OPFLOW Final Report: Options on a Pre-Commercial Demonstration Project for Floating Wind

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Work Package 5: Synthesis

Deliverable 5.1 FINAL SYNTHESIS REPORT

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Glossary of acronyms

AFLOWT Accelerating market uptake of Floating Offshore Wind Technology

AHTV Anchor Handling Tug Supply vessels

CAPEX Capital Expenditure

CfD Contracts for Difference

CLV Cable Laying Vessel

CTV Crew Transfer Vessel

DCACNT Department of Climate Action, Communications Networks and Transport

DECEX Decommissioning Expenditure

DSV Diving Support Vessel

EEZ Exclusive Economic Zone

EIB European Investment Bank

FLOW	Floating Offshore Wind
GIS	Geographic Information Systems
Hs	Significant Wave Height
iCfD	Innovation Contracts for Difference
LCOE	Levelized Cost of Energy
MPDM	Marine Planning and Development Management
NMPF	National Marine Planning Framework
NREL	National Renewable Energy Lab
O&M	Operations and Maintenance
OPEX	Operational Expenditure
ORE	Offshore Renewable Energy
OREDP	Offshore Renewable Energy Development Plan
RES-E	Renewable Energy Sources of Electricity
RESS	Renewable Electricity Support Scheme
SEAI	Sustainable Energy Authority of Ireland
SEM	Single Electricity Market
SMAZs	Strategic Marine Activity Zones
SPAR	Single Point Anchor Reservoir
SPV	Special Purpose Vessels
SROCs	Scottish Renewables Obligation Certificates
TLP	Tension Leg Platform
TRLs	Technology Readiness Levels
UK	United Kingdom
ZOPs	Zones of Potential

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Executive Summary

Due to the abundant wind resource, the demand for renewable energy in Europe, and government support for the development of 30GW of floating offshore wind (FLOW), particularly off the west coast, there is a window of opportunity for Ireland to seize a tactical advantage as an early mover in FLOW. While the sector gears up for full-scale FLOW commercial, the question of a pre-commercial demonstrator, to kick-start FLOW in Irish waters, arises. Pre-commercial projects utilise new technology which is at the top end of the 'learning curve' and, thus, lead to reduced costs. We are that an Irish demonstrator is a critical step to commercialisation of our enormous western and southern wind resources.

The OPFLOW project, a desktop study funded by the Sustainable Energy Authority of Ireland (SEAI), was designed to address this question. OPFLOW ran from January to July 2020. It was delivered by a research team through MaREI, in University College Cork, in collaboration with the ORE Catapult in the UK. The aim of the OPFLOW project was to establish if there is a case for a pre-commercial pilot project for FLOW in Ireland, and if so, to propose an appropriate scale and a strategic location, or locations, for such an initiative.

The logic of strategic locations off the Cork and Clare coasts was tested. It showed that there are potential areas suited to FLOW projects off both coasts. These zones are indicative only and were mapped at a high level, and the focus on these areas is for the purpose of this research only. A semi-submersible (semi-sub) platform was used in the approach to financial modelling for these zones of potential. As more FLOW foundation concepts are tested in an operational environment, both Hybrid and Tension Leg Platform (TLP) solutions are also viable options for each location.

In order to understand and determine the possible options for offshore wind procurement for the FLOW pre-commercial demonstration projects, three mechanisms were reviewed: i). open awards (the approach in Scotland); ii). auctions (France); and iii). a government-led process (Japan). Based on this international analysis, a competitive auction was identified as the preferred procurement option for promoting a pre-commercial demonstrator. However, it is critical that the auction is balanced and does not focus solely on lowest cost. Ideally, the mechanism used for procurement of pre-commercial FLOW capacity will be the same, or at least reflective of, the mechanism to be used for longer-term commercial-scale procurement. In an Irish context, this means alignment with the Renewable Energy Support Scheme (RESS).

A review of FLOW deployments around the world shows rapid advances in the deployment of pre-commercial arrays (e.g. Scotland, Portugal, France, California, S Korea). Single unit demonstrators are not desired at this point of departure in terms of validating technology, de-risking or driving down costs. In order to catch-up with other jurisdictions, acquire the learnings from pre-commercial deployments, accelerate the enormous FLOW opportunity for Ireland, and add value to existing knowledge and practice in trends for FLOW, a 'catch-up' scenario of 120MW (8*15MW turbines) for a pre-commercial demonstrator was analysed. (a sensitivity analysis reviewed associated costs of an electricity substation). An 'enabling' scenario (300MW) was also analysed as a likely threshold for a commercially viable project coming onstream towards the end of the decade. These two scenarios were envisaged in OPFLOW as initial steps to be taken by government in the build-up to a framework for 30GW in the 2030s:

Step 1: Initial FLOW specific RESS auction, designed to support *at least one* 120MW pre-commercial demonstration project, coming on-stream mid-decade.

Step 2: A follow-up enabling RESS auction, designed to support *at least one* 300MW commercial enabling project in the second half of the decade.

The financial modelling in OPFLOW examined the Levelized Cost of Energy (LCOE) for 120MW and 300MW projects coming onstream off the coasts of Cork and Clare in 2025 and 2028 respectively, in order to estimate strike prices and the cost of early financial support. Actual power prices were also estimated over a 15-year period. The south coast results for 120MW showed a LCOE of €104 /MWh and a 300MW LCOE of €77/MWh, which were both competitive results. The west coast results were: 120MW LCOE of €131/MWh and 300MW LCOE of €97/MWh. These were also competitive results but marginally higher than anticipated for the 300MW scenario.

The outputs outlined above, for each of the four potential pre-commercial sites, were used to estimate the cost of revenue support for each project. The cost of revenue support was modelled by ORE Catapult assuming a competitive auction awarding a 15-year strike price to successful projects. While the strike price is primarily determined by project costs and required returns, there is an associated risk with the uncertainty of future power prices beyond the 15-year strike price period. High and low strike prices based on a long-term market view were estimated. For example, the Co. Cork 120MW project was given a high strike price of €120/MWh, on the basis of low post-year 15 market prices. The same project was given a low strike price of €115/MWh on the basis of high post-year 15 market prices.

The calculation of the lifetime costs of financial support for the projects required taking a view of future electricity prices for the Irish Single Electricity Markey (SEM) versus British wholesale electricity prices. The analysis showed the greatest uncertainty to be the lack of a clear forecast of Irish electricity prices.

The analysis showed that the 300MW south coast site would always be lowest cost per MWh and, depending on market prices, may even be lowest in absolute terms (in fact close to subsidy-free if market prices are sufficiently high, confirming that this scale is at the threshold of commerciality). The 120MW south coast site was lowest cost in a low market price scenario and second to the 300MW site in all other scenarios. For example, the 15 year revenue support cost of the 120MW south coast site ranged from €277m (best case scenario), to €318 (mid case 1 scenario), to €475m (mid case 2 scenario), to €516m (worst case scenario). Based on the outcomes of this research, should cost be a defining factor, a Celtic Sea location may be preferable for an initial pre-commercial demonstration project for Ireland. However, the Celtic Sea and Atlantic could both be activated, with pre-commercial demonstration projects designed on a regional level, to open-up these two different offshore wind production zones. Ireland's unique selling point and challenge is proving the viability of FLOW in challenging metocean conditions with high capacity factors.

The focus of the OPFLOW study was on sites, scales and supports. Ultimately, the approach to kick-starting FLOW needs to be designed, taking short-term costs, long term regional benefits for coastal communities, and national interest, into consideration. There are many other factors that also need to be factored into the decision-making process, such as port capacity, grid and community engagement.

Ireland needs to have pre-commercial demonstration projects fully operational by the latter part of the decade to ‘get in the game’ for FLOW (France is about to support three FLOW projects of 250MW each). Assuming that the Marine Planning and Development Management Bill (2019) will be enacted in 2021, RESS design for FLOW is *the* critical enabling factor. RESS design for FLOW needs to start now, to be ready for FLOW specific auctions between 2025-2030, for pre-commercial activity to commence this decade. A pre-commercial demonstration plan for Ireland also needs to be nested in a long-term roadmap, to avoid a repeat of the Arklow Bank experience in Ireland for bottom fixed wind.

Image courtesy of Principle Power. Artist name: Dock90

Section 1: Introduction

1 Introduction

1.1 Background

Traditional barriers to the development of offshore wind in Ireland are gradually being removed, with clarity emerging through the Renewable Energy Support Scheme (RESS) and progress towards the National Marine Planning Framework and new consenting system. The Programme for Government, which targets 5GW of offshore wind by 2030, and signals the potential for 30GW of floating wind in the Atlantic area alone, makes Ireland an increasingly attractive emerging market (Government of Ireland, 2020). The benefits of developing offshore wind in Ireland are detailed in Cummins and McKeogh (2020), including energy security, decarbonisation of the economy, job creation, and regional development.

Due to the abundant wind resource and the demand for renewable energy in Europe, there is a particular opportunity for Ireland to seize a strategic advantage as an early mover in Floating Offshore Wind (FLOW). While the sector in Europe gears up for full FLOW commercial reality towards the end of the decade, the question of a pre-commercial demonstrator, to kick-start FLOW in Irish waters, arises. The OPFLOW project, a desktop study funded by the Sustainable Energy Authority of Ireland (SEAI), designed to address this question, ran from January to July 2020. It was led by a research team through MaREI, in University College Cork, in collaboration with ORE Catapult, UK.

The aim of the OPFLOW project was to recommend if there is merit in a pre-commercial pilot project for FLOW in Ireland, and if so, to propose an appropriate scale and a strategic location for such an initiative.

1.2 Pre-Commercial Demonstrator Concept

The main objective of a pre-commercial demonstration project is to prove the commercial viability of a concept by bridging the gap between early demonstrations and commercial scale to increase confidence for investments and lenders (Friends of Floating Offshore Wind, 2018). Small-scale demonstrators typically have very high costs, (ORE Catapult, 2018). Increased scale is needed to achieve cost and technical maturity (ORE Catapult, 2018). Only a limited number of FLOW concepts have reached technical maturity (TRL8) required for pre-commercial projects (Friends of Floating Offshore Wind, 2018; Hastings et al, 2020a).

- Pre-commercial projects are those which lead underdeveloped markets and are typically smaller scale grid-connection developments as opposed to full commercial-scale projects.
- These differ from pilot or test-scale projects as these stages fulfil a need to prove technology.
- Pre-commercial projects utilise maturing new technology which has not yet benefited from economy of scale etc. effects and is a critical step to commercialisation.
- Pre-commercial demonstration projects require specific supports for early stage technologies that are not yet competitive, to set them on their way.

