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Floating offshore wind – an overview of marine spatial planning and the needs of the industry

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Abstract. The International Energy Agency (IEA) Wind Task 49 aims to accelerate the commercialisation of floating wind. Work package 4 of the task analyses and incorporates the views of key stakeholders to ensure the Task is aligned with industrial needs. Work package 4 is broadly split into innovation management and marine spatial planning (MSP). The innovation management section evaluates the potential social, environmental and economic impact of floating wind innovations by surveying a multidisciplinary group of stakeholders to ask them to compare the potential impact of identified innovations. The survey results will inform a scored ranking of floating wind innovations, and the future research directions for the Task. In the MSP section representatives from partner countries are interviewed to assess their domestic offshore wind sector and discuss the approach the country has taken to MSP, with a focus on floating wind. The other explored parameters include MSP regulations, offshore wind policy and targets, supply chain capabilities, and environmental and fisheries impact assessments. A synthesis of what stakeholders perceive as impactful innovation, and an understanding of the direction of the industry and policy can be built from the two parts. This paper describes the methodology used to create this synthesis and findings from the first year of work are shared.

1. Introduction

The Global Wind Energy Council (GWEC) forecasts that wind energy will play an important role into the future with 15% growth rate and an average of 136 GW of new installations per year up to 2027 [1]. Offshore wind (OW) has seen a steep rise in installed capacity in the past two decades. Reasons for this include OW being more popular with the public than onshore wind by offering less visual and noise pollution [2]; the significant cost declines in OW over the past decade; the greater scale of projects that can be built offshore; and the stronger wind speeds available offshore. According to the Global Wind Energy Council (GWEC), 26 GW of offshore wind will be deployed annually between 2023-27 [1] (19% of all new wind projects for that time range). GWEC finds that

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around 80% of all offshore wind energy potential is located over water deeper than what is the current limit of deployment of fixed wind turbine foundations (60 metres) and floating foundation technology must be used to exploit most of the resource [3].

The Levelized Cost of Electricity (LCoE) of floating offshore wind (FLOW) in favourable conditions of the European Atlantic is in the region of 100-160 €/MWh [4]. A similar price is reflected in the Contracts for Difference (CfD) round 4 results where an offshore wind project had a strike price of 87.30 £/MW in 2012 prices [5] (140 €/MWh in 2024 prices) A Fraunhofer renewable energy LCoE report states values of 40-60 €/MWh for onshore wind and 50-70 €/MWh for OW in favourable conditions [6]. FLOW is more expensive, but can unlock new markets, because not all markets have access to shallow water, and some may run out of space for fixed bottom OW. Aside from the two Hywind projects (Scotland and Tampen) and the Kincardine offshore wind farm, there are several projects demonstrating and developing technologies for FLOW, like WindFloat Atlantic, TetraSpar, or DemoSATH. To help bridge the gap between these and GW-scale projects, the International Energy Agency (IEA) Wind Task 49 aims to build a set of open access data: reference designs, reference site conditions, specific marine spatial planning (MSP) requirements, and more.

This paper describes a working framework by which a survey of current MSP practices relevant to FLOW is conducted and suggests a way of prioritising innovation areas within the FLOW industry.

1.1. IEA Wind Task 49

The IEA Wind Task 49 – Integrated Design of Floating Wind Arrays – is a collaborative effort to speed up the commercialisation of FLOW. This task was defined at the 99th IEA Wind Topical Experts Meeting (TEM#99) "Floating Offshore Wind Array Challenges and Opportunities" and aims to support the IEA Wind strategic goals, as stated in the task proposal [7]: Lower the cost of offshore energy, facilitate wind energy deployment, and foster collaborative research in offshore wind.

The effort of the Task 49 group is divided into four work packages – reference sites and metocean conditions, reference farm designs, failure and risk identification and stakeholder integration. The objectives of Task 49 are to create a catalogue of open-source reference designs of FLOW arrays as well as a databank of various information (met-ocean conditions, socio-ecological factors, ambient noise, distance to shore, port availability, grid connectivity, and more) for typical sites where FLOW will be deployed. In addition, the task will identify array-level failure modes and assign risk ratings to these to help investors, insurance providers and farm operators understand and manage risk more efficiently. Finally, FLOW stakeholders from the Task 49 partner countries are interviewed to assess each country's approach to MSP and to find out what innovative areas in FLOW are considered to be the most potentially beneficial to the industry.

