Fostering future Scottish-French research and development collaboration in floating wind and green hydrogen

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List of acronyms

- ADEME – French Agency for the Ecological Transition
- ANR – French National Research Agency
- BEIS – the UK Government Department for Business, Energy and Industrial Strategy
- BIG HIT - Building Innovative Green Hydrogen Systems in Isolated Territories project
- CEA – the French Alternative Energies and Atomic Energy Commission
- FCH JU – Fuel Cells and Hydrogen Joint Undertaking
- FLW JIP - Floating Offshore Wind Joint Industry Programme
- FRH2 – the French Hydrogen Research Federation
- GW – gigawatt
- MW – megawatt
- MWh – megawatt-hour
- UK – United Kingdom of Great Britain and Northern Ireland

Executive Summary

Ambitions are high for the future commercialisation of floating wind and hydrogen in both Scotland and France. There is good recognition from policy makers at all levels of government in both countries that these two energy technologies can meaningfully contribute to delivering energy system transition, as well as providing opportunities for organisations within energy supply chains.

This report sets out the findings of a study undertaken for the Scottish Government which has reviewed the opportunities for Scottish and French organisations to work together to deliver collaborative innovation in floating wind and hydrogen. This study commenced with a technical evidence review which explored the development status of floating wind and hydrogen components and systems. This review highlighted a number of outstanding innovation needs and research questions, which are summarised in detail in the sections that follow. Cross-cutting challenges were identified around working at sea, likely far from shore. Technology-specific areas of focus were also clarified, for example, highlighting an ongoing need to identify the most appropriate means of stabilising floating wind platforms. Various hydrogen development needs were highlighted, notably varying depending upon whether offshore hydrogen production is pursued in earnest. Furthermore, the evidence review informed stakeholder engagement exercises which involved supply chain organisations, researchers, policy makers and enterprise agency staff in both Scotland and France. These stakeholders shared reflections on their own experiences of collaborative innovation. All of these inputs informed the development of recommendations for the Scottish Government on possible initiatives which could be used to foster further collaborative activities between Scotland and France. The sequence of these activities is summarised in Figure 1.

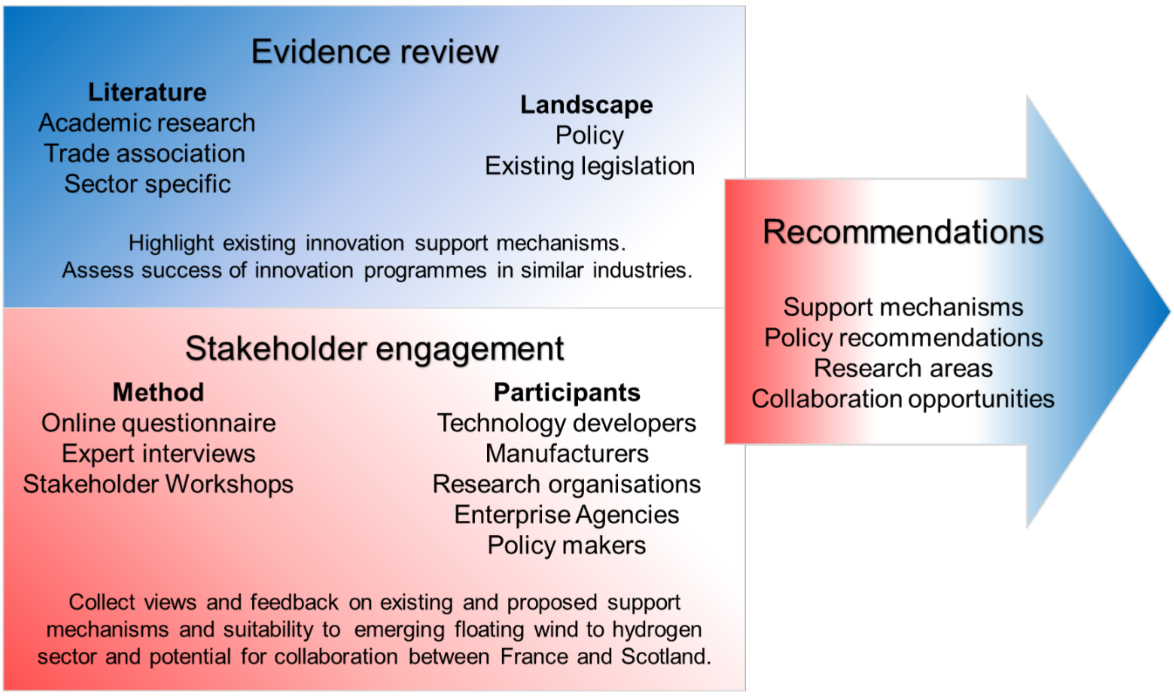

Figure 1. A summary of the workstreams undertaken in delivering this project.

Stakeholder feedback provided to the project team was overwhelmingly in favour of further collaborative working between Scottish and French organisations. These stakeholders encouraged a focus for support mechanisms on de-risking future investments in large scale deployments of floating wind and hydrogen systems in both countries. A number of possible research focus areas were suggested and these are summarised in the sections which follow.

Reflecting on the research needs identified in conducting this study, and the stakeholder feedback received, the project team developed four recommendations for the Scottish Government. In order to develop further opportunities for joint working between the French and Scottish supply chains, the Scottish Government is encouraged to:

1. **Target engagement at regional levels in France**. In recognition of shared ambition and also comparative governance structures, resource availabilities and geographies, collaborative working with counterparts in the French regions is recommended. Representatives from Brittany and Occitanie provided particularly robust feedback to the project team, and the focus for innovation activities in these two regions make them prime candidates for engagement with the Scottish supply chain. Stakeholders who participated in project engagement activities requested structured support from the relevant governments and enterprise agencies in funding and facilitating inter-regional initiatives.

2. **Encourage research collaboration through network building**. Networking can be essential in kickstarting collaborative working and in helping supply chain organisations to know who to approach when opportunities arise. Specific proposed next steps for fostering these relationships are detailed in subsequent sections, however stakeholder asks worth highlighting include a desire for facilitated matchmaking activities to pair Scottish and French counterparts, and access to market intelligence materials focused on highlighting areas of strength in each respective supply chain.

3. **Develop a research, test and demonstration platform specifically targeting projects showcasing the integration of floating wind and hydrogen systems**. A range of research questions of shared interest have been identified and summarised in this report, and there is clear appetite from both Scottish and French organisations to work together to progress these.

4. **Instil a focus on 'Just Transition' and skills development in these initiatives**. Delivering opportunities for organisations currently embedded in traditional energy supply chains to re-focus their efforts on servicing emerging renewable energy markets is a key priority in both Scotland and France. Stakeholders feeding back to the project team suggested that all initiatives arising following this study should prioritise addressing this opportunity.

Further detail on the proposed means of implementing these recommendations, as well as the findings which have informed them, is provided in the sections which follow.

Introduction

Setting the scene

Scotland and France are both uniquely placed to benefit from ongoing and future growth in the deployment of offshore wind. The territorial waters around Scotland host a quarter of Europe's offshore wind resource [1], with France being second only to the United Kingdom (UK) in terms of the potential for the exploitation of wind energy [2].

Wind farm developers increasingly prioritise floating offshore wind turbines to take advantage of increased wind speeds further from shore. Floating turbines can operate in deeper waters due to their lack of fixed foundations (which can be expensive and logistically challenging to develop, especially in deeper waters). This is an important factor for developments around the coasts of Scotland, where waters are deeper than those elsewhere in the UK [1], and where floating platforms are likely to be more widely used.

Similarly, for future developments in French waters, floating wind technologies are expected to be the key to delivering offshore wind deployments in the south. Like Scotland, water depths in the Mediterranean Sea far exceed those along the west and north of the country [2]. However, a key challenge in delivering floating offshore wind farms far from shore is dealing with the substantial costs associated with transmitting large quantities of power back to land and often across significant distances to populated centres of demand.

As the offshore wind sector grows and searches for the most suitable sites, there will be an increasing requirement to transmit and store significant amounts of energy across long distances. By providing an efficient means of storing and transporting energy produced from renewable sources in remote locations, hydrogen is seen by many as a key technology in this area. Adopting hydrogen across the energy system could also help to reduce the impact of renewable intermittency.

Furthermore, technical challenges may restrict the scope for electrification to deliver deep decarbonisation in energy-intensive sectors such as heavy-duty transport and in heavy industries. For example, scaling batteries to provide sufficient storage capacity for long-distance journeys may be impractical.

These limitations suggest that alternative, decarbonised fuels such as hydrogen may be required. As a result, there is widespread interest in developing hydrogen production projects to demonstrate the feasibility and cost of generating hydrogen from renewable resources. Due to the impact of intermittency on the production costs of hydrogen, the relatively high load factors associated with floating offshore wind farms make these an attractive source of power for generating hydrogen, or a hydrogen derivative.

Confirming the role that green hydrogen[1] can play in the future energy system is a high priority in both Scotland and France. £100m of capital support from 2021-26, was confirmed in the Scottish Government's recent Hydrogen Policy Statement [3]. Meanwhile, in its 'Stratégie Nationale' for hydrogen, the French government committed to providing €7 billion of investment to support hydrogen developments [4], a core element of the French green recovery plan announced earlier in 2020.

The Scottish Government recognises the importance of international and inter-regional collaboration in realising these ambitions. Innovative floating offshore wind and offshore hydrogen production projects will face technical and logistical challenges associated with operating in harsh marine environments. Innovation, skills and supply chain developments will be required to address these challenges.

This research study aimed to identify research priorities and collaboration opportunities of joint interest between the Scottish and French supply chains. This will inform the development of policies which will encourage organisations in the two countries to work together. Specifically, this study sought to review the technical status, shared challenges and potential collaboration opportunities in Scotland and in France for the allied floating offshore wind and offshore hydrogen production sectors.

Methodology

The sequence of project activities is outlined in Figure 2. This study began with an evidence-based review of the status of the technologies and innovation activity in the floating wind and hydrogen sectors in Scotland and in France. The analysis narrated in this report sets up the context for these two sectors in the energy transition and identifies cross-cutting technical challenges faced by developers in both sectors (and those seeking to integrate the two technology sets). Subsequent project activity concerned engaging with key industry and innovation agency stakeholders to elicit feedback on prior experiences of collaborative innovation projects. Participants verified the project team's analysis of the technical and innovation challenges foreseen in floating wind and hydrogen. They also provided perspectives on the best means of supporting collaborative activities which might contribute to addressing these challenges. Feedback from these stakeholders has been used to formulate recommendations to the Scottish Government.

Figure 2. The sequence of project activities.

[1] 'Green' hydrogen refers to hydrogen produced using an electrolyser powered by renewable electricity. Green hydrogen can be used to provide power or heat without the release of greenhouse gas emissions.