1.3 Status of FLOW Demonstrations

The FLOW industry is currently at the pre-commercial stage. Before this, small-scale prototypes and pilots were deployed (ORE Catapult, 2018). Europe is the global leader in bottom-fixed offshore wind and has been an early leader in demonstrating new FLOW technology. The first pre-commercial FLOW project was Hywind Scotland in 2017 - a 30MW wind farm consisting of five 6MW turbines using SPAR technology (Equinor, 2020). Pre-commercial European and international projects can be seen in **Table 1.1**. The status of what has *actually* been installed is very different to what is *planned* for the latter part of the decade. As can be seen in the table, many of the projects in planning lack detail at this point in time.

Table 1.1 Current and planned pre-commercial and potential commercial FLOW projects (2017-2027) adapted from (US DOE, 2019)

COD	Status	Country	Wind Farm	Capacity (MW)	Depth	Platform Type	Concept	No. of Turbines	Rating (MW)	Turbine Supplier
2017	Installed	UK	Hywind	30MW	100m	SPAR	Hywind	5	6MW	Siemens
2019/20	Installed	Portugal	WindFloat Atlantic	25MW	50m	Semi-sub	WindFloat	3	8.4MW	MHI Vestas
2020	Consent Submitted	Spain	Flocan 5 Canary	25MW	-	-	-	-	-	-
2021	Approved	France	Provence Grand Large	25.2MW	30m	TLP	SBM	3	8MW	Siemens Gamesa
2021	2MW operating since 2018 with 47.5 currently Under Construction	UK	Kincardine	49.5MW	62m	Semi-sub	WindFloat	6	2 & 9.5MW	MHI Vestas

2021	Approved	UK	Dounreay Trí	10MW	76m	Multi-turbine	Hexicon	2	5MW	-
2022	Approved	France	Groix & Belle-ile	28.5MW	62m	Semi-sub	Naval Energies	3	9.5MW	MHI Vestas
2022	Approved	France	EFGL	30MW	71m	Semi-sub	WindFloat	3	10MW	MHI Vestas
2022	Pre-Construction	Norway	Hywind Tampen	88MW	110m	SPAR	Hywind	11	8MW	Siemens Gamesa
2022	Dormant	UK	Katanes	32MW	-	Mixed energy	Floating Power Plant	-	5-10MW	-
2023	Dormant	Norway	NOAKA	TBD	130m	-	-	-	-	-

2024	Permitting	Japan	Hitachi Zosen	400MW	-	Semi-sub	TBD	TBD	TBD	TBD
2025	Planning	Japan	Macquarie Japan	500MW	100m	TBD	TBD	TBD	TBD	TBD
2025	Planning	Taiwan	Floating W1N	500MW	-	-	-	-	-	-
2025	Planning	US	Redwood Coast	150MW	550m	Semi-sub	WindFloat		8+	TBD
2025/26	Planning	UK	Erebus	96MW	70m	Semi-sub	WindFloat	-	-	TBD
2027	Planning	US	Castle Wind	1GW	900m	Semi-sub	-	TBD	8+	TBD
2027	Planning	US	Oahu North	400MW	850m	Semi-sub	-	TBD	6+	TBD
2027	Planning	US	Oahu South	400MW	600m	Semi-sub	-	TBD	6+	TBD

2027	Planning	US	Progression Wind	400MW	650m	Semi-sub	-	TBD	6+	TBD
2027	Planning	South Korea	Donghae KNOC – Equinor	TBD	TBD	TBD	TBD	TBD	TBD	TBD
2027	Planning	South Korea	Ulsan Shell, Coens, Hexicon	200MW	TBD	TBD	TBD	TBD	TBD	TBD
2027	Planning	South Korea	Ulsan Macquarie	200MW	TBD	TBD	TBD	TBD	TBD	TBD
2027	Planning	South Korea	Ulsan SK E&S – CIP	200MW	TBD	TBD	TBD	TBD	TBD	TBD
2027	Planning	South Korea	Ulsan KFWind – Principle Power – Wind Power Korea	500MW	TBD	Semi-sub	WindFloat	TBD	TBD	TBD

Pre-commercial projects to date typically entail full-scale deployment of turbine and platform units using the state-of-the-art technology over a full life cycle, but on a relatively smaller wind farm, typically using 5-12 units with a capacity between 25-96MW (Friends of Floating Offshore Wind, 2018).

Rapid advancements in turbine sizes for offshore wind, means that larger pre-commercial demonstrators are likely to emerge. For example, as seen in **Table 1.1** the first pre-commercial demonstrator was Hywind with a farm capacity of 30MW using five units. With new turbines that have been announced (i.e. 15MW (Siemens Gamesa, 2020)) the same farm capacity could be achieved with two units. However, more units would need to be deployed for an array suitable to the purpose of a pre-commercial demonstration project (e.g. to prove cost reductions of larger wind farms than installed/planned projects up to 100MW, to facilitate supply chain development etc.).

Floating offshore technology requires development at volume and scale, to bring costs down. In order to achieve this, FLOW requires treatment as an emerging technology with respect to government financial support mechanisms, which should differ from mature and established technologies. The combination of the early stage of this technology and of Ireland's enormous resource means that we have the opportunity to 'leapfrog' potential competitors and become a major player in FLOW provided that Ireland takes an early decision to support demonstration projects as outlined in this report.

1.5 Status of FLOW in Ireland

The pioneering AFLOWT project, Ireland's first FLOW pilot, will demonstrate the survivability and cost competitiveness of the pilot technology at the Sustainable Energy Authority of Ireland (SEAI) test site, near Belmullet in County Mayo. It will deploy a single 6MW turbine on a hybrid TLP FLOW concept designed by Saipem. The project draws from expertise across Europe through the EU Interreg programme. The turbine is to be tested at sea over one year in the early 2020s.

The EirWind Blueprint provides a roadmap for FLOW off the south and west coasts (Cummins & McKeogh, 2020). If Ireland is to realise its FLOW potential, planning for pre-commercial demonstration is a logical next step. **The window of opportunity for planning for the pre-commercial demonstration phase of FLOW is limited**. After that, it is likely that countries will commence FLOW at full commercial scales. The benefits of acting now to realise a FLOW demonstrator in Ireland are:

- **Kick start** FLOW in the Celtic Sea and/or the Atlantic to enable government policy
- Facilitate the stepping-stone approach (ORE Catapult, 2018) to the development of the **supply chain** (leveraging initial capacity building from bottom-fixed in the Irish Sea)
- Send a signal to the international **marketplace** on government support for offshore wind, that Ireland is 'open for business' to stimulate the sector
- Enable an approach to achieving **long-term competitiveness** where projects demonstrate cost reductions and/or value-added opportunities

- Achieve **energy security** by decreasing Ireland's dependency on imported fuel. The development of FLOW at scale in Ireland could transform Ireland's energy outlook, whereby Ireland becomes a **net energy exporter** in the decades ahead.
- **Decarbonisation** targets can be further facilitated by FLOW (e.g. onshore wind may be unable to achieve the sites needed to meet renewable energy targets; FLOW could potentially deliver some of the 5GW target for offshore wind by 2030 in Ireland)
- **Open new export markets** (innovative solutions, such as green hydrogen production, arising from to route to market from FLOW)
- Build **confidence** (e.g. an incremental approach to building capacity for FLOW in Ireland is critical to avoid the consequences of prematurely commercialising floating wind in challenging metocean conditions such as in the Celtic Sea and the Atlantic, and damaging confidence in the marketplace)

1.6 Project Approach

The overall objective of the OPFLOW project was to provide insights on the development of a pre-commercial demonstrator for Floating Offshore Wind in Ireland. The research tested the hypothesis that existing locational attributes such as port location and strategic infrastructure create advantageous FLOW development contexts. In the proposal to SEAI, it was argued that proving the hypothesis would provide **insights to policymakers on if, and how, to realise a pre-commercial demonstration FLOW project in the national interest.**

Taking locational advantages into consideration, two locations were considered for analysis in the research. The first was in proximity to the **Cork coast,** - with an electricity load centre and significant port facilities in Cork Harbour. This location also features the Kinsale Gas Fields, currently being decommissioned. A previous study outlined the potential for utilising the gas pipeline for a 100MW cable and the value of existing metocean data (Consub and MaREI, 2019). The second location, off **the coast of County Clare**, benefits from the grid transmission of Moneypoint Power Station and port facilities in Shannon Foynes. These two locations represent opportunities for FLOW in the Celtic Sea Production Zone and in the Atlantic Production Zone, respectively as outlined by Cummins & McKeogh (2020).

Specific objectives of the OPFLOW project were to:

i. Investigate the potential for FLOW deployment by mapping the locational attributes relevant to the areas of interest off the Cork and Clare coasts (**Site desktop review)**
ii. Review and identify state-of-the art technology for pre-commercial project scenarios **(Technology review)**
iii. Determine scale options for a demonstration project in the context of weighted constraints mapping for each site **(Pre-commercial demonstration project viability)**
iv. Identify consenting, financial and public procurement pathways to enable one or more pre-commercial demonstrator option **(Consenting, financing and public procurement)**

The project was delivered according to four technical work packages (**Table 1.2**). The objective of WP1 was to identify technical, logistical and environmental data and information for FLOW pre-commercial demonstration scenarios off the Cork and Clare coasts[1]. This was mapped using Geographic Information Systems (GIS). Work Package 2 aimed to assess FLOW platforms and offshore wind turbine technologies. Based on the review, at least one suitable FLOW platform and offshore turbine technology was to be selected as input to WP3. Work Package 3 assessed the two locations in terms of DEVEX, CAPEX, OPEX and DECEX and how these impact on the Levelised Cost of Energy (LCOE) models. Work Package 4 incorporated the LCOE data and information to identify the cost of financial support measures for the modelled FLOW scenarios. It also examined critical enablers relating to the option of auction and consenting pathways.

Table 1.2 – List of Work Packages

No.	Title
WP1	Desktop Review
WP2	Technology Review
WP3	Pre-commercial Demonstration Project Viability
WP4	Consenting, Financing and Procurement
WP5	Research Synthesis

A project kick-off meeting involving the researchers and industry collaborators, held in MaREI in February 2020, determined the key criteria for identification of the scenarios for site selection. The key assumptions that underpinned the modelling are outlined in **Table 1.3**. It was agreed that there was no significant value in modelling a 30MW scale project (as outlined in the original proposal to SEAI), as FLOW projects are already being facilitated at a much greater order of magnitude (**Table 1.1** above). For example, at the time of writing, (July 2020), France signalled it will hold three new tenders, starting next year, to encourage three FLOW projects of 250MW each: each almost three times the scale of the Hywind Tampen scheme. The first auction for a floating wind farm in France is scheduled for 2021.