1.2. Work package 4: Stakeholder integration

Work package 4 of Task 49 is focused on keeping the work of the task relevant to the industry using two main areas: innovation management and MSP surveys, which are backed by extensive research of MSP methods and individual markets. These are designed to work in synergy – innovation management helps map out the technological landscape and find out which are the technical challenges that, if solved, could have the most impact on the industry. MSP consultation and research are carried out to find the processes and considerations regulators look at when designating an area of the sea as suitable for OW and FLOW use. During the interviews, participants are also asked about what direction their OW market is heading, what are the deployment targets for the near future and how is policy being shaped to reach these. The synthesis of these two parts will create an overview of the global OW and FLOW market and deployment expectations, while shedding some light on what technologies and policies can make this happen quicker, thus identifying focus topics for the future.

1.3. Marine spatial planning
There are many sea users and stakeholders who use marine resources. These include industrial users: the fishing, oil & gas, shipping, tourism, military, sub-sea mining, or offshore renewables industries as well as nature protection agencies or civil and military radar users. This variety of sometimes conflicting use cases leads to a requirement for management of the sea and its division into areas where specific activities are permitted. The process of allocating the space is conceptually like urban planning and is called marine spatial planning [8].

Developing a marine spatial plan is a strategic decision by a government and lays out the long-term plan of how the sea will be used in the country. To make that decision fair, plan development should involve various stakeholders from an early stage, to help create a dialogue between representatives from all industries and reach a compromise. The plan should consider the environment and sustainability, and cumulative effects of activities specified by it and because conditions change over time, the plan needs to be adaptable, with a clear approach for how any changes will be made [9]. Local governments and representatives of coastal communities must be included in MSP creation. These communities often express great interest in offshore renewable projects [10] and what possible social, environmental and economic impacts the construction of these will have on them and their way of life

Most countries with an OW market have their own MSP policy. Typically, this is set by a government organisation which oversees the creation and revision of MSP by setting up a committee with representatives from the various stakeholder groups and relevant ministries. A preliminary plan is written and made available for public consultation. Based on the consultation and the views and requirements of the committee, a marine spatial plan is formed. In the EU, member states are required to have an MSP policy in place as per the 2014/89/EU Directive on MSP.

2. The methods of research
Work package 4 uses a combination of desk studies, surveys, and interviews to provide information about the technological and innovative landscape and trends in MSP.

2.1. Innovation management
The combined Task 49 effort will produce innovative solutions to some of the industry's challenges using the combined work of experts from various parts of the OW field and different countries. It is important to make sure that focus is on the innovations which could have the most positive impact on the industry. During the TEM#99 meeting, it was defined that the benefits of the FLOW industry can be sorted into three categories: social, environmental, and economic. The first deliverable of work package 4 is therefore focused on producing a ranked list of what industry stakeholders perceive to be the potentially most impactful innovations based on their potential social, environmental, and economic effects. The effects of innovations can be positive and negative: low-CO_2 energy, and marine mammal displacement, creation of well-paying jobs, and disruption to traditional way of life, increased economic activity in local area, and lower income for fishermen.

In this investigation, the focus is on “what could be the best possible impact, if this technology is developed” and categorizing in the three groups - social, environmental, and economic effects.

The initial list of considered innovations was taken from the FLOW technology roadmap published by Offshore Renewable Energy Catapult’s [11] Offshore Wind Innovation Hub. The list of innovations from this roadmap was condensed with feedback from Task 49 members to cut the list down to the eight most potentially impactful areas of innovation. The list as used in work package 4 is as follows:

