European
Commission

Study on Lessons for Ocean Energy Development

Final Report

April – 2017

ECORYS

Fraunhofer

EUROPEAN COMMISSION

Directorate-General for Research & Innovation
Directorate G – Energy
Unit G.3 – Renewable Energy Sources

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2017

EUR 27984 EN

LEGAL NOTICE

Luxembourg: Publications Office of the European Union, 2017

Pdf KI-NA-27-984-EN-N ISBN 978-92-79-59747-3 ISSN 1831-9424 DOI 10.2777/389418

ABSTRACT

Europe has a significant ocean energy resource which could contribute to the decarbonisation of the energy system and create a new industry with export opportunities worldwide. Despite advancements in the last two decades, tapping into this resource has turned out to be a challenge. This study has reviewed failures, lessons learnt and good practices in wave and tidal technology. This review revealed a consolidation in tidal and a fragmentation in the wave segment. The main conclusion of the study is that root causes and barriers to development are diverse and interrelated. They call for an integrated approach, involving all stakeholders. Change of behaviour towards embracing good practices and learning from past experiences is urgent. There is a need for a ‘covenant’ between the industry and public sector, which should (1) coordinate technology development; (2) promote certification, performance guarantees, standardisation and accreditation; (3) align framework conditions and support activities; (4) base technology development support on a staged approach; and (5) build and use an OET Monitoring Framework applying performance criteria on both technological and non-technological readiness. The study recommends to apply such a framework to define phased ‘ex ante conditionality’ for future funding, resulting in a more efficient support to wave and tidal energy.

RÉSUMÉ

L'Europe dispose d'une importante ressource énergétique océanique qui pourrait contribuer à la décarbonisation du système énergétique et créer une nouvelle industrie avec des opportunités d'exportation dans le monde entier. Malgré les progrès réalisés au cours des deux dernières décennies, l'utilisation de cette ressource s'est révélée être un défi. Cette étude a examiné les échecs, les enseignements et les bonnes pratiques en matière de technologie houlomotrices et marémotrices. Cette revue a révélé une consolidation dans le domaine des énergies marémotrices et une fragmentation dans les énergies houlomotrices. La principale conclusion de l'étude est que les causes profondes et les obstacles au développement sont diversifiés et interdépendants. Ils demandent une approche intégrée impliquant toutes les parties prenantes. Un changement de comportement prenant en compte les bonnes pratiques et l'apprentissage des expériences passées est urgent. Il faut une «convention» entre l'industrie et le secteur public, qui devrait (1) coordonner le développement technologique; (2) promouvoir la certification, les garanties de performance, la normalisation et l'homologation; (3) aligner les conditions cadres et les activités de soutien; (4) soutenir le développement technologique fondé sur une approche progressive ; (5) construire et utiliser un « Tableau de Bord » des technologies de l'énergie océanique en utilisant des critères de performance liés à la maturité technologique et sectorielle. L'étude recommande d'appliquer un tel cadre pour définir une «conditionnalité ex ante» progressive pour les futurs financements, ce qui entraînera un soutien plus efficient à l'énergie houlomotrice et marémotrice.

EXECUTIVE SUMMARY

(I) Objectives of the study

Europe has an identified ocean energy resource in the range of 1000-1500 TWh of wave energy and around 150 TWh of tidal energy annually.[1] This represents the largest known untapped resource that can contribute to a sustainable energy supply. However, tapping into this resource has turned out to be a challenge. Despite dedicated development efforts in both tidal and wave energy, over at least two decades, as well as substantial progress in various domains, technological and non-technological progress in the sector has been slower than initially expected a decade ago.

Against this background, the objective of this study is to point to failures and good practices/lessons learnt in Ocean Energy technology development in Europe in relation to tidal and wave energy.[2] The focus has been on both technological and non-technological (finance, IPR, business operation or other) issues and barriers to cooperation. Based on the collected information, the aim has been to in a structured way identify the most important key issues for further development of the sector.

(II) Methodology and approach

The research commenced with extensive desk research, including a factual description of the state of play of ocean energy technologies. The key technological characteristics have been explained, and a chronology of technology development has been developed. An overview of supply chain characteristics has also been provided. As ocean energy technology developments have been concentrated in several Member States, country-specific experiences have been investigated, based both on desk research and interviews.

During the subsequent field investigations, a total of 57 stakeholders have been consulted (mostly in the form of semi-structured interviews) on the critical barriers in ocean energy technology development, including aspects of sectoral cooperation and knowledge sharing. The interviews have been balanced between wave and tidal, with transversal/general issues as a third category. Overall, 2/3 of the interviews have been held with the business sector, mostly with developers and industry/manufacturers. About 1/4 of interviews were conducted with the public sector and 1 out of 7 were held with academic stakeholders. Analysis of the survey results was carried out using the qualitative data analysis tool Atlas.ti. This analysis has been complemented by a project-based analysis of successes and failures, and has resulted in a critical and systematic review of the lessons learnt.

The prospective research component, including the section on promoting innovation, collaboration and knowledge building, has been based on 4 focus groups held in Dublin (Ireland), Paris (France), Bilbao (Spain) and Lisbon (Portugal), supplemented by targeted interviews and attendance at industry events. The section about the tool for monitoring OET development is based on expert judgment and team analysis. The draft final report has been presented and discussed in a validation workshop, held at DG Research and Innovation in January 2017. The comments received during and after the workshop have been integrated in this final report.

(III) Main findings of the study

State of play of the sector

The Ocean energy sector is relatively young and is still emerging. It has benefited from EU support (about € 200 m. over the past 30 years[3]) and has since innovated and moved forward, although at different speeds. The sector remains promising, especially when niche markets (e.g. islands, remote locations) and export potential are considered.

The main report presents a chronological overview of developments in the sector. In tidal energy, significant convergence has taken place. The amount of transfers of components, staff and technologies/components indicate that a certain degree of knowledge transfer occurred in the tidal sector. Initially, wave energy technology appeared to mature more quickly than tidal. It attempted to reach higher technological readiness levels and managed to involve large industrial players early

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[1] Ocean energy is understood by us as a set of distinct technologies including wave and tidal energy, salient gradient and OTEC. In some countries (e.g. France), ocean energy also includes (floating) offshore wind, however that is not the case in our definition. This study exclusively focuses on tidal and wave energy.

[2] Other forms of Ocean Energy technology, notably OTEC and salient gradient power lie outside the scope of this study.

[3] In the framework programmes and Horizon 2020 (source: Fraunhofer IWES, based on information from the European Commission through Cordis).

in the process. However, various relevant device developers either did not pursue the concept or entered into administration. Due to the diverse nature of the wave resource in both deep and shallow water, as well as the inherent complexity of extracting energy from waves, there has always been a wide range of technical solutions under development, focusing on different parts of the resource and using a range of different solutions. The evolution of wave energy technology is therefore rather fragmented and evidence of collaboration and sharing of experience and knowledge is less obvious.

Review of barriers encountered

Defining 'failure' in technology development is ambiguous:

In the context of this study, the term "failure" has been used to characterise situations in which:

- Technical problems were encountered, e.g. the device failed partially or completely due to component issues (e.g. rotor blades), structural problems, station keeping (mooring lines or anchors), survivability problems during storms (extreme loads), rapid wearing or corrosion due to fatigue or inadequate designs/materials;
- Financial problems occurred, e.g. providing the matching funds for public grants at demo scale or having to increase the shareholder contribution from private equity due to not meeting milestones.

In practice, the term 'failure' illustrates the fact that a planned deployment and/or timeline, a cost reduction target or a financial framework has not been met, or not met in time, to enable continued technology development. A technical failure typically results in higher cost, a delay, or not achieving a critical milestone. This has often led to the termination of a project or development, although this can also depend on competition for funding and other public support with other (more mature) ocean energy or renewable energy technologies. In other words, failure can be seen as a lack of competitiveness: unique selling points are no longer applicable or convincing and market -pull mechanisms have become inactive.

Admittedly, 'failures' and subsequent 'shake-outs' are inherent to any emerging industry and should not always be perceived negatively: a failure often provides significant learning experiences for the sector, and this knowledge can be captured by the supply chain. Furthermore, an abandoned technological development can help to narrow down future options or to more easily identify financial or technological preconditions for developments. The qualification of success or failure thus depends on the extent to which the sector, as a whole, has been able to draw learning and benefit from such experiences.

Root causes of development are both technological and non-technological in nature

A key conclusion from the study is that not one, but rather a range of barriers hold the sector back, e.g. exogenous factors, research support/framework conditions, technological innovation, critical mass, and project finance. It is important to acknowledge that all these factors play their role. It is also equally important to discern symptoms from root causes: for example, when stakeholders mention 'lack of funding' as a barrier, it could be considered as a symptom rather than a root cause.

While developers are improving technological performance and exploring the scope for LCOE reduction, the shake-out involves more than technological barriers. The failure of both Pelamis and Aquamarine serve as examples, where a mix of technological barriers and non-technological barriers strongly impeded the projects' advancement. Taken together, experience suggests that sufficient phasing and checks & balances are required when supporting technologies.

Importance of LCOE increases as technology matures

When a concept has arrived at a frozen design with sufficient scope for LCOE reduction, the relative weighting of the barriers moves from purely technological towards non-technological, such as those in the area of supply chain and project finance (upscaling of projects). As demonstrated by the tidal sector, attention shifts from the development of a prototype towards that of an industrial supply chain. For wave technology development, it is essential to first arrive at robust and performing devices and installations which withstand open-sea tests. Only then will it be possible to optimise devices, scale up, and arrive at the degree of standardisation needed to build out a supply chain and build investor confidence. Although levelised cost of energy (LCOE) should be an integral consideration behind all design choices, bringing down the actual LCOE of prototypes – essential in the longer run – should occur at a later stage. This implies that competition for funding with other ocean or renewable energy technologies will not provide the right incentives for the wave sector.

Promoting innovation, collaboration and knowledge sharing

The sector urgently needs a change of behaviour towards embracing good practices and learning from past experiences

In the recent past, the 'wheel has been reinvented' many times and lessons have not always been learned. A thoughtful attitude towards sharing experience is still not common across the sector, where an IP dominated business model has been the norm. Given the public support provided, it is imperative that (new) players build on existing knowledge. Successful companies build on previous experiences and practices (e.g. staff exchange, joint ventures, take-overs). They need to incorporate solid corporate management practices, involve larger industrial players, share knowledge along the value chain, and manage expectations.

Knowledge and experience sharing are key to enhancing learning

The following functioning exchange mechanisms have been identified:

- Academics, public research institutions and test centres work together in research consortia across Europe;
- Industrial actors, both developers, OEM's, utilities and suppliers work together and share information within the context of consortia;
- Business, academia and government actors share together in geographically confined spaces, notably through clusters;
- In addition, industrial actors and developers, as well as academia, exchange information through industry associations (e.g. Ocean Energy Europe).

Both formal and Informal exchange mechanisms are key, and this should be acknowledged in public support schemes. An example is to incentivise technology development by consortia, rather than by individual developers, to promote exchange. Furthermore, this mitigates the risk of losing knowledge if technology development activities are discontinued. Another example is provided by Wave Energy Scotland, where dissemination of knowledge and experiences are remunerated.

Tailor knowledge exchange mechanisms to the situation

The different knowledge sharing techniques should be related to the type of project and the stage of the development (of both the project as well as the industry). In early stages of concept and technological development, sharing information about approaches that did not work should be actively encouraged by financially rewarding the sharing of knowledge, either through competitions, or through a stage-gated approach such as that of Wave Energy Scotland. In addition, frontline research by universities should be actively shared within the community. The aim here is to be very careful about IP protection, while acknowledging that it is to everybody's benefit to learn from past mistakes and approaches. In more developed projects during the testing phase, access to testing infrastructure and centres should be a priority. These locations will then form hubs where sharing about implementation of ideas is key, rather than specific solutions that are extremely IP sensitive and are not in anyone's commercial interest to share. Finally, in pre-commercial and commercial stages, knowledge sharing marketplaces, competitions and platforms and knowledge sharing within consortia or through the supply chain are the most appropriate to share unsuccessful or unused solutions/IP.

Ocean Energy Clusters provide a promising angle for promoting collaboration and exchange

Ocean energy technology development requires specific metocean conditions, a critical mass of players, access to technology and testing centres, a relevant skills base as well as appropriate support infrastructure, such as an offshore supply chain. Above all, ocean energy technology development requires high levels of trust between the actors along the supply chain, thus allowing for the necessary and quick transfer of large amounts of knowledge and experience. Ocean Energy clusters therefore provide a promising angle for promoting collaboration and knowledge sharing. Whilst many actors in the sector promote the idea of specialised Ocean Energy Clusters, our research on maritime clusters suggests that critical mass and synergy often require engagement with other Blue Growth sectors (e.g. offshore oil/gas, offshore wind).

(IV) Conclusions and recommendations

Need for a 'covenant' between industry and public sector

The diversity and interrelatedness of the root causes behind barriers to development call for an integrated approach, consisting of an orchestrated involvement of various public and private actors, who all have their role to play. Irrespective of the technology or location at stake, it is essential that industry as well as market conditions are fulfilled – and aligned with public support conditions.

a) Management of expectations in technology development
In hindsight, many stakeholders identified that in the past expectations have been raised that could not be met. This suggests that a more prudent and hard-headed approach is required in the future, and that improvement is needed in the methodologies and metrics currently applied to due diligence and evaluation of technologies;

b) Certification, performance guarantees, standardisation and accreditation
The pilot plants that are now being rolled out should assist in providing a basis for performance guarantees, certification, standardisation and accreditation. All these can help to 'professionalise' the sector, deliver confidence to investors, enable bankability, and reduce risk premiums and LCOE;

c) A strong need to align framework conditions and support activities
In parallel, a conducive and stable policy framework is essential. Currently, these are favourable only in a certain number of Member States and regions (e.g. Scotland, Ireland, France, Basque region). Alignment of public funding activities is called for, especially between several EU funds (e.g. Horizon 2020 and ERDF), as well as national and regional funding schemes. Initiatives such as OCEANERA-NET are useful, but further coordination within and between EU and Member State levels is vital;

d) Technology development support should be based on a staged approach
Within such a conducive support framework, and building on existing experience (notably Wave Energy Scotland), it is essential to use limited funds with discernment. Whilst 'picking winners' is unwise for a public sector which is supposed to be technology-agnostic, convergence of technologies can be accelerated by encouraging the right players and by defining the right performance criteria, tailored to a specific technological readiness level. In tandem with an understanding of commercial readiness levels, and other project management indicators, funding authorities should have an "industrial logic at heart". This will require adopting a strict approach regarding conditions for continued funding and at what point it is better to stop;

e) Towards an OET Monitoring Framework – applying performance criteria on technological and sectoral readiness
Focus is required on performance and stronger steering through agreed performance criteria. Technological performance criteria can be characterised by the so-called 'ability's'[4]: survivability, affordability, controllability, maintainability, reliability, installability, manufacturability, acceptability and energy capture and conversion. Equally important is sectoral readiness, which concerns 'softer' and sector-wide performance regarding involvement of the supply chain, embracing of knowledge sharing and investor confidence.

Performance requires measurement, transparency and accountability. Progress needs to be monitored, which can be done by further developing and applying an 'Ocean Energy Technology (OET) Monitoring Framework', which is presented in the structure overleaf. Implementation aspects need further elaboration, but this could be done, e.g. by involving a High Level Expert Group, the JRC, or otherwise. The Monitoring Framework as presented in the report acknowledges the role that all actors need to play, each with corresponding responsibilities, which transcend solely technical and financial commitments. One could call it a 'covenant' between industry and public actors.