Evidence review

The evidence review carried out included an analysis of the policy landscape (including national and multilateral development strategies) and innovation support context in the two countries. This clarified which programmes exist to facilitate research and development activities. The review looked at how these have typically been accessed by organisations working within the target sectors in both countries.

In undertaking this review of evidence, the project team surveyed academic and trade literature to establish the status of innovation activities in the two target sectors. Findings from prior research on this, undertaken by sector specialist organisations and trade associations, were reviewed.

To summarise the prevailing policy context, the team also reviewed key position papers and legislation introduced by governments and relevant departments in Scotland and France. Finally, industry publications and innovation project reports were used to identify the key innovation and funding programmes which have delivered projects identified as having previously contributed to technical improvements in the two focus sectors.

This evidence review focused on clarifying the degree to which existing and planned support programmes have helped to deliver upon development ambitions in these sectors. Findings from these investigations are summarised in this report. This analysis was also used to inform the design of engagement activities, concerned with exploring stakeholder experience of carrying out (collaborative) innovation activity in these sectors.

Stakeholder engagement

The second priority for the study concerned stakeholder engagement activities aimed at verifying evidence review findings and broadening the range of technical development challenges considered.

In delivering the study described, the project team conducted:

- an online questionnaire, intended to provide quantitative insight from a broader pool of stakeholders than could logistically be included in subsequent activities. Questions sought details from supply chain stakeholders on their participation in the floating wind and hydrogen sectors in Scotland and in France, and in collaborative innovation. The survey was also used to gather initial feedback on desired support mechanisms for future research collaboration;

- expert interviews, with stakeholders in both Scotland and France known to be actively pursuing and/or facilitating collaborative innovation activities in the floating wind and hydrogen sectors. These interviews explored stakeholder experience of joint working initiatives and collected feedback on aspects to consider in formulating project recommendations;

- discursive workshops with supply chain participants from both Scotland and France, which provided the opportunity for the project team to share project findings and draft recommendations with stakeholders to elicit feedback and to validate the research already undertaken. Breakout discussions with smaller groups (10 or fewer) stakeholders were used to explore innovation support needs in floating wind and hydrogen, and to elicit feedback from stakeholders on the draft recommendations developed by the project team. Participants were guided through a structured discussion, and their views were recorded anonymously for subsequent analysis by the project team.

36 questionnaire responses were received, from 12 organisations in Scotland and 24 in France. Five expert interviews were conducted, with three Scottish stakeholder organisations and two in France. Of the workshops, three were held. The first, which had a technical focus and was targeted at Scottish stakeholders only, drew 31 attendees representing 20 organisations. The second workshop, also with a technical focus and for French stakeholders only, had 21 attendees representing 15 organisations. The third workshop brought together a mixed group of Scottish and French stakeholders to discuss collaborative innovation initiatives, with 16 participants representing 11 organisations. Of those organisations, four were based in France and seven were based in Scotland.

Stakeholder organisations in both Scotland and in France who are active in either or both the floating wind and/or hydrogen sectors were invited to take part in these forums. A press release in both English and French was circulated among mainstream and industry media organisations in both countries, and was also shared widely on social media by the project consortium organisations. This press release encouraged stakeholders to contact the project team to register their interest in informing the research undertaken. All of the organisations who contacted the project team were involved in the subsequent activities. Further stakeholders with demonstrated experience in floating wind and hydrogen were identified by the project team based upon evidence review findings, and were directly invited to take part in engagement activities. Some of the respondents and participants who took part in project engagement activities were not based in Scotland or France (especially for those representing multinational supply chain organisations, in particular including staff based elsewhere in the UK). These individuals were asked to reflect specifically on their organisation’s activities in Scotland and in France.

Participant organisations were drawn from across the full value chains relating to each sector, from:

- technology developers,
- manufacturers,
- technical service providers,
- project developers,
- utilities and energy majors,
- trade associations,
- research organisations (both academic and private sector),
- enterprise agencies, and
- policy makers at all levels, including representatives of the Scottish Government and local, regional and national government in France.

These engagement activities were used to assess supply chain and wider stakeholder appetite for collaboration between organisations in the two countries. These engagement activities sought feedback from value chain participants:

- to understand their sentiment towards, and experience of, existing support programmes,
- to gather their feedback on the recommendations developed by the project team for future programmes, and
- to document their priorities for the support that will be required from the Scottish Government and others to ensure maximum development in these sectors.

The primary aim of these activities was to inform the recommendations set out in this report for the Scottish Government. These recommendations propose policy interventions and support schemes which should be developed to support (collaborative) innovation activities in these target sectors and geographies.

Context and technical outlook

Many in the energy industry now foresee a vital role for hydrogen in facilitating the energy transition which will be required to deliver upon global climate change mitigation and net zero targets. As an energy vector (a way of storing, transmitting or consuming energy), hydrogen offers a means of decarbonising sectors where it is 'difficult to meaningfully reduce emissions' [5], due to technical challenges which may limit the utility of other solutions.

In particular, it is expected that there will be a role for hydrogen in providing fuel for heavy duty and long-range road, rail, marine and perhaps even air transport. In addition, hydrogen may also be a suitable means of providing heat and chemical inputs in industrial processes such as the production of ammonia, steel or concrete.

One of the merits associated with using hydrogen in both transport and industrial sectors is the opportunity to provide the required energy inputs without releasing any greenhouse gas emissions at the point of use. In the longer term, hydrogen is also considered to be a credible energy storage solution with application in the storage of renewably-produced power over daily, weekly or even seasonal timescales [5].

Synergies and links exist between the offshore wind and hydrogen sectors, in that cost reductions in the power produced by offshore wind farms can lead to the realisation of significant reductions in the costs of producing hydrogen via electrolysis [6]. Perhaps more importantly when considering floating wind to hydrogen projects, hydrogen is expected to offer an efficient method of large scale, long-distance energy transmission. This means it is well placed to help integrate ever-increasing shares of power produced by offshore wind generators where the most abundant sources are often long distances from significant demand centres.

Any future energy system dominated by renewable generation, including wind power, would likely rely on large scale upgrades in electricity transmission and distribution infrastructure to manage the flow of the power produced. This is especially true of offshore wind, and even more so of floating wind, which is expected to be deployed in ever deeper waters, further away from shore.

Floating wind turbines are expected to provide higher capacity factor[2] power generation than that gained from existing offshore wind farms due to the ability to access stronger, more reliable winds far out to sea. However, locating floating wind farms further from shore also increases the cost and logistical challenges associated with transmitting the power produced back to shore, and on to locations of power demand.

[2] A measure of the real-world output of a turbine or wind farm relative to the theoretical rated capacity for the turbine or farm. Capacity factor is influenced by wind speed and wind availability.

Hydrogen is expected to play a role in addressing this challenge, either by reducing the transport and handling costs directly – from a technical perspective gas can often be more conveniently transported than electricity [7]. Hydrogen may also provide opportunities for producers of renewable power to access additional, high value markets for the energy that they produce, for example in providing renewably-produced fuel for hard-to-decarbonise sectors like aviation and shipping.

Many of the innovation activities described subsequently in this report are seeking to develop solutions to facilitate exactly the scenario described here. Some outstanding technical challenges will need to be addressed to pave the way for widespread deployment of the technologies and systems described.

The world's first floating wind farm was deployed in Scottish waters in 2017 by Equinor, who developed the Hywind Scotland project. The Hywind demonstration project saw the deployment of five six megawatt (MW) floating wind turbines in waters east of Peterhead, in the north east of Scotland [8]. Since then, a 24 MW project has also been deployed off the coast of Portugal, within the WindFloat Atlantic project [9]. The Kincardine floating wind farm, which will be the world's largest at 50 MW, is also currently under construction in Scottish waters and due for commissioning in 2021 [10].

Europe is also arguably leading the world in developing renewable hydrogen research and demonstration projects, with electrolysis capacity in the pipeline for the continent having scaled from 0.1 gigawatt (GW) in 2016 to ambitions for around 10 GW announced by mid-2020 [11].

Cross-cutting technical challenges

Across both sectors, these initial research, development and demonstration projects have contributed to identifying and proposing solutions to several outstanding technical challenges which are itemised below.

A few cross-cutting technical and logistical challenges are evident in both sectors. These challenges and innovation needs largely apply globally, though there are localised dynamics influencing the degree to which they may impede the development of floating wind and hydrogen in Scotland and in France. These relate primarily to supply chain readiness and the relative availability or state of development of the infrastructure required for large scale developments and deployments of the technologies required. In floating wind these challenges primarily relate to the availability of suitably equipped ports to enable the transport of components (such as cranes to move wind turbine blades and cabling) and systems (relating both to the equipment needed to move integrated, bulky equipment such as floating support platforms, but also the working practices required to do so safely). The absence of suitably developed port infrastructure and vessels may also make it more difficult to access wind farms for maintenance. A further key challenge is in understanding how to conduct maintenance on floating wind turbines once they are deployed far out at sea. Both aspects rely on expertise and capabilities which are as underdeveloped as the industry is nascent. This challenge also applies to the hydrogen sector, where a skills shortage is observed internationally in the wider supply chain, constraining the full value chain from product development, through manufacture and deployment, and into maintenance. This is an obstacle to ensuring that equipment can be looked after appropriately once deployed. In considering floating wind to hydrogen integration, potentially offshore, this manifests particularly in questions around the degree to which supply chains are equipped and/or trained to maintain integrated floating wind and hydrogen assets at sea. There may be significant opportunities for existing offshore engineering specialists to refocus their efforts in applying skills, capabilities and services developed for the oil and gas sectors for floating wind and hydrogen projects offshore. Like other northern European countries with established oil and gas supply chains, there is good scope for Scottish and French organisations to explore these opportunities.

Both sectors also experience challenges with regard to conforming to extensive and varying health, safety and environmental standards, particularly in the marine environment, and developing systems and practices to ensure safe and responsible ways of working. Linked to environmental standards is the challenge of consenting offshore energy projects of all varieties, as a result of understandably stringent marine environment protection requirements and planning processes. The effects of waste products (predominantly heat, saline water and oxygen) must be further studied and the associated survey and monitoring requirements understood.

Addressing these cross-cutting challenges will require novel systems and procedures, as well as investment in infrastructure and training. Across the world, innovation projects seeking to develop these new systems are underway, and some relevant projects being carried out in Scotland and in France are described in subsequent sections of this report.

Floating wind challenges

In floating wind specifically, there is a challenge in providing efficient and cost-effective mooring and anchoring solutions to ensure the platforms remain in position [9]. There are different designs for the floating platform to support the wind turbine; these different designs each have different implications for their fabrication, installation and maintenance.

Hydrogen integration challenges

As noted already, power transmission challenges for floating wind developers are a potential enabler for future hydrogen markets. However, the circumstances which give rise to this opportunity also create inherent challenges. If hydrogen is to be produced in the vicinity of floating wind farms to reduce reliance on electricity transmission infrastructure, then solutions will need to be developed for transporting that hydrogen back to shore safely and at scale.