1. **New floating wind turbine configurations:** Coming up with concepts other than a horizontal axis wind turbines mounted on a monopile tower which will pose advantages for OW applications.
2. **Design of a floating platform substation:** Designing a dedicated floating substation.
3. **Design for whole lifecycle cost reduction:** Design with LCoE as main design driver, considering operations & maintenance (O&M) and decommissioning costs in the design process.
4. **Consolidation in the number of designs:** Reduce the number of platform, mooring and wind turbine concepts to help speed up the onset of economies of scale effects.
5. **Optimised O&M and major component service strategies and condition monitoring for floating conditions:** O&M specifically designed for FLOW machines.
6. **Manufacturing of current and disruptive floating concepts:** Improve and standardise manufacturing methods to facilitate serial production.
7. **Port infrastructure improvement to enable substructure manufacturing:** Making more ports capable of FLOW operations and producing the floating platforms.
8. **Floating electrical and mooring system connections:** Designing dedicated FLOW mooring and cable connectors to speed up and de-risk O&M and installation procedures.

The innovations are ranked based on the potential to increase the social, environmental, or economic benefits of the FLOW industry, as perceived by industry stakeholders. The method of ranking is based on the analytical hierarchy process (AHP) as described by Saaty in 1987 [12].

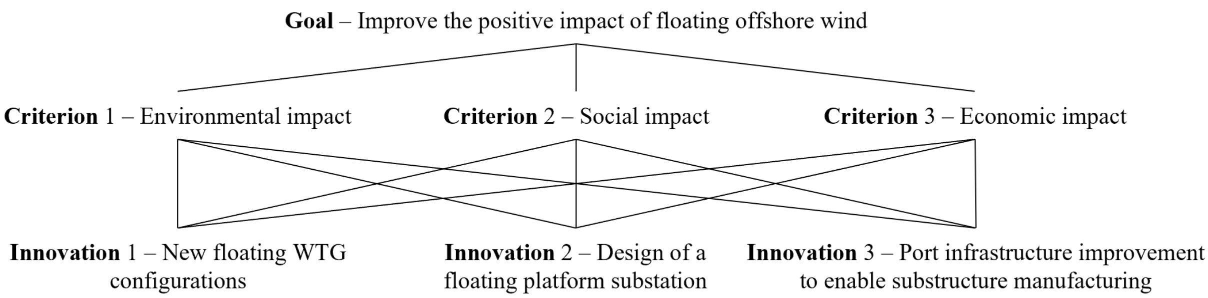
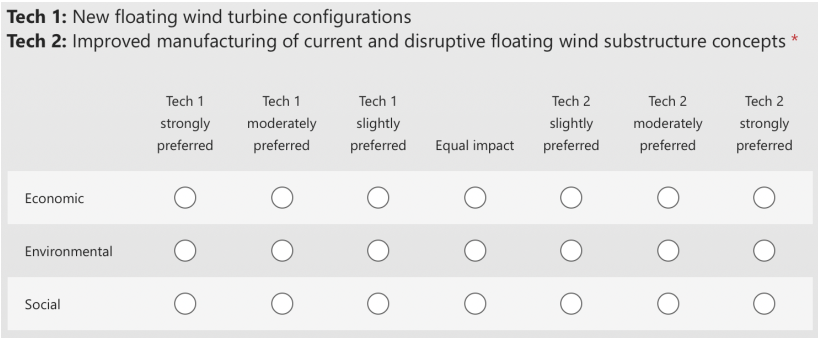


Figure 1 Analytical hierarchy process relationship tree, adapted from Bohan and Dvorak [13].

In this method, a goal is identified – to help maximise the positive impact of FLOW by supporting the potentially most impactful technologies. The success of this goal is measured by three criteria – the environmental, social, and economic impacts of FLOW. To reach the goal, there are alternative ways to progress – the various innovations. Each of these innovations will bring unique environmental, social, and economic impacts on the industry. The goal of the AHP ranking is to assess which will have the largest overall impact. A diagram describing the AHP approach for this case is presented in Figure 1. AHP uses pair-wise comparisons to make strategic decisions – here it means comparing a pair of innovations to see which one will have a stronger environmental, social, and economic impact.


Tech 1: New floating wind turbine configurations
Tech 2: Improved manufacturing of current and disruptive floating wind substructure concepts *

	Tech 1 strongly preferred	Tech 1 moderately preferred	Tech 1 slightly preferred	Equal impact	Tech 2 slightly preferred	Tech 2 moderately preferred	Tech 2 strongly preferred
Economic	○	○	○	○	○	○	○
Environmental	○	○	○	○	○	○	○
Social	○	○	○	○	○	○	○

Figure 2 An example of a question from the AHP innovation questionnaire – Which of the two technologies has a higher potential to have a positive social/environmental/economic impact?