Implication: build up an 'ex ante conditionality' for more selective and targeted support

An important implication of applying such measures is that public support to wave and tidal development activities in the future would be conditional upon meeting certain performance criteria. It is proposed to include the '*ex ante* conditionality' (as used in European Structural and Investment Funds) into the selection criteria for evaluating research proposals in the field of ocean energy. Criteria for fulfilment of the *ex ante* conditionality could be included in the description of

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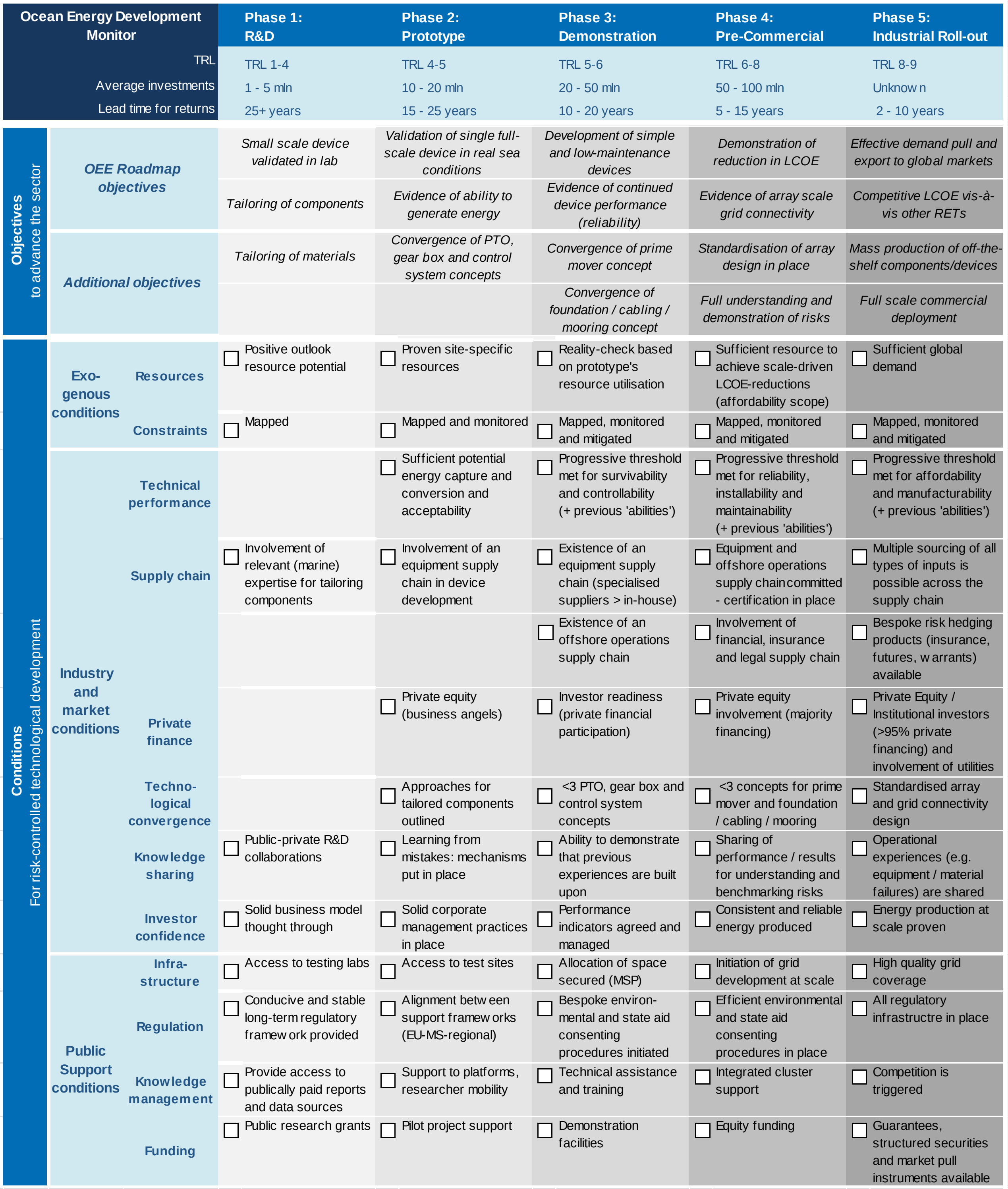
[4] This originates from the Stage Gate Metrics workshop from September 2016.

future calls for proposals, to guarantee that the projects supported under the next EU research programme (FP9) are targeted to the most promising projects. A systematic use of the *ex ante* conditionality across all funding mechanisms would substantially reduce the risks of loss of sunk investments in technology development, increase the effectiveness and efficiency of public support, as well as further increase future investor confidence in the sector.



Ocean Energy Development Monitor			Phase 1: R&D	Phase 2: Prototype	Phase 3: Demonstration	Phase 4: Pre-Commercial	Phase 5: Industrial Roll-out
		TRL	TRL 1-4	TRL 4-5	TRL 5-6	TRL 6-8	TRL 8-9
		Average investments	1 - 5 mln	10 - 20 mln	20 - 50 mln	50 - 100 mln	Unknown
		Lead time for returns	25+ years	15 - 25 years	10 - 20 years	5 - 15 years	2 - 10 years
Objectives to advance the sector	***OEE Roadmap objectives***		*Small scale device validated in lab*	*Validation of single full-scale device in real sea conditions*	*Development of simple and low-maintenance devices*	*Demonstration of reduction in LCOE*	*Effective demand pull and export to global markets*
			Tailoring of components	*Evidence of ability to generate energy*	*Evidence of continued device performance (reliability)*	*Evidence of array scale grid connectivity*	*Competitive LCOE vis-à-vis other RETs*
	Additional objectives		*Tailoring of materials*	*Convergence of PTO, gear box and control system concepts*	*Convergence of prime mover concept*	*Standardisation of array design in place*	*Mass production of off-the-shelf components/devices*
					Convergence of foundation / cabling / mooring concept	*Full understanding and demonstration of risks*	*Full scale commercial deployment*
Conditions For risk-controlled technological development	**Exo-genous conditions**	**Resources**	☐ Positive outlook resource potential	☐ Proven site-specific resources	☐ Reality-check based on prototype's resource utilisation	☐ Sufficient resource to achieve scale-driven LCOE-reductions (affordability scope)	☐ Sufficient global demand
		Constraints	☐ Mapped	☐ Mapped and monitored	☐ Mapped, monitored and mitigated	☐ Mapped, monitored and mitigated	☐ Mapped, monitored and mitigated
	Industry and market conditions	**Technical performance**		☐ Sufficient potential energy capture and conversion and acceptability	☐ Progressive threshold met for survivability and controllability (+ previous 'abilities')	☐ Progressive threshold met for reliability, installability and maintainability (+ previous 'abilities')	☐ Progressive threshold met for affordability and manufacturability (+ previous 'abilities')
		Supply chain	☐ Involvement of relevant (marine) expertise for tailoring components	☐ Involvement of an equipment supply chain in device development	☐ Existence of an equipment supply chain (specialised suppliers > in-house)	☐ Equipment and offshore operations supply chain committed - certification in place	☐ Multiple sourcing of all types of inputs is possible across the supply chain
					☐ Existence of an offshore operations supply chain	☐ Involvement of financial, insurance and legal supply chain	☐ Bespoke risk hedging products (insurance, futures, warrants) available
		Private finance		☐ Private equity (business angels)	☐ Investor readiness (private financial participation)	☐ Private equity involvement (majority financing)	☐ Private Equity / Institutional investors (>95% private financing) and involvement of utilities
		Techno-logical convergence		☐ Approaches for tailored components outlined	☐ <3 PTO, gear box and control system concepts	☐ <3 concepts for prime mover and foundation / cabling / mooring	☐ Standardised array and grid connectivity design
		Knowledge sharing	☐ Public-private R&D collaborations	☐ Learning from mistakes: mechanisms put in place	☐ Ability to demonstrate that previous experiences are built upon	☐ Sharing of performance / results for understanding and benchmarking risks	☐ Operational experiences (e.g. equipment / material failures) are shared
		Investor confidence	☐ Solid business model thought through	☐ Solid corporate management practices in place	☐ Performance indicators agreed and managed	☐ Consistent and reliable energy produced	☐ Energy production at scale proven
	Public Support conditions	**Infra-structure**	☐ Access to testing labs	☐ Access to test sites	☐ Allocation of space secured (MSP)	☐ Initiation of grid development at scale	☐ High quality grid coverage
		Regulation	☐ Conducive and stable long-term regulatory framework provided	☐ Alignment between support frameworks (EU-MS-regional)	☐ Bespoke environ-mental and state aid consenting procedures initiated	☐ Efficient environmental and state aid consenting procedures in place	☐ All regulatory infrastructre in place
		Knowledge management	☐ Provide access to publically paid reports and data sources	☐ Support to platforms, researcher mobility	☐ Technical assistance and training	☐ Integrated cluster support	☐ Competition is triggered
		Funding	☐ Public research grants	☐ Pilot project support	☐ Demonstration facilities	☐ Equity funding	☐ Guarantees, structured securities and market pull instruments available

Figure 0.1: Ocean Energy Technology Monitoring Framework
Source: Ecorys and Fraunhofer.

The above figure outlines the conditions (bottom part) which need to be in place for investments aimed at reaching the objectives (top part) in order to achieve risk-controlled technological development. Both conditions and objectives are highly specific to the relevant phase of technological development, and become more restrictive as technology matures.

RÉSUMÉ ANALYTIQUE

(I) Objectifs de l'étude

L'Europe possède une ressource énergétique marine qui génère 1000 à 1500 TWh/an d'énergie houlomotrice et environ 100 TWh/an d'énergie marémotrice.[5] Elle représente la plus grande ressource identifiée et inexploitée, pouvant contribuer à un approvisionnement en énergie durable. Toutefois, il s'est révélé que son exploitation pose un défi. Malgré les efforts de développement déployés ces deux dernières décennies tant à l'énergie marémotrice qu'à l'énergie houlomotrice et les progrès substantiels accomplis dans divers domaines, les avancées ont été plus lentes que celles prévues initialement, il y a une dizaine d'années.

Dans ce contexte, l'objectif de cette étude est de pointer les échecs et les bon(ne)s pratiques/enseignements tirés du développement des technologies de l'énergie marine en Europe par rapport aux énergies houlomotrices et marémotrices.[6] Le focus a porté sur les problèmes tant technologiques et technologiques (financement, PI, opérations commerciales ou autres) et sur les obstacles à la coopération. Partant des informations recueillies, l'objectif a été d'identifier les principaux problèmes qui se posent au développement du secteur.

(II) Méthodologie et approche

L'étude a débuté par une recherche documentaire, avec notamment une description détaillée des technologies de l'énergie marine. Les caractéristiques technologiques clés ont été expliquées et une chronologie du développement technologique a été établie. Un aperçu des caractéristiques de la chaîne d'approvisionnement a été dressé. Comme les développements de la technologie de l'énergie marine ont été concentrés dans plusieurs États membres, les expériences spécifiques aux pays ont été étudiées sur la base de recherches documentaires et d'entretiens.

Lors des enquêtes terrain, 57 parties prenantes ont été consultées (essentiellement lors d'entretiens semi-structurés) sur les obstacles majeurs au développement des technologies de l'énergie marine, notamment sur t la coopération sectorielle et le partage des connaissances. Les entretiens se sont concentrés sur l'énergie houlomotrice, l'énergie marémotrice et les questions transversales/générales. Globalement, 2/3 des entretiens ont eu lieu avec des entreprises, principalement des développeurs de technologies et des industriels/fabricants. Environ 1/4 des entretiens ont été menés avec le secteur public et 1 entretien sur 7 avec des universitaires. L'analyse des résultats de l'enquête a été effectuée à l'aide de l'outil d'analyse de données qualitatives « Atlas.ti ». Complétée par une analyse de réussites et d'échecs de projets, elle a abouti à un examen critique et systématique des leçons retenues.

Le volet prospectif de l'étude, dont la partie portant sur la promotion de l'innovation, de la collaboration et de l'acquisition de connaissances, est issu de 4 groupes de discussion organisés à Dublin (Irlande), Paris (France), Bilbao (Espagne) et Lisbonne (Portugal) et complété par des entretiens ciblés et la participation à des salons industriels. Le volet relatif à l'outil servant au suivi du développement des TEM (Technologies d'Energie Marine) est basé sur des jugements d'experts. Le projet de rapport final a été présenté et discuté lors d'un atelier de validation, organisé en janvier 2017 à la DG Recherche et Innovation. Les commentaires reçus pendant et après l'atelier ont été intégrés dans le rapport final.

(III) Principaux résultats de l'étude

État des lieux du secteur

Le secteur de l'énergie marine est relativement jeune et encore émergent. Il a bénéficié d'un soutien européen (environ 200 millions € au cours des 30 dernières années)[7])et a, depuis, innové et avancé, mais à différentes allures. Le secteur reste prometteur, notamment si les marchés de niches (îles, sites éloignés par exemple) et le potentiel d'exportation sont pris en considération.

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[5] Nous concevons l'énergie marine comme un ensemble de technologies distinctes incluant l'énergie houlomotrice et l'énergie marémotrice, le gradient de salinité et conversion de l'énergie thermique des océans (CETO). Dans certains pays (la France par exemple), l'énergie marine comprend également le vent de reflux (structures flottantes), mais ce n'est pas le cas dans notre définition. Cette étude est exclusivement consacrée à l'énergie houlomotrice et à l'énergie marémotrice.

[6] Les autres formes de technologie Ocean Energy, notamment la CETO et l'énergie des gradients de salinité sortent du cadre de cette étude.

[7] Dans les Programmes-cadres et Horizon 2020 (source: Fraunhofer IWES, basé sur l'information de la Commission Européenne via Cordis).

Le rapport présente un aperçu chronologique des développements du secteur. Une convergence significative est observée dans l'énergie houlomotrice. Le volume de transferts de personnel et de technologies/composants indique qu'un certain niveau de transfert de connaissances a lieu dans le secteur de l'énergie houlomotrice. Au début, la technologie de l'énergie houlomotrice semblait mûrir plus rapidement que celle de l'énergie marémotrice. Ce secteur a tenté d'atteindre des niveaux de maturité technologique plus élevés et a réussi à engager de grands acteurs industriels au début du processus. Toutefois, Certaines entreprises développant des dispositifs pertinents n'ont cependant par poursuivi leurs efforts ou ont fait faillite. En raison de la diversité des ressources houlomotrices tant en eaux profondes et qu'en eaux peu profondes, ainsi que de la complexité inhérente à l'extraction de l'énergie des vagues, il y a toujours eu un large éventail de solutions techniques en cours de développement, focalisées sur différentes parties des ressources et utilisant diverses solutions. L'évolution technologique de l'énergie houlomotrice est donc plutôt fragmentée et les signes de collaboration et de partage des expériences et des connaissances sont moins évidents.

Revue des obstacles rencontrés

Définir un 'échec' dans le développement technologique n'est pas simple

Dans le cadre cette étude, le terme 'échec' a servi à caractériser des situations où:

- Des problèmes techniques ont été rencontrés, par ex. un dispositif partiellement ou totalement défaillant en raison de problèmes de composants (pales d'une hélice par exemple), de problèmes structurels, de maintien en position (aussières d'amarrage ou ancres), de résistance aux tempêtes (charges extrêmes), l'usure rapide ou la corrosion due à la fatigue ou à des conceptions/matériaux inadéquats;
- Des problèmes financiers, par ex. l'apport de cofinancement en contrepartie de subventions publiques pour les projets de démonstration ou la nécessité de devoir augmenter la contribution des investisseurs privés lorsque les objectifs intermédiaires n'ont pas été atteints.

En pratique, le terme 'échec' illustre le fait qu'un déploiement, ou un objectif de réduction des coûts n'aient pas été atteints ou ne l'ont pas été à temps pour la poursuite du développement technologique. Un échec technique se traduit généralement par un coût plus élevé, un retard ou la non-réalisation d'un objectif intermédiaire majeur. Cela a souvent conduit à l'arrêt d'un projet ou d'un développement, même si cela dépend également de la concurrence pour le financement et d'autres formes de soutien public avec d'autres technologies d'énergies marines ou renouvelables (plus mûres). En d'autres termes, un échec peut être considéré comme un manque de compétitivité: les avantages compétitifs escomptés ne sont plus applicables ou convaincants et les mécanismes de « market-pull » sont devenus inactifs.

Les 'échecs' et les 'consolidations' qui en résultent sont, certes, inhérents à toute industrie émergente et ne doivent pas toujours être perçus négativement: un échec offre souvent des leçons intéressantes pour le secteur et ces connaissances peuvent être utilisés par les acteurs de la filière. De plus, l'abandon d'un développement technologique peut aider à restreindre les options futures ou à identifier plus facilement les conditions financières ou technologiques nécessaires à de futurs développements. La qualification de succès ou d'échec dépend donc de la façon dont le secteur, dans son ensemble, est capable de tirer des leçons de ces expériences.