More important, perhaps, is the fact that in order to produce hydrogen offshore via electrolysis there are some outstanding research questions in terms of guaranteeing affordable fresh water availability. Fresh, purified water is currently required for electrolysis, as contaminants (including dissolved salts in seawater) can take part in undesirable chemical reactions within the systems, leading to damage to components. The use of seawater in specially designed saline electrolysers may help to resolve this, however further innovation is required to develop such systems. In this instance there are mooring, anchoring and stabilisation challenges for electrolyser developers to contend with; it is so far unclear whether an electrolysis platform moving with the motion of waves could feasibly operate and to what extent motion will affect electrolyser performance and longevity. This issue is further complicated by the range of electrolysis technologies available and being developed.

Beyond the transport of the hydrogen produced, some form of storage will be required and, as yet, no fully optimised hydrogen storage system has been developed or optimised for the marine environment onboard a floating wind turbine.

Further additional challenges emerge when attempting to integrate floating wind and hydrogen production and handling systems. The first and most obvious challenge relates to how devices should be connected electrically and the design of the required onboard microgrid. Furthermore, the presence of elevated oxygen levels and the potential for hydrogen building up in the vicinity of the turbine (due to venting) must be fully investigated. Methods of protecting electrical and mechanical systems operating in these environments must be understood, and protection systems will need to be developed where necessary.

Having made hydrogen offshore, and assuming that a suitable storage and transport system or procedure has been developed, there is also a question of identifying the most appropriate markets and applications for hydrogen. This will be a very important element for any would-be developer of integrated floating wind and hydrogen projects.

Proposing solutions to these challenges is beyond the scope of this report, but the following sections seek to elaborate on the policy and innovation contexts underpinning efforts to move these sectors forward in both Scotland and France.

Policy and innovation frameworks: Scotland

Policy context

The Climate Change (Scotland) Act 2009 first established a statutory duty for the Scottish Government to pursue greenhouse gas emission reduction targets, aiming for an 80% reduction in emissions by 2050 against a 1990 baseline [12]. This Act was amended by the Scottish Parliament in 2019 to reflect advice provided by the UK's Committee on Climate Change, which recommended that the Scottish Government facilitate a full reduction to 'net zero' greenhouse gas emissions by 2045 [13]. The Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 [14] passed into law as a result, making provision for steeper targets, and for the frameworks required to implement plans for more rapid reduction in greenhouse gas emissions in Scotland.

In this context, the Scottish energy system has been closely scrutinised. The Scottish Government has prioritised developing frameworks to support development in the key sustainable energy technologies which can play a role in facilitating transition in Scotland. Indeed, the Scottish Government has recently published policy statements outlining the future positions envisaged for offshore wind and hydrogen in the Scottish energy system [1, 3]. These policy statements also provide an overview of current support schemes, and others under development, to fund innovation activity and to develop supply chain capacity in these sectors. Both statements also highlight measures intended to ensure that economic development and employment opportunities associated with the deployment of these technologies in Scotland is felt locally in Scotland. This aspect is key to delivering the Scottish Government's 'green recovery' and 'just transition' ambitions, in relation to retaining skills and experience developed in the oil and gas industry in Scotland, and in using economic recovery levers resulting from the disruption caused by the COVID-19 pandemic to mobilise investment to deliver these projects sooner than might otherwise have been foreseen. The Scottish Government will further publish a Hydrogen Action Plan later in 2021, which will elaborate on the policy mechanisms intended to deliver upon the ambitions outlined in the Policy Statement [3].

In the context of this work, it is also worth highlighting that both policy statements recognise an opportunity for international collaboration that is inherent to further development in these sectors in Scotland, particularly in sharing lessons learned in preliminary deployment projects in Scotland. In its 'Offshore Wind Policy Statement' specifically, the Scottish Government acknowledges the 'huge economic opportunity' associated with deploying floating wind systems in Scottish waters, in no small part due to the depth of the waters around Scotland noted above. The statement also recognises the added value that oil and gas knowledge and expertise in Scotland can contribute to making projects further and further out to sea more technically feasible [1]. Noting that hydrogen is less well developed as an energy system technology or solution, the Scottish Government's 'Hydrogen Policy Statement' commits the government to deliver £100 million of funding in 2021-2025 for the development of the Scottish hydrogen economy. The statement also highlights the important role for research, development and demonstration activity to reduce perceived risk for future hydrogen projects, and to drive private sector investment to deliver these solutions at scale. Significantly for this work, the statement notes the importance of (international) collaborative innovation activity and commits the Scottish Government to working with other parties to pursue the development of an international 'shared hydrogen economy'. It is worth highlighting a recent research study undertaken for the Scottish Government analysing Franco-Scottish research collaborations. Through engaging with stakeholders actively involved in cross-border collaborative research in the two countries, this study found that uncertainties regarding the future innovation funding regime following the UK's withdrawal from the European Union had negatively impacted upon the ease of working together, at least in the context of academic research. This study highlighted the relief researchers felt at the UK's continued participation in the Horizon Europe programme [15], for which the work programme is likely to include opportunities for joint working on floating wind and hydrogen.

The UK government, and in particular the Department for Business, Energy and Industrial Strategy (BEIS), are also working to deliver against a 2050 target for the reduction of UK-wide greenhouse gas emissions to 'net zero'. A number of policy areas and legislative powers of relevance to the development of floating wind and hydrogen technologies in Scotland are reserved to the UK Government, and specifically to BEIS. BEIS brought forward the UK offshore wind Sector Deal in 2019, committing alongside the industry to invest to deliver offshore wind as a key component of the UK energy system. The Sector Deal includes specific reference to the importance of innovation in delivering future, low-cost offshore wind technologies and systems, especially in applications such as floating wind [16]. BEIS has committed to a target for 1 GW of installed floating wind capacity in UK waters by 2030. BEIS is also developing UK strategy for the deployment of hydrogen as a key vector towards delivering 'net zero'. The UK hydrogen strategy is due to be published in 2021 and is expected to articulate the UK's vision for delivering a future hydrogen economy, likely to include significant investment in research, development and demonstration activities. Importantly, this document will also include details on future market structures and revenue supports to develop hydrogen production capacity at scale. Energy market structure is also an area of policy reserved to the UK Government, so these developments will be of great importance to future hydrogen projects in Scotland. A particular priority for BEIS has been the decarbonisation of industrial sectors, and the potential role for hydrogen produced from (floating) wind to facilitate transition in these sectors. Innovation programmes intended to develop these future technologies and systems are described in the following section.

In addition to the Scottish and UK Governments, a range of public sector bodies and development organisations are playing important roles in facilitating development in these technology areas in Scotland. Some of these are summarised here.

- The Scottish economic development agencies Scottish Enterprise, Highlands and Islands Enterprise, South of Scotland Enterprise and Scottish Development International all play vital roles in bringing stakeholders together and promoting developments within their areas of focus. Scottish Enterprise recently commissioned Xodus Group to carry out an opportunity assessment which looked at opportunities in, and supply chain readiness for, linking up the Scottish wind and hydrogen sectors [17]. Meanwhile, the DeepWind Cluster, organised by Highlands and Islands Enterprise, brings together the largest grouping of offshore wind supply chain organisations in the UK. The DeepWind Cluster has specific floating wind and Power-to-X subgroups, looking to facilitate collaborations to deliver innovation activity in these areas [18].

- Academic networks have also been very active in driving forward innovation activity in these sectors and in contributing thought leadership to influence the roadmaps developing for the deployment of both floating wind and hydrogen technologies in Scotland. 2020 saw the notable formation of the Hydrogen Accelerator at the University of St Andrews funded by Transport Scotland. The Accelerator will support policy makers and innovators in Scotland to implement hydrogen technologies and support economic growth in these sectors [19]. The Universities of Edinburgh and Strathclyde co-host centres of research excellence in marine energies, including the Industrial Centre for Doctoral Training for Offshore Renewable Energy and the Centre for Doctoral Training in Wind and Marine Energy. Both institutes have explored several relevant topics to developing floating wind and hydrogen systems, and their integration together.

- In addition, partnerships between public and private sector organisations have also delivered development in the deployment of both floating wind and hydrogen systems in Scotland. This has been particularly well demonstrated in Aberdeen, where collaboration between Aberdeen City Council and various private sector partners has developed a thriving hydrogen ecosystem building upon demonstration deployments of hydrogen fuel cell buses, supported by the Scottish Government, the UK Government and European innovation programmes [20]. A further public-private partnership in Dundee has seen the development of the Michelin Scotland Innovation Parc in a joint venture between Michelin, Scottish Enterprise and Dundee City Council. The Parc will host research, development and manufacturing facilities for organisations developing emerging sustainable technologies, including hydrogen systems and fuel cells [21]. Perhaps the best example on the floating wind side would be the Floating Offshore Wind Joint Industry Programme (FLW JIP), managed by the Carbon Trust, which has leveraged Scottish Government investment to bring private sector developers together to collaborate on and address technical challenges [22]. Trade associations including RenewableUK, Scottish Renewables and the Scottish Hydrogen & Fuel Cell Association assist in bringing together disparate industry groups and representing them in public spheres.

These disparate stakeholder groups have come together to deliver a wide range of innovation activity within the floating wind and hydrogen sectors, and at the interface between the two. The following section characterises the innovation context for those activities.

Innovation landscape

As noted, a wide range of organisations across public and private sectors have come together to facilitate the current developments in Scotland in deploying floating wind and hydrogen systems. These collaborative activities have often occurred within the bounds of funding programmes specifically designed to encourage such activities, whether organised at Scottish, UK or European levels. A non-exhaustive overview of relevant programmes in these sectors is summarised below (Table 1).

Table 1. A summary of innovation programmes in the floating wind and hydrogen sectors accessed by Scotland-based stakeholders.

Funder	Name	Timeframe	Funds	Description
European Commission	Fuel Cells and Hydrogen Joint Undertaking (FCH JU)	2004-2020	~€2bn	A European public-private partnership supporting research, technological development and demonstration activities in fuel cells and hydrogen.
European Commission	Clean Hydrogen for Europe Partnership	2021-2027	TBC	Successor public-private partnership to the FCH JU, with a focus on delivering hydrogen innovation to contribute to the European energy transition.
BEIS	Low Carbon Hydrogen Supply Competition	2018-2024	£33m	Innovation competition intended to accelerate the development of low carbon bulk hydrogen supply solutions in the UK.