A key question to be addressed in the research design, concerned the identification of a scale of analysis in the OPFLOW project, that might also present a plausible and meaningful scenario for policy development. The research team considered:

- That in order to catch-up with other jurisdictions, accelerate the enormous FLOW opportunity for Ireland, and add value to existing knowledge and practice in trends for FLOW

[1] *The original proposal was designed to focus on the territorial waters, to align with the foreshore consenting legislation. However, in the period that passed between proposal submission and project implementation, the Marine Planning and Development Management (MPDM) Bill was published. Following consultation with SEAI, the project scope was broadened to relevant water depths in the new Maritime Area.*

demonstration, **a 'catch-up' scenario (circa 100MW)** for a pre-commercial demonstrator would be analysed

- That Ireland needs to have a pre-commercial demonstration project in operation **by the latter part of the decade** to 'get in the game' for FLOW
- An '**enabling' scenario (circa 300MW)** would be analysed as a likely threshold for a commercially viable project coming onstream towards the end of the decade for comparative purposes

The research was framed according to the '**Stepping-Stone' approach** promoted by the ORE Catapult (2018), with Step 1 (120MW) followed by Step 2 (300MW). The logic was to take a more integrated view of the supports required to unlock this level of potential in the decade ahead.

Taking a 120MW pre-commercial scale into account as the first step in a larger project, was justified on the basis of eight * 15MW turbines providing an ambitious but do-able array scenario. 300MW is arguably on the boundary between pre-commercial and commercial, and hence it provides a good threshold for the upper end of analysis. The French approach shows that there is a basis for larger demonstrator projects. Furthermore, the Crown Estate in the UK generally determines pre-commercial projects to be of the order of 100MW, with scope for future support for pre-commercial demonstrators up to 300MW (*pers comm, Simply Blue Energy, 2020).* **Table 1.3** outlines how this shaped the overall framing of the case studies.

Table 1.3: Overview of OPFLOW Case Studies

Site Characteristics	Co. Cork (CS1 & 1.1)		Co. Clare (CS2 & 2.1)	
Location	Cork		Clare	
Water Depth	90m		100m	
Distance from Shore	44km		30km	
Distance from Port	60km		60 & 89km	
Distance from Grid	50km (Offshore) & 7km (Land)		44km (Offshore) & 22km (Land)	
Mean Wind Speed at 151m	10.35m/s		10.66m/s	
Average Hs	1.87m		2.66m	
Average Tp	9.88s		10.8s	
Seabed Sediment	Coarse sediment		Coarse sediment & muddy sand	
Bedrock	Sedimentary (sandstone/ limestone)			
Project Details	**CS1**	**CS1.1**	**CS2**	**CS2.2**
Start Date of installation	2025	2028	2025	2028
Installed Capacity	120MW	300MW	120MW	300MW
Turbine Size	8 x 15MW	20 x 15MW	8 x 15MW	8 x 20MW
Platform Type	Semi-submersible			
Seabed Fixing	Catenary moorings with drag embedment anchors			
Export Cable	220kV HVAC			
Inter Array Cable	66kV			
Cable Burial Depth	1.5m			
Grid Connection	Aghada		Moneypoint	
Lifecycle Processes	**Co. Cork (CS1 & 1.1)**		**Co. Clare (CS2 & 2.1)**	
INST **Turbine**	Pre-installed at quayside on platform with onshore crane			

	Platform	Towed to site by tugs, pre-installed anchors by Anchor Handling Tug Supply vessels (AHTV) at site. Moorings and cables are connected	
	Cable	Pre-trenching, simultaneous lay and burial with Cable Laying Vessel (CLV)	
	Port	Cork	Shannon Foynes
	Vessels	AHTV, Tugs, CLV	
O&M	**Process**	Corrective and preventive maintenance on turbine, platform and cables. Major repairs will be towed back to shore	
	Port	Cork	Fenit & Shannon Foynes
	Vessels	AHTV, CTV, SOV, CLV, Diving Support Vessel (DSV), Tugs & ROV	
DECOM	**Process**	Reverse of installation	
	Port	Cork	Shannon Foynes
	Vessels	AHTV & Tugs	
	Disposal	Recycling & Landfill	

The rest of this document synthesises the research reports produced for each of the individual work packages:

- Hastings, R., Dinh, N., Murphy, J., and Cummins, V. (2020a). *OPFLOW Desktop Review- Final report on Work Package 1*. Internal work package document.
- Hastings, R., Dinh, N., Murphy, J., and Cummins, V. (2020b). OPFLOW *D2.2: Technology Review - Review report on floating wind platform technologies and recommendations.* Internal work package document.
- Hastings, R., Dinh, N., Murphy, J., and Cummins, V. (2020c). *OPFLOW D2.3 - Technology Review- A review report on offshore wind turbine technologies, selection methods and recommendations.* Internal work package document.
- Hastings, R., Devoy, F., Dinh, N., Murphy, J., and Cummins, V. (2020d). OPFLOW *Final Report for Work Package 3*. Internal work package document.
- O'Hanlon, Z., O'Hagan, A.M. Cummins, V. 2020. *OPFLOW FLOW Consenting Pathways.* Internal work package document.
- ORE Catapult, 2020a. *Financing and Procurement Options for Floating Offshore Wind Pre-Commercial Demonstration Projects - Final report for the OPFLOW Project.*
- ORE Catapult, 2020b. *Floating wind demonstration support mechanisms - A summary report for the OPFLOW project*.

The subsequent sections provide an overview of the Zones of Potential identified by the GIS work (Section 2); the Technology Review (Section 3); and the Critical Enablers (Section 4).

Section 2: Zones of Potential

2. Zones of Potential

WP1 (Hastings et al, 2020a) adopted established site selection methodologies for offshore wind (e.g. (Cradden, et al., 2016; Kim, et al., 2018; The Crown Estate, 2019a). A four phased GIS approach was used to identify potential sites for FLOW off the Cork and Clare coasts. The four phases are summarised below and conceptualised in **Figure 2.1**.

1. **Technical opportunity model**: This model identified an area of technical opportunity favourable to the development of FLOW.
2. **Hard constraints model:** The hard constraints model created an exclusion layer which included geographically defined areas protected by law or areas not favourable to the construction of a FLOW farm.
3. **Soft constraints model:** This model encompassed restrictive criteria from environmental, economic and sociocultural perspectives. It included areas important to other sea users.
4. **Zones of potential (ZOPs):** The model outputs were analysed in greater detail at this step to identify possible grid connection scenarios.

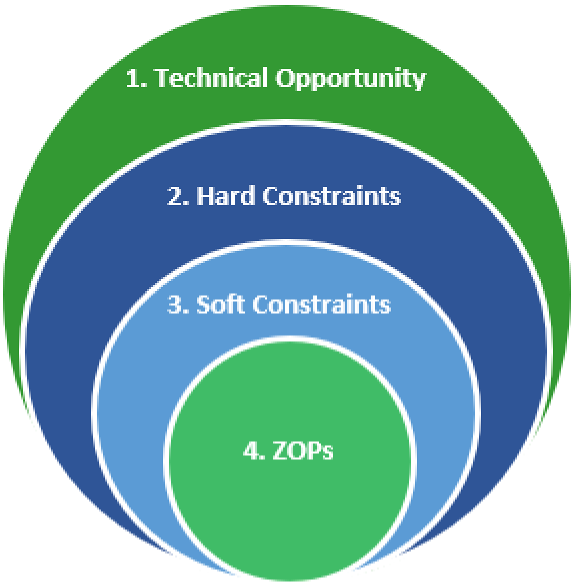

Figure 2.1: Conceptual diagram of the key phases of the constraint model which shows the reduced area at each phase. [Adapted from The Crown Estate, 2019a].

The initial study areas were defined by four factors:

- Within the Irish Exclusive Economic Zone (EEZ)
- Within 50-150m depth contours – optimum depth range for floating wind technologies and potential to be competitive to fixed offshore wind (James & Costa Ros, 2015).
- Within 50km from shore – 50km land buffer as beyond this Operations and Maintenance (O&M) strategies become challenging (Dewan & Asgarpour, 2016).

- Beyond 20km from shore – 20km buffer from shore to minimise visual impact on coastal communities and habitats (The Crown Estate, 2019a).

The 50km buffer and 50m depth contours were used to mask areas for the geoprocessing of data layers. The areas were further refined through the cable route assessment process. The data layers used for these models were all equally weighted. In a real-world scenario these layers would usually be further refined through expert consultation. An iterative approach to the constraint mapping carried out in WP1 was applied following the technology recommendations in WP2. For example, the increased distances in seascape buffers were extended from the original recommended 20km (The Crown Estate, 2019a) to 30km based on the report carried out by White Consultants (White, et al., 2020), factoring in larger turbine sizes. **Figure 2.2 and Figure 2.3 show that there are potential areas suited to FLOW projects off the Cork and Clare coasts. These zones are indicative only and are mapped here at a very high level.** For example, certain details were not factored into the assessment, including the incorporation of a substation, which would be required for a project over circa 90MW. This is dealt with later in the sensitivity analysis. The zones are influenced by the distance to port and grid connection points (for example, Aghada and Moneypoint).