Les obstacles au développement sont de nature technologique et non technologique

Une conclusion importante de l'étude est que pas une seule mais une série d'obstacles freinent le secteur. Il s'agit, par exemple, de facteurs exogènes, des conditions de soutien/du cadre de la recherche, de l'innovation technologique, de la masse critique et du financement des projets. Il est important d'admettre que tous ces facteurs jouent leur rôle. Il importe aussi de distinguer les symptômes des causes profondes: par exemple, lorsque les parties prenantes mentionnent le 'manque de financement' comme un obstacle, on le peut considérer comme un symptôme plutôt qu'une cause profonde.

Tandis que les développeurs améliorent les performances technologiques et explorent l'ampleur de la réduction des « coûts actualisés de l'énergie LCOE[8] »,, les consolidations impliquent plus que des obstacles technologiques. L'échec de Pelamis et d'Aquamarine servent d'exemples, où la conjonction d'obstacles technologiques et non technologiques a fortement entravé l'avancement des projets. Dans l'ensemble, l'expérience suggère qu'une mise en place progressive, avec des

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[8] LCOE, acronyme anglais de Levelized Cost of Energy.

étapes de contrôles suffisants (checks & balances) sont nécessaires pour soutenir le développement des technologies.

L'importance du «coût actualisé de l'énergie LCOE» augmente au fur et à mesure qu'une technologie mûrit.

Quand un concept est arrivé à un état de maturité technologique suffisant pour engager une réduction des coûts, l'importance relative des obstacles bascule du « purement technologique » au « non-technologique » (obstacles liés à la chaîne d'approvisionnement et au financement de projets. Comme l'a démontré le secteur de l'énergie marémotrice, l'attention passe du développement d'un prototype à celui d'une chaîne d'approvisionnement industrielle. Pour le développement de la technologie houlomotrice, il est essentiel de parvenir au préalable à des dispositifs et installations robustes et performants qui résistent aux essais en haute mer. C'est seulement alors qu'il sera possible d'optimiser les dispositifs, d'en augmenter l'échelle et d'arriver au degré de normalisation nécessaire pour construire une chaîne d'approvisionnement et accroître la confiance des investisseurs. Bien que «coûts actualisés de l'énergie LCOE» doivent être intégralement pris en compte dans les tous les choix de conception, la réduction des coûts réelles des prototypes - qui est essentielle à long terme - doit avoir lieu à un stade ultérieur. Cela signifie qu'une concurrence pour le financement avec d'autres technologies d'énergie marine et d'énergies renouvelables n'induira pas d'incitations appropriées pour le secteur de l'énergie houlomotrice.

Promouvoir l'innovation, la collaboration et le partage des connaissances

Le secteur a un besoin urgent d'un changement de comportement pour l'adoption des bonnes pratiques et pour tirer les leçons des expériences passées

Dans le passé récent, la 'roue a été réinventée' de nombreuses fois et les leçons n'ont pas toujours été apprises. Une attitude orientée vers le partage d'expérience n'est pas encore courante dans le secteur, où la norme est un modèle commercial dominé par la propriété intellectuelle. Compte tenu du soutien public fourni, il est impératif que de (nouveaux) acteurs s'appuient sur les connaissances acquises. Les entreprises qui réussissent s'appuient sur les expériences et pratiques antérieures (par exemple, échange de personnels, joint-ventures, prises de contrôle). Elles doivent intégrer de solides pratiques de gestion d'entreprise, impliquer des acteurs industriels plus grands, partager les connaissances tout au long de la de la chaîne de valeur et mieux « gérer les attentes ».

Le partage des connaissances et de l'expérience est la clé de l'amélioration de l'apprentissage

Les mécanismes d'échange suivants ont été identifiés:

- Universitaires, instituts de recherche publics et centres d'essais travaillent ensemble dans des consortiums de recherche européens;
- Acteurs industriels, développeurs, équipementiers, services publics et fournisseurs travaillent ensemble et partagent les informations dans le cadre des consortiums;
- Les acteurs commerciaux, universitaires et gouvernementaux échangent dans des espaces géographiquement restreints, notamment par l'intermédiaire de clusters;
- Les acteurs industriels et développeurs, ainsi que des universitaires, échangent des informations via des associations industrielles (Ocean Energy Europe par exemple).

Les mécanismes d'échange aussi bien formels et qu'informels sont essentiels et doivent être reconnu dans les mécanismes de soutien publique. Un exemple est d'encourager le développement technologique par des consortiums plutôt que par des développeurs individuels, pour promouvoir l'échange. Ceci permettra notamment de réduire le risque de perdre des connaissances si les développements technologiques sont interrompus. Un autre exemple est celui de « Wave Energy Scotland » où la diffusion des connaissances et des expériences est rémunérée.

Adapter les mécanismes d'échange de connaissances à la situation

Les différentes techniques de partage des connaissances doivent être liées au type de projet et au stade de développement (aussi bien du projet que de l'industrie).

Dans les premiers stades du concept et du développement technologique, il convient d'encourager le partage d'informations sur les approches qui n'ont pas fonctionné en rémunérant le partage des connaissances, soit par des concours soit par une approche progressive[9] comme celle de « Wave Energy Scotland ». En outre, les résultats de la recherche universitaire doit être activement partagée au sein de la communauté. À cet égard, l'objectif est d'être très prudent quant à la protection de la propriété intellectuelle tout en admettant qu'il est dans l'intérêt de tous de tirer des leçons des erreurs et approches du passé.

Dans les projets plus avancés, pendant les phases de tests, l'accès aux infrastructures et aux centres d'essai doit être une priorité. Ces centres d'essais formeront des plates-formes où le partage d'idées sur la mise en œuvre des technologies jouera un rôle plus important que les travaux sur des solutions particulières qui sont extrêmement délicates en termes de propriété intellectuelle et dont le partage n'est dans l'intérêt commercial de personne.

Enfin, dans les phases pré-commerciales et commerciales, les « marchés de connaissances », concours et plates-formes ainsi que le partage des connaissances au sein des consortiums ou via la chaîne d'approvisionnement sont les plus appropriés pour partager les solutions/PI non réussies ou inutilisées.

Les clusters d'Ocean Energy offrent un angle prometteur pour promouvoir la collaboration et l'échange

Le développement technologique de l'énergie marine exige des conditions marines spécifiques, une masse critique d'acteurs, un accès à la technologie et des centres d'essais, une base de compétences appropriée ainsi qu'une infrastructure de soutien appropriée comme une chaîne d'approvisionnement offshore. Avant tout, le développement technologique de l'énergie marine nécessite un haut niveau de confiance entre les acteurs tout au long de la chaîne d'approvisionnement, permettant ainsi le transfert rapide de connaissances et d'expériences. Les « clusters d'Ocean Energy » offrent par conséquent un angle prometteur pour promouvoir la collaboration et l'échange de connaissances. Alors que plusieurs acteurs du secteur promeuvent l'idée de « clusters Ocean Energy » spécialisés, notre étude sur les pôles maritimes suggèrent que la masse critique et la synergie requièrent souvent un engagement avec d'autres secteurs de la Croissance bleue (Blue Growth) (par exemple, le pétrole/ gaz offshore, éolienne offshore).

(IV) Conclusions et recommandations

Nécessité d'un 'convention' entre l'industrie et le secteur public

La diversité et l'interrelation des causes profondes des obstacles au développement exigent une approche intégrée, consistant en une participation orchestrée de divers acteurs publics et privés, qui ont tous leur rôle à jouer. Indépendamment de la technologie ou du site en jeu, il est essentiel que les conditions du marché soient remplies - et alignées sur celles du soutien public.

a) ***Gestion des attentes dans le développement technologique***
Rétrospectivement, plusieurs parties prenantes ont signalé que, dans le passé, des attentes ont été exprimées mais n'ont pas pu être satisfaites. Cela suggère qu'à l'avenir, une approche plus prudente est nécessaire et que des améliorations s'imposent dans les méthodologies et les mesures actuellement appliquées pour l'évaluation des technologies ;

b) ***Certification, garanties de performance, normalisation et homologation***
Les installations pilotes en cours de lancement ou d'extension doivent aider à fournir une base pour la certification, la normalisation et l'homologation. Tout cela peut aider à 'professionnaliser le secteur, à donner confiance aux investisseurs et à réduire les primes de risque et les coûts ;

c) ***Une nécessité d'aligner les conditions cadres et les activités de soutien***
Parallèlement, un cadre politique favorable et stable est essentiel. Actuellement, les conditions ne sont favorables que dans quelques États membres et régions (par ex., Écosse, Irlande, France, Pays Basque). Un alignement des opérations de financement public est nécessaire, notamment entre plusieurs fonds de l'UE (par ex. Horizon 2020 et FEDER), ainsi que des mécanismes de financement nationaux et régionaux. Des initiatives comme OCEANERA-NET sont utiles mais une bonne coordination au sein et entre l'UE et les États membres est vitale ;

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[9] Stage-gated approach.

d) *Le soutien au développement technologique doit être fondé sur une approche progressive*

Dans un cadre d'appui favorable, et en s'appuyant sur l'expérience acquise (notamment de Wave Energy Scotland), il est essentiel d'utiliser les financements avec discernement. Alors que la 'sélection de gagnants' n'est pas raisonnable pour un secteur public censé être 'agnostique' en termes de technologie, il est possible d'accélérer la convergence des technologies en encourageant les bons acteurs et en utilisant de bons critères de performance, adaptés à chaque niveau de maturité technologique. En combinant une compréhension des « niveaux de maturité commerciale »[10] avec d'autres indicateurs de gestion de projet, les autorités de financement doivent avoir une "logique industrielle à cœur". Cela nécessite l'adoption d'une approche stricte pour décider des conditions à remplir pour décider de la continuité ou de l'arrêt des financements ;

e) *Vers un tableau de bord des technologies de l'énergie océanique ('Ocean Energy Technology (OET) Monitoring Framework') – application de critères de performance liés à la maturité technologique et sectorielle*

L'accent doit être mis sur la performance et un pilotage objectif via des critères de performance convenus. Les critères de performance technologique peuvent être caractérisés par ce qu'on appelle les 'capacités'[11]:durabilité, faisabilité budgétaire, contrôlabilité, facilité d'entretien, fiabilité, facilité d'installation, possibilité de fabrication, acceptabilité et capture et conversion de l'énergie. Tout aussi importante est le degré de maturité du secteur, qui concerne les performances 'plus douces' à l'échelle sectorielle concernant l'implication de la chaîne d'approvisionnement, l'adoption du partage des connaissances et la confiance des investisseurs.

La performance exige mesures, transparence et responsabilité. Le progrès pourrait être mesuré en s'appuyant sur le tableau de bord des technologies de l'énergie océanique[12] 'Ocean Energy Technology (OET) Monitoring Framework', présenté page suivante. La mise en œuvre de ce tableau de bord nécessite une élaboration plus aboutie qui pourrait être réalisée en impliquant, par exemple, un groupe d'experts à haut niveau ou le JRC. Le tableau de bord présenté dans le rapport reconnaît le rôle que tous les acteurs doivent jouer, chacun avec ses responsabilités, et qui dépassent les seuls engagements techniques et financiers. On pourrait l'appeler une 'convention' entre industrie et secteur public.

Implication: développer une « conditionnalité ex ante» pour un soutien plus sélectif et ciblé

Une conséquence importante de l'application de ces recommandations est que le soutien public aux futures activités de développement des énergies houlomotrices et marémotrices pourrait être conditionné à des critères de performance. Il est ainsi proposé d'inclure une 'conditionnalité *ex ante*' (telle qu'elle est utilisée dans les « Fonds structurels et d'investissement européens –ESIF ») dans les critères de sélection des propositions de recherche en énergie marine. Les critères pour mesurer la « conditionnalité *ex ante* » pourraient être inclus dans la description des futurs appels à propositions pour garantir que les projets soutenus dans le prochain programme de recherche de l'UE (FP9) soient ciblés sur les projets les plus prometteurs. L'usage systématique de la conditionnalité *ex ante* dans tous les mécanismes de financement réduirait considérablement les risques de perte d'investissements dans le développement technologique, augmenterait l'efficacité et l'efficience du soutien public et renforcerait la confiance future des investisseurs dans le secteur.

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[10] Commercial Readiness level.

[11] Résultats du workshop 'Stage Gate Metrics' de septembre 2016.

[12] Ocean Energy Technology (OET) Monitoring Framework.

Ocean Energy Development Monitor			**Phase 1: R&D**	**Phase 2: Prototype**	**Phase 3: Demonstration**	**Phase 4: Pre-Commercial**	**Phase 5: Industrial Roll-out**
		TRL	TRL 1-4	TRL 4-5	TRL 5-6	TRL 6-8	TRL 8-9
		Average investments	1 - 5 mln	10 - 20 mln	20 - 50 mln	50 - 100 mln	Unknown
		Lead time for returns	25+ years	15 - 25 years	10 - 20 years	5 - 15 years	2 - 10 years
Objectives to advance the sector	*OEE Roadmap objectives*		*Small scale device validated in lab*	*Validation of single full-scale device in real sea conditions*	*Development of simple and low-maintenance devices*	*Demonstration of reduction in LCOE*	*Effective demand pull and export to global markets*
			Tailoring of components	*Evidence of ability to generate energy*	*Evidence of continued device performance (reliability)*	*Evidence of array scale grid connectivity*	*Competitive LCOE vis-à-vis other RETs*
	Additional objectives		*Tailoring of materials*	*Convergence of PTO, gear box and control system concepts*	*Convergence of prime mover concept*	*Standardisation of array design in place*	*Mass production of off-the-shelf components/devices*
					Convergence of foundation / cabling / mooring concept	*Full understanding and demonstration of risks*	*Full scale commercial deployment*
Conditions For risk-controlled technological development	Exo-genous conditions	Resources	☐ Positive outlook resource potential	☐ Proven site-specific resources	☐ Reality-check based on prototype's resource utilisation	☐ Sufficient resource to achieve scale-driven LCOE-reductions (affordability scope)	☐ Sufficient global demand
		Constraints	☐ Mapped	☐ Mapped and monitored	☐ Mapped, monitored and mitigated	☐ Mapped, monitored and mitigated	☐ Mapped, monitored and mitigated
	Industry and market conditions	Technical performance		☐ Sufficient potential energy capture and conversion and acceptability	☐ Progressive threshold met for survivability and controllability (+ previous 'abilities')	☐ Progressive threshold met for reliability, installability and maintainability (+ previous 'abilities')	☐ Progressive threshold met for affordability and manufacturability (+ previous 'abilities')
		Supply chain	☐ Involvement of relevant (marine) expertise for tailoring components	☐ Involvement of an equipment supply chain in device development	☐ Existence of an equipment supply chain (specialised suppliers > in-house)	☐ Equipment and offshore operations supply chain committed - certification in place	☐ Multiple sourcing of all types of inputs is possible across the supply chain
					☐ Existence of an offshore operations supply chain	☐ Involvement of financial, insurance and legal supply chain	☐ Bespoke risk hedging products (insurance, futures, warrants) available
		Private finance		☐ Private equity (business angels)	☐ Investor readiness (private financial participation)	☐ Private equity involvement (majority financing)	☐ Private Equity / Institutional investors (>95% private financing) and involvement of utilities
		Techno-logical convergence		☐ Approaches for tailored components outlined	☐ <3 PTO, gear box and control system concepts	☐ <3 concepts for prime mover and foundation / cabling / mooring	☐ Standardised array and grid connectivity design
		Knowledge sharing	☐ Public-private R&D collaborations	☐ Learning from mistakes: mechanisms put in place	☐ Ability to demonstrate that previous experiences are built upon	☐ Sharing of performance / results for understanding and benchmarking risks	☐ Operational experiences (e.g. equipment / material failures) are shared
		Investor confidence	☐ Solid business model thought through	☐ Solid corporate management practices in place	☐ Performance indicators agreed and managed	☐ Consistent and reliable energy produced	☐ Energy production at scale proven
	Public Support conditions	Infra-structure	☐ Access to testing labs	☐ Access to test sites	☐ Allocation of space secured (MSP)	☐ Initiation of grid development at scale	☐ High quality grid coverage
		Regulation	☐ Conducive and stable long-term regulatory framework provided	☐ Alignment between support frameworks (EU-MS-regional)	☐ Bespoke environ-mental and state aid consenting procedures initiated	☐ Efficient environmental and state aid consenting procedures in place	☐ All regulatory infrastructre in place
		Knowledge management	☐ Provide access to publically paid reports and data sources	☐ Support to platforms, researcher mobility	☐ Technical assistance and training	☐ Integrated cluster support	☐ Competition is triggered
		Funding	☐ Public research grants	☐ Pilot project support	☐ Demonstration facilities	☐ Equity funding	☐ Guarantees, structured securities and market pull instruments available

Figure 0.2: Cadre de surveillance des technologies d'énergies marines
Source: Ecorys and Fraunhofer.