Carbon Trust (Scottish Government)	Floating Wind Joint Industry Programme	2016-future	£9.5m	A collaborative research and development initiative aiming to investigate challenges and opportunities for large-scale commercial floating wind farms.
Scottish Government	Energy Transition Fund	2020-2025	£62m	Support for businesses in the oil, gas and energy sectors in Scotland, to facilitate development projects aimed at diversification.
Scottish Government	Emerging Energy Technologies Fund	2021-2026	£180m	Investment across carbon capture and storage, negative emissions technologies, and hydrogen production, with £100m of funding specifically allocated for hydrogen projects
Scottish Government (with support from the European Regional Development Fund)	Low Carbon Infrastructure Transition Programme	2015-2021	~£60m so far	Provides financial and practical support to infrastructure development projects intended to support the realisation of Scotland's energy transition.
BEIS	Net Zero Hydrogen Fund	2021-future	£240m	Funds to be developed through the UK hydrogen strategy, expected to co-fund low carbon hydrogen deployment projects.
BEIS	Floating Offshore Wind Demonstration Programme	2021-future	£17.5m	Programme of activities aimed at developing components and systems for future floating wind technologies.

Offshore Renewable Energy Catapult	Floating Offshore Wind Centre of Excellence	2020-future	TBC	Development of a centre of excellence to support the cost reduction of floating offshore wind.
Offshore Wind Industry Council	Offshore Wind Growth Parternship	2020-2030	TBC	Long-term business transformation programme established as part of the UK Offshore Wind Sector Deal. Promotes closer collaboration across the supply chain.

Drawing from project examples across these programmes, a few seminal projects have been identified which have influenced the wider sectors. The role for collaborative European innovation projects in pushing activity in the hydrogen sector forward cannot easily be overstated. In Scotland, projects in Aberdeen and Orkney in particular have benefitted from European investment and from cross-border collaboration with European partners.

- The **Aberdeen 'Hydrogen Hub'** programme has emerged to build upon prior successes through, for example, the European Commission-funded Fuel Cells and Hydrogen Joint Undertaking (FCH JU) HighVLOCity, HyTransit and JIVE projects, which have invested in hydrogen fuel cell public transport vehicles and infrastructure in cities across Europe, especially in Aberdeen. These activities have inspired subsequent projects funded by others, including the European Interreg programmes which promote collaboration across national borders within European regions, as well as the Scottish and UK governments [20].

- In Orkney, flagship hydrogen projects like the **Building Innovative Green Hydrogen Systems in Isolated Territories** (BIG HIT) project, also funded by the FCH JU and involving partners from Spain, Denmark, Italy and Malta, have further developed capacities for hydrogen production, handling and use in the Orkney Islands [23]. In both areas, these initial projects have seeded subsequent activities and raised ambitions for the next phase and scale of hydrogen system deployments.

- The **Floating Wind Joint Industry Programme (FLW JIP)** has leveraged Scottish Government support to facilitate collaborative innovation activity between a wide range of international offshore wind developers. Key findings from FLW JIP projects have demonstrated the feasibility of fitting state of the art wind turbines on floating platforms, while also proposing new solutions for the offshore vessel operations which will be required to install and maintain future wind farms.

Projects currently in development under the programme are tackling a wide range of issues including the development of future mooring systems for challenging environments, as well as assessing the technical and logistical feasibility of towing floating turbines back to ports for maintenance [26]. These research projects have all been undertaken in collaborative activities between a range of private sector actors, perhaps demonstrating what can be achieved when organisations are brought together to build towards a shared goal.

- Early innovation activities are underway seeking to demonstrate how floating wind and hydrogen systems might best be integrated. TechnipFMC, a developer headquartered in London but with a presence in Scotland, have been developing designs for an integrated offshore wind-offshore hydrogen production system during their **Deep Purple™** project. Offshore hydrogen production and storage systems will be deployed alongside a fixed offshore wind farm off the coast of Norway, where hydrogen will be produced at times of low demand for power [27].

- In addition, through funding allocated by BEIS in the Hydrogen Supply Competition noted in Table 1, Aberdeen-based ERM have been investigating the development of integrated floating wind and hydrogen production systems through their **Dolphyn** project. To date the project consortium has completed a feasibility study and they are currently undertaking front-end engineering design activities towards the deployment of a 10 MW system. The pilot installation is expected to be deployed off the coast of Aberdeen by 2024 [28].

- More recent projects have emerged with a focus on researching and demonstrating the role for hydrogen in decarbonising other sectors such as heating, and in industrial processes. These projects are expected to play a key role in developing demand-side case studies and thus de-risking future off-take for hydrogen supply in Scotland. Key emerging sectors include:

    - In domestic heating, the SGN **H100 Fife** project will deliver a 100% hydrogen gas network which will bring locally produced, zero-emission hydrogen gas into around 3,000 homes in a world-first pilot demonstration [24].

    - In industrial applications, a number of projects have emerged which have focused on evaluating the technical feasibility of deploying hydrogen systems in the distilling sector [25].

Policy and innovation frameworks: France

Policy context

The energy transition roadmap in France is governed by the overall strategy stated in the Low Carbon National Strategy (‘Stratégie nationale bas-carbone’, [29]). First introduced in 2015 and later revised to include the more ambitious strategy resulting from the Paris Agreement, i.e. carbon neutrality by 2050, the document is a roadmap towards CO_2 emission reductions and provides specific targets within each sector. The document suggests using hydrogen as a way of reducing emissions for the transport sector (air, marine and road) and identifies the use of hydrogen as a possible solution to reduce emissions from the chemical and steel industries but does not provide a specific framework for green hydrogen development.

This overarching strategy is deployed in a more specific plan for the energy sector in the *Multiannual Energy Programme* (‘Programmation Pluriannuelle de l’Energie’, [30]). This document, updated every five years, sets out a roadmap for the evolution of the French energy mix at short and medium term, for example, the latest edition from April 2020 covers the periods 2019-2023 and 2024-2028. The previous edition in 2016 included the first specific targets for Marine Renewables Energy (floating wind, tidal, etc.): at least 100 MW capacity should be installed by the end of 2023 – with awarded projects at this date totalling between 200 MW and 2 GW, depending on price conditions and lessons learned from pilot farms. This resulted in the tender and award of four pilot floating wind farms, currently under development. In addition, the 2020 edition states that tenders will be released for utility-scale development of floating wind farms as follows: 250 MW in South Brittany in 2021 (tendered at a price of 120 €/MWh), two 250 MW projects in the Mediterranean Sea in 2022 (tendered at a price of 110 €/MWh), and then 1 GW of offshore wind per year between 2024 and 2028, either fixed or floating depending on prices and sites availability. The strategy for low-carbon hydrogen sets the following targets: 10% of green hydrogen in the national mix of hydrogen used by the industry in 2023, then 20-40% by 2028. In addition, the ambition for hydrogen-powered vehicles is to reach 5,000 light vehicles and 200 heavy vehicles by 2023, and then 20,000-50,000 and 800-2,000 respectively by 2028. This ambition is translated in terms of number of filling stations nationwide as follows: from approximately 30 at the end of 2019 to 100 by 2023, then 400 to 1,000 by 2028. These commitments represent very significant volumes of hydrogen demand over the coming decade.

These national targets for green hydrogen development are further developed in the *Hydrogen Plan* (‘Plan Hydrogène’, [4]). This seven-billion-euro investment plan sets up three priorities for green hydrogen development in France by 2030: to reduce industrial carbon footprint with a French electrolysis supply chain, develop heavy transport powered with green hydrogen, and support research, development and demonstration, as well as skills development to enhance future uses of low-carbon hydrogen. The plan is developed following several funding schemes (Table 2).

Table 2. Funding schemes of the French Hydrogen Plan.

Funder	Name	Timeframe	Funds	Description
Agence de la Transition Ecologique	Call for Projects EcosysH2 'local hydrogen hubs'	2020-2023	€275m	Development of large-scale regional hubs by consortiums joining the public and private sectors to concentrate several uses and allow for economies of scale.
Agence de la Transition Ecologique	Call for projects INODEMO H2 'Technology bricks and demonstrators'	2020-2023	€350m	Develop or improve components and systems related to hydrogen production, transport, or uses.
Various, French government	Investments for the Future Fund			Corportate financing for companies developing innovative technologies, industrialization or pilot projects in energy infrastructures.
Various, European Commission and member state governments	Hydrogen Important Projects of Common European Interest	2021+	€1.5bn	Support to research and industrialisation of electrolysers, industrialization of key components in the European supply chain.
Various, French government	Expression of Interst for the Hydrogen Applications	2021+	€65m	Support to early-phase research on the future of hydrogen production (batteries, reservoirs, materials, electrolysers).
Agence de la Transition Ecologique	Tender on green hydrogen production	2022	Supple-mentary revenue	Utility-scale projects

Key public players in the combined floating wind-green hydrogen sector at national level have been identified:

- The Ministry of Ecological Transition is in charge of establishing, reviewing and editing the programmes and laws governing the main national policies regarding floating offshore and green hydrogen development, e.g. Hydrogen Plan, Multiannual Energy Plan.

- The French Agency for Ecological Transition (ADEME) is a public agency under the joint authority of the Ministry for an Ecological Transition and the Ministry for Higher Education, Research and Innovation. The ADEME is in charge of coordinating several research and development funding and calls for projects, for instance in the context of the Hydrogen Plan.

- The French National Research Agency (ANR) is a public administrative institution under the authority of the French Ministry of Higher Education, Research and Innovation. Since 2010, the ANR is in charge of managing the research and development national investment for the Futures programme. Ongoing research and development projects funded by the ANR and relevant to our study include CREATIF, which focuses on control and real time simulation of floating wind turbines and their integration to the grid, and EPIC-H2, concerning modelling and control of microbial consortium for green hydrogen production.

- The newly-founded National Hydrogen Council aims at guaranteeing an efficient communication between the French State and the main industrial stakeholders of the green hydrogen development. Its members have been approved by the relevant ministries, including the Ministry of Ecological Transition and the Ministry of Higher Education, Research and Innovation. At the time of writing, the council’s co-presidents are Patrick Koller (Faurecia’s Managing Director) and Benoit Potier (Air Liquide’s chief executive officer).

- The French regional governments and authorities also play a key role in developing and implementing energy strategies, as well as in distributing European and national funding. Regional development agencies also work with private organisations in public-private partnerships in order to deliver innovation activities. The central role for the French regions is evident in a number of important areas of note to this study:

- Régions de France is an institution that represents the French regions’ common interests. Established in 1998, it is one of the primary organisations championing French political decentralisation and encouraging the realisation of schemes that will deliver positive development outcomes in the regions. Notably, the delivery of the French energy transition (transition énergétique) is a central priority for the organisation, as highlighted in Figure 3.