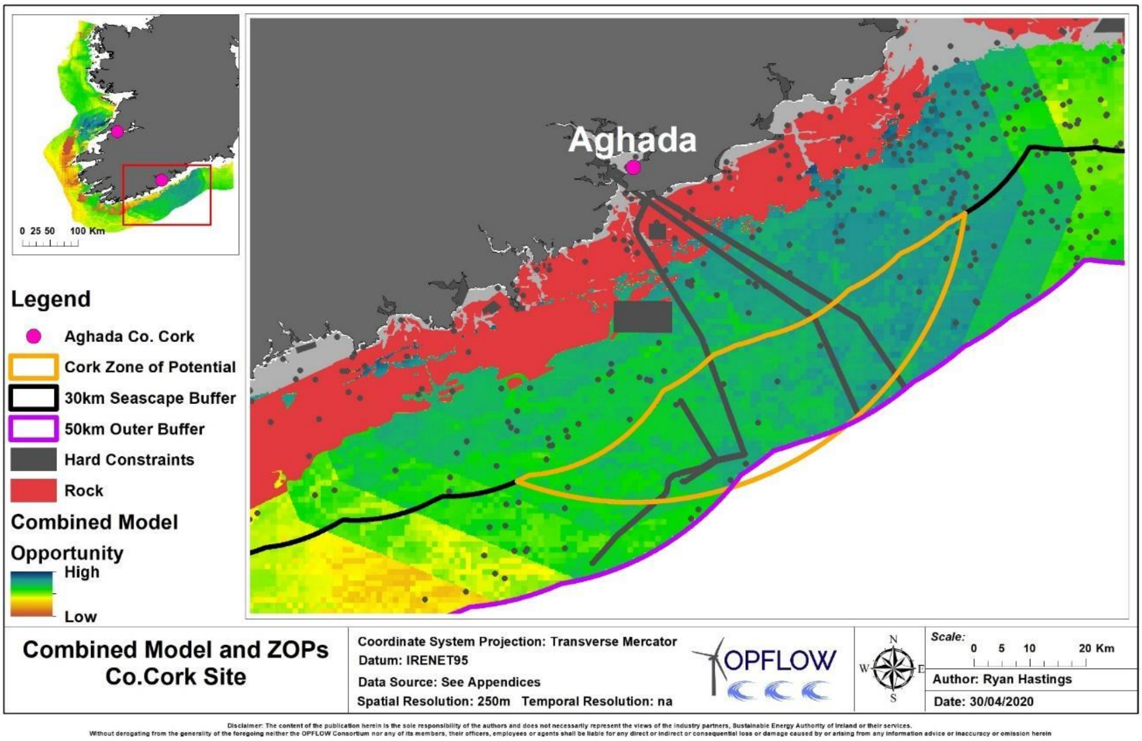

Figure 2.2: Potential areas suited to FLOW projects off the Cork coast

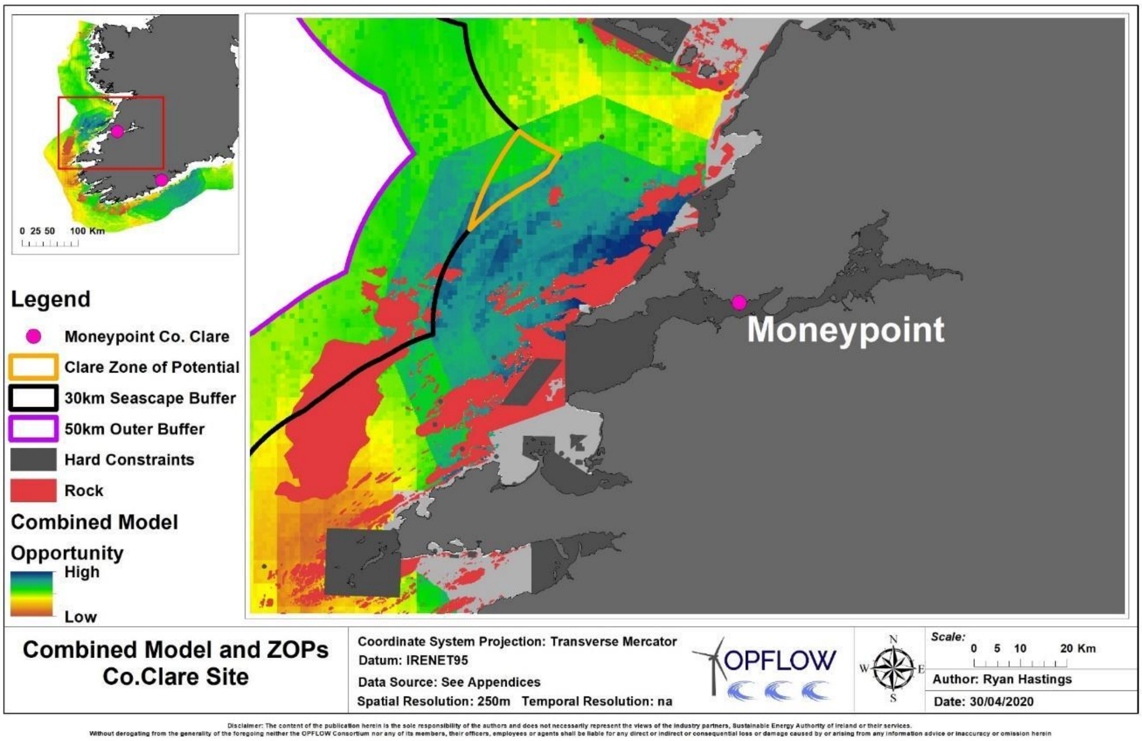

Figure 2.3: Potential areas suited to FLOW projects off the Clare coast

Section 3: Technology for a Pre-Commercial FLOW

3. Technology for a Pre-Commercial FLOW

3.1 Status and Turbine Technology Options

The largest capital expenditure for a FLOW project is the turbine and equates to approximately >40% of the total capital (CAPEX) costs (Carbon Trust, 2015) and influences the O&M (OPEX) and decommissioning (DECEX) costs. Therefore, turbine selection is a critical decision for the success of a project. FLOW foundations mostly claim to be 'turbine agnostic' and can utilise the majority of manufactured offshore turbines. The review done in OPFLOW, (Hastings et al., 2020c) showed a significant growth in turbine sizes in recent years. It is projected that by the mid to late 2020s turbines are expected to be 12-15MW capacity and by 2030 larger 20MW turbines are expected to be commercially available (US DOE, 2019). Currently, the largest turbine installed on a floating platform is the V164 8.4MW by MHI Vestas on the WindFloat concept in the WindFloat Atlantic project (Principle Power, 2019). There are significant benefits to using larger turbines (i.e. increased power extraction per unit of area, non-linear scaling of MW/tonne of steel, and reduction in overall costs, O&M and environmental impact, including carbon footprint) yet there are still initial challenges (i.e. increased height requires increased distances from shore for visual intrusion, stronger wind resource required, increased loads on platform and moorings, increased height and weight for installation).

Three main suppliers (i.e. Siemens Gamesa, MHI Vestas and GE Renewables) dominate the market. Siemens Gamesa has just announced that their new SG 14-222 DD offshore wind turbine, which has a nominal power of 14MW but, with assisted power boost of 15MW, will be commercially available by 2024 (Siemens Gamesa, 2020) as seen below in **Figure 3.1**. The strong growth in demand for wind turbines may lead to demand and supply challenges.

Figure 3.1: Siemens SG 14-222 DD (Siemens Gamesa, 2020)

A key challenge for research in offshore wind financial modelling is the lack of available technical specifications as they are confidential. To overcome this reference turbines have been developed for research purposes by agencies such as the US National Renewable Energy Lab (NREL). The reference turbines provide detailed technical specifications and are generally validated by industry. **NREL released the 15MW prototype turbine to be used for modelling foundations and they used both a fixed foundation and a semi-sub (NREL, 2020). The OPFLOW model used reference turbines by NREL.**

3.2 Status and FLOW Foundation Options

Using the optimum platform is an effective way of reducing costs for FLOW projects (Gentils, et al., 2017). Platforms are considered the second highest cost of CAPEX after turbines to a FLOW project (Carbon Trust, 2015). Furthermore, **there are approximately 40 different foundation concepts for FLOW (Carbon Trust, 2018). Lack of harmonisation is believed to be a contributing factor for slowing the development of FLOW (Leimeister, et al., 2018)**. The industry is predicted to only consider a few of the leading designs emerging from European and US companies (Carbon Trust, 2018). Thus, **there is a need to develop an effective methodology for identifying leading designs and selecting a design most suitable to a specific site.**

Forty-nine variations of FLOW concepts, (broadly classified into Barge, Semi-sub, SPAR, TLP and Hybrid) were systematically reviewed by the MaREI team via an elimination matrix in the OPFLOW project (**Appendix 1 Table 6.1 and 6.2**). The process was based on proven technology (focused on TRL8+ based on a technology that has been tested in an operational environment that could reach TRL9); site specifics (operational draft with respect to site depth); and supporting infrastructure (installation port navigational depth in relation to a technology's quayside and towing requirements). (Full report Hastings et al, 2020b).

The review indicated that **a semi-submersible (semi-sub) platform is presently a viable FLOW technology option for both study sites (Co. Cork Coast and Co. Clare Coast). However, it should be noted in the future after more concepts have been tested in an operational environment, both Hybrid and Tension Leg Platforms (TLPs) could also be viable options for each location.** The site specifics of both locations further limited the platform technology choice. For example, for both locations some SPAR concepts would not be feasible due to minimum depth requirements in ports. Technologies that offered full setup at quayside were determined to be most advantageous. With relevant attributes in terms of technology readiness and water depth requirements, the profile of the WindFloat Gen 3 foundation was selected for analysis. According to Principle Power (2019) the next generation of WindFloat is believed to be able to support turbines from 6-15MW. This version is believed to be selected for the Redwood Coast (150MW) and Progression South (400MW) projects in the US (QuestFWE, 2020), and on the Eoliennes Flottantes du Golfe du Lion project. This attribute also made it relevant to the SG 14-222 turbine in the OPFLOW analysis.

Section 4: Enabling Mechanisms

4. Enabling Mechanisms

This section aims to provide greater understanding of financing, procurement and consenting options in support of floating offshore wind (FLOW) pre-commercial demonstration projects for policy makers, and to estimate the cost of providing financial support for pre-commercial demonstration projects of different sizes. The work undertaken in OPFLOW included ORE Catapult, 2020a; ORE Catapult, 2020b, O' Hanlon et al., 2020).

A review of FLOW demonstration support mechanisms was initially undertaken by ORE Catapult. **The summary of FLOW offshore wind procurement in selected countries, undertaken as part of this work, is outlined below, presenting insights from mechanisms such as open awards (Scotland), auctions (France), and a government-led process (Japan)** (ORE Catapult, 2020b).

4.1 Scotland's open award (no auction)

Scotland has been at the forefront of floating offshore wind and is home to the world's first commercial floating offshore wind farm, Hywind Scotland. Early projects benefited from attractive revenue support, receiving 3.5 SROCs (Scottish Renewables Obligation Certificates) per MWh. This is equivalent to approximately £171/MWh (€190/MWh) in 2019 terms. The ROC scheme (in Scotland and UK-wide) came to an end in October 2018. Scotland's open award (no auction) under the previous scheme has driven initial deployment, but the lack of formal supply chain plans under that scheme has put the focus going forward on local economic benefit.

Any projects without at least the first tranche of capacity installed would not be eligible for ROC support. This led to the Kincardine project adapting plans and procuring the retired WindFloat One 2MW turbine to be commissioned in September 2018 just in time to receive ROC accreditation with a further five 9.5MW turbines being added under the same scheme (September 2020). No other projects beyond Hywind Scotland and Kincardine have been able to accredit under the 3.5 ROC scheme.

The ROC scheme has been replaced by the Contracts for Difference (CfD) auction mechanism. Initially, floating wind had to compete with fixed bottom projects in auctions for revenue support. However, an ongoing consultation is looking at ring fencing a pot of funds for innovative projects including floating wind.

The success of the Hywind Scotland project was due to a combination of excellent wind conditions; secure and sufficient revenue support; an established and stable offshore wind consenting regime; an experienced and financially strong project developer; and supportive national government.

4.2 France's 2015 tender (auction)

The 2015 auction was well-subscribed with a generous tariff, but the lengthy consenting process and local supply chain challenges means the 96MW procured will only come online in 2022. In 2015, the French Environment and Energy Management Agency (ADEME), launched a tender for floating wind installations at four sites. ADEME committed €150 million for the projects, with €50 million in subsidies and €100 million for loans.