La figure ci-dessus décrit les conditions (partie inférieure) à mettre en place pour les investissements visant à atteindre les objectifs (partie supérieure) pour parvenir à un développement technologique où les risques sont maîtrisés. Les conditions et les objectifs sont hautement spécifiques à la phase pertinente du développement technologique et deviennent plus restrictifs au fur et à mesure que la technologie mûrit.

Table of Contents

1. INTRODUCTION

1.1. Background and aims of the study

Europe has an identified ocean energy resource in particular along the Atlantic Arc in the range of 1000-1500 TWh of wave energy and around 150 TWh of tidal energy annually.[13] This represents the largest known untapped resource to contribute to a sustainable energy supply. However, tapping into this resource has turned out to be a challenge. Despite dedicated development efforts in both tidal and wave energy over some two decades, and substantial progress in various domains, technological and non-technological progress in the sector have been slower than expected a decade ago.

Current discussions about the evolution of the ocean energy sector therefore concern the slow pace towards commercialisation. Market expectations have been downscaled, suggesting that technology developers have been overambitious. Concerns have also been raised regarding the large numbers of projects and devices under development, and budgetary limitations in relation to current market size. Furthermore, there is a lack of clarity with regard to the deeper root causes behind this development path: are these mostly technological – related to the reliability of devices and components? Or are they related to the huge challenges of installation and maintenance? Are they due to the limited investor confidence, or to piecemeal and often eroding policy support to renewable energy in general and ocean energy technology in particular? Furthermore, there appears to be a lack of clarity about cooperation within the sector. This concerns public-private cooperation, but also cooperation amongst for example industrial actors and amongst national and European funding authorities.

In this context, the sector launched in November 2016 after an intensive work of 2 years an Ocean Energy Strategy Roadmap[14] by and for all stakeholders active in ocean energy. It presents four Action Plans – and focuses on maximising inputs by private and public actors. This Roadmap has been acknowledged by the study team and taken into account in the work of the study team.

Against this background, the aim of this Report is to *point to failures and good practices/lessons learnt in Ocean Energy technology development in Europe – as far as tidal and wave energy is concerned.*[15] *Focus is on both technological and non-technological (finance, IPR, business operation or other) issues and barriers for cooperation. Based on the information collected, the aim is to identify in a structured way which are the most important key issues (technological/non-technological) for further development of the sector.*

The study overall covers four themes that coincide with the main chapters of this report, and each come with a variety of questions. These questions have guided the research and are implicitly addressed in each chapter. Specific answers to the research questions are provided in Annex IX.

1. Review of failures in ocean energy technology development and identification of the key barriers (Chapters 2 and 3):

a. What has been the chronological development of various ocean energy technologies? (Chapter 2)
b. What have been the root causes behind failures? Were they technological or non-technological in nature?
c. Which initiatives, technologies and past pathways have been abandoned and why?
d. Have such failures led to the evolution and adjustment of existing technologies and/or applications?
e. Have failures been similar or different across various tidal and wave technologies?
f. What has been the root causes behind the barriers to development? Were they technological or non-technological in nature?
g. To which extent is there consensus about these barriers? And if not, what are the reasons for the existence of diverging perspectives?

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[13] Ocean energy is understood by us as a set of distinct technologies including wave and tidal energy, salient gradient and OTEC. In some countries (e.g. France), ocean energy is also including (floating) offshore wind, however that is not the case in our definition. This study exclusively focuses on tidal and wave energy.

[14] European Commission, 2017 – Ocean energy forum.

[15] Other forms of Ocean Energy technology, notably OTEC and salient gradient power lie outside the scope of this study.

2. Review of innovation, collaboration and knowledge sharing in the sector (Chapter 4):

a. What are the patterns and mechanisms for innovation, knowledge and cooperation in the sector?
b. What is the overall capacity and track record of learning within the sector?
c. What is the importance of Intellectual Property Rights (IPR) and underlying business models?
d. To what extent do other technological and non-technological factors (including financial factors) play a role in preventing knowledge sharing?
e. To what extent do changes in the actors (businesses coming and leaving the stage) affect continuity?
f. Which are functioning knowledge and cooperation exchange mechanisms? Are they part of past and current research cooperation initiatives?
g. What is the role of EU and national funding mechanisms?
h. What are the root causes behind such barriers to cooperation and knowledge exchange?

3. Embracing good practices and lessons learnt, both from the sector and from other (maritime) sectors (Chapter 5):

a. Building on the survey of failures above, what are the areas in which to look for good practices? (technology development, grids, finance and markets, environment and/or regulatory issues).
b. What do these good practices consist of?
c. How do these practices impact the feasibility and costs for specific technologies?
d. Can these good practices be replicated to other ocean energy technologies?
e. What are the similarities/differences between various ocean technologies when it comes to generating good practices?
f. What are the areas for Ocean energy technology development?
g. What sectors and activities lend themselves to comparison? And for what type of ocean energy technology are they most relevant?
h. What scope for synergies with these sectors/activities can be identified along the supply chain and how?
i. What good (knowledge exchange) practices and lessons can be learnt from these sectors and activities?
j. Under what circumstances can these lessons be replicated/used?
k. What mechanisms and initiatives can help to improve the exchange of such experiences across sectoral boundaries? (e.g. fora, platforms, networks, clusters, value chains and webs).

4. Reflect on identifying the best pathway for OET development (Chapter 5.3).

a. Which wave and tidal technologies appear to be most promising in terms of potential and ability to overcome barriers?
b. When can these technologies expect to be investment ready?
c. Which key actors are needed to accelerate/boost these technologies?
d. What can be the role of EU and national public initiatives in this?
e. Are there any possible implications for future Horizon 2020 and/or other EU funding?

1.2. Methodology and structure of the report

The research has started with extensive **desk research**, including a factual description of the state of play of ocean energy technologies. The key technological characteristics are explained, and the chronology of technology development is presented in ***Chapter 2***. More extensive explanations, both within the sector as well as in adjacent sectors are provided in Annex II and VI. An overview of supply chain characteristics is also provided in Annex III.

As ocean energy technology developments have been concentrated in several countries, with important differences between countries, **country-specific experiences** have been investigated, based both on desk research and interviews. The experiences of several prominent technologies which have been developed in those countries are provided in Annex IV.

During the subsequent **field investigations**, stakeholders have been consulted (mostly in the form of **structured interviews**) on the critical barriers in ocean energy technology development, including elements of sectoral cooperation and knowledge sharing. The findings have been reported in ***Chapter 3***.

Table 1.1 Number of stakeholders interviewed during the *field investigations* [1]

Stakeholder type	Wave	Tidal	Transversal/general	Total
Academics	1	3	1	5
Public	3	2	4	9
Business/non-developer[2]	5	13	10	28
Business/developer[2]	1	9	5	15
Total	**10**	**27**	**20**	**57**

1) These figures exclude the stakeholders with whom we have interacted during focus groups or the validation workshop. Annex I shows a complete overview of stakeholders whom have been involved in the study.
2) Business stakeholders have been split between technology developers and all other types of business stakeholders (e.g. supply chain, utility, engineer, association, etc.).

The table above provides the number of interviews realised across the sector. The interviews have been balanced between wave and tidal, with transversal/general as a third category. Overall, 2/3 of the interviews have been held with the business sector, above all with developers and industry/manufacturers. About 1/4 of interviews have been with the public sector and 1 out of 7 have been with academic stakeholders. The nature of the data collected, being information-rich but therefore also unstructured, does not allow a closed-questions survey type of analysis. To analyse the survey results, the **qualitative data analysis tool Atlas.ti** has been used. The collected data is supplemented with stakeholder characteristics, such as type of actors (main categories public, academic and business), technology and geographic origin, to subsequently assess systematic preferences / biases of types of stakeholder characteristics towards certain barriers. This analysis has been complemented by a **project-based analysis** of successes and failures. This analysis has resulted in a critical and systematic review of the lessons learnt.

The research underlying ***chapter 4*** on promoting innovation, collaboration and knowledge building has been based on 4 **focus groups** held in Dublin (Ireland), Paris (France), Bilbao (Spain) and Lisbon (Portugal), supplemented by **targeted interviews** and **attendance at industry events** – notably in the UK and Brussels.

The final piece of the research (***chapter 5***) focusing on embracing good practices is based on interviews and focus groups, interpreted, however, by the study team. The sections about the tool for monitoring OET development is based on **expert judgment** and **team analysis.**

The results presented in the draft final report have been subject of review by a **Validation Workshop**, held on 23rd January 2017. Comments received during and after the workshop have been integrated in this final report.

A separate document contains all the **Annexes** of the Final Report of the Study on Lessons for Ocean Energy Development:

- Annex I: Overview of stakeholders involved, showing an overview of all stakeholders who have contributed to the study;
- Annex II: Technological explanations, providing details on different technological concepts in tidal stream and offshore wave;
- Annex III: Overview of supply chain characteristics, discussing components of a mature supply chain for ocean energy;
- Annex IV: Country-specific experiences, discussing in detail the technological developments in France, Ireland, Portugal, Spain, the United Kingdom and a few other countries;
- Annex V: Bibliography;
- Annex VI: Learning from other sectors, discussing what lessons can be learned from other technological sectors: Offshore Wind, Offshore Oil & Gas and Concentrated Solar Power;
- Annex VII: Focus Group reports;
- Annex VIII: Validation Workshop Report;
- Annex IX: Answers to the research questions, discussing in detail how we have answered the research questions of the study.

2. STATE OF PLAY OF OET DEVELOPMENT

2.1. Overview

2.1.1. *About potential and ambitions*

Europe has an identified ocean energy resource, in particular along the Atlantic Arc, in the range of 1000-1500 TWh of wave energy and around 150 TWh of tidal energy annually.[16] This represents the largest known untapped resource to contribute to a sustainable energy supply. Figure 2.1 below shows how the potential is distributed across European countries.

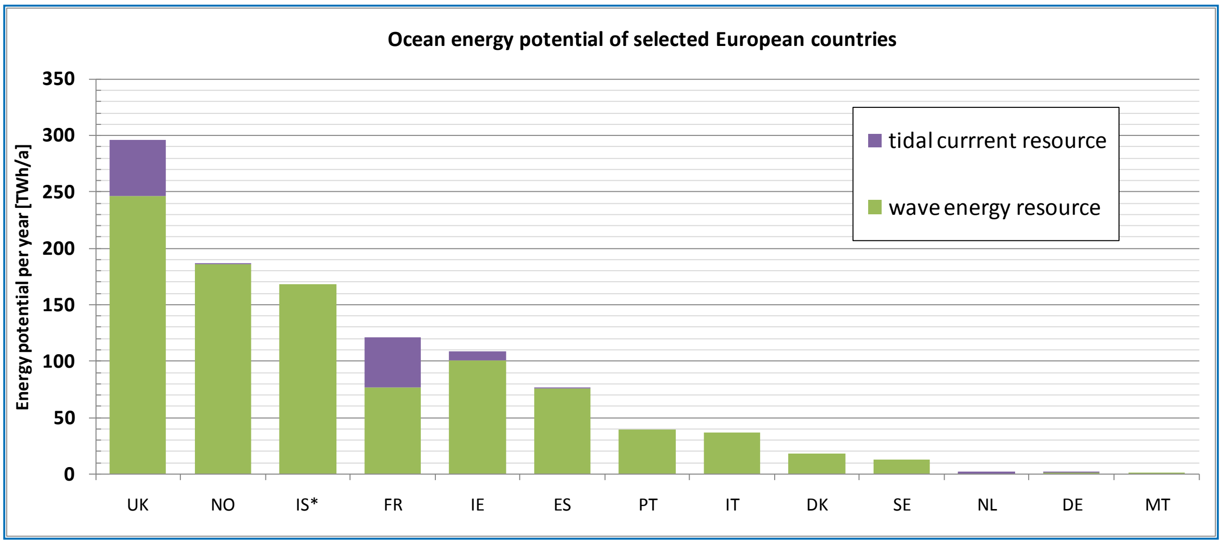

Figure 2.1 Ocean energy resource potential across European countries
Source: Fraunhofer IWES.

At EU level, ambitious targets of 3600 MW capacity for 2020 had been set, at the beginning of the century, by the European Ocean Energy Association. Under the NREAP scheme, the ambition was to deploy up to 1.8 GW of mainly wave and tidal arrays with more than half of the capacity in the UK alone.

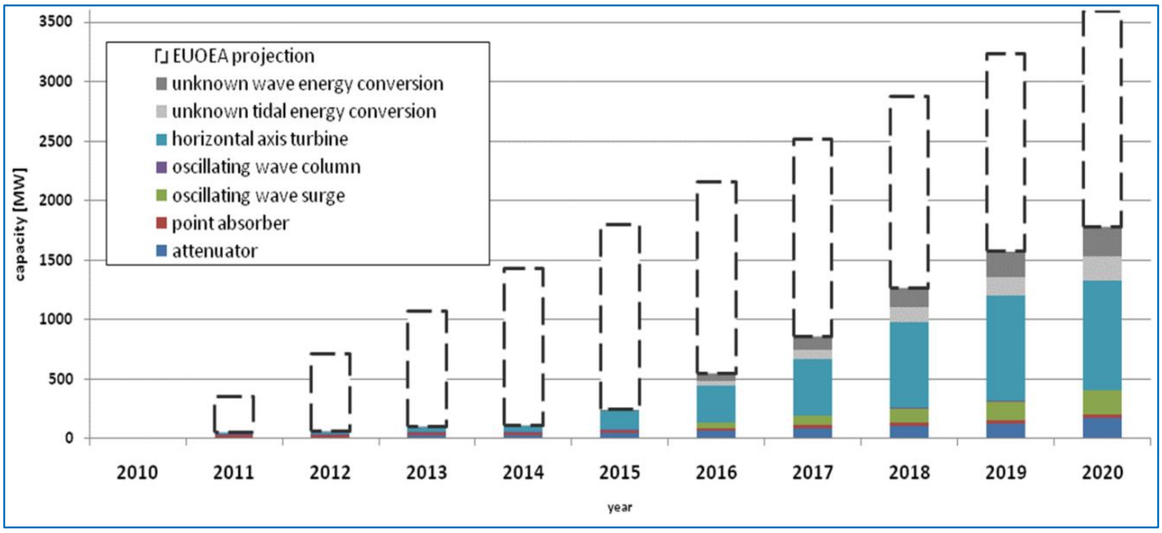

Figure 2.2 The European Ocean Energy Association vision in the year 2010
Source: Fraunhofer IWES.

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[16] Ocean energy is understood by us as a set of distinct technologies including wave and tidal energy, salient gradient and OTEC. In some countries (e.g. France), ocean energy is also including (floating) offshore wind, however that is not the case in our definition. This study exclusively focuses on tidal and wave energy.

At the beginning of this decade, the European Ocean Energy Association claimed that up to 3600 MW of capacity could be realised by 2020, whereas at the same time a project pipeline based on announced and planned array projects identified around Europe would only show around 1800 MW (see Figure 1.2). The EU27 NREAP targets for 2020 were set at 1880 MW or 6 TWh (UK: 1300 MW, PT: 250 MW, FR:140 MW, ES: 100 MW, IE: 75 MW, IT: 3 MW). However, these were not substantiated with actual projects as these targets were driven by the top level Member State energy policy.

Renewable UK stated in 2013 that "*while the current installed capacity is fairly modest at almost 9 MW, the industry is on track to deliver over 120 MW by 2020 – making a meaningful contribution to the UK's energy mix*".[17] This represents a project-based estimate for the UK and a very different but much more plausible market forecast. Despite the fact that today over 150 MW of wave and tidal projects are consented by the Crown Estate in the UK, only one first tidal array, the Meygen phase 1a, has reached financial closure and has started construction (cable, access road etc.). It is the first build-out phase of the MeyGen Tidal Energy Project in the Inner Sound of the Pentland Firth. With a capacity of 6MW (4 x 1.5 MW turbines) it represents the world's first multi-turbine tidal stream energy project. A French consortium is following a similar path, and now working on pilot farms in the Raz Blanchard zone of Normandy.