This is done using an online questionnaire, where responders are asked questions about pairs of innovations to decide which innovative technology they think is preferred based on its potential impacts. An example question is shown in Figure 2. The responses are averaged across responders and analysed using the AHP algorithm. The ranking methodology as well as the AHP is described in detail in the first deliverable of work package 4 published on the MaREI website [13]. The information from this analysis will be used to inform the work of the technical work packages of Task 49 to make sure the efforts are directed to the parts of the industry where there is likely to be the most impact. The results can also be used by organisations in charge of allocating research funding to channel the money into the most important research areas. Finally, companies in the industry or prospective entrants can look at the ranked innovation list to identify projects/innovation areas which they could address to establish themselves in the market.

2.2. Interviews with MSP experts
The second part of work package 4 work is focused on stakeholder integration. The research and interviews consider partner countries of the Task 49 project. During the first round, two groups of people were interviewed – people working in MSP and people working in OW or FLOW. One group is interviewed because they can provide country-specific knowledge of stakeholder engagement methods, key documents and sites, etc. with regards to MSP and share information about how MSP is addressed in their market and whether this method has been successful. The other group is selected for their understanding of the FLOW market in their country and can talk about challenges presented by that market as well as plans and targets.

Participants are asked about national OW and FLOW targets in their country before moving to a discussion about what the country is doing in terms of MSP to meet these targets – who is the relevant MSP authority, what is the approach to OW development (plan-led or developer-led), what is the most important piece of MSP legislation and whether zones have been identified specifically for FLOW. The interview then progresses to questions about the domestic FLOW market – when will there be 500 MW+ scale FLOW farms in your country? Will FLOW be more able to coexist with other industries and the environment compared to OW and could it be more acceptable to people in coastal communities? How ready is the domestic supply chain and port infrastructure to get involved in the growing industry?

The final part of the interview is a moderated discussion about what factors are considered when designating an OW site in the country (wind resource, bathymetry, proximity to shore…) and what technological innovations and MSP factors would be most helpful to speed up FLOW deployment in the country. At the end, participants are asked to mark areas on a map where they anticipate OW and FLOW development, and associated timeline for development. In addition to the information gathered during the interview, each country and its market is researched with a desk study before and after the interview. The first round of interviews has been conducted in 2023 with two more rounds scheduled.

3. The findings so far

So far, one year of work package 4 activities has been completed. Experts from France, Germany, Ireland, Italy, Japan, the Netherlands, Norway, Portugal, South Korea, Spain, the United Kingdom and USA have been consulted.

Figure 3 is based on a market review conducted in parallel with the MSP interviews using the 4C Offshore OW project database, accessed under a licence [14]. It shows project data where it is available but should not be taken as a solid forecast of future projects, as some of these projects won't be developed, but more as a general indication of trends and the direction the industry is taking. The projects are displayed based on what type of floating foundation they are expected to use. The results suggest that turbine capacity will steadily increase, that most projects, regardless of site, are expected to use semi-submersible platforms, with some spar platform use expected.