The tender was designed to promote deployment of more than one technology and over more than one location. These projects benefit from index-linked revenue support starting at €240/MWh for 20 years. The price awarded may be revised downward if the projects exceed specific profitability metrics. An integral element of French tender rounds is the supply chain plan, which forms part of the scoring of bids. The bidder sets out aspects such as use of new factories based in France; job creation; amount of business given to French SMEs; training to be provided. The four projects are Eoliennes Flottantes du Golfe du Lion (Ocean Winds); EolMed (Total); Groix and Belle Ile (EOLFI, CGN and Banque des Territories); and Provence Grand Large (EDF). As mentioned previously, France is now gearing up for three 250MW FLOW auction rounds. It aims to become a "world leader" in floating offshore wind, first offering a 250MW site off south Brittany in 2021, with a target price of €120/MWh, and then two 250MW projects in the Mediterranean in 2022, when it sees prices falling to €110/MWh.

4.3 Public investment in Japan

Japan has provided significant public investment, but this has potentially hindered the natural commercially led development of the industry which appears to have stalled to some extent. Problems arose with the approach to supply chain, with concepts driven from limited expertise/experience but requirements for high local content. Japanese projects have benefited from a feed-in tariff since 2014 for offshore wind. The tariff is set at 36JPY/kWh (€300/MWh). Despite this, offshore wind has struggled to grow for several reasons including limited grid capacity, delays to environmental assessments and opposition from fisheries. Arguably, the Japanese approach has not been successful given the lack of progress beyond individual demonstrator turbines and the low levels of electricity generation achieved.

This year the Ministry of Environment has commenced work on several zoning projects for offshore wind energy development (O'Hagan, 2020).

4.4 Procurement Options

There are a number of options potentially available for financing and procurement of pre-commercial FLOW projects. The preferred option will depend on the desired outcome from funding the project(s). As extreme examples, if the key policy driver is maximum FLOW capacity, then a large amount of public funding with low qualification criteria may be pursued; if the key driver is low-cost procurement then a competitive auction process is likely to be more effective. However, the drivers and resulting policy choices are seldom as clear-cut as this. Each option has advantages and disadvantages and the appropriate approach depends on the desired outcomes from funding pre-commercial projects. **The differences between government-led (Japan); competitive auction (France) and fixed-price open award (Scotland) are presented in Table 4.1. Based on this analysis, a competitive auction is the preferred method for procuring pre-commercial FLOW capacity**. Auctions are not a panacea. There is a minimum viable threshold for a competitive auction to work – (e.g. the cost of a 33Kv or 66kv cable is fixed and needs to be overcome. Grid connection charges have created issues for viability of projects in the past).

Table 4.1 Procurement Options Assessment Matrix (Source: **ORE Catapult, 2020a**)

	Government-led (e.g. Japan)	**Competitive Auction (e.g. France)**	**Fixed-price open award (e.g. Scotland)**
Competitiveness	**Low** High levels of public funding have led to high costs and lack of commercial drive	**High** Competitive process drives low-cost bids from the early stages of industry life	**Low** Capacity awarded based on non-cost criteria (but project must be economic)
Market Signals/Stimulation	**Low** No clear market signal of private sector opportunity	**High** Recognised market mechanism with reputable process	**Medium** High levels of support may not be sustainable; not clearly repeatable process
Supply Chain and Economic Development	**Medium** Potential to promote local technology but may be anti-competitive	**Medium** Favour low-cost over all other factors; potential for more balanced approach	**Medium** Mainly at project developer discretion; potential for more balanced approach
Energy Security	**Low** Lack of market signal does not support long-term deployment	**High** Positive market signal and competitiveness support long-term deployment	**Medium** Lack of clear route to future process could hinder long-term deployment
Decarbonisation	**Low** Lack of market signal does not support long-term deployment	**High** Positive market signal and competitiveness support long-term deployment	**Medium** Lack of clear route to future process could hinder long-term deployment
Reflective of Future Procurement Process	**Low** Not consistent with expected competitive process in line with RESS1	**High** Consistent with expected competitive process in line with RESS1	**Low** Not consistent with expected competitive process in line with RESS1

In general, grants and government-backed finance are used to support innovation in energy technology. Grants tend to be used for pilots (e.g. SEAI's Prototype Development Find), while public finance tends to be provided to larger scale projects that are closer to commercialisation.

In July 2020, Ireland received State Aid approval from the European Commission to operate the new Renewable Electricity Support Scheme (RESS) out to 2025. The RESS is a competitive auction-based scheme which invites renewable electricity projects to bid for capacity and receive a guaranteed price for the electricity they generate for a maximum of 16 years. The overarching policy objective of the RESS is to incentivise the development of sufficient renewable electricity generation, (i.e. from offshore wind and solar) to deliver on policy objectives and meet Ireland's RES-E (Renewable Energy Sources of Electricity) targets out to 2030. The scheme will include two auctions for offshore wind in 2022 and 2024. These are likely to be focused on supports for bottom-fixed offshore wind, and on the 'Relevant Projects' in the Irish Sea.

The Programme for Government refers to "a whole-of-government plan" that will set out "*how we will deliver at least 70% renewable electricity by 2030 and how we will develop the necessary skills base, supply chains, legislation and infrastructure to enable that. This new plan will make recommendations for how the deployment of renewable electricity can be speeded up, for example the provision and permissioning of grid connections*" (Government of Ireland, (2020) p.34).

In this context, the new OREDP provides a policy opportunity to confirm RESS as the support mechanism to subsidise pre-commercial FLOW. One option would be to create an innovation orientated RESS pot that allows for competition within a specific, expensive pre-commercial technology for a guaranteed strike price. This is examined in more detail in Section 4.5 below. For example, Innovation Contracts for Difference (iCfD) have been proposed for FLOW in the UK for more expensive emergent marine energy technologies, offering strike prices above £150/MWh (Hannon et al., 2019).

EU funding may also be an important enabler to kick-start FLOW in Ireland. The InnovFin Energy programme provides loans, loan guarantees and equity-type products to projects deemed too risky to access other sources of funding on affordable terms. For example, it was used to provide a €60m loan as part of the finance towards the 25MW WindFloat Atlantic project.

4.5 Balanced Auctions

The WP4 analysis suggests that a competitive auction is the preferred procurement option for promoting the goals for a pre-commercial demonstrator outlined above (ORE Catapult, 2020a). However, it is critical that the auction is balanced and does not focus solely on lowest cost. A mechanism which sets a price cap, above which bids will be rejected, but below which price is not necessarily the deciding factor, can help with achieving many goals at once. This is particularly important when considering early-stage technologies, which are not yet truly cost-competitive, but which hold the potential for long-term economic benefit and low-carbon energy security.

Ideally, the mechanism used for procurement of pre-commercial FLOW capacity will be the same, or at least reflective of, the mechanism to be used for longer-term commercial-scale procurement.

This allows project developers, supply chain and government to implement processes and systems applicable for long-term market participation rather than one-off, inefficient, processes. **For the OPFLOW cost analysis, it is assumed that future procurement of FLOW capacity in Ireland will use a mechanism substantially similar to the conditions set out for the first competition under the RESS.**

4.6 Pre-commercial demonstrator cost scenarios

Four potential pre-commercial sites (120MW and 300MW off the South coast and 120MW and 300MW off the West coast) have been analysed by the research team in MaREI and the outputs from this analysis used to estimate the cost of revenue support for each project (**Table 4.2** and **Appendix 2 Table 6.3**).

Table 4.2 Summary of the main results for the four OPFLOW scenarios (see previous Table 1.3 for scenarios).

Outputs	Cork Coast 120MW **CS1**	Cork Coast 300MW **CS1.1**	Clare Coast 120MW **CS2**	Clare Coast 300MW **CS2.1**
CAPEX	€477m	€961m	€541m	€1,094m
OPEX	€265m	€473m	€337m	€586m
DECEX	€29m	€72m	€67m	€157m
Salvage	€5m	€13m	€5m	€14m
Availability	91.57%	91.12%	83.78%	81.89%
LCOE	**€104/MWh**	**€77MW/h**	**€131MW/h**	**€97MW/h**

Economies of scale can be achieved with the 300MW Co. Cork scenario (CS1.1), which has the lowest LCOE, followed by the 300MW Co. Clare scenario (CS2.1). The highest LCOE value is the Co. Clare 120MW scenario (CS2). This is to be expected with more challenging Atlantic conditions and increased distances from ports. The 120MW Co. Cork scenario (CS1) is close to the 300MW Co. Clare scenario (CS2.1) despite having a reduced scale. In general, it can be seen that the Co. Cork location is more favourable than the Co. Clare location irrespective of the scale that is implemented. **Appendix 2 Table 6.3** gives a more detailed breakdown of OPFLOW scenarios results for Co. Cork (CS1 & 1.1) and Co. Clare (CS2 &2.1). The main reasons the Co. Cork scenarios have a lower LCOE are as follows:

- The substructure and cables are more expensive for Co. Clare (distance and depth)
- The distance is greater from the installation port and there is a more challenging wave regime in Co. Clare
- The met-ocean conditions affecting the availability of vessels for the lifecycle processes
- Increased downtime due to less accessible site -vessels waiting for suitable weather windows

The Co. Cork 120MW LCOE of €104 /MWh and 300MW LCOE of €77/MWh are both competitive results. The Co. Clare 120MW LCOE of €131/MWh and 300MW LCOE of €97/MWh are also

competitive results but marginally higher than anticipated for the 300MW scenario. The reduction in LCOE from 120-300MW is approximately 26% showing an economy through scale.

4.6.1 Sensitivity analysis

Sensitivity analysis was carried out to determine the impact of adding an offshore substation to all scenarios. The difference in results can be seen below in **Table 4.3**.

Table 4.3: Sensitivity analysis of scenarios through the inclusion of offshore substations

Outputs	Cork Coast 120MW **CS1**	Cork Coast 300MW **CS1.1**	Clare Coast 120MW **CS2**	Cork Coast 300MW **CS2.1**
LCOE	€107/MWh	€81MW/h	€133MW/h	€102MW/h
Base Case LCOE	€104/MWh	€77MW/h	€131MW/h	€97MW/h

The inclusion of offshore substations increased the LCOE due to the increase in CAPEX. This was more pronounced in the 300MW scenarios. There was a reduction in CAPEX in the 120MW scenarios due to reduced export cable costs. Costs could be optimised at both locations by making components such as turbines more reliable. Increased vessel fleet capabilities are also possible - using new Special Purpose Vessels (SPV) which are operational in up to 4m Significant Weight Height (Hs) (commercially available 2022) and utilise hydrogen propulsion (expected commercially available 2025) (Edda Wind, 2020) or even helicopters which are less affected by wave heights.