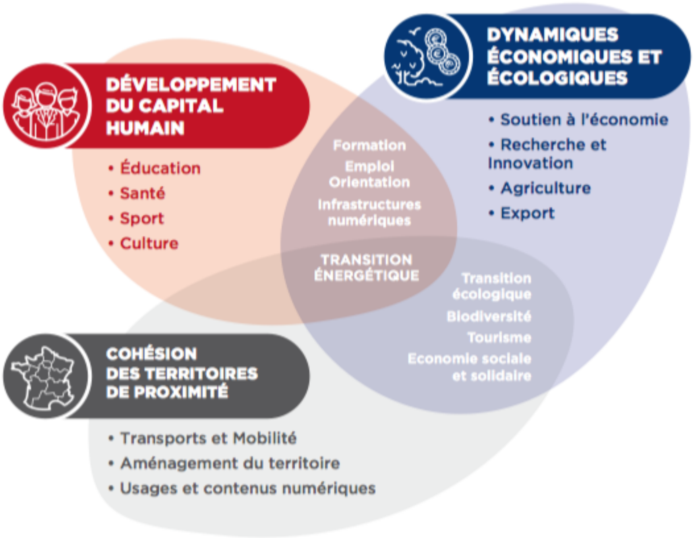

Figure 3. Priorities for the French regions in their areas of competence [34].

- Regional roadmaps for hydrogen deployment have been developed to varying degrees of detail in Brittany, Pays de la Loire, Occitanie and Normandie. The Brittany roadmap introduced by the Department for Climate, Environment, Water and Biodiversity (‘Direction du Climat, de l’Environnement, de l’Eau et de la Biodiversité’), for example, details plans to develop logistics capacity and supply chain competencies, particularly in the maritime contexts and with a specific focus on floating components and infrastructure [31]. Normandie is also very active in this sector and was the first region to develop a hydrogen roadmap in 2018, with a €15 m fund spread over 3 years aiming to accelerate the energy transition.
- In floating wind, a recently announced partnership between four littoral regions (Provence-Alpes-Côte d'Azur, Occitanie, Brittany, and Pays de la Loire) will pursue the introduction of a supportive, collaborative ecosystem and industry development programme to facilitate growing wind farm deployments. This collaborative arrangement will focus on coordination activities between supply chain organisations in the four regions, as well as providing financial investments [32].

In the public sector, other key stakeholders include research institutes active in the floating wind and green hydrogen sectors:

- The French Alternative Energies and Atomic Energy Commission (CEA) is active in research, development and demonstration in low carbon energies. In particular the CEA has studied hydrogen and fuel cells since the late 1980s, aiming to increase the economic interest of this energy option, and to be at the leading edge of hydrogen technology, supporting industrial companies.

- The French National Centre for Scientific Research has led the creation of the FRH2 federation: the Hydrogen Research Federation. With more than

270 research workers from 28 different laboratories, the FRH2's mission is to gather and coordinate research efforts for the development of green hydrogen, its cleansing and storage and progress towards fully-integrated systems covering production to end-use through fuel cells.

- The French Institute of Petroleum and Renewable Energies has released in 2019 the results of a joint research effort with SINTEF, a Norwegian research centre: 'Hydrogen for Europe'. The study aims to identify existing knowledge for the production and distribution of 'low-emission energy carriers' and assess the potential of hydrogen in Europe.

- France Energies Marine, the French institute for energy transition dedicated to offshore renewable energies, is a public-private body working in collaboration with seven other institutes for energy transition and eight technological research institutes. As the main French research institute for offshore renewable energies, France Energies Marines is active in several floating wind Joint Industry Projects.

Trade associations gather private sector stakeholders in each sector:

- For hydrogen in general and green hydrogen in particular, the French Association for Hydrogen and Fuel Cells (France Hydrogène) acts as the main contact between public decision makers and its members, which comprise large industry companies, small to medium enterprises, and start-ups across the hydrogen value chain. The prospective study 'Developing Hydrogen for the French Economy' [33] led by the association, offers an interesting view of the ambitions of the private stakeholders in the industry. Key members of the association include McPhy, Air Liquide, Total, Engie, Lhyfe, H2V, GrDF, Helion, Qair, etc.
- For renewable energy in general and floating offshore wind in particular, the French Renewable Energy Trade Association is one of the main associations that plays this role of promoting the interests of industrials and professionals in the sector to public decision-makers. Key members of the association include Ideol, SBM France, EDF Renouvelables, EOLFI-Shell, Engie, Qair, etc.
- Principle Power and RTE – the French Transmission System Operator – are among other key private stakeholders for floating wind energy in France.

Innovation landscape

No specific research programme on floating wind and green hydrogen combination has been identified to date. However, the following completed or ongoing research projects are relevant to the topic:

- **Jupiter 1000** has prepared for the deployment of the Power-to-Gas network in France, with a 1 MW hydrogen production platform in the Provence-Alpes-Côte d'Azur South region. Selected by GRTGaz, McPhy has equipped the project with a 1 MW hydrogen production platform. Commissioned in 2019, the system allowed testing the performance of two electrolysis technologies (alkaline & PEM) under real operational conditions.

- **HyBalance** is a project that demonstrates the use of hydrogen in energy systems. The hydrogen is produced from water electrolysis, enabling the storage of cheap renewable electricity from wind turbines. It can help balance the grid, and the hydrogen is used for clean transportation and in the industrial sector. Air Liquide is a key contributor of this project, funded by a 15-million-euro grant from the European Commission under the H2020 scheme.
- **Masshylia** is a collaborative research project between Total and Engie that aims at designing, developing, building and operating France's largest renewable hydrogen production, in the Provence-Alpes-Côte d'Azur South region. The project includes a direct current connection between a photovoltaic farm and the electrolyser to improve the energy balance.
- The **GRHYD** hydrogen energy storage demonstrator project, led by Engie and launched in 2014 for five years, trialled the injection of hydrogen into the natural gas distribution network of a new neighbourhood in the Hauts de France region, and an NGV refuelling station for buses located in the Dunkirk Urban Community.
- Led by Lhyfe and anchored in the Pays de la Loire region, **H2Ouest** aims to deploy a 100% green hydrogen sector in the region starting in 2021. Green hydrogen will be produced using 100% renewable energies and by electrolysis of water- it is described as a proof of concept that will eventually be replicable in a wide range of geographies.
- **H2V59**, led by H2V INDUSTRY, aims at creating a green hydrogen factory within Dunkirk Harbor. Works by RTE will start in the coming months to realize electrical connection to the grid, following a public consultation that established an overall support of the local public.
- The **Littoral+** project is led by the Occitanie region and aims to prepare for the upcoming climate change consequences on the region’s coastline. Developing the production of marine renewable energies in combination with massive green hydrogen for low-carbon transport is identified as one of the four pillars of this €91 million project: the H2 Littoral action, led by the energy producer Qair.

Among the ongoing research projects identified, H2Ouest and Littoral+ offer the clearest synergy between floating wind and green hydrogen. Both projects are anchored in regions where floating wind pilot farms are being developed, and where commercial floating wind farms are being planned. Both project statements also state the link between wind/marine renewable energies and green hydrogen production. No specific national programme in France to date has combined both floating wind and hydrogen.

Findings from engaging with supply chain stakeholders

As noted previously, supply chain stakeholders were engaged during the delivery of this research project. These stakeholders were invited to share views with the project team regarding the technical challenges they would prioritise for future research activities and their experiences of collaborative innovation projects. Participants were also asked to comment on their research and development support needs, and on proposed recommendations for possible Scottish Government intervention to develop Franco-Scottish collaborations. Stakeholders were engaged through questionnaires, expert interviews and discursive workshops.

36 questionnaire responses were received, from 12 organisations in Scotland and 24 in France. Five expert interviews were conducted, with three Scottish stakeholder organisations and two in France. Of the workshops, three were held. The first, which had a technical focus and was targeted at Scottish stakeholders only, drew 31 attendees representing 20 organisations. The second workshop, also with a technical focus and for French stakeholders only, had 21 attendees representing 15 organisations. The third workshop brought together a mixed group of Scottish and French stakeholders to discuss collaborative innovation initiatives, with 16 participants representing 11 organisations. Of those organisations, four were based in France and seven were based in Scotland.

Themes from Scottish stakeholder feedback from expert interviews and a technical workshop:

- **Innovation should support technology deployments at scale**: discussions with Scotland-based organisations placed very clear and explicit emphasis on a need for any initiatives targeting floating wind and hydrogen to support technology deployments at scale. Feedback suggested that driving deployments through innovation programmes could facilitate cost reductions more effectively than incremental innovation focused on improving individual system components. In these discussions, stakeholders suggested that industry representatives may be well placed to help shape the research focus required to address relevant technology challenges. Stakeholders reflected favourably on experiences of joint industry working.

"[We] need to be moving faster to deploy these technologies now. Typical renewable energy development timelines can run to ten years; it would be great if we could use research and innovation projects to short-circuit that to deliver cost reductions sooner".

Quote from one Scottish supply chain stakeholder focused on the development of the hydrogen sector.

- **Research could be used to de-risk future investment**: underneath the notion of using future innovation initiatives to 'support' deployments at scale was an encouragement from stakeholders to prioritise research, development and demonstration activities which would de-risk future investment. This manifested in a request from stakeholders to ensure that future research programme design would anticipate investor perspectives and seek to develop activities which could contribute to easing the path for future commercial projects.

  A key element of this feedback referred to perceptions shared by some stakeholders that it seems premature to consider in earnest an integration at scale of hydrogen and floating wind systems, when both are still in-development technologies in their own right. These stakeholders suggested that commercial projects at the interface of these technologies would likely be very risky currently. These stakeholders recommended that innovation activities focus specifically on continuing to mature the two technologies, alongside preliminary demonstrations of their co-deployment.

- **Use collaborative innovation initiatives to build upon the existing skills base and supply chain competencies**: supply chain strengths in Scotland in subsea engineering and in other services traditionally provided to the oil and gas sectors were highlighted by stakeholders. There was consensus among those consulted that future innovation developments in Scotland (and in outward international collaborations) should prioritise the identification of opportunities to leverage these skills and competencies in emerging sectors like floating wind and hydrogen. Stakeholders clearly recognised the value and importance of taking advantage of 'Just Transition' opportunities in delivering Scotland's energy future.

One of the stakeholders also shared a positive experience regarding the impact of an employment support grant during the COVID-19 pandemic. Their organisation had been able to use the grant received to dedicate a staff member to carrying out an innovation, research and development audit, which provided scope to identify new opportunities for them in emerging energy technology developments. In this discussion, other stakeholders reflected on the challenge of developing innovation project pipelines while trying to manage their day-to-day business. Participants suggested that 'Just Transition' grant support mechanisms could be used similarly, to provide the financial headroom required for supply chain organisations to wrestle with the potential future opportunities emerging in floating wind and hydrogen. A further practical suggestion shared by stakeholders concerned a specific recommendation for a joint Franco-Scottish study looking at the technical feasibility of repurposing offshore energy infrastructure for hydrogen production and transport.