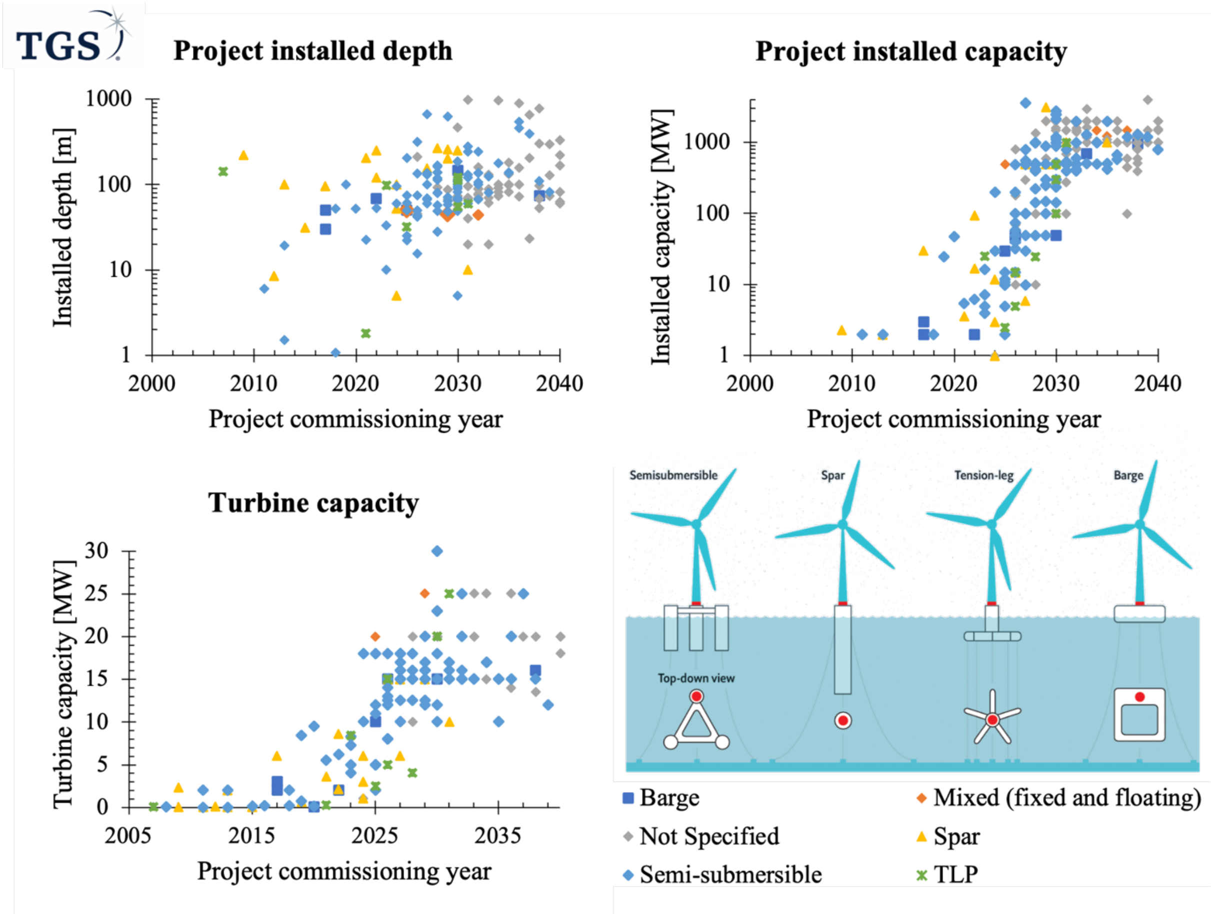


Figure 3 The global FLOW project pipeline [14], data under licence from TGS 4C Offshore in November 2023. Includes test-scale projects. Foundation diagram adapted from [15].

This shows the industry converging on one or two platform types. This convergence could be a signal for the whole industry that it should focus on standardisation of designs and decreasing the number of concepts on the market to try and maximise the effort going into innovating existing technology. Task 49 offers reference designs and a step towards standardisation.

There is an expectation that it will be possible to deploy FLOW in depths of up to 1000 m as early as 2030, but most projects are expected to be in depths up to 300 m. As manufacturers develop more powerful machines, the FLOW industry is expected to always deploy as much power per platform as possible. Machines over 20 MW capacity could be installed on floating platforms around 2030, but it is unclear whether manufacturers will be able to deliver the machines and if they will be single rotor horizontal axis wind turbines or a different concept.

3.1. Important areas of innovation in the floating offshore wind sector

During the 2024 EERA DeepWind conference, IEA Wind Task 49 partners met at a workshop on ranking the innovations separately from the survey. The preliminary results from the survey and the ones from the workshop are presented in Table 1. The overall ranking was created from a sum of the workshop and survey rankings with the survey having 10% more weight to settle any ties.