In 2015, Ocean Energy Europe updated its market forecast. This led to a downscaled market expectation from 3.6 GW to 0.3 GW to be in operation in 2020, with two-thirds coming from tidal stream projects.

2.1.2. European funding landscape

From an early stage of the emerging ocean energy sector, the European Commission has been funding ocean energy market and technology development projects. The chart below shows the amount of funding since the first Framework Programme.

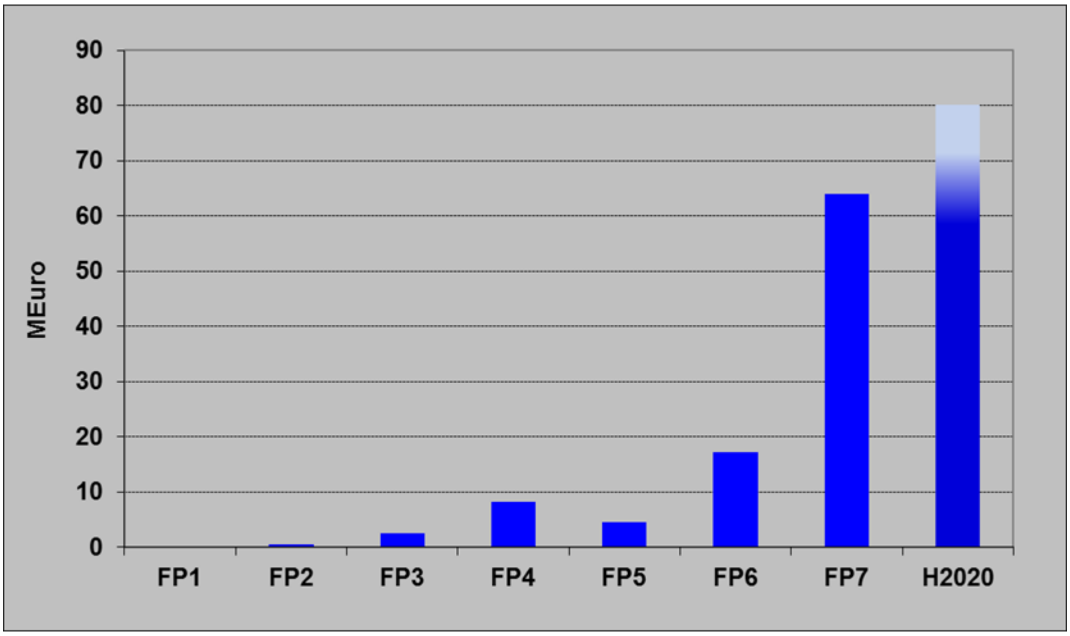

Figure 2.3 Development of funding from the European Commission for Ocean Energy projects in the framework programmes
Source: Fraunhofer IWES, based on information from the EC (Cordis).

It stands out that the most significant increase of funding was realised in FP7, with a total of €62 million offered to ocean energy projects across the different FP7 funding streams. In H2020, around €86 million has been awarded to the sector in just two years (2014 and 2015). In addition, the NER 300 funding programme supports five ocean energy projects. Excluding the NEMO OTEC project of €72 million, they will receive about €70 million obtained from the sale of emission allowances from the new entrants' reserve (NER) of the EU Emissions Trading System.

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[17] Renewable UK (2013).

2.1.3. *Categorisation of tidal and wave energy*

The figure below presents an overview of the ocean energy sector, as far as it concerns tidal energy and wave energy. Within tidal energy, the focus has been on tidal stream technology (both floating and fixed devices). For tidal range technology the roll-out potential with some forty sites worldwide is limited[18], and the technological core is relatively mature civil engineering technology. For wave energy, the focus has been on offshore wave (both floating and fixed devices). For shoreline wave technology, the roll-out potential is also quite limited because of available resources and the necessity of integrating the technology in existing civil engineering structures.

Figure 2.4 Categorisation of Ocean Energy Technologies
Source: Ecorys and Fraunhofer.

Ocean Energy Technologies are categorised based on type of resource (wave or tidal) and supply chain requirements (civil or mechanical engineering) and location of the resource (shoreline or offshore). It shows that both 1) and 3) and 2) and 4) have similarities in terms of supply chain requirements and resource location.

This study focuses on tidal stream technology and offshore wave technology, and the state of play in both technologies is presented in details in section 2.2 (tidal stream) and 2.3 (offshore wave energy).

2.2. Tidal Stream

2.2.1. *About the resource potential*

One of the major advantages of tidal energy is its dependability, since low and high tides occur twice every day at most European sites with accurate and long-term forecasting possible. However, tidal power systems cannot generate constant power 24 hours per day. Tidal range (making use of the difference in water level between high and low tide) differs from tidal stream (tapping the energy from currents), and both have their advantages and limitations. Tidal range generates power for some 14 hours per day and tidal stream power generation drops when the tide is switching from ebb to flow. Even the best tidal systems only generate power for 20 hours/day at most. Tidal stream technology also has to work in hostile environments and cope with corrosion and currents.

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[18] Etemadi, A., Emami, Y., AsefAfshar, O., Emdadi, A. (2011) Electricity Generation by the Tidal Barrages, Energy Procedia, Volume 12, 2011, Pages 928-935.

The energy resource of tidal stream motions is generally usable by common turbine designs, when certain geographical features are present which act like a hydraulic nozzle and force the water current to accelerate above a technically viable velocity threshold. This can be the case e.g. in straights and between islands with water depths in a certain bandwidth (usually water depth >15 m). Taking the UK as example, the majority of the tidal stream resource is found in water depths of 25 m and over, though around 20% is still available at shallower depths. Only a small proportion of the resource is in depths over 75 m. The total global theoretical potential is vast. Although tidal energy conversion requires significant tidal flows (2.0 m/s for tidal stream), the IEA Energy Technology Perspectives estimates up to 240 GW of marine capacity could be deployed by 2050.

The technically viable tidal stream resource in Europe is concentrated at a small number of hot spots, mainly around the Scottish Orkney islands, off the coast of Northern Ireland, off the coast of Normandy and Brittany and between the Greek islands Korfu and Paxi and the Greek mainland. Other tidal resources have been identified in Norway[19], although this has not been studied in great detail. The resource potential is based on geographically distributed values of water flux (unit of measurement m^3/s) in connection with power density, water depth, area, and other parameters. Based on data provided by the MARINA Platform project, other significant tidal stream resources in Western European countries including Spain, the Netherlands and Denmark but also in the Mediterranean countries could not be identified. The general absence of major tidal stream resources in shielded water bodies such as the Mediterranean Sea and the Baltic Sea can be explained by the significantly lower tidal range compared to water bodies connected to the open ocean. However, the Netherlands host tidal stream projects in connection with the utilisation of dams, barrages and flood protection systems as artificial hydraulic nozzles. In that way the lack of natural resources can be partially compensated.

In terms of roll-out potential, tidal range is limited to resource-intensive areas. This is less stringent for tidal stream resources. However, the implication for industrial development is that although the available resource is vast, each resource type requires a tailored device to in order for the resource to be utilised[20]. This also implies that the roll-out potential of devices which harvest weaker flows is higher. These elements are a nuance to the potential economies of scale which can be achieved by tidal stream roll-out.

2.2.2. Key characteristics of tidal stream

As the technology becomes more mature, there is a convergence towards several main types of technological solutions, while each company/projects works out the fine details which determine a successful project.

Turbines

Horizontal axis turbines extract energy from moving water in much the same way as wind turbines extract energy from moving air. The tidal stream causes the rotors to rotate around the horizontal axis and generate power. There has been a convergence around this technology. In 2011, 76% of all research and development (R&D) investments into tidal current technologies went into horizontal axis turbines.[21] A more detailed overview is provided in Annex I.

Methods to fix the TEC to the seabed

Despite the convergence in tidal current technologies towards horizontal axis designs, there is still quite a variety in mooring technologies used. Of the different tidal current concepts and projects developed so far, 56% use rigid connection (mostly seabed), 36% uses mooring, and 4% monopiles (IRENA, 2014). For example, Marine Current Turbines (MCT)/Siemens' SeaGen changed from a proposed monopile support structure to a new tripod design, which was then realised. Alstom, on the other hand, was working on turbines with individual components that can be mounted on different kinds of mooring structures.

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[19] Grabbe et al. (2009), http://www.sciencedirect.com/science/article/pii/S136403210900032X.

[20] Different resource characteristics, with e.g. short length wind waves in shallow water near the coast versus long wavelength (and high period) swell in deep water further off the coast, cannot be harvested with the same type of device economically. In addition, a variety of wave climates requires adjusting certain resonating types e.g. point absorber to be tuned to the local conditions for optimal performance. Other renewable energy technologies face similar challenges. Different wind turbine models are available for different wind classes and wind conditions, and in hydropower, each power plant differs from the next even along the same river stretch. Differences in resource characteristics thus do not block development altogether, but it does contribute to the cost reduction challenge.

[21] Corsatea, T.D. and Magagna, D. (2014) Overview of European Innovation Activities in Marine Energy Technology.

i) Seabed mounted / gravity base

This is physically attached to the seabed or is fixed by virtue of its massive weight. In some cases there may be additional fixing to the seabed.

ii) Pile mounted

This principle is analogous to that used to mount most large wind turbines, whereby the device is attached to a pile penetrating the ocean floor. Horizontal axis devices will often be able to yaw about this structure. This may also allow the turbine to be raised above the water level for maintenance.

iii) Floating (with three sub-divisions)

Flexible mooring: the device is tethered via a cable/chain to the seabed allowing considerable freedom of movement. This allows a device to swing as the tidal current direction changes with the tide.

Rigid mooring: the device is secured into position using a fixed mooring system, allowing minimal leeway.

Floating structure: this allows several turbines to be mounted to a single platform, which can move in relation to changes in sea level.

iv) Hydrofoil inducing downforce

This device uses a number of fixed hydrofoils mounted on a frame to induce a downforce from the tidal current flow. Provided that the ratio of surface areas is such that the downforce generated exceeds the overturning moment, then the device will remain in position. In deep water, hydrofoils can also be used to generate a lift that will support the mooring system and buoyant floaters to maintain the vertical position of the rotor in the water column. It is a concept which is used by e.g. Nautricity.

Types of blades

The concept behind wind turbines, based on a free stream horizontal axis rotor, had very early been identified as a suitable means of extracting energy from water currents. However, unlike wind, the water resource is vertically constrained between the bottom of the sea and the water surface as well as horizontally by the near shoreline. These constraints cause so-called two directional flow regimes during the tidal cycle which leads to different technical solutions for the necessary alignment of the horizontal axis rotor.

The rotor and blade designs therefore differ from any other application, but design experience from hydropower, ship propellers and wind turbines have been applied in the development of tidal blades and rotor concepts. Despite the much lower current velocities compared to wind the density of water leads to a significantly higher thrust and thus bending moments than in wind turbine blades. For typical tidal rotor designs the resulting bending moments are around 5 to 10 times higher than for wind turbine blades. In addition, water currents in the ocean are superimposed by wave induced velocities which can cause frequent very high load cycles for the rotor and the structure.

At many tidal current sites high turbulence intensities are found. They can be caused by a rough seabed topology or by other topographical obstacles upstream which generate large eddies that travel long distances downstream and create a very dynamic flow field. The combined velocity variations in time and space introduce further dynamic loads into the blades and the structure.

One constraint in the blade design of tidal turbines is the fact that - similar to water pumps or conventional hydro turbines – too high velocities at the blade tip can create cavitation which can damage the blade very quickly. The design has to ensure that conditions leading to cavitation are avoided reliably. The rotor speed is therefore to a tip speed ratio of typically 5-6 – which in return leads to a rapidly increasing design torque with increasing rotor diameters. The increasing torque drives the cost of the PTO system.

Another aspect of the operation under water is the high ambient water pressure which oscillates as the blade travels around the centre shaft. Filling the blades with water to compensate for that has the disadvantage of introducing centrifugal forces inside the blade.

The characterisation of such site specific combined effects of tidal currents, wave and turbulence require highly sophisticated measurement systems and data processing algorithms for the flow field characterisation. This input is however necessary to calculate e.g. the damage equivalent load as one major design parameter for the rotor blades. The uncertainty in the load calculations combined with a variety of site specific conditions turn the cost of developing optimised and reliable generic blade design into a very complicated challenge. This can lead to either unreliable blade designs, sometimes based on a too simplified transfer of wind turbine experience, causing blade failures as has been reported repeatedly, or to very sturdy over- engineered designs that are far from optimum, economically. In many tidal turbine rotor designs a higher solidity compared to wind turbine rotors is used to generate a higher starting torque and reduce load balancing issues.[22] Large wind turbine blades are made out of glass fibre reinforced polymers (GFRP). Due to the rapidly increasing loads with increasing rotor diameters carbon fibres are considered and used due to their higher strength, if the higher cost compared to glass fibre can be justified. With a high specific strength such compound materials are also suitable for application in tidal blades, with the additional benefit that they do not show corrosion. However composite materials show degradation due to the exposure to seawater. In addition compound materials do take up moisture if used under water. A water saturated compound material has reduced strength with a range of around 80-90% of the initial dry value.[23]

Compared to wind turbine blades the thickness of the laminate is much higher in tidal blades to accomplish the higher bending forces. Despite the much shorter span, a tidal blade therefore requires more compound material than a blade of a wind turbine with a similar power rating. This also has implications on the transition from the circular shape at the blade root to the lift generating flat wing geometry at the larger radii and towards the tip.

This fact also provides a limitation to scale tidal turbine rotors. For large tidal turbine blades, with a length of 10 and more meters, GFRP is not sufficiently strong and needs to be supported e.g. by mixing in carbon fibres or additional structural support e.g. by a solid spar in the blade centre.

Types of grid connection

Turbines far offshore, need to be connected to each other through array cables (e.g. 33 kilovolt (kV)). The array is then connected to an offshore substation, which is connected through an export cable (typically 150 kV) to an onshore substation and eventually to the grid (the International Energy Agency implementing agreement for Renewable Energy Technology Deployment (IEA-RETD, 2012). With the development of wind farms off shore, there is now considerable experience in developing both offshore alternating current (AC) and direct current (DC) grid infrastructures. Yet, grid connection remains one of the critical aspects for tidal energy deployment as delays and the costs for grid connection could put many projects at risk (RenewableUK, 2013).

However, the vast majority of current installations occur in intermediate waters and straits, relatively near the shore. This reduces the need for sub-stations, yet given that the current is very powerful, fixing of cables and/or burying the cables needs to be considered.

Optimal spacing

Another technical aspect for tidal current technologies is their deployment in the form of farms or arrays. Individual generator units are limited in capacity, so multi-row arrays of tidal turbines need to be built to capture the full potential of tidal currents. However, turbines have an impact on the current flows, so the configuration in which they are placed is a critical factor to determine their potential yield and output (SI Ocean, 2012).

2.2.3. Chronology of technology development

The schematic overview on the next page depicts the chronological market development of tidal stream technology.

It can be noted that about half of the operations mapped have been closed down, whilst the other half are still active. However, a large share of the actions closed down has been able to transfer the knowledge in part or in full – either through mergers & acquisitions or through staff mobility.

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[22] Grogan, D.M., S.B. Leen, C.R. Kennedy, C.M. Ó Brádaigh (2013) Design of composite tidal turbine blades, Renewable Energy Volume 57, September 2013, Pages 151–162.

[23] McEwen, L.N., R. Evans and M. Meunier (2013) Cost-effective Tidal Turbine Blades, 4th International Conference on Ocean Energy, 17 October, Dublin.