- **Inter-regional collaboration may be ideally placed to address identified shared challenges and ambitions**: Scottish stakeholders recognised the shared ambitions for floating wind and hydrogen development expressed by a number of leading regions in France. Reflections in these discussions also acknowledged that French regions are similar in scale (population, geography, economy) to Scotland, suggesting that inter-regional co-operation may be the most appropriate means of developing further Franco-Scottish joint working. In these discussions, stakeholders also noted the value of identifying challenges (and opportunities) shared by different regions between Scotland and France. Specifically, stakeholders expressed interest in establishing whether industrialised French regions may have similarly well-equipped oil and gas supply chains which could be transitioned towards working in floating wind and hydrogen development. Identifying supply chain competencies which are particular strengths in Scotland and in relevant French regions may provide fertile ground for exploring future collaborative programmes, for example, through knowledge exchange schemes.

Themes from French stakeholder feedback from expert interviews and a technical workshop:

- **Fundamental technical questions and uncertainties were prominent in discussions with French stakeholders**: the French participant group highlighted a keen need to understand where and how hydrogen would be produced in integrating the floating wind and hydrogen sectors. A key concern shared by French stakeholders was a lack of clarity in future market structures and market dynamics for floating wind and hydrogen in France (and internationally). This feedback further manifested in an expression of interest in seeing research activities specifically dedicated to developing commercial frameworks and business cases for these future sectors. These stakeholders would like to see research undertaken to better understand the energy system value of the offshore wind power that will be produced, before considering hydrogen business cases, but would also welcome research to clarify hydrogen supply and demand dynamics in Europe. Participants reflected on the role such work could play in de-risking commercial investments in future.

"The business cases for floating wind and hydrogen are not yet fully developed on their own [in France]. It would be helpful to better understand the commercial opportunity for each technology separately to inform future decision making".

(Translated) reflection from a French supply chain stakeholder on research priorities for the floating wind and hydrogen sectors.

- On a technical front, these discussions highlighted interest among stakeholders in fundamental research looking at better understanding the implications of the range of scenarios envisaged for integrating floating wind and hydrogen. These participants encouraged the development of evidence bases establishing the advantages and challenges anticipated for deploying hydrogen production facilities onshore, with power connections to floating wind farms, or rather offshore, located adjacent to or within those wind farms. In the latter case, stakeholders would like to better understand the technicalities of whether electrolysis plants should be integrated within individual wind turbine platforms or centralised in a floating hydrogen plant. These discussions highlighted a number of uncertainties associated with integrating hydrogen and floating wind and set out clear priorities for initial further work which stakeholders would like to see undertaken.

  In part stemming from shared perceptions that floating wind and hydrogen are relatively immature prospects in France, the role for early stage academic research was emphasised strongly in these discussions. In this regard, stakeholders acknowledged strong existing collaborations between French and Scottish institutions.

- **Scottish 'Just Transition' ambitions are shared in France**: in similar terms to discussions with Scottish stakeholders, French participants expressed a keenness to see research, development and innovation initiatives further explore opportunities for oil and gas supply chains to be supported in refocusing their efforts on supplying services for floating wind and hydrogen developments. Stakeholders specifically reflected on the potential value of inter-regional collaboration between Scotland and industrialised, littoral French regions in researching best practice in facilitating supply chain transition, and in exchanging knowledge on relative and complementary competencies of established organisations in both countries.

- **There is nuance in the appropriate administrative level at which each challenge should be addressed**: the French stakeholder group gave clear feedback to the project team regarding the need for initiatives to strictly be undertaken at the appropriate regional, national or European level, according to the division of administrative and legislative powers prevailing in France. In particular, participants focused on a need for many of the market and regulatory challenges highlighted by the project team to be addressed at a European level, given their cross-border implications.

  However, these stakeholders also emphasised the opportunities for French regions with strong ambitions in floating wind and hydrogen to both learn from and share lessons with Scotland, and for organisations in the supply chains in these regions to work with Scottish counterparts. As noted above, participants shared a keenness to explore measures to support knowledge exchange and the sharing of best practice.

Themes in feedback from joint Franco-Scottish stakeholders on promoting collaborative innovation, from expert interviews and a technical workshop:

- **International collaboration will be vital in further developing floating wind and hydrogen**: across all stakeholder engagement activities undertaken for this research, stakeholders clearly expressed recognition of the value of, and need for, working together internationally. This is necessitated by the scale of the challenges and opportunities presented by developing both floating wind and hydrogen, and the roles foreseen for the two sectors respectively in delivering global energy transition. This ethos clearly underpinned all stakeholder feedback. This theme also manifested in stakeholder recognition that markets for both floating wind and hydrogen will develop across borders, and as such, innovation opportunities and energy supply-demand dynamics should be considered with international markets in mind. Across various sessions, stakeholders specifically encouraged efforts to avoid future innovation activities becoming 'siloed' as a result of not accounting for international aspects.

  There was no ambiguity in stakeholder feedback regarding international collaboration: in every discussion undertaken in delivering this project, participants responded positively to, or explicitly recommended the virtues of, working together across borders to address outstanding research challenges. Stakeholders shared nuanced feedback in these discussions which recognised that valuable innovation activity need not necessarily or explicitly be undertaken in joint projects, given the reality that some solutions may be more appropriate for one market and not in another. Instead, these discussions focused on the need to better share findings from existing and future innovation activity, to better co-ordinate research activity and to disseminate the 'lessons learned'. Practically speaking this feedback manifested in a recommendation or request from stakeholders for any proposed future Franco-Scottish initiatives to prioritise knowledge exchange in support of joint project delivery.

“[Scotland] cannot drive this alone. To deliver upon these ambitions for floating wind and hydrogen, there needs to be a collaborative push at a European level. Europe should be leading in this, and Scotland should be supporting that”.

A reflection from a Scottish supply chain stakeholder highlighting the importance of working together internationally.

- **Cluster-building and networking initiatives support and facilitate future collaboration**: stakeholders from both countries shared experiences with the project team regarding the importance of establishing connections to unlock opportunities for collaborative working. Cluster-building activities which bring together industry and supply chain organisations were recognised as enabling future activity in two ways. Firstly, discussion and knowledge exchange between representatives of organisations with different perspectives on a sector have been seen to encourage new ways of thinking, and have highlighted shared research interests. These exchanges have also enabled participants to move quickly together to address opportunities which emerge for collaborative working, for example, through funded innovation programmes. The latter aspect was noted by participants as being keenly important for developing collaborative consortia to pursue Horizon Europe projects and other similar funding streams.

  Participants shared experiences on best practice in facilitating these connections and recognised that some exchanges occur organically through the meeting of stakeholders at industry events and conferences. However, comparatively formal and facilitated engagements through industry networks were also highlighted as useful measures. The Scottish Enterprise DeepWind cluster and in particular, its Power-to-X sub-group, were identified by participants as providing a particularly good case study of such an initiative through its facilitation of various collaborative industry and supply chain efforts.

“Maintaining awareness of what is happening elsewhere can be very difficult when you are busy. It can be easy to take a narrow view with a full inbox! International networks can help to provide prompts to flag new opportunities, and to make vital links”.

Feedback from an innovation consultant in Scotland, reflecting on the vital role that networks can play in driving collaborative activity.

Quantitative feedback from both Scottish and French stakeholders, from online questionnaire:

As noted above and in prior sections of this report, an online questionnaire was conducted and supply chain stakeholders from Scotland and France were invited to share their experiences in developing projects in the floating wind and hydrogen sectors. Respondees also shared their views on the state of the development of these sectors, and on the ways in which they could be supported to undertake collaborative innovation with their French or Scottish counterparts. The questionnaire drew 36 responses, including views from 12 Scottish organisations and 24 French organisations.

Respondee organisations were invited to participate through public-facing press releases promoting project research activities. Further potential participant organisations known to be actively undertaking projects in floating wind and hydrogen were contacted directly by the project team to invite them to participate. As such and given the relatively small sample size, results from this questionnaire should not be taken to be representative of these wider sectors and their supply chains. Instead these questionnaire findings provide a useful insight into stakeholder perceptions among a limited sample group, and could be used to scope and inform further research work in the future.

Stakeholders were asked to comment on when they foresaw commercial viability for hydrogen produced using power from floating wind farms, in Scotland and in France. Responses are summarised in Figure 4, with participants suggesting that they expect more rapid commercialisation in these sectors in Scotland. These findings also show lower overall confidence in the development of these sectors in France and reinforce stakeholder perceptions noted in the interview and workshop feedback narrated above.

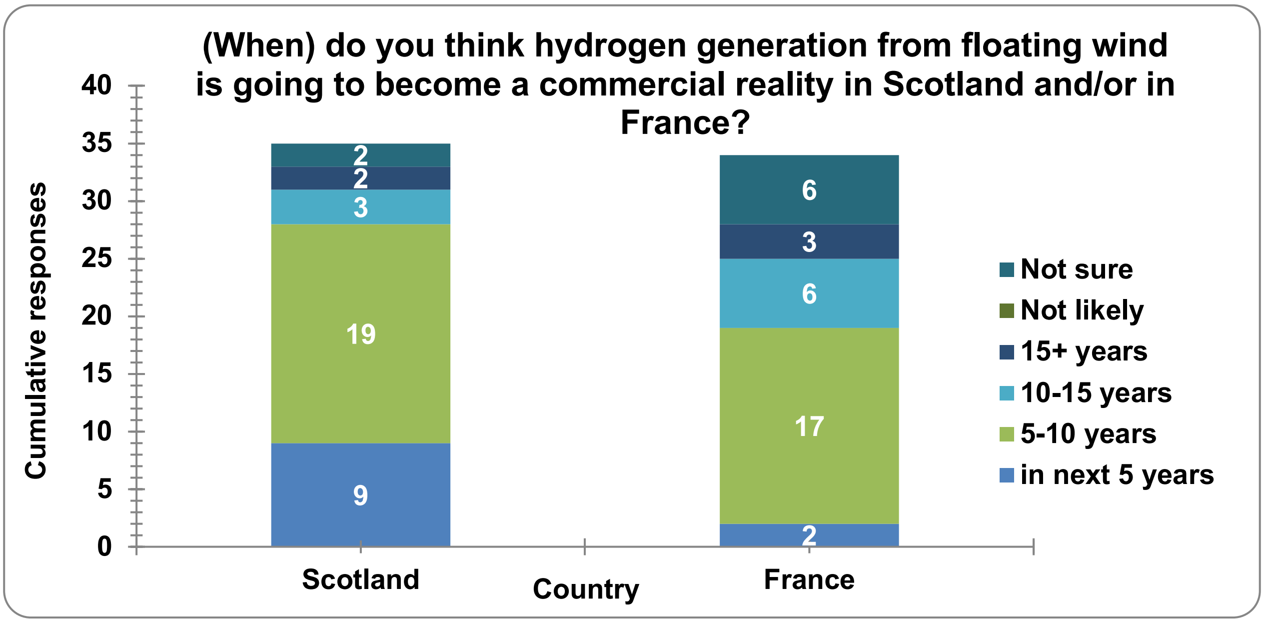

Figure 4. Questionnaire response regarding expected commercialisation timescales for hydrogen produced using power from floating wind, in Scotland and in France comparatively. Number of responses: 35.

