is not representative of the anticipated developed product.
2	Generic technology **concept and/or application formulated**, not considered in the context of any specific product and not validated through any physical testing. Examples include computer simulations of a technology's properties.
1	**Basic principles observed**, but neither tested nor translated into a design concept. Examples include paper studies / preliminary simulations.

Appendix C. Detail of gross value added and employment method

Conventional modelling of economic impacts for most industrial sectors relies on government statistics, for example those based on industry classification codes and use input-output tables and other production and employment ratios.

Industry classification code data can be appropriate for traditional industries at a national level. The development of new codes for a maturing sector, however, takes time. This means that conventional industry classification analyses of ORE need to map existing data onto ORE activities, which is not easy and a source of uncertainty. Analyses using industry classification codes also have to rely on generalized data.

Offshore wind is ideally suited to a more robust approach that considers current and future capability of local supply chains because offshore wind projects tend to:

- Be large and have distinct procurement processes from one another; and
- Use comparable technologies and share supply chains.

It therefore enables a realistic analysis of the local, regional and national content of projects even where there are gaps in the data.

The methodology used here was developed jointly by BVG Associates and Steve Westbrook of the University of the Highlands and Islands, UK, and has been used for many major clients, including The Crown Estate, UK Government and World Bank Group.

The methodology's first input is the cost per MW of each of the supply chain categories at the time of project completion.

The remaining expenditure is analogous to the direct and indirect GVA created. GVA is the aggregate of labour costs and operational profits. FTE employment can therefore be modelled from GVA, provided an understanding of some key variables. Employment impacts are calculated using the following equation:

$$\mathrm{FTE_a} = \frac{(\mathrm{GVA} - \mathrm{M})}{\mathrm{Y_a} + \mathrm{W}_a}$$

Where:
$\mathrm{FTE_a}$ = Annual FTE employment
GVA = Gross value added
M = Total operating margin
$\mathrm{Y_a}$ = Average annual wage, and
$\mathrm{W_a}$ = Non-wage average annual cost of employment.

To make robust assessments, therefore, each major component in the ORE supply chain is considered and typical salary levels, costs of employment, and profit margins are estimated, based on specific sector knowledge and research into typical labour costs for the work undertaken in each supply chain level 2 category.

FTEs relate to full time equivalent job years, with part-time or part-year work considered appropriate. A full-time job would normally be at least 7 hours per day over 230 working days of the year. If an individual works significantly more than this over a year, FTE attribution would be more than 1 FTE (for example, 1.5 FTEs if working long hours over 7 days per week).

FTEs are by workplace rather than by residence and will include migrant/temporary resident workers. Where work in a local area (for example, on an assembly site) is carried out by people who have moved temporarily from overseas and live in temporary accommodation while working on site, their daily expenditures on accommodation, food, and drink, leisure and the like create employment impacts locally and within Ireland more widely. These impacts have been considered in the indirect impacts because these payments are likely to be covered through subsistence expenses rather than personal expenditures.

In this report, GVA and earnings impacts have not been discounted prior to aggregation.

Definitions and assumptions

The economic analysis was structured around a typical project for each technology. For each technology, judgements were made about local content for each of the supply chain categories defined in *Table 30* based on the scenarios defined in Section 3. Project costs in 2025, 2030, 2040 and 2050 were taken from the LCOE modelling described in Section 2. To simplify this analysis, it was assumed that there is no real terms increase in salaries and that changes in cost for the projects between 2025 and 2050 are due to changes to technology and industry learning. As a result, the analysis is likely to underestimate the GVA.

To model economic impacts between 2025, 2030, 2040 and 2050, costs and local content were interpolated between these years.