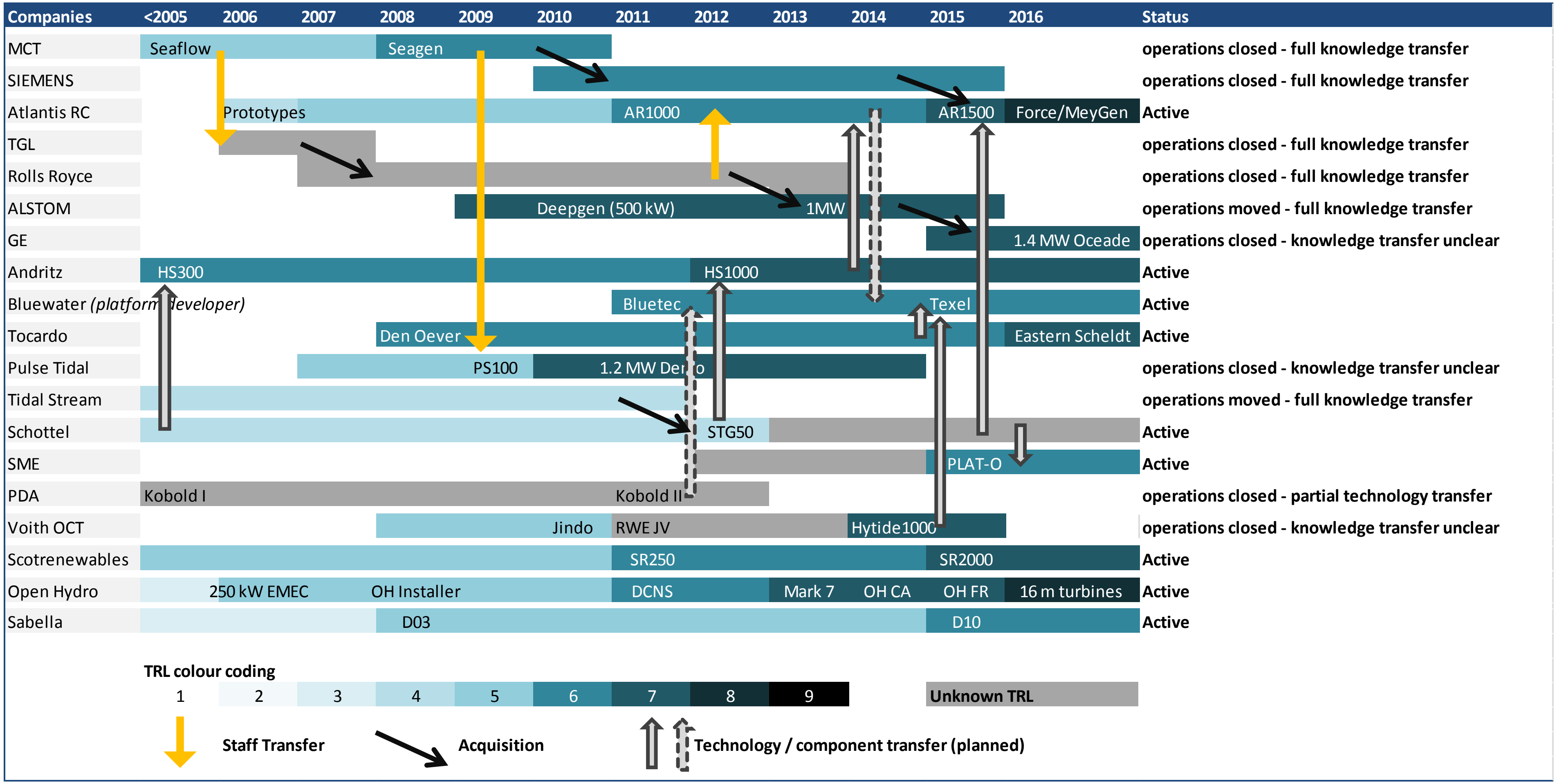

Figure 2.5 Schematic overview of chronologic development of the tidal energy sector.

The above figure shows for individual companies the technology development in terms of maturity (colour coding, light to dark) and demonstration projects (text). The arrows represent staff transfer, acquisition and technology / component transfer (dashed lines indicate a planned transfer), and together with the status of technology development this gives an indication of the extent of knowledge and experience transfer and collaboration in the technology development activities.

< 2000 Historically, the utilisation of the rise and fall of tides as well as the associated currents dates back to the Middle Ages when mechanical tide mills were used as a reliable drive system for a range of applications – in the same way floating river mills were used. One of the first modern in-stream turbine developments was a horizontal axis tidal generator developed by Peter Fraenkel in 1992. The system with 15 kW shaft power and a 3.5 m rotor diameter was tested in the Corran Narrows Loch Linnhe, Scotland, using a floating pontoon. This development marks the beginning of what grew into the Marine Current Turbine (MCT) branch of Siemens two decades later. In 1993 first resource and technology studies on tidal currents were launched in the UK.

2001 A first concept using a vertical axis turbine with oscillating blades mounted under a circular floating hull dates back to around 1995 resulting in a patent from Italy in 1998. After some years of development using numerical modelling of the rotor and lab scale flume tests the Kobold pilot system with a rated capacity of 60 kW was commissioned in 2001 in the Strait of Messina, Italy. In 2005 the system was grid connected and equipped with automatic controls for unmanned operation. In 2004 the company was awarded a UNIDO project to provide energy to island villages in China, Indonesia and the Philippines. Only one device with a rated capacity of 150 kW was developed and built but the cost of the installation could not be covered anymore by the project. The installation was never commissioned and the company went out of business in 2012.

2002 Scotrenewables Tidal Power Limited was founded in Orkney, Scotland, near the European Marine Energy Centre (EMEC). The concept under development was a floating turbine with two rotors mounted on retractable legs on each side of the floater allowing it to be towed to and from site using relatively small vessels. From 2003-2009, the company tested its technology at increasing scales, with investment support from TOTAL, France, Fred Olsen, Norway and ABB Technology Ventures, Switzerland. In 2011, the company launched the grid connected SR250 250 kW, for a 2 ½ year testing programme at EMEC. A lease from the Crown Estate has been awarded in 2012 for the development of a tidal array at Lashy Sound, Orkney. The project is currently progressing with environmental data gathering to inform an application for consent for a first phase of up to 10 MW of installed capacity. The company has announced plans to launch the SR 2000 turbine with 2 MW rated power in 2016.

2003 The first industrial scale marine current turbine SEAFLOW was commissioned in June of that year in the Bristol Channel of the North Devon Coast, UK. Due to the lack of a grid connection for which funding was refused the system produced electricity but used resistor banks instead. The turbine with a two bladed rotor at a diameter of 15 m was installed in 20 m water depth. The total budget of the project, starting in 1998, of around €5 m was supported in a combined effort by the European Commission with additional funding from the British and German governments. The turbine was in operation until 2007 and was decommissioned when the 1.2 MW Seagen device was installed in the Strangford Narrows, Northern Ireland in 2008 by a similar consortium. In 1999, the company MCT was established. In 2010 Siemens first became a minority shareholder in MCT and acquired the remaining shares in 2012. In July 2015 MCT was purchased by Atlantis Resources Ltd.

2003 Hammerfest Strom commissioned, in November, a tidal turbine in the Kvalsund, Norway, which was grid connected in 2004. The fully submerged machine with a pressurised nacelle operated in 50 m water depth allowing for ship traffic above the rotor. The 3-bladed 20 m rotor provided a power of 300 kW. The system was designed using expertise from Rolls-Royce, UK. The mechanical pitch system was delivered by Schottel, Germany. In 2009 the turbine was maintained and put back into operation. It achieved an availability of 98% during more than 17,000 operating hours, equalling 1.5 GWh of electrical energy in total. In order to access the promising UK market an office was opened in Glasgow in 2008. In 2010 the Austrian hydropower manufacturer Andritz Hydro acquired a 33% stake in Hammerfest Strom. In December 2011 a 1MW tidal turbine - the HS100- was installed at EMEC. The rotor diameter was 21 m and the water depths 52 m. In 2012, Andritz increased its stake to 55.4%. The other shareholders are the Norwegian Hammerfest Energi and the Spanish utility Iberdrola. The new company operates under the name Andritz Hydro Hammerfest. In 2011 ScottishPower renewables received consent for a demonstration array in the Sound of Islay, Scotland, using 10 of the HS1000 machines. The application was renewed in 2014 and approved in 2015. This project with a support of €20.65m represents one out of three ocean energy projects awarded for funding under the NER300 programme. The project will generate about 30GWh/a of electricity.

2005 Bristol-based Tidal Generation Limited was founded by former MCT staff. Building on their experience from Seaflow and Seagen they developed the 500 kW tidal turbine Deepgen. Sea trials began in September 2010 at EMEC. In March 2012 the device had generated over 200MWh. In 2008 Rolls-Royce invested into TGL before acquiring the company completely in 2009. In 2013 TGL was acquired by Alstom. In the framework of the ETI funded ReDAPT project, a 1MW turbine was installed reusing the existing tripod support structure in the same year. In 2015 the tidal technology, as part of Alstom's energy business, was transferred to GE. At the beginning of 2017 GE announced its abandonment of tidal technology completely. As a result the Netphyd project, with a plan to install 4 Oceade tidal turbines of 1.4 MW each at Raz Blanchard, was abandoned by Engie (former GDF Suez), due to a lack of alternative suppliers.[24]

2005 Open Hydro was founded in Ireland to commercialise an open centre tidal turbine concept which had been developed in the US in the 1990s. In 2006 the company became the first tidal device developer to install and test a tidal turbine at EMEC. In 2008 the device began to feed electricity into the grid. Due to the significant tidal resource in France (around 15 TWh – the 2nd largest in Europe), EDF showed an increasing interest in the sector. In 2011 EDF installed a first 1MW device from Open Hydro off the Brittany coast near Paimpol-Bréhat. The initial plan had been to install an array of 4 and later up to 10 devices. However the device was decommissioned in 2012 and after some modification reinstalled in 2013. In 2011 the French government-owned naval defence and energy company DCNS acquired 8% of Open Hydro shares, followed by an increase of its holding to around 60% in 2013. In December 2014 Open Hydro DCNS, in partnership with EDF Energies Nouvelles, were awarded a 14MW project off the Normandy coast near Raz Blanchard by the French Environment and Energy Management Agency (ADEME). The project plan is to install 7 machines of 2 MW each by2018. Further projects are in the pipeline in Canada, Northern Ireland and Alderney off the French coast.

2008 The French engineering and project development company Sabella installed a 1:3 scale tidal stream turbine in an estuary in Benodet, Brittany, France and tested the device for a whole year. On this basis, a series of turbine solutions have been developed, with rotor diameters from 10 to 15 m and a power range from 0.3 to 2.5 MW. A first prototype of the new turbine design, the D10 with a capacity of 500 kW was installed off the French Island Ushant and started to produce electricity in November 2015. At the end of 2015 Sabella signed a memorandum of agreement in the Philippines, with developer H&WB Asia Pacific, to develop a 5 MW proof of concept tidal power project.

2008 Singapore- based Atlantis Resource Corporation opens an office in London. The company had started testing different tidal generator technologies in Australian waters between 2002 and 2006, with a first grid connect device at 100 kW capacity. In 2008 further turbine tests were made with a new 150 kW device - the AN150. In 2010, Atlantis was part of a consortium that received development rights for the Inner Sound of the Pentland Firth, UK under the 1st Crown Estate leasing round. In August 2011, the 1MW AR1000 machine was installed, and subsequently grid connected. During 2013, Atlantis continued the development of the next generation tidal turbine using a variable pitch design and became the 100% owner of the MeyGen project. In cooperation with technology partner Lockheed Martin the development of the current 1.5 megawatt AR1500 tidal turbine system was completed. In 2015 Atlantis RC acquired MCT from Siemens.

Another former recipient of NER300 funding, with an award of almost €18.4 million, was SeaGeneration (Kyle Rhea) Ltd, a development company set up by Marine Current Turbines (MCT), which was proposing to develop a tidal stream array at the Kyle Rhea site between the Isle of Skye and the west coast of Scotland. Following completion of the MCT acquisition from Siemens, Atlantis applied to the European Commission, with the support of the Scottish and UK governments to have this funding transferred from the Kyle Rhea project to Project Stroma, which enables the funding to be retained for the benefit of a more advanced Scottish tidal energy project. The proposed array should consist of four SeaGen devices and have a total capacity of up to 8 MW. In 2015 the European Commission's Climate Change Committee approved the transfer of €17 million of funding from the Kyle Rhea project to Atlantis's MeyGen Phase 1B (Project Stroma) to accelerate the development of the MeyGen project. The Meygen phase 1a reached financial closure and has started construction (cable, access road etc.). It is the first build-out phase of the MeyGen Tidal Energy Project in the

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[24] renews.biz, dated 09/01/2017.

Inner Sound of the Pentland Firth with a second phase targeted to reach financial close and commence construction during 2016.

2008 Voith Hydro Ocean Current Technologies, a subsidiary of the German hydro power manufacturer Voith Hydro, started the development of a tidal turbine. A first 110 kW pilot installation had been installed in 2011 at a site off the coast of South Korea near the island of Jindo. This test facility was built as a 1:3 scale model to demonstrate the technology under real operating conditions. The turbine had a rotor diameter of 5.3 m and used a gravity foundation. A second device with 1 MW capacity was installed at the European Marine Energy Centre (EMEC) for testing, with funding from the UK Marine Renewables Proving Fund (MRPF). This turbine was basically an up-scaled version of the system in Jindo but mounted on to a monopile drilled into the seabed. The 1MW horizontal axis turbine – HyTide – which is 13m in diameter and weighs 200 tons was successfully installed in 2013 (source EMEC).

2009 The French engineering group Alstom got involved in tidal energy by signing a licence agreement with the Canadian company Clean Current Power Systems, which had installed and operated a tidal device to power a small island off the British Columbia coast since 2006. In 2010 Alstom announced the establishment of their ocean energy business in Nantes, France, where the Beluga 9 tidal device had been developed, with a plan to install a 1 MW prototype in the Bay of Fundy, Canada in 2012. The Beluga concept was later abandoned.

2012 GDF SUEZ announced the selection of Voith's HyTide technology for a tidal power project at Raz Blanchard in Lower Normandy, with a plan to install up to 100 turbines at this site. In 2013 an industrial partnership agreement involving further partners was signed, to develop the pilot site at Raz Blanchard in 2016, which was expected to have a capacity between 3 and 12 MW. Toward the end of 2014 tests at EMEC were stopped and the turbine decommissioned. The company Voith OCT was terminated end of 2015.

2013 Alstom acquired Bristol-based Tidal Generation limited from Rolls Royce, followed by the installation of a 1MW device at EMEC. End of 2014, Alstom announced the improved turbine design called Oceade with an 18 m rotor and a capacity of 1.4 MW. In the same year, Alstom, as part of a GDF Suez led consortium, was supported, as the 2nd supplier, to install four 1.4 MW Oceade turbines as well as the electrical subsea hub for the Raz Blanchard site in Normandy. In November 2015 Alstom completed the sale of its energy business to GE with the consequence that the tidal turbine development is now continued under GE's renewable energy business.

2014 The German ship propulsion specialist Schottel created the 100% subsidiary Schottel Hydro with a focus on developing and distributing components for tidal turbines as well as small scale turbine systems. In 2011 the company had supplied the pitch mechanism to the Andritz Hammerfest HS1000 turbine and been contracted to supply the hub and pitch mechanism for the Atlantis AR 1500 machines in the MeyGen project. Schottel developed a 50 kW in- stream turbine (SIT), two of which had been sold to PLAT-O, UK, and another 4 contracted for the Dutch BLUETec platform. The Schottel subsidiary Black Rock Tidal Power (BRTP) was awarded a berth at the Fundy Ocean Research Centre for Energy (FORCE) Nova Scotia, Canada and is currently building a TRITON platform for the Bay of Fundy, Canada. The device will be installed in 2016 with 40 SITs, with a total capacity of 2.5 MW. A second platform will be installed in 2017.

2.3. Offshore Wave Energy

2.3.1. About the resource potential

The variation of resource regimes requires specifically adapted wave energy devices. The volatility of the energy intensity, particularly, affects design, as devices need to maximise energy capture from the waves whilst surviving extreme loads without damage. The highest average power level, with more than 70 kW/m, is found in the Atlantic Ocean west of Ireland and off Scotland (UK). In the most Northern and Southern European Atlantic sites, power levels are found to be of similar magnitude (around 40 kW/m). However, the distribution of wave periods shows that waves of longer periods are more common near Lisbon than at the Haltenbanken in Norway. Power levels around 20 kW/m occur in the fetch -limited central region of the North Sea where wind-sea is predominant and, thus, shorter wave periods are found.

According to the SI-Ocean project[25], an assessment was made of six countries under EU jurisdiction with a significant wave energy resource within the given scenario parameters, namely the United Kingdom, Ireland, Spain, Portugal, France and Denmark. Summing up, the offshore wave energy resource for the assessed countries is increasing with distance to coast and water depth, resulting in a total maximum theoretical wave resource of 166 GW and 1,456 TWh/a.