4.7 The Cost of Support

The cost of support has been modelled assuming a 15-year strike price. While the strike price is primarily driven by project costs and required returns, there is a risk associated with the uncertainty in future power prices beyond the 15-year fixed strike price period. If the project developer has a view that power prices will be low post-year 15, they will seek a higher strike price to generate higher revenue in the shorter term to make up for the expectation of lower long-term prices. Conversely, if the developer has a view that power prices will be higher post-year 15, they may accept a lower strike price. These are shown in **Table 4.4**.

Table 4.4. Strike price based on long-term market view (€/MWh) [Source: **ORE Catapult, 2020a**]

Developer Market View	***Units***	Cork Coast 120MW **CS1.0**	Cork Coast 300MW **CS1.1**	Clare Coast 120MW **CS2.0**	Clare Coast 300MW **CS2.1**
Expect low post-Year 15 market prices – High Strike Price Case	*€/MWh*	120	85	150	110
Expect high post-Year 15 market prices – Low Strike Price Case	*€/MWh*	115	80	145	105

To calculate the lifetime cost of financial support for the projects, the ORE Catapult team incorporated a view of future electricity prices for the Irish Single Electricity Market (SEM) based on the historic price uplift versus British wholesale electricity prices, using bi-annual data sourced from the Eurostat Data Explorer (**Table 4.5**). **Revenue support analysis has shown that the greatest uncertainty is lack of a clear forecast of Irish electricity prices.** (Full model parameters in ORE Catapult, 2020a).

Table 4.5. Wholesale electricity price forecast for Irish market (€/MWh, 2020real) [Source: **ORE Catapult,2020a**]

Wholesale Electricity Price	**Units**	**2025**	**2030**	**2035**	**2040**
High Case	*€/MWh*	80.30	81.54	79.04	79.04
Low Case	*€/MWh*	51.98	53.29	60.29	60.29

To provide a view on the range of possible support costs, four scenarios were modelled for each site, varying wholesale electricity price strike prices between the high and low shown in **Figure 4.1** below.

Worst case – developers have a view there will be low market prices post year 15 so need high strike prices; actual power prices are low during the subsidy period (regardless of what happens post-Year 15) and so the cost of subsidy is high.

Best case – developers have a view there will be high market prices post year 15 so need lower strike prices; actual power prices are high during the subsidy period (regardless of what happens post-Year 15) and so the cost of subsidy is low.

Mid case 1 – developers have a view there will be low market prices post year 15 so need high strike prices; actual power prices are high during the subsidy period (regardless of what happens post-Year 15) and so the cost of subsidy is somewhere in between.

Mid case 2 – developers have a view there will be high market prices post year 15 so need low strike prices; actual power prices are low during the subsidy period (regardless of what happens post-Year 15) and so the cost of subsidy is somewhere in between.

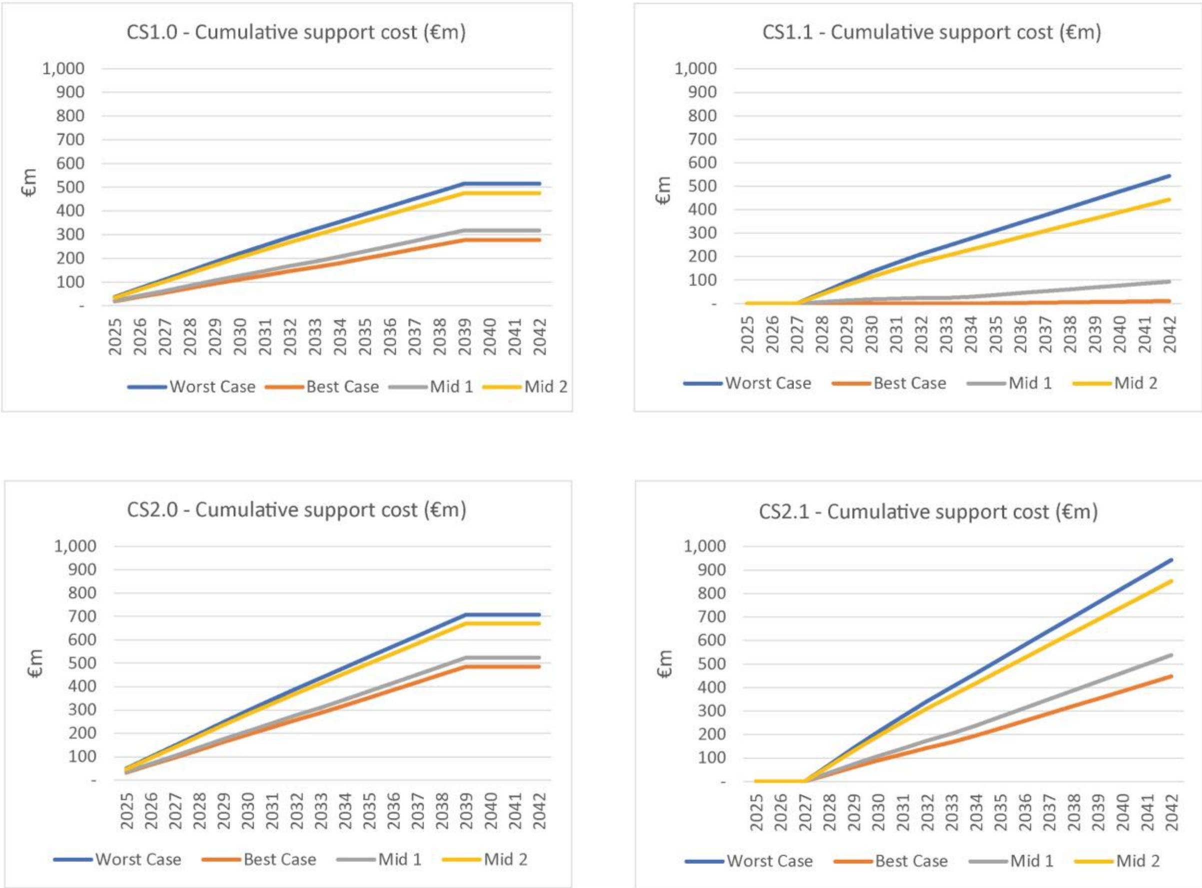

Figure 4.1 Cumulative support cost for the four scenarios modelled for each site (CS1.0 120MW Cork Coast; CS1.1 300MW Cork Coast; CS2.0 120MW Clare Coast; CS 2.1 300MW Clare Coast)

The ORE Catapult analysis (Figure 4.1 and Table 4.6) showed that the 300MW Cork coast site would always be the lowest cost per MWh and, depending on market prices, may even be lowest in absolute terms (in fact close to subsidy-free if market prices are sufficiently high). This is a key finding as it suggests that the difference in cost per MWh between the two Cork scenarios is great enough to make procuring 300MW off the Cork coast more cost-effective than procuring 120MW in that location at most price points, and only marginally (5%) more expensive in the worst case. **However, there will be practical considerations in terms of consenting, public acceptance and supply readiness with a pre-commercial project of 300MW.**

The 120MW Cork coast site was lowest cost in a low market price scenario and second to the 300MW site in all other scenarios. **The cost of supporting the 120MW Cork coast site ranges between approximately €300m and €500m over the 15-year lifetime.** Table 4.6 shows the average revenue support cost per MWh produced during the 15-year support period. In the Worst-Case Scenario, the 300MW Clare Coast project has the highest total revenue support cost of the sites at €943m, however on a per MWh basis, the 120MW Clare Coast site has a higher support cost of €93.44 per MWh (versus €51.81 per MWh for the larger site).

In the Worst-Case Scenario, the highest annual support cost for any scenario is €72m, associated with CS2.1 in 2029. In the Best-Case Scenario, the highest annual support cost is €33m, associated with CS2.0 between 2035 - 2039.

The significant differences between the cost of supporting each project in the high and low electricity market price cases highlights the need to form as clear a view as possible on future market prices in order to narrow the range of expected exposure for the public purse.

Table 4.6. Average Revenue Support Cost of Pre-Commercial Floating Wind Case Studies (€/MWh, 2020 real)

Average Revenue Support Cost	Units	Cork Coast CS1.0	Cork Coast CS1.1	Clare Coast CS2.0	Clare Coast CS2.1
Worst Case	*€/MWh*	63.44	26.81	93.44	51.81
Best Case	*€/MWh*	34.13	0.53	64.13	24.57
Mid 1	*€/MWh*	39.13	4.59	69.13	29.57
Mid 2	*€/MWh*	58.44	21.81	88.44	46.81

4.8 Consenting

The consenting system is currently under reform. Efforts to streamline the process have been introduced through the Marine Planning and Development Management (MPDM) Bill (2019 version) for offshore developments. The Bill aims to introduce a requirement for a Planning Interest and Maritime Area Consent to be granted prior to developing offshore. Mapping out legislative and development timelines as in Figure 4.2 under the MPDM Bill taking into consideration respective grid and RESS requirements, indicates a timeline for a prospective offshore wind project to 2030. **Assuming the new marine consenting legislation is enacted next year, it will be challenging, but possible to get FLOW projects 'in the water' this decade.** The hypothetical timeline depicted below, envisages a FLOW RESS auction in 2025. This would be additional to the two RESS auctions currently planned for offshore wind in 2022 and 2024, which will focus on bottom-fixed projects. **A dedicated FLOW auction would have the advantage of distinguishing FLOW as an emerging technology to avoid competition**

with established bottom-fixed counterparts. This would allow projects to commence operations in 2028, which is the later of the two timelines modelled above. For a project to commence in 2025, (as per the more ambitious timeline outlined in Table 1.3), **key milestones related to the enactment of the consenting legislation, would need to be met, and corresponding regulatory processes would need to be in place.**

The experience gained from the process of achieving approvals on **State Aid rules from the EU,** for the first two offshore wind auctions for Ireland, should be of value. Much can also be learned from other countries, such as the French FLOW auctions coming onstream in 2021. The question is how fast Ireland, which has been a relatively slow starter, can catch up. According to Judge et al., (2020), a critical issue is investment in more government personnel to enable capacity building in both development planning and consenting.