The results show that industry stakeholders are not too concerned with the current state of wind turbine technology as provided by manufacturers, but more with optimising how projects are operated, built, and maintained, as well as improving infrastructure and driving down costs. The respondents appear to think that the wind turbine technology has converged sufficiently, and that the floater technology should do the same to enable better economies of scale, but they consider this less important than the other innovation areas. There is an interesting trend emerging – the innovation priority ranking is mostly driven by the perceived potential environmental and economic benefits, with social benefits of the innovations being less important to survey responders. However, not all innovation is related to technology. Even though the interviews are conducted with a focus mainly on MSP, there are also sections about technology and challenges of the given market. Interviewees from emerging markets (Italy, Norway, Japan…) have mentioned that innovation is required in the permitting process, which must become clearer and faster.

Table 1 Innovation ranking preliminary results (data combined from the IEA Wind Task 49 workshop in January 2024 in Trondheim and from the AHP survey results up to January 2024)

Innovation	Workshop	Survey	Overall rank
Optimised O&M and major component service strategies and condition monitoring for floating conditions	2	1	1
Design for whole lifecycle cost reduction	4	2	2
Port infrastructure improvement to enable substructure manufacturing	3	3	3
Manufacturing of current and disruptive floating wind concepts	1	5	4
Floating electrical and mooring systems connection	6	4	5
Consolidation in the number of designs	5	7	6
Design of floating platform substation	7	6	7
New floating wind turbine configurations	8	8	8

3.2. Insights from current MSP practices for offshore wind

Most countries currently active in the OW industry already have an MSP policy in place. Having an MSP is also a legal requirement for EU member states [16]. Countries which previously did not have offshore industries requiring permanent installations, like oil & gas, deep sea mining, or OW often don't have an MSP policy. Without these industries, it is possible to use the sea without designating special use zones except for military exclusion zones and marine protection areas. When a developer wants to build an OW project in a country without an MSP policy, the regulator might lack a framework to award the permission, which will make the process slow [16].

Italy's Beleolico wind farm took 14 years to complete due to issues with permits and the supply chain [17]. This is a 30 MW project outside the Taranto harbour and the developers had to submit bespoke impact assessments for the project without any regulator-determined guidelines. The lack of clear approach of how to award a permit, results in Italy having one of the largest project pipelines (over 70 GW of OW and FLOW projects). These are stuck in the planning and permitting stages due to bottlenecks in the permitting framework, which stem from the absence of a marine spatial plan. MSP presents a roadblock preventing one of the most promising European emerging markets from being developed. Italian agencies are working to create the country's first MSP policy.

Judging by the responses from representatives of countries with a developed OW industry, the most efficient approach to building OW is to operate with a plan-led model, which has been implemented in most European markets (UK, Norway, Germany…). This means the MSP authority identifies the areas, where wind farms can be built. Then the government asks developers to either tender for projects in these areas (for example in the USA) or organises a lease auction system (like in the UK). Typically, areas are put up for lease sequentially. Often parallel to the seabed lease, there are applications for financial support (like in the UK with the CfD rounds). This process is made simpler with advanced MSP which considers OW developments. Such a policy and plan are often created by an agency which is a subsidiary of the most relevant ministry.

Based on what the interviewees said, this is typically the ministry of energy, or infrastructure, or the environment or an equivalent relevant for the given country. This agency then consults with representatives from other relevant ministries to involve various stakeholder groups in the negotiations for the division of use of the ocean space. This consultation phase is called the MSP stakeholder engagement. During the negotiations a compromise between the sometimes-conflicting requirements of all interested parties needs to be reached.

For OW developers, this means having a clear idea of where they would preferably like to build projects before arriving at the discussion table. The output is a document describing which activities are permitted in given parts of the ocean and this document forms the backbone of an MSP policy. A scheme of this process is shown in Figure 4.