Table 30: Breakdown of cost categorisation for each of the technologies considered

Level 1 category	Level 2 category
Fixed offshore wind	
Development and project management	Development and consenting services
	Environmental surveys
	Resource and metocean assessment
	Geological and hydrographical surveys
	Engineering and consultancy
	Project management
Turbine	Nacelle and Hub
	Blades
	Tower
	Electrical system
	Array cables
Balance of plant	Export cables
	Monopile foundation
	Offshore substation
	Onshore substation
	Offshore substation

Level 1 category	Level 2 category
	Offshore cables
	Onshore export cables
Installation and commissioning	Turbine and foundation
	Inbound transport
	Construction port – fixed
	Offshore logistics
	Onshore substation
Operations and maintenance	Operations
	Maintenance
	Major repair
	Offshore vessels and logistics
	OMS port
Decommissioning	Decommissioning
Floating offshore wind	
Development and project management	Development and Consenting services
	Environmental Surveys
	Resource and Metocean Assessment
	Geological and Hydrographical Surveys
	Engineering and Consultancy
	Project Management
Turbine	Nacelle and hub
	Blades
	Tower
	Electrical System
Balance of plant	Array cables
	Export cables

Level 1 category	Level 2 category
	Semi-submersible floating foundation
	Mooring system
	Offshore Substation
	Onshore substation
Installation and commissioning	Offshore Substation
	Offshore Cables
	Onshore export cables
	Mooring system
	Turbine and foundation
	Inbound transport
	Marshalling and integration
	Offshore logistics
	Onshore substation
Operations and maintenance	Operations
	Maintenance
	Major repair
	Offshore vessels and logistics
	OMS port
Decommissioning	Decommissioning
Wave Energy	
Development and project management	Development and project management
Device	Generating device
Balance of plant	Electrical system
Installation and commissioning	Generating device installation
	Balance of plant installation
Operations, maintenance and service	Operations and maintenance

Level 1 category	Level 2 category
Decommissioning	Decommissioning

Appendix D. Comparison of local content levels within ORE technologies

Table 31 shows Irish content levels over time for each ORE technology in each scenario, to facilitate comparison. Figures represent the percentage of total spend within that cost category which is captured by Ireland.

Table 31: Comparison table of local content level within ORE technologies across time and across scenarios

Fixed offshore wind	**Scenario 1**			**Scenario 2**			**Scenario 3**			**Scenario 4**		
Year	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Project development	66%	66%	66%	67%	69%	71%	67%	69%	71%	67%	69%	71%
Turbine	0%	0%	0%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Balance of plant	3%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Installation and commissioning	8%	9%	11%	8%	10%	11%	8%	10%	11%	8%	10%	11%
O&M	51%	51%	51%	52%	56%	59%	52%	56%	59%	52%	56%	59%
Decommissioning	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Overall local content	**20%**	**18%**	**18%**	**21%**	**20%**	**21%**	**21%**	**20%**	**21%**	**21%**	**20%**	**21%**

Floating offshore wind	**Scenario 1**			**Scenario 2**			**Scenario 3**			**Scenario 4**		
Project development	66%	66%	66%	67%	69%	71%	67%	69%	71%	67%	69%	71%
Turbine	0%	0%	0%	3%	2%	2%	3%	2%	2%	3%	3%	2%
Balance of plant	1%	2%	2%	2%	13%	10%	2%	10%	9%	2%	13%	12%
Installation and commissioning	10%	10%	11%	12%	14%	14%	12%	14%	14%	10%	15%	15%
O&M	51%	51%	51%	53%	56%	60%	53%	56%	60%	53%	56%	59%
Decommissioning	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Overall local content	**17%**	**16%**	**15%**	**18%**	**21%**	**21%**	**18%**	**20%**	**20%**	**18%**	**21%**	**21%**

Wave	**Scenario 1**			**Scenario 2**			**Scenario 3**			**Scenario 4**		
Project development	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%
Turbine	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Balance of plant	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Installation and commissioning	28%	27%	27%	28%	27%	27%	28%	27%	27%	28%	27%	27%
O&M	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%

Decommissioning	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
Overall local content	**26%**	**25%**	**25%**	**26%**	**25%**	**25%**	**26%**	**25%**	**25%**	**26%**	**25%**	**25%**

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