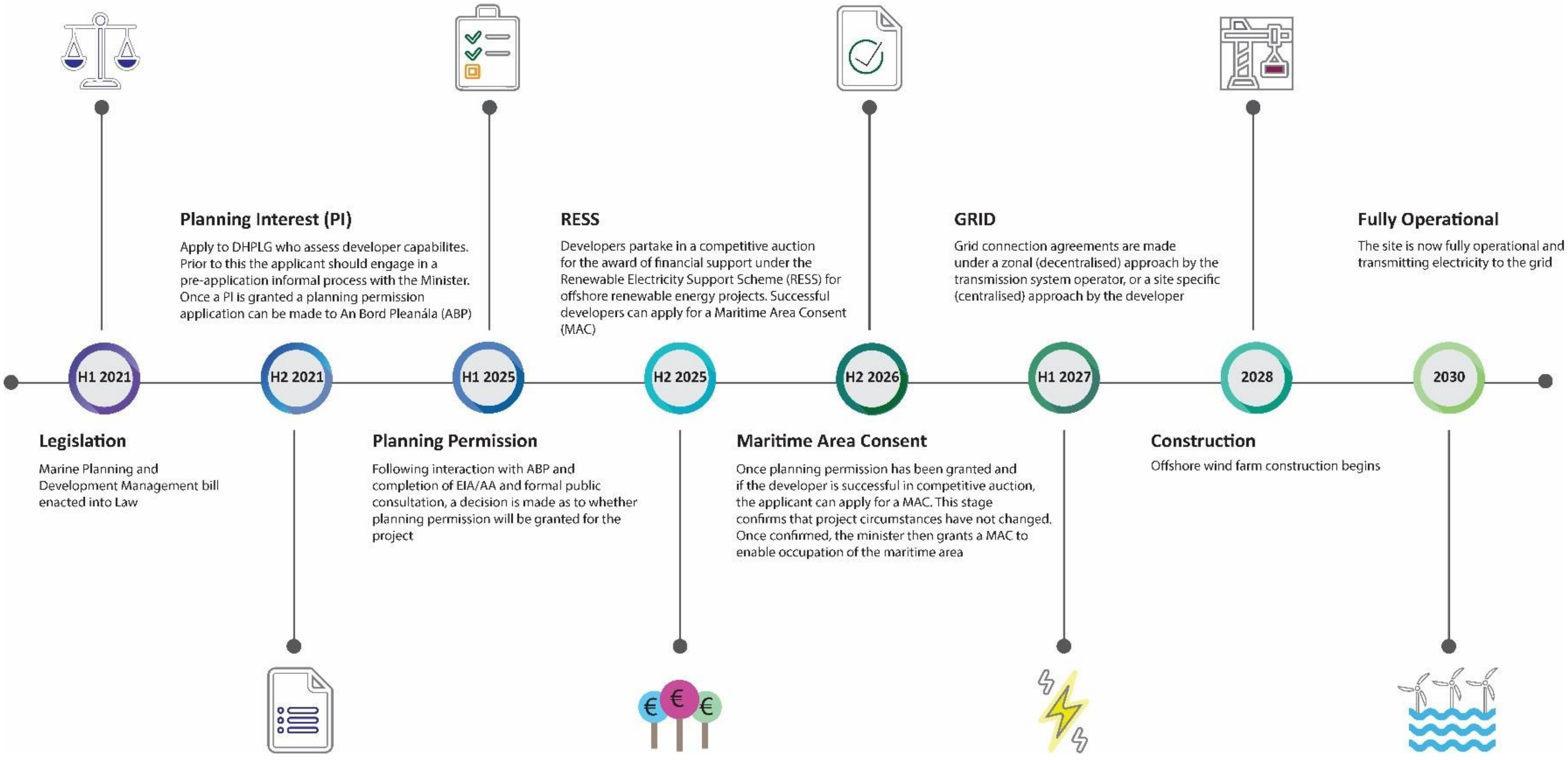

Figure 4.2: Hypothetical timeline under the Marine Planning and Development Management Bill 2019. H1 (Half-year January-June) and H2 (Half-year July-December)

In reviewing pathways for pre-commercial projects, Head 31 of the MPDM Bill states that '*due consideration has been given to the maturity and costs of technologies recognising that specific provisions may be required for offshore test sites*' (DHPLG, 2019). Given that the MPDM Bill will be open to a consultation period, there are opportunities to suggest amendments to this provision in order to ensure FLOW pre-commercial demonstration projects are captured. This could distinguish between 'test' as solely pilot-stage projects fulfilling a need to prove the technology and 'demonstration' projects as those at pre-commercial stages providing the route to fully commercialised projects. There may be scope within the proposed Strategic Marine Activity Zones (SMAZ's) to cater for demonstration sites for pre-commercial FLOW in the first instance. However, the question of the scale of demonstration sites is a question that arises here.

Stakeholder engagement is particularly important given the issue of community support where communication on the type of project being proposed could have long-lasting effects. There is also scope for clarification within the National Marine Planning Framework (NMPF) in addressing distinctions between 'pilot- test sites' and 'pre-commercial demonstrators' to ensure legislative and policy coherency.

Policy considerations under the full review of the OREDP (scheduled 2020/2021) should examine the implementation of these locations for pre-commercial projects off the south and west coasts, the scale of such projects, and the support mechanism.

The analysis of Strengths, Weaknesses, Opportunities and Threats (SWOT) below (**Table 4.7**) shows the broader range of domestic and international issues that need to be factored into the decision-making process, in addition to the above.

Table 4.7 SWOT analysis of a progressing a pre-commercial demonstration project in Ireland

Pre-commercial demonstrator **strengths** ● Enables Ireland to accelerate entry to FLOW to realise energy and enterprise opportunities ● Kicks off the development of the local supply chain ● Takes strategic advantage of Ireland's abundant offshore wind and maritime resources	Pre-commercial demonstrator **weaknesses** ● Needs to be developed at a scale that will be impactful for technology demonstration – requiring public supports ● Potential delays with MPDM Bill through the Oireachtas may have implications for project consenting ● Needs a social licence to operate ● Not a panacea for planning and development of floating offshore wind, but a vital first step
Pre-commercial demonstrator **opportunities** ● Positive signal to the international marketplace ● Promotes investment in renewables and ability to decarbonise ● New Green Deal funding from Europe ● Opportunity to be ambitious and to signal commitment to pre-commercial steps at circa 100MW and 300MWs ● Public co-investment with the private sectors in strategic port assets	Pre-commercial demonstrator **threats** ● Failure to trigger local supply chain opportunities ● Economic decline as a result of COVID may limit revenue support available for FLOW demonstration ● Narrow window of opportunity: Ireland may fail to move fast enough, losing interest from international investors in Ireland as an attractive emerging market

5 Discussion, Conclusions and Recommendations

5.1 Discussion and conclusions

This project asked, is there merit in a pre-commercial demonstration project for FLOW in Ireland; are there suitable locations; and what scale would be appropriate? There is a strong case for a pre-commercial demonstrator. In fact, it is a logical next step, as Ireland is intent on FLOW as part of the energy mix, as outlined in the Programme for Government (Government of Ireland, 2020). However, a position needs to be taken, as the window of opportunity is narrowing, in terms of time available before FLOW becomes fully commercial. This research provides some insights into zones of potential off the Cork and Clare coasts. These are by no way exclusive of other potential locations, but there is a strong logic that favours these locations. Initial analysis undertaken through this study indicates that these strategic locations are viable for FLOW. As such, there is potential to consider these areas as priority FLOW areas, by specifying demonstration zones in the MPDM Bill, or considering these sites in the context of a future Strategic Marine Activity Zone.

The technology options for FLOW are moving fast. The selection of turbine and foundation technology is ultimately a factor that is decided upon by the developer at the project design stage. However, it is clear from the research that there are available, deployable technology options for both the Cork and Clare sites. Because of the challenging metocean conditions in the Irish part of the Celtic Sea, and particularly in the Atlantic, technology demonstration here, in these conditions, may be appealing to technology developers, to unlock the next FLOW frontier. This provides a niche for the Irish supply chain (e.g. remote monitoring for operations and maintenance building on IT skills in the country).

With things moving so fast, (since the proposal was submitted to SEAI in Feb 2019), the research team had to deliberate on whether there was value in a pre-commercial initiative or whether Ireland's entry to FLOW might ultimately be at a commercial level. The value proposition *to* Ireland concerns the benefits of offshore wind that have been captured elsewhere and provides the context to this report (Cummins & McKeogh, 2020; Kandrot et al., 2020, Leahy et al., 2020). The value proposition *from* Ireland concerns technology demonstration in more challenging marine environments than previously achieved elsewhere in the world.

The research has indicated the level of financial support required from the government to facilitate pre-commercial project scenarios. It could be argued, that an ambitious approach is needed to ensure Ireland meets its climate targets, particularly given the Supreme Court ruling (31st July 2020), which found that the government's National Mitigation Plan falls "well short" of being specific enough to provide the transparency required to comply with the Climate Action and Low Carbon Development Act 2015. An ambitious approach could pave the way for not one, but two sequential auctions, one for circa 100MW and one for circa 300MW. This would pave the way for supply chain development. An ambitious approach would also designate, not one, but two potential pre-commercial demonstration zones, dealing with the Celtic Sea and the Atlantic respectively. The research has shown that the economics for the 300MW Cork site appear attractive and may cost less than what may have been expected. Consenting, public acceptance and supply chain readiness are likely to be more critical if an enabling project of 300MW is to be seriously considered for support.

In each of the above potential pathways, a competitive auction is envisaged. However, there is scope for a hybrid approach to the procurement of such an initiative that might provide for a blend of financing, including, perhaps funding from the European Investment Bank (EIB), or other European funds.

Alternative routes to market for FLOW (e.g. the production of green hydrogen from electricity generated by floating wind), have not been considered in this study. Further research should be undertaken to identify the costs and support mechanisms for FLOW and hydrogen production facilities.

The analysis undertaken for the scenarios assessed in this study was limited by data quality and availability. For example, mapping the Zones of Potential was done at a very high level, and was limited by a lack of data such as geotechnical and geophysical layers. The bias towards the Cork and Clare coasts was influenced by the hypothesis to be tested, which suggested these as strategic locations for FLOW. The outcome was positive, but the research was limited in its focus, with no other comparative analysis. Data limitations also influenced the financial modelling. For example, forming a clear view of future wholesale electricity market prices is critical to estimating the public cost of support and is a key recommended focus for further work. The assumptions made on key dates for modelling purposes (2025 and 2028) were based on a best guess at the time. It appears that progress is being made towards the enactment of the Marine Planning and Development Management Bill, but timelines for reaching Planning Interest milestones are, as yet, details that are unknown.

The strengths, weaknesses, opportunities and threats (SWOT) associated with a pre-commercial demonstration project show that there are a broad range of strategic issues that need to be considered from a national interest perspective. These include externalities such as global economic downturn as a result of the COVID pandemic, or conversely, the response to rebuilding the European economy through the New Green Deal. Most of the factors that need to be considered are at a national level, with multiple pathways open for policy interventions (e.g. MPDM, NMPF and OREDP). However, the biggest influencing factor is likely to be decisions on the scale of support palatable to government. The focus of this study was on sites, scales and supports. There are many other factors that need to be factored into the decision-making process, such as port capacity, grid and community engagement.

5.2 Recommendations

Based on the analysis in this report, the following are suggested as key considerations in designing a mechanism for procurement and site selection for pre-commercial FLOW capacity in Ireland:

A balanced auction mechanism (where cost is not necessarily the main success criterion) appears the preferred procurement mechanism. This provides the required market signals for sustainable deployment and promotes the appropriate level of price competition while recognising that value from FLOW projects is not just related to lowest cost achievable today.