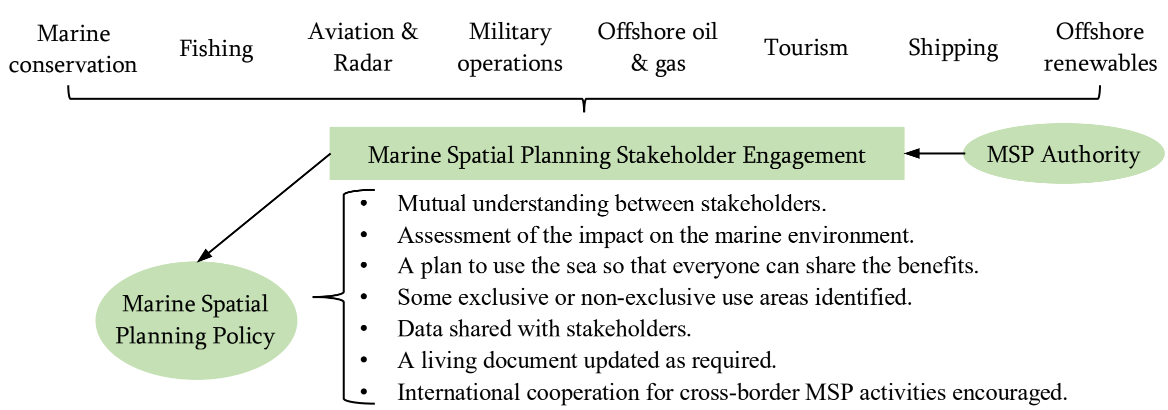


Figure 4 Scheme of the process of forming a marine spatial plan.

3.3. Brief outlook for the floating offshore wind industry
Governments are optimistic about the role OW and FLOW will play in their energy generation plans. Most markets studied include a specific deployment target for OW, there is however some divide between FLOW-specific targets. Some countries prefer to keep their targets technology-agnostic to give the developers more freedom, others set floating targets to support development in deeper waters. We reviewed close to 600 FLOW projects being considered or built in 29 countries, with a total capacity of almost 500 GW [14]. These numbers show a will of governments and industry to support and develop FLOW. The markets to watch include Italy, China, Philippines, the UK, the USA, Australia, South Korea, Japan, France, Norway, and Ireland.

3.4. Examples from the Scottish FLOW market
Two high profile FLOW developments are the Kincardine farm and Hywind Scotland, both in Scotland. These projects were not developed using any of the auction systems in the UK (CfD or ScotWind). The developers applied for a seabed lease to The Crown Estate Scotland and for a marine use licence to Marine Scotland and submitted a full environmental and socio-economic impact assessment. Both generate income via a power purchase agreement.

The Pentland offshore wind farm, currently under development also secured a separate seabed lease and marine license. The developers are planning to apply to CfD round six. 13 additional FLOW projects were auctioned off during the ScotWind round and a further 12 during the Innovation and Targeted Oil & Gas round. Both rounds were for areas marked out earlier in the British MSP as designated for offshore renewables. Projects awarded leases in these rounds are likely to apply for future CfD rounds for energy trading purposes.

4. Future direction of research
Many countries who develop their OW resource share a sea boundary with another OW market, it will be useful to study the creation of international MSP policies, like the SIMCelt project [18] or international grid integration. The aim is also to speak to a more diverse group of stakeholders and representatives from organisations like WindEurope. The future interviews will look at co-existence of sea user groups in multi-use areas and local supply chain content development.

5. Conclusions
Most countries with a FLOW market already have MSP policies and are making considerations for offshore renewables in their plans. In some cases, these are technology-agnostic, others explicitly include OW and FLOW. These plans typically go hand in hand with national deployment targets. Creating robust MSP policies and related permitting frameworks should be one of the priorities for countries looking to grow their OW and FLOW markets. Future MSP policies should look at international cooperation and sea-user coexistence in multi-use areas. Governments should also consider the growth of the domestic supply chain while supporting offshore renewables.

Existing FLOW design concepts are fit-for-purpose and the industry should focus on supporting them with robust O&M strategies, better manufacturing methods and standardisation. Governments recognize the potential of FLOW and the project pipeline reflects this – almost 30 nations are considering FLOW deployments and these can be expected to breach the 1 GW mark sometime early in the upcoming decade and will be typically moored in around 200-300 m of depth. The stage is set for growth in the FLOW industry. Our results from the stakeholder consultations indicate the need to remove permitting and regulatory bottlenecks by implementing more transparent and predictable frameworks to increase permitting speed and reduce uncertainty. This institutional support should be done in parallel with the industry increasing the level of standardisation to simplify incremental innovation in the sector and improve manufacturing and O&M procedures.

Acknowledgements
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