In a subsequent question, stakeholders were asked to reflect upon the support needed broadly speaking to facilitate the commercialisation of hydrogen produced using power from floating wind. Responses are collated in Figure 5. Stakeholders notably expressed mainly favourable opinions to all of the proposed support measures. The highest scoring possible measure is that of grant funding for demonstration projects involving hydrogen and floating wind systems. This was followed by support from stakeholders for collaborative research and development co-ordination initiatives between public and private sector organisations, as well as the possibility of technology development competitions. These findings echo Scottish stakeholder workshop feedback, which reflected positively on experiences of joint industry project approaches to industrial research and late-stage technology innovation.

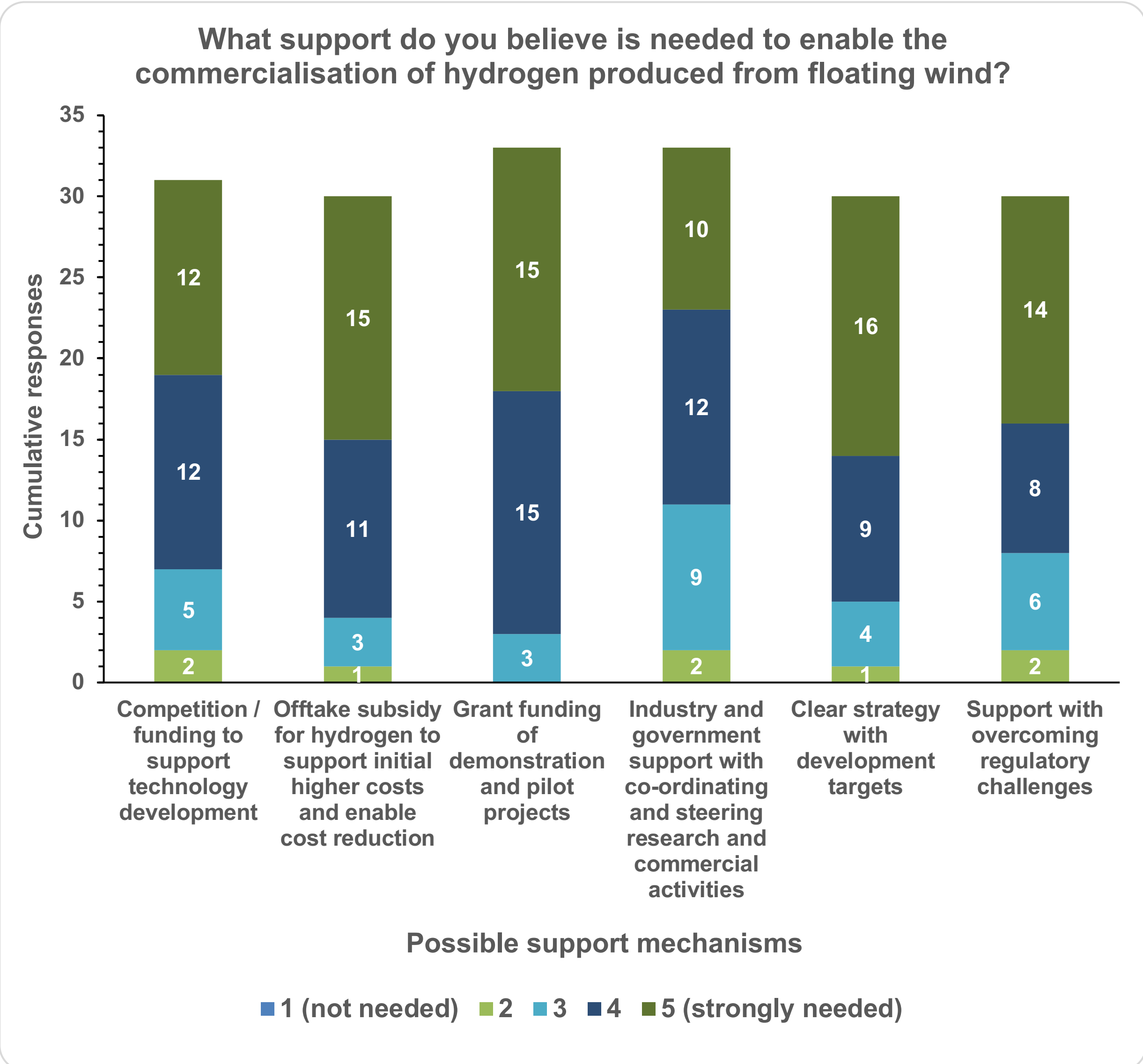

Figure 5. Reflections on relative need for a range of possible support mechanisms which could best support the commercialisation of hydrogen produced from floating wind power. Number of responses: 34.

Finally, responding stakeholders were also asked to comment upon specific measures which could be used to encourage collaboration between the French and Scottish supply chains. Participant feedback is summarised in Figure 6. Stakeholders were especially supportive of the potential for joint Franco-Scottish demonstration programmes in floating wind and hydrogen. The second most popular proposal relates to international trade delegations or visits. Both of these findings align closely to previously narrated observations from both prior questions, and discursive workshop and interview feedback. In particular, the high positive score for possible trade delegations and visits in the future aligns well with stakeholder feedback which recommended a strong focus in future initiatives on cluster-building and networking as key supportive activities for fomenting future joint working.

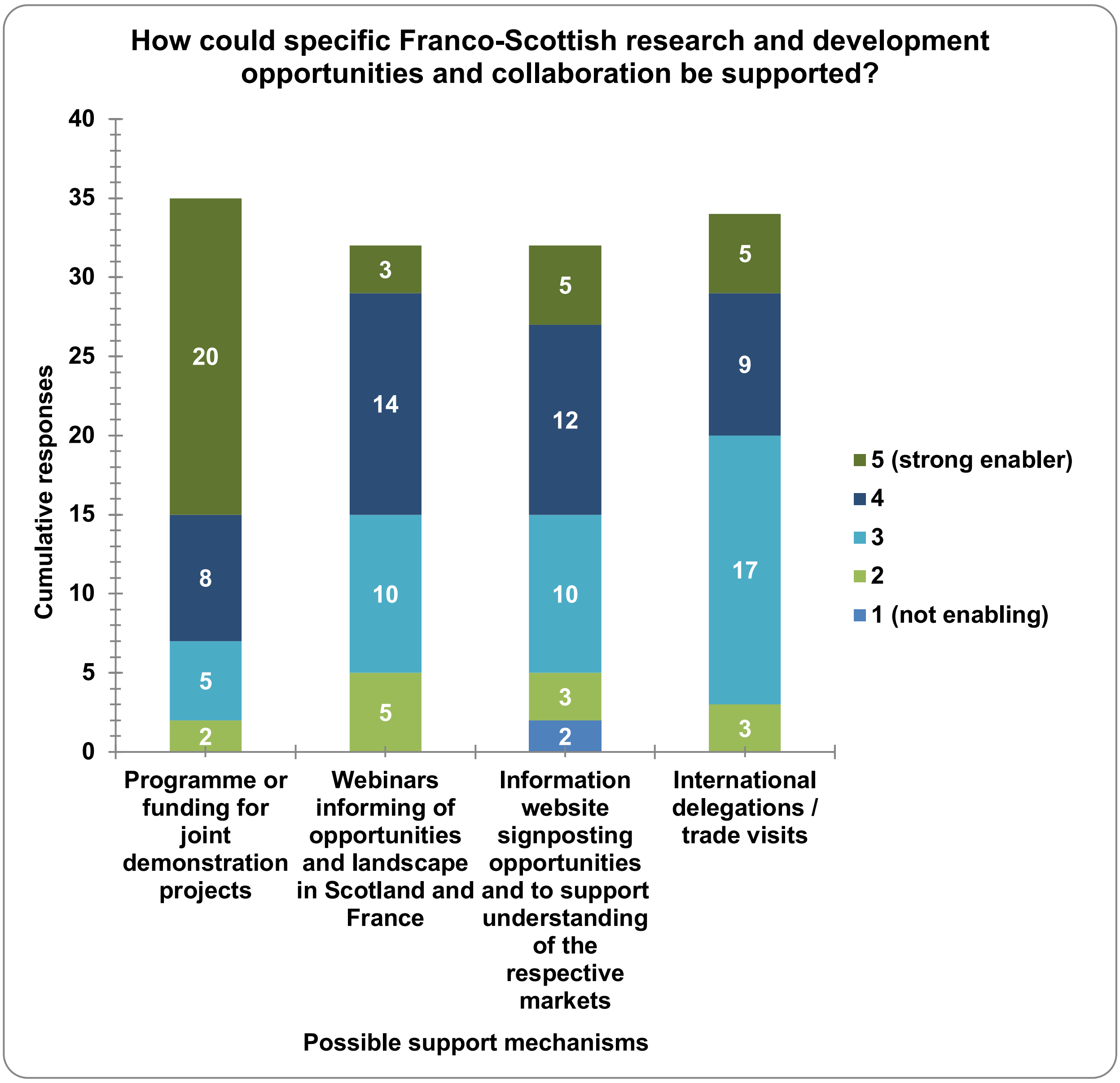

Figure 6. Stakeholder feedback on possible mechanisms which could support Franco-Scottish research and development collaboration in floating wind and hydrogen. Number of responses: 35.

Conclusions from engaging with supply chain stakeholders

In comparing and contrasting the range of stakeholder feedback provided to the project team, a number of clear shared innovation priorities and preferences emerge. The participants engaged through this study resoundingly support the development of joint research and development, and specifically demonstration projects, which should bring Scottish and French organisations together. Although stakeholders appeared to perceive the hydrogen and floating wind sectors to be more mature in Scotland than in France, there was also shared recognition from stakeholders that further work is required to understand how these two sectors can best be integrated.

Stakeholder groups in both countries also expressed great interest in understanding how existing skills and supply chain strengths from established oil and gas sector organisations could be applied to floating wind and hydrogen developments **in practice**. Given that the delivery of a 'Just Transition' is a core focus of the Scottish Government's planning for these two target sectors, this would appear to be a very ripe area for future joint working initiatives. In discursive sessions with both Scottish and French stakeholder groups, participants specifically expressed an interest in seeing knowledge exchange and in the development of means of sharing best practice from prior transition programmes.

Stakeholders frequently reflected very positively on the value of and the need for networking and cluster-building activities. These initiatives were viewed as vital elements in forming project consortia ahead of funding calls.

These reflections from stakeholders informed the development of the recommendations set out in the following section.

Conclusions and recommendations

This report has summarised analysis of the policy contexts and innovation landscapes influencing the development of floating wind and hydrogen projects in Scotland and in France. It has shown the important influence of national strategies on the shaping of innovation programmes delivering projects in these sectors, and at their interface. This analysis has pointed to commonalities between successful projects, which have inspired subsequent activity with ever-increasing ambition for these vital energy system sectors. Furthermore, this study has identified technical challenges and innovation needs in common between these sectors and shared by organisations in Scotland and in France.