2.3.2. Key characteristics of the technology

Offshore wave devices generate energy in very different ways. Therefore, the number of generation principles and concepts is significantly higher than of those in the tidal energy sector. Based on a categorisation for wave energy conversion principles as proposed by EMEC, the wave energy part of the JRC Ocean Energy Status Report 2014 (JRC 2014) identifies promising combinations of wave energy conversion principles and well-established PTO concepts. From these combinations, those with a potential for use in deep offshore waters have been selected to be in scope for this study. Table shows the selection of offshore wave conversion principles.

Table 2.1 Offshore Wave Conversion Principles (adapted from JRC 2014)
Source: JRC (2014).

Conv. Principle	Example device	PTO concept	Status of example
Attenuator	Pelamis	Hydraulic circuit driving rotating electrical generator.	Project cancelled
Point Absorber	Wavebob	Hydraulic circuit driving linear electrical generator.	Project cancelled
	Seabased WEC	Direct driven linear electrical generator.	Ongoing development, first commercial projects
Oscillating Wave Converter (OWC)	CORES OE-Buoy	Airflow through a Wells or Impulse turbine, driving a rotational electrical generator.	Ongoing prototype development
Overtopping	Wave Dragon	Water level difference drives low-head hydraulic turbine driving a rotational electrical generator.	Project cancelled
Rotating Mass	Wello's Penguin	Rotation mass drives rotating electrical generator.	H2020 field test (CEFOW)
Wave Surge	Oyster	Hydraulic circuit connecting all units in an array and driving a land based common rotating electrical generator.	project cancelled
	Waveroller	Individual hydraulic circuit in each device, hermetically isolated from sea water, driving a rotating electrical generator.	Prototype installation successful, ongoing development

Most of the concepts/projects listed in Table 2.1 no longer exist, but for a study with the intention to depict lessons learned, they might be useful, for this very reason. Some projects are still under development, receiving public funding, e. g. the Penguin faces a field test within the framework of the H2020 project CEFOW. Annex I provides a more detailed overview of technological characteristics.

2.3.3. Chronology of technology development

A chronological overview of main installations of wave technology and the main companies behind these is given in the schematic overview on the next page.

It can be noted that about half of the operations mapped have been closed down, whilst the other half is still active. However, and contrary to tidal energy, only a few of the closed projects have managed to transfer the knowledge gained, in part or in full – either through mergers & acquisitions or through staff mobility.

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[25] www.si-ocean.eu.

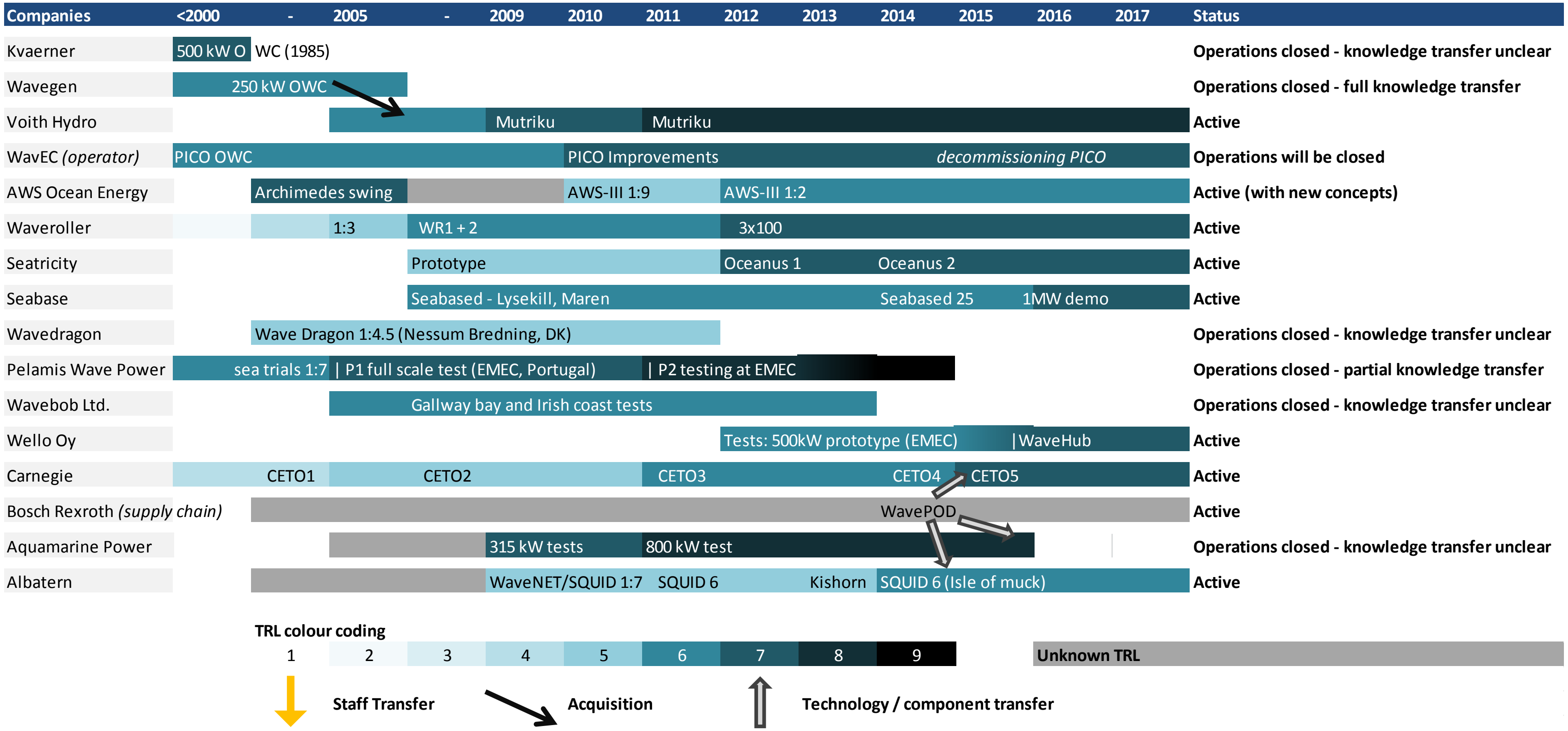

Figure 2.6 Schematic overview of chronologic development of the wave energy sector

The above figure shows for individual companies the technology development in terms of maturity (colour coding, light to dark) and demonstration projects (text). The arrows represent staff transfer, acquisition and technology / component transfer (dashed lines indicate a planned transfer), and together with the status of technology development this gives an indication of the extent of knowledge and experience transfer and collaboration in the technology development activities.

<1990 The oil crisis in the early 1970s triggered a wide interest in all kinds of renewable energy sources - including wave energy. For almost two decades the technology developments took place through national programmes, mostly in the United Kingdom, Portugal, Ireland, Norway, Sweden and Denmark. The objective was to develop commercial wave power conversion technologies in the medium and long term resulting in a number of installations across Europe, such as the 500 kW tapered channel installation in Toftestallen, Norway in 1985 and a 75 kW OWC on Islay, Scotland in 1991.

1990 Wavegen Ltd was founded in Inverness, Scotland. In 2005 the company was acquired by Voith Hydro. The Limpet installation had been continuously in operation from 2001 to 2013 making it the only wave-powered plant worldwide to have continually produced power for over 10 years. Up until the end of 2011, it had been running for more than 75 000 operating hours. The system availability had achieved over 98% during its last 4 years of operation. After the successful completion of the Mutriku project in 2011, a follow-up project with a total capacity of 4 MW had been planned on the Isle of Lewis (Siadar wave energy project). Although the £30 million project had received approval by the Scottish Government in 2009 it was cancelled in 2012 after the main investor withdrew. There were no further projects in the pipeline using this technology. Voith shut down the Wavegen branch in 2013.

1994 The growing interest at Member State level leads to the introduction of wave energy in the R&D programme of the European Commission. After some initial projects, focussing on resource assessments, theoretical investigations and development of recommendations, in the early 1990s,, the fourth framework programme, with a total budget of close to 10 M Euro, kicked off the European wide development of wave energy devices.

2000 The Limpet shoreline Oscillating Water Column (OWC) system is commissioned on Islay with an installed capacity of 250 kW. Together with a similar concept with 400 kW installed on the Pico Island (Azores, Portugal) these became the first wave energy technology milestones supported by the EC. At the same time, the construction of the 2 MW Archimedes Wave swing device had started with the initial plan to install off Portugal in 2001. After installation trials in 2001 and 2002 had failed, due to unexpected motions during the submersion of the structure, a new consortium successfully commissioned the device in 2004 in the North of Portugal. This was the first wave energy converter to use a linear generator as power take off system.

2005 Aquamarine Power was founded in Edinburgh, Scotland to commercialise a wave surging device using oscillating flaps hinged on the sea bed in shallow water- the “Oyster”. The concept originated from studies conducted in 2003 by a research team at Queen's University, Belfast. These studies were co-funded by the Engineering and Physical Sciences Research Council and Allan Thomson. In 2009 the company announced an investment of £8m by the ABB Group. The company deployed and tested two full-scale Oyster devices, the 315kW Oyster 1 in 2009 and the second-generation 800kW Oyster 800 in 2011 which was grid-connected in June 2012 at the European Marine Energy Centre (EMEC) on the Orkney islands. In October 2015 the company went into administration and was shut down one month later, failing to find a buyer and losing 13 jobs. The test programme was stopped. Another surge device had been developed by the Finnish Company Waveroller with sea trials at EMEC starting in 2005. PTO testing and further sea trials of scaled devices were made in Portugal in the years 2007 and 2008. In 2012 a Waveroller using three flaps with a total capacity of 300 kW was successfully installed off Peniche in Portugal. The system was funded under FP7.

2007 Floating versions of OWCs are developed – after a first downward facing 500 kW system from Oceanlinx in Australia in 2005 - a modification of the concept, in the form of a so-called backward bent duct, had been commissioned and tested in Galway Bay, Ireland by OceanEnergy. The same hull was later used in the context of an FP6 project to develop the turbine technology further. In 2012 the technology was chosen to be installed at Wave Hub, a UK offshore marine energy test site off the Cornwall coast. The company had to abandon plans to develop a full scale device due to difficulties with match-funding and, operations were suspended. With support from the US DoE, a 500KW version of the technology is now being prepared for deployment at the US Naval test facility in Hawaii. Subsequent repowering to 1MW will follow with a grant approved by DoE for deployment in EMEC in 2018/2019. The Power take-off air turbine generator system, together with grid connection electronics, are supplied by Dresser Rand Siemens for both 500kW and 1MW deployments.

2011 The largest shoreline OWC system currently in operation is a breakwater integrated system off Mutriku in the North of Spain using Wavegen turbines with a capacity of around 300 kW, commissioned in 2011 using funding under FP7. The turbine technology used for this installation had been tested in more than 15.000 operating hours at the Limpet site prior to manufacturing.

Seatricity started testing their Oceanus 1 buoy at EMEC. Wave energy converters using oscillating bodies, that use the heave motion to absorb wave energy, were developed from the 1980s onwards in Norway and later in the US, Ireland and Sweden. This company started development in 2007 with a small prototype. The 160 kW Oceanus 2 device was first tested at EMEC in 2012. In September 2014 the device was deployed at WaveHub, the offshore renewable energy test facility in Cornwall, UK, with plans to develop a 10MW array over the next two years at the site.

2013 The Swedish company Seabased, a spin-off from Uppsala University, commissioned a buoy using a linear generator- based PTO, leading to a first small array configuration with three devices. First sea trials of this technology were started in 2006 by Uppsala University near Lysekil. In November 2011 the company signed contracts with Fortum to deliver a 10 MW demonstration plant - the Sotenäs wave energy farm. The Swedish Energy Agency contributed co-funding. In December 2015 a 120 ton subsea switchgear was deployed and connected to the Swedish National Grid via a 10 km subsea cable. 36 wave energy converters corresponding to 3 MW have been deployed. The wave power plant was initially grid connected in January 2016. After a positive evaluation of the first batch another 9 MW are planned to be installed at the site.

Table 2.2 Timeline of the Pelamis project

Year	Description
1998	The company "Ocean Power Delivery" was founded to develop the Pelamis concept commercially. The Pelamis concept itself was developed as a pitching device on the basis of principles of earlier concepts namely the "Cockerell Raft" as well as the "McCabe wave pump" which date back to the 1970s and 1980s. In the initial phase the Pelamis concept was developed using computer models and scale tank testing.
2001	Sea trials of 7th scale model in the Firth of Forth.
2003	Lab testing of a full scale PTO module at Leith in Edinburgh.
2004	Sea trial of the 750 kW full scale prototype (TRL), the first floating wave energy device feeding electricity into a public grid at EMEC.
2007	Change of name to "Pelamis Wave Power" PWP.
2008	Commissioning of the world's first wave energy farm consisting of three Pelamis devices with a rated capacity of 750 kW each off the Northern Portuguese coast near Agucadoura. The € 9 million Agucadoura farm with three machines represented the first phase of a project with a total capacity of 22 MW (25 devices). Only two month after the official commissioning of the farm on September 23, the devices were taken back to the harbour in November of the same year. Technical problems were encountered e.g. with the buoyance of the mid water buoy, a part of the mooring system as well as with the bearings in the hinges. The connection system, which was designed for quick hook-up and release, used foam to maintain its buoyancy. That foam however was not capable of withstanding the higher water pressure as a result of the deeper water it was operating in, compared to the previous sea trials in Scotland. The P1 one design of the separated hinged joints had to carry very high loads introduced from the combined motions of the floaters. The resulting high friction in the bearings affected their lifetime dramatically and compromised the overall efficiency. The problem was overcome in the P2 device by combining two axes in one joint which required a new bearing solution, moving back some TRLs for this component. For both problems engineering solutions were found but it took a couple of month to realise those. The main project owner Enersys, a Portuguese renewable energy company, was bought by the Australian company Babcock and Brown who went into administration at the beginning of 2009 and was seeking to sell their shares in the project (equal to 77%). Pelamis wave power, as the 2nd project shareholder, then decided not to put any further efforts into fixing these problems but rather move to the next generation device.
2009	EON UK orders the first device with the new design, P2. In a joint venture with Vattenfall, called Aegir Wave Power, Pelamis had announced plans to develop the Aegir wave farm (Shetland) with an initial capacity of 10 MW and three more in the Pentland Firth with a total capacity of 150 MW as part of the 1st Crown Estates leasing round.
2010	Scottish Power renewables orders the 2nd P2 device in March. On October 2010, P2-1 is

Year	Description
	commissioned at EMEC and tests started.
2011	PWP announced a reduction in the number of staff in March. P2-2 is completed in July.
2012	Commissioning of the P2-2 at EMEC. Following the demise of the company, the P2-001 device was acquired by Wave Energy Scotland, having completed over 15,000 hours of operation. The device was decommissioned in April 2016. The other device, P2-002 was sold to the European Marine Energy Centre for use as a test rig.[26]
2014	PWP goes into administration with around 15 million pounds of debts. The newly founded consulting company Qoceant retains most of the knowledge and IPR of Pelamis.

2.4. Development of tidal and wave ocean energy: key findings

The review implemented in the study demonstrates that a range of both tidal stream and offshore wave technologies have been developed since the 1990s. The chronologies show that for both wave and tidal a shake-out of companies has taken place. Several companies have entered and subsequently left the sector or closed their operations altogether. Figures 2.5 (page 11) and 2.6 (page 17) present schematic overviews of the past initiatives, technologies and pathways. It can be noted that about half of the operations mapped for wave and tidal energy have been closed down, whilst the other half is still active. However, and in contrast to tidal energy, for wave energy only a few of the projects that have closed down have managed to transfer the knowledge gained, in part or in full, through mergers & acquisitions or through staff mobility.

At first sight it would appear that wave energy technology matured more quickly, having attempted to reach higher technological readiness levels and attracting the involvement of large players early in the process. Wave energy development indeed appeared to be more fast-paced, although the relevant actors in the end either did not pursue the concept or went into administration. To date, the development of wave energy technology shows very little technological convergence. Due to the diverse nature of the wave resource in deep water and shallow water as well as the complexity of extracting energy from waves, there has always been a wide range of technical solutions under development, focusing on different parts of the resource and using a range of different solutions. The evolution of wave energy technology is therefore rather fragmented and indications of collaboration and sharing of experience and knowledge are less obvious.