Short-term cost for long-term benefit. Procurement of pre-commercial scale projects will (almost invariably) be more expensive than procuring more established technologies. This initial increase in cost needs to be viewed in the context of it being a relatively small contributor to overall system costs and can be justified when considering longer-term economic and system benefits of new technologies.

Agree specific goals and targets with policy makers for key auction elements. Cost of supply will always be an important factor as this has an impact on consumer electricity rates and/or state subsidy levels. However, very low strike prices may stifle local supply chain development, as local manufacturing companies new to the sector will struggle to compete with more established players overseas.

Provide a consenting framework that can facilitate pre-commercial demonstration projects. Ensure that FLOW projects can be enabled through the enactment of the MPDM Bill, including prioritisation of FLOW demonstration areas in the context of a SMAZ.

Act now. The cost of floating wind will take several years to reach parity with bottom-fixed, so capacity deployment should be staggered through the 2020s. Delaying too long will risk missing national climate/renewables targets, and slow development of expertise and the supply chain.

Use a pre-commercial FLOW auction(s) as a springboard for wider FLOW deployment. A transparent auction process that remains consistent between pre-commercial and commercial sites will attract developers and investors into the sector. A pre-commercial site(s) will also provide invaluable information on turbine performance, metocean data and grid integration. Combining this data with the AFLOWT floating project in Co. Mayo will give more clarity to support the identification of optimal sites and technology for floating wind in Ireland.

Schedule auctions with sufficient capacity and regularity to allow for local supply chain growth and attract international developers. A visible pipeline of auctions will give confidence to the sector, bolstering local SMEs and providing inward investment. This involves the unpacking of the 30GW target (e.g. 2GW of FLOW per year from 2030 as an attractive level of commitment for investors such as technology providers).

The public cost to support any of the four projects analysed in this report is most sensitive to the prices achievable on the electricity market. Forming a clear view of future wholesale electricity market prices is critical to estimating the public cost of support and is a key recommended focus for further work.

Pre-commercial project selection must consider factors including public support. The expected cost per MW and per MWh for the 300MW sites analysed are sufficiently lower than those for the 120MW sites analysed that they would cost less to support. However, consenting, public acceptance and supply readiness are likely to be more critical if a pre-commercial project of 300MW is to be considered.

6 Appendices

Appendix 1

Table 6.1 Elimination Matrix for Co. Cork site. A tick symbolises meeting criteria, a cross for elimination and a question mark for insufficient data

Elimination Matrix Co. Cork			Proven Technology	Site Specifics	Infrastructure
No.	**Concept**	**Developer**	**TRL 8+**	**Operational Depth <73m**	**Quayside Installation**
1	Advanced Spar	IHI	✓	×	×
2	AFW Tower	Nautica	×	?	×
3	Blue-H Semi	Blue H	×	?	✓
4	Blue SATH	Saitec Offshore	×	✓	✓
5	Damping Pool - Concrete 1	Ideol	✓	✓	✓
6	Damping Pool - Concrete 2	Ideol	×	✓	✓
7	Damping Pool - Concrete 3	Ideol	×	✓	✓
8	Damping Pool - Steel 1	Ideol	✓	✓	✓
9	Damping Pool - Steel 2	Ideol	×	✓	✓
10	Eco TLP	DBD Systems LLC	×	×	×
11	Eolink (Full scale)	Eolink	×	✓	✓
12	Eolink Demonstrator	Eolink	×	✓	✓
13	Floating TLP	Bluewater	×	×	✓
14	Gicon	Gicon	×	✓	✓
15	Gravity Floater	Seawind/Olav Olsen	×	✓	×
16	Hexafloat	Saipem	×	×	✓
17	Hexicon	Hexicon	×	✓	×

18	Hexicon 2	Hexicon	×	✓	×
19	Hybrid Semi-Spar	ACS Cobra	×	✓	?
20	Hywind 1	Equinor	✓	×	×
21	Hywind 2	Equinor	✓	×	×
22	Hywind 3	Equinor	✓	×	×
23	Nautilus	Nautilus	×	✓	✓
24	OO - Star	Olave Olsen	×	✓	✓
25	Pelastar	Glosten	×	×	✓
26	Poesidon P80	Floating Power Plant	×	?	?
27	SBM Windfloater	SBM Offshore	×	✓	✓
28	SCDNezzy	Aerodyn Engineering	×	✓	✓
29	SCDNezzy2	Aerodyn Engineering	×	✓	✓
30	SeaReed	Naval Energies	×	✓	×
31	SeaTwirl 2	SeaTwirl AB	×	×	×
32	SKWID	MODEC	×	?	×
33	Spinwind1	Gwind	×	?	×
34	TetraFloat	TetraFloat	×	✓	✓
35	TetraSpar	Stiesdal	×	✓	✓
36	Toda Spar	Toda	✓	×	×
37	Tri-Floater	GutoMSC	×	×	✓
38	Triple Spar	DTU Wind Energy	×	?	×
39	TrussFloat	Dietswell	×	✓	✓
40	V Shape Semi - Shimpuu	MHI	✓	✓	✓
41	Volturn US	Umaine	×	✓	✓

42	W2Power	W2Power	✗	**?**	✓
43	Windcrete	Catalunya Univeristy	✗	✗	✗
44	WindFloat	Principle Power	✓	✓	✓
45	WindFloat Gen 2	Principle Power	✓	✓	✓
46	WindFloat Gen 3	Principle Power	✓	✓	✓
47	WindLens	Riam/Kyushu Univeristy	✗	**?**	?
48	Windsea	Force Technology	✗	**?**	?
49	X1Wind	X1Wind	✗	✓	✓

Table 6.2: Elimination Matrix for Co. Clare site. A tick symbolises meeting criteria, a cross for elimination and a question mark for insufficient data

Elimination Matrix Co. Clare			Proven Technology	Site Specifics	Infrastructure
No.	**Concept**	**Developer**	**TRL 8+**	**Operational Depth <83m**	**Quayside Installation**
1	Advanced Spar	IHI	✓	✓	×
2	AFW Tower	Nautica	×	?	×
3	Blue-H Semi	Blue H	×	?	✓
4	Blue SATH	Saitec Offshore	×	✓	✓
5	Damping Pool - Concrete 1	Ideol	✓	✓	✓
6	Damping Pool - Concrete 2	Ideol	×	✓	✓
7	Damping Pool - Concrete 3	Ideol	×	✓	✓
8	Damping Pool - Steel 1	Ideol	✓	✓	✓
9	Damping Pool - Steel 2	Ideol	×	✓	✓
10	Eco TLP	DBD Systems LLC	×	×	×
11	Eolink (Full scale)	Eolink	×	✓	✓
12	Eolink Demonstrator	Eolink	×	✓	✓
13	Floating TLP	Bluewater	×	✓	✓
14	Gicon	Gicon	×	✓	✓
15	Gravity Floater	Seawind/Olav Olsen	×	✓	×
16	Hexafloat	Saipem	×	×	✓
17	Hexicon	Hexicon	×	✓	×
18	Hexicon 2	Hexicon	×	✓	×
19	Hybrid Semi-Spar	ACS Cobra	×	✓	?
20	Hywind 1	Equinor	✓	×	×

21	Hywind 2	Equinor	✓	×	×
22	Hywind 3	Equinor	✓	×	×
23	Nautilus	Nautilus	×	✓	✓
24	OO - Star	Olave Olsen	×	✓	✓
25	Pelastar	Glosten	×	✓	✓
26	Poesidon P80	Floating Power Plant	×	?	?
27	SBM Windfloater	SBM Offshore	×	✓	✓
28	SCDNezzy	Aerodyn Engineering	×	✓	✓
29	SCDNezzy2	Aerodyn Engineering	×	✓	✓
30	SeaReed	Naval Energies	×	✓	×
31	SeaTwirl 2	SeaTwirl AB	×	×	×
32	SKWID	MODEC	×	?	×
33	Spinwind1	Gwind	×	?	×
34	TetraFloat	TetraFloat	×	✓	✓
35	TetraSpar	Stiesdal	×	✓	✓
36	Toda Spar	Toda	✓	×	×
37	Tri-Floater	GutoMSC	×	×	✓
38	Triple Spar	DTU Wind Energy	×	?	×
39	TrussFloat	Dietswell	×	✓	✓
40	V Shape Semi - Shimpuu	MHI	✓	✓	✓
41	Volturn US	Umaine	×	✓	✓
42	W2Power	W2Power	×	?	✓
43	Windcrete	Catalunya University	×	×	×
44	WindFloat	Principle Power	✓	✓	✓

45	WindFloat Gen 2	Principle Power	✓	✓	✓
46	WindFloat Gen 3	Principle Power	✓	✓	✓
47	WindLens	Riam/Kyushu University	✗	✓	?
48	Windsea	Force Technology	✗	✓	?
49	X1Wind	X1Wind	✗	✓	✓

Appendix 2

Table 6.3. Detailed summary of OPFLOW scenarios results for Co. Cork (CS1 & 1.1) and Co. Clare (CS2 &2.1)

Case study	CS1	CS1.1	CS2	CS2.1
Site location	South coast	South coast	West coast	West coast
Start date-installation	2025	2028	2025	2028
Farm lifecycle	25 years	25 years	25 years	25 years
Farm capacity	120MW	300MW	120MW	300MW
Turbine	8 x 15MW	20 x 15MW	8 x 15MW	20 x 15MW
Substructure	Semi-sub	Semi-sub	Semi-sub	Semi-sub
Discount rate	8%	7%	8%	7%
Costs (NPV)	€595,189,717	€1,190,215,347	€695,607,178	€1,386,852,451
Energy (NPV) (MWh)	5,720,546	15,529,028	5,316,053	14,329,492
LCOE (€/kWh)	€0.10	€ 0.08	€0.13	€0.10
LCOE (€/MWh)	€104.04	€76.64	€130.85	€96.78
CAPEX (incl. installation) (€/MW)	€3,977,673	€3,202,905	€4,508,436	€3,647,762
Installation (€/MW)	€269,896	€180,119	€547,299	€413,774

OPEX (undiscounted) (€/MW/yr)	€88,194	€63,081	€112,379	€78,198
DECEX (undiscounted) (€/MW)	€238,058	€240,856	€558,477	€524,750
Salvage revenue (undiscounted) (€/MW)	€39,226	€42,588	€43,634	€47,375
Farm lifetime energy production (MWh)	13,319,673	33,134,062	12,617,408	30,831,463
Availability (time-based)	92.36%	91.92%	84.63%	82.96%
Availability (energy-based)	91.57%	91.12%	83.78%	81.85%
Capacity factor	50.68%	50.43%	48.01%	46.93%

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