Through engaging with supply chain organisations through questionnaires, expert interviews, and workshops, the project team have also elicited feedback regarding stakeholder experience of collaborative innovation programmes. These activities have highlighted a clear participant preference for initiatives aiming to support Franco-Scottish collaboration in these sectors to focus on delivering demonstration projects and, in particular, to consider how the two technologies should best be integrated in practice. Stakeholders also shared reflections on the best means of facilitating future collaboration and expressed interest in initiatives focused both on building connections between the French and Scottish supply chains, as well as in sharing knowledge between participant organisations.

This study was intended to provide recommendations to the Scottish Government regarding how future collaborative innovation activity between Scottish and French stakeholders might best be supported. This study has sought to interrogate the degree to which ambitions, opportunities and innovation challenges are shared between the two nations, to inform future activities. Policy statements, position papers and strategies in the two countries both have a focus on supporting research, development and innovation activities to facilitate cost reductions in the target technologies, and to resolve outstanding technical challenges which may otherwise impede deployments. Furthermore, both countries have articulated high relative ambitions for financially supporting deployments of both floating wind and hydrogen production capacity. However, as noted in our survey in the preceding sections, floating wind is arguably a more commercially mature prospect in Scotland so there is some difference in the scale of readiness between the Scottish and French sectors, and the supporting supply chains. The other inequality worth highlighting between the two nations is one of scale: the French state is much larger than Scotland, being a nation state with a sovereign government, and, as a result, has greater resources available both from a fiscal and political autonomy perspectives. In the current constitutional framework in Scotland, it may be more pertinent for the Scottish Government to engage bilaterally with French regions, which are more closely aligned to Scotland in terms of scale and resources, as well as in terms of ambition for the target sectors.

Recommendations

In order to promote Franco-Scottish collaboration in the floating wind and hydrogen sectors, the Scottish Government could:

1. **Target engagement at regional levels in France:** in recognition of shared ambitions and comparable priorities, work with like-minded authorities and development agencies in leading French regions. Brittany and Occitanie both have well-developed plans for both floating wind and hydrogen, as well as developed supply chains which preliminary feedback suggests may be very complementary to that of organisations in Scotland. Representatives from both regions engaged very constructively with the project team throughout the delivery of this study and their feedback has helped to shape these recommendations.

   A useful first step would be to develop opportunities for structured networking and knowledge exchange for organisations in Scotland and in Brittany and/or Occitanie. The activities underpinning this recommendation are developed further below.

   Given the relative position of leadership which Scotland enjoys in floating wind (and to a lesser extent hydrogen), there are likely to be a range of 'lessons learned' which Scottish organisations and developers could share with French counterparts in these regions. The developers of the initial floating wind projects highlighted in preceding sections of this report could be invited to share experiences with stakeholders in Brittany and Occitanie, alongside the research organisations and technology providers who have supported their efforts. Furthermore, there is fertile ground for joint initiatives and knowledge exchange opportunities in hydrogen, particularly when seeking to leverage Breton and Occitan experience in developing supply chain capacities in logistics. As noted in the recommendations which follow, these knowledge exchange initiatives should be structured to enable participants to better understand key supply chain strengths in Scotland, Brittany and Occitanie, respectively. A key means of approaching this could involve inviting industry organisations to share innovation case studies with one another.

   Some stakeholders engaged through the project also requested a more formalised supply chain matchmaking approach, whereby organisations in Scotland could be directly introduced to potential partners in the target French region(s) based upon defined needs. This could build upon work undertaken for the Scottish Enterprise offshore wind to hydrogen opportunity assessment published in 2020 [17].

Fully implementing this recommendation would require both short and long term planning and investment. Networking activities seeking to kickstart engagement between private sector organisations in Scotland and in Brittany/Occitanie should be pursued as soon as is practical. However, there is good scope for the Scottish Government and Scottish Development International to build more strategic and long term inter-governmental and inter-agency relationships in pursuit of shared goals with authorities and agencies in the two French regions. Doing so would likely contribute to ensuring future impact for the initiatives proposed below.

2. **Encourage research collaboration through network building:** encourage partnerships between private and public sector research organisations in Scotland, Brittany and Occitanie, in order that key stakeholders are primed to work together to seize emerging commercial opportunities in both countries. This recommendation builds upon the first and is based upon clear stakeholder feedback which recognised the importance of relationship building in enabling future joint working.

   In practical terms, this could involve providing or facilitating further matchmaking support to private sector organisations, or perhaps providing market intelligence through economic development agencies. Stakeholder feedback suggested that matchmaking through trade delegations and facilitated workshops would be appreciated to help to build connections between Scottish and French organisations in different parts of the hydrogen and floating wind value chains. Facilitated matchmaking would best be informed by an exercise in understanding supply chain strengths in Scotland and in Brittany/Occitanie. Stakeholder interest in such an exercise is reinforced in the perceptions which informed Recommendation 4, in regards to evaluating transferrable strengths in allied sectors such as oil and gas services. Stakeholders referred to sub-sea engineering as a specific Scottish supply chain strength, for example. Further detail on comparative strengths and opportunities for joint working could be elaborated through targeted engagement as well as collaboration between enterprise agencies in Scotland, Brittany and Occitanie.

   Building upon stakeholder feedback regarding the challenges of trying to develop innovation opportunities alongside more commercially orientated work, there could be scope for funding knowledge exchange placements for both private and public sector professionals as well as students/academics, or secondments of staff between Scottish and French organisations. An additional strand in this activity could focus on providing opportunities for project developers to explore opportunities for greater import/export of components, systems and hydrogen itself between the two countries through feasibility studies. Stakeholders in both countries identified commercial and business case barriers as key challenges, so participant interest in such initiative is likely to be high.

3. **Develop a research, test and demonstration platform** specifically targeting projects showcasing the integration of floating wind and hydrogen systems, in order to draw on a broad range of complementary experience in Scotland and in France. Scottish organisations are arguably currently leading in deploying these technologies and systems. However, as a result of sustained innovation activity, a number of promising early-stage French developers of novel solutions in these sectors are emerging. An opportunity may exist to leverage complementary experience in the two countries to encourage more efficient and cost-effective development.

   Specifically, this platform should target research and demonstration activities which can contribute to addressing the technical challenges highlighted in the evidence review narrated above, as well as those discussed in the stakeholder feedback summarised. Recognising that a wide range of challenges have been identified, the platform should focus on addressing a shortlist of these, and ideally prioritise those which are of greatest interest to both Scottish and French supply chains. The following areas of focus were prominent in stakeholder discussions undertaken in delivering this project:

   - At a **component** level, stakeholders expressed interest in seeing further opportunities to research, develop and demonstrate novel floating platform systems and the components required to secure these. Although most naturally targeted at floating wind turbines, a research programme concerning these platforms could also look to explore the best means of supporting offshore electrolysis plants.

   - At **systems** level, the primary research needs which stakeholders raised referred to the integration of hydrogen and floating wind technologies. Some stakeholders suggested that it is too early in the development of these technologies to consider integrating them together in practice. Others stated that this relative immaturity is exactly why research and demonstration activities should focus on testing hydrogen and floating wind co-deployments.

     There are multiple possible approaches to addressing this feedback and these research needs, with the most appropriate option depending on Scottish Government policy priorities and resources. Some desk-based feasibility study work analysing the technicalities of the best approach to integrating floating wind and hydrogen could be undertaken collaboratively with French supply chain partners. This would likely look to assess the technical readiness of the components, systems and working practices which would be required in various deployment scenarios (hydrogen produced onshore with direct power connection to a floating wind farm, hydrogen produced offshore from a centralised floating electrolyser platform, or electrolyser integration on-board individual floating wind turbine platforms). Building upon this, stakeholders were very enthusiastic about the prospects of collaborative testing and demonstration regimes involving Scottish and

French partners, which would seek to deploy systems in the above configurations to test these in practice.

- **Non-technical research needs** have also been defined, suggesting significant stakeholder interest in exploring the market dynamics associated with integrating the two technologies. Feedback provided to the project team suggested that there would be significant merit in collaborative desk-based research studies which could identify international market opportunities for hydrogen produced from floating wind power. These studies could also consider aspects such as investment readiness and insurability of such projects. Consenting risks were also highlighted by stakeholders, along with a number of health and safety considerations discussed in prior sections which could warrant collaborative feasibility study work.

Stakeholder feedback suggested that a joint-industry project approach would be favoured for delivering work within any joint research and development platform. In practice this would likely mean Scottish Government appointing a programme management organisation and providing funding which could be distributed to a range of projects either proposed or co-sponsored by industry organisations. This programme could pick up on a number of different themes in terms of the research areas highlighted.

Looking to the timescale for such an initiative, the organisations who fed into the project team were clear in their recommendation for these measures to be pursued as soon as possible. These activities are anticipated to support commercialisation and technology deployment by contributing to de-risking in the two target markets. In practice the range of project timescales will vary according to the scale of ambition for the programme. It may be prudent to conduct activities across phases or streams, to invite a broad range of desk-based research and feasibility studies in a first phase over the course of six months. This phase could then be followed by demonstration activities which could be expected to take place over a longer time frame, in the course of multi-annual projects, perhaps running for up to three years.

4. **Instil a focus on 'Just Transition' and skills development in these initiatives**. Stakeholders in both countries expressed a strong desire to see demonstration initiatives in these sectors leverage existing supply chain competence and skills which can be translated from well-developed oil and gas sectors. This is a clear, shared priority for stakeholders and an ideal focal point for collaboration and knowledge exchange. This recommendation is largely a supportive element expected to broaden the impact of the adoption of the other recommendations; for example, a knowledge exchange or cluster-building scheme with a sub-focus on skills development and supply chain transferability could deliver against various policy objectives simultaneously. Similarly, any initiative under the research, test and demonstration platform could include a specific incentive for project consortia to include partners transitioning from the conventional energy supply chain

and working in new areas, to embed ‘Just Transition’ outcomes in the programme design.

Stakeholders queried whether substantive reviews had been undertaken to understand the competitiveness and ease of transferability (to floating wind and hydrogen) of oil and gas service providers and supply chains in the two countries. Delivering such an analysis focused on comparing organisations in Scotland and Brittany and/or Occitanie could facilitate further collaboration in the future by identifying collaborative areas of strength (and areas in which each respective supply chain could be bolstered by the others).

Next steps

As noted already, both Scottish and French stakeholders shared resoundingly positive feedback regarding the prospects for the two supply chains coming together to solve shared challenges as the floating wind and hydrogen sectors mature. There is great scope for collaborative working towards achieving shared aims and realising the high ambition for the contribution that floating wind and hydrogen can make to the energy transition in both countries. If adopted, the recommendations outlined here could help to ensure that Scottish supply chain organisations can seize the opportunities presented in these vital sectors.

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