In the case of tidal energy, it can be observed from the chronology that significant technological convergence has taken place. Several (un)successful attempts towards higher technological readiness have been made. Importantly, the extent of transfer of components, staff and technologies/components indicate that a certain degree of knowledge transfer occurred in the sector. Chapter 3 discusses differences between tidal and wave regarding the root causes of failures.

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[26] Wave Energy Scotland workshop, November 2016.

3. REVIEW OF CRITICAL BARRIERS ENCOUNTERED AND LESSONS LEARNT

3.1. Overview

This chapter provides a review of critical barriers encountered and of raisons for failures in ocean energy technology development. The chapter also provides an overview of projects that have succeeded and failed over time – information is provided in the form of boxes. Failure in technology development is defined as follows.

Defining 'failure' in technology development is ambiguous

In the context of this study, the term "failure" has been used to characterise situations in which:

- Technical problems were encountered, e.g. the device failed partially or completely due to component issues (e.g. rotor blades), structural problems, station keeping (mooring lines or anchors), survivability problems during storms (extreme loads), rapid wearing or corrosion due to fatigue or inadequate designs/materials;
- Financial problems occurred, e.g. providing the matching funds for public grants at demo scale or having to increase the shareholder contribution from private equity due to not meeting milestones.

In practice, the term 'failure' illustrates the fact that a planned deployment and/or timeline, a cost reduction target or a financial framework has not been met or not in time to continue with technology development. A technical failure typically results in higher cost, a delay or not achieving a milestone. This has often led to the termination of a project or development, although this can also depend on competition for support with other (more mature) ocean energy or renewable energy technologies. Put in other words, failure can be seen as a lack of competitiveness, i.e. unique selling points are no longer applicable or convincing and market pull mechanisms have become inactive.

Admittedly, 'failures' and subsequent 'shake-outs' are inherent to any emerging industry and should not always be perceived negatively: a failure can provide significant learning experiences for the sector if the knowledge is captured by the supply chain. Furthermore, an abandoned technological development should help to narrow down future options or to identify financial or technological preconditions for developments. What defines a success or failure is thus the extent to which the sector, as a whole, has been able to draw learning and benefit from such experiences.

The table below presents an overview of the barriers perceived by stakeholders The figures indicate the relative importance of the seven types of barriers (based on relative frequency of answers to the question of barrier identification), specified for several types of stakeholders.

Table 3.1 Overview of relative frequency [%] of barriers perceived by stakeholder's sector focus

Source: Ecorys.

Barrier	Wave	Tidal	Transversal/ General	All stakeholders
Exogenous factors	3%	5%	2%	3%
Research support barriers	13%	7%	7%	10%
Technological Innovation & Development barriers	8%	17%	17%	13%
Critical Mass and supply chain barriers	9%	15%	21%	15%
Project Finance barriers	28%	24%	27%	27%
Framework and regulatory conditions barriers	29%	27%	22%	25%
Performance & Market barriers	10%	5%	4%	7%
Total	100%	100%	100%	100%

An observation that can be derived from the above table is that a range of barriers hold the sector back, ranging from exogenous factors to research support/framework conditions, technological innovation, critical mass and project finance. It is important to acknowledge that all these factors play their role. Simultaneously, it is equally important to discern symptoms from root causes. This is most prevalent when 'lack of funding' is raised as a barrier, which, more often than not, may be a symptom rather than a root cause.

Table 3.2 Overview of relative frequency [%] of barriers perceived by stakeholder category

Source: Ecorys.

Barrier	Academics	Business/ developers	Business/ Other	Public
Exogenous factors	4%	0%	3%	6%
Research support barriers	15%	15%	6%	10%
Technological Innovation & Development barriers	15%	8%	11%	19%
Critical Mass and supply chain barriers	13%	18%	16%	14%
Project Finance barriers	21%	23%	27%	28%
Framework and regulatory conditions barriers	28%	33%	29%	19%
Performance & Market barriers	4%	3%	8%	4%
Total	100%	100%	100%	100%

According to Table 3.2, developers and industry representatives point rather to non-technological reasons, including framework and regulatory conditions, research and finance support as the main hurdles. Public sector representatives see technological factors as a more important barrier. An interesting observation in this context is that much of this information arises from interviews that have taken place with business leaders, CEO's etc. In contrast, we have noticed that lower management and expert level stakeholders tend to give more prominence to technological barriers.

While developers are improving technological performance and exploring the scope for LCOE reduction, the shake-out moves beyond technological barriers. The failure of both Pelamis and Aquamarine serve as examples, where a mix of technological barriers and non-technological barriers put a strong brake on the projects' advancement. Importantly, at this stage we do not see a shake-out of concepts, but rather of companies. Yes, there can still be concerns about the technological performance and LCOE potential, but these type of failures do not prove that the concept has failed.

When the concept has arrived at a final design, with sufficient scope for LCOE reduction, the weight of the barriers moves towards Critical Mass and Project Finance (upscaling of projects). In other words, the challenge becomes the development of an industry, which is where the tidal sector can currently be placed. Concepts can still fail at this stage, of which the OWC concept provides a good example. Despite the mature design and performance levels, the resource-LCOE potential for this concept is currently not considered sufficiently attractive.

The remainder of this chapter presents more detail with regard to each of the barriers encountered, supplemented by information on projects, both failed and successful. It will do so in a structured manner:

- Exogenous barriers, mostly related to resource potential, including maritime space and environmental constraints (3.2);
- Endogenous barriers for industry, including technological innovation, critical mass and performance (3.3);
- Support barriers, related to research support, project finance and framework & regulatory conditions (3.4).

3.2. Exogenous factors

The following exogenous factors are considered the most important by stakeholders interviewed: metocean condition (resource potential), geological / geotechnical, ecological and social conditions.

Metocean conditions (resource potential)

In order to make a convincing business case that proves the viability of a marine energy project, an estimation of the energy resource is insufficient. Eventually the resource needs to be evaluated in detail with the help of accurate data gained in high resolution and long term measurements. The actual local metocean conditions have a strong impact on technical considerations and financial aspects. The interviews showed that inaccurate knowledge of the actual resource has led to the cancellation of marine energy projects where the initial estimation of the resource was apparently exaggerated.

Unlike wave resources, tidal resources are not widely distributed but can only be found in few distinguished hot spots. This limits the overall availability of the resource as such and consequently reduces the attractiveness of exploiting it at a large scale. Some stakeholders are therefore sceptical about the long term roll-out potential. The most recent LCOE trends suggest that an LCOE of € 120/MWh can be reached after 10 GW of cumulative deployment.[27] Put in perspective, the global market potential is estimated at 25 to possibly greater than 120 GW[28]. The global theoretical resource has been estimated in the order of 800 TWh or around 250 GW of capacity. There is however a high uncertainty in estimating the technical and economically feasible fraction of that resource, as the numbers above indicate.

The precision of the estimates above is hampered by the fact that only a few countries worldwide are actively engaged in the development of tidal stream industries and projects and have performed detailed resource assessments. Detailed studies in the US have shown that the technical potential of tidal streams as well as ocean currents add up to 267-497 TWh/a[29] representing around 50-60% of the theoretical resource. The tidal energy resource assessment for Ireland identified the accessible resource to be only 1.5% of the theoretical potential. The 120 GW figure for the global tidal stream market would represent up to 50% of the known resources and can, therefore, only be seen as a technical resource, in contrast to a significantly smaller future economic resource.

One can compare the resource potential and learning-by-doing-induced cost reductions to offshore wind. Here, resource potential is estimated to be some 74,000 GW.[30] LCoE trends for offshore wind suggest that a cost of €100/MWh can be reached at an installed capacity global of 7.86GW.[31] This would mean that offshore wind will have utilised only <0,1% of its potential resource availability for cost-competitiveness to be reached. This is a low figure compared to the 2 to 12,6%[32] for tidal energy, suggesting that resource potential for tidal energy could become a bottleneck for driving down costs, at least with current technology concepts.

Another barrier within this context is that the variety of tidal resource regimes often requires tailored devices. For example, there is an extraordinary diversity of seabeds, which has implications for the way in which devices are mounted. By the same token, differences in water depth are important too – as some turbines have a diameter as much as 18 meters. An important question is also to what extent technology needs to be tailored to these resource regimes at a component level. For specific tailored components, this will affect the potential for economies of scale and moving down the learning curve. More specifically, tidal energy resource sites differ with regard to the flow patterns as well as the water depth and soil conditions. The structure (piles, gravity foundations, floating), rotor and blade concepts will react differently on flow variations. The level of technical homogeneity between different sites is, however, much higher than in wave energy and is comparable to offshore wind energy including floating concepts: similar rotors and PTOs can be used everywhere, but e.g. structures and consequently installation methods will vary.

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[27] OES (2015), International Levelized Cost Of Energy for Ocean Energy Technologies.

[28] http://atlantisresourcesltd.com/marine-power/global-resources.html and http://www.marineturbines.com/Tidal-Energy.

[29] https://www.energy.gov/eere/water/marine-and-hydrokinetic-resource-assessment-and-characterization.

[30] Appendix A of NREL (2012), Improved Offshore Wind Resource Assessment in Global Climate Stabilization Scenarios. http://www.nrel.gov/docs/fy13osti/55049.pdf.

[31] Roland Berger (2013) Offshore Wind Toward 2020; https://www.rolandberger.com/media/pdf/Roland_Berger_Offshore_Wind_Study_20130506.pdf.

[32] An installed capacity of 7.86GW would utilize 7,86 * capacity factor of 0,3 to 0,4 = 2,4 to 3,1 GW of raw resource. Compared to the raw resource of 25 to 120 GW, this represents 2,4 / 120 and 3,1 / 25 = 2% to 12,6% of raw resource.

Moreover, the tidal resource regimes can differ significantly regarding the amplitudes of tidal rise and fall, and diurnal, semidiurnal or mixed occurrence. This results in significantly differing on-site working time windows and issues regarding the capabilities of installation and maintenance vessels and the utilised equipment. The extent to which economies of scale can be achieved in the offshore supply chain is therefore also affected.

Finally, the remote resource concentration leads to the necessity to perform costly and extended metocean measurement campaigns for each single spot potential installation site.

Text Box 3.1. Mutriku and the metocean conditions

Mutriku is the largest shoreline OWC system currently in operation. The breakwater integrated system in the North of Spain has a capacity of around 300 kW and was funded under FP6. The turbine technology used for this installation had been tested in more than 15.000 operating hours at the Limpet site prior to manufacturing. Nevertheless, the behaviour of waves and energy density appeared to be location-specific and difficult to capture or model. A 1/100 years storm took place before the plant was commissioned, causing severe damage to the caissons which turned out to have been built inadequately in the first place.

The OWC concept is also a good example of the importance of limitations on resource potential. Indeed, the Limpet installation had been continuously in operation since 2001 using more and more advanced turbine technologies which brought the technical availability, from an initial value around 20%, to around 90% in 2008. Despite this technological progress, a follow-up project with a total capacity of 4 MW, planned for the Isle of Lewis (Siadar wave energy project), did not materialise, as the main investor had withdrawn. Based on the experiences of Mutriku, one interviewee indicated that revenues are only sufficient to cover O&M, and that any new shoreline OWC system can only be competitive when realised as an add-on to planned coastal protection works (e.g. a wave breaker) which would cover the majority of the civil engineering investment costs. Ultimately, these limitations reduce the resource potential to such low levels that successful commercialisation of the concept became questionable.

The overall theoretical resource potential for wave energy is much higher than for tidal energy. Nevertheless, the basic choice of appropriate wave energy converters and their advanced tuning is dependent on the specific local wave climate, comprising the statistical occurrence of wave lengths and heights. The interviews revealed that economically interesting wave sites are generally considered to be most hostile for man and machine, and that the actual occurrence of energetic waves is, in contrast to tidal cycles, less predictable. This leads to a difficult situation regarding survivability and maintenance of the devices, with very high technical demands on the device side and the planning and performance of maintenance operations.

Geotechnical conditions

In the interviews, stakeholders referred to difficult bathymetry, discovered after performing second-step geotechnical surveys of potential sites, and which led to the cancellation of projects. In this context, bottom mounted devices - especially with gravity foundations - require a flat seabed with very little slope and a sufficient load capacity. In practically all cases the seabed needs to be prepared to match the technological requirements.

Environmental and ecological conditions

The regulatory framework for environmental protection pertinent to projects on ocean energy, including the Strategic Environmental Assessment (SEA) Directive, the Environmental Impact Assessment (EIA) Directive, Water Framework Directive (WFD), Marine Strategy Framework Directive (MSFD) and the Nature Directives, is consolidated at EU level, but implementation specificities can still differ at national level. Especially for the assessments to be performed under the SEA, EIA and the Nature Directives, responsibilities for these Directives often lie with different Competent Authorities within the Member State, each of them putting emphasis on different parts of the impact assessments. At a potential site and along the route of the planned export cable the complete marine ecosystem comprising plants and animals in and on the ground, the water column and, in the case of surface piercing structures, also the air space, is by law required to be evaluated by seasonal observations. The efforts to perform these surveys are considered to be a financial risk since the outcome of such surveys can lead to the rejection of a marine energy project. In this context it was also mentioned in the interviews that the impact of marine energy devices on their environment is not fully understood, an uncertainty which additionally hinders project consent.

Environmental conditions have proven to be a potential breaking point for tidal barrier (tidal barrage and tidal lagoon) technologies which are currently not at the centre of development attention.[33] Environmental conditions can however also be a risk for other technologies (e.g. delay in obtaining permits). A further complexity/uncertainty lies in the fact that the environmental impact of devices is not understood well.

Social acceptance

Public opinion towards ocean energy projects is considerably more favourable than towards conventional offshore wind, not to speak of offshore oil and gas operations. Indeed, people in economically underdeveloped regions tend to welcome a marine energy project as a positive investment possibility, as long as they are informed about it properly. However, citizens and stakeholders in regions with strong fishery or tourism sectors tend to be more reluctant to embrace the same marine energy project as it can compete for space with such activities.

3.3. Endogenous barriers to industry

3.3.1. Technological innovation and development

Surprisingly, technological innovation and development barriers are not mentioned as frequently as one would expect in such a sector. A critical analysis of interview results points to a number of reasons for stakeholders involved to give such low prominence to this barrier e.g. many of the interviewees are associated with developers, companies and investors which have important stakes in the sector; hence, openly admitting that these barriers are so vital would possibly undermine investor confidence. Evidently, business developers need to have a confidence and belief in their ventures – which may lead to a degree of entrepreneurial optimism. Noteworthy in this context is that technological barriers were stated more often by the tidal community (more confident already?) than by wave stakeholders. Equally, public sector stakeholders (with some more distance from business interests) pointed to this barrier being more important than private sector stakeholders.

A closer analysis reveals that, while technological innovation and development is not to be denied, some stakeholders comment that the industry has overpromised and under-delivered from a technical and performance point of view. This calls for the need to improve methods and metrics currently applied to due diligence and evaluation of technologies.

The main generic themes of the technological barriers currently addressed by the stakeholders are:

- Reliability of the devices;
- High cost of offshore operations around the deployment, operation and maintenance of installations;
- Lack of tailored grid connection components (cables, connectors, substations) and methods (cable laying and connection).

Wave

In wave energy, such a due diligence and more realistic evaluation of the state of play, together with a wider collaboration across the value chain as well as across technologies and projects, is expected to support future development.

Many stakeholders are concerned about *the large number of wave technologies and concepts* still in place – and pointed to divergence rather than convergence. However, the variety of wave energy conversion principles and a wide range of metocean and other site specific conditions has hindered technological convergence: in the last decade many different devices at higher TRL levels have been tested in the water. The need to reduce the range of devices under development to a smaller number of technologies and to overcome the lack of design convergence in the wave sector is, therefore, seen as a major challenge. This can be addressed by focusing the technological development on sub- components and other generic technical elements – as is currently done in the case of Wave Energy Scotland (WES).

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[33] The most well known example La Rance tidal barrage in France; more recent initiatives in the UK (Mersey and Severn) have been put on hold mostly due to the refusal to obtain environmental permits due to large environmental impacts.

Text Box 3.2. Aquamarine and the importance of spreading support

Technological development of Aquamarine Power's Oyster stopped in 2015 when the company went into administration. Technological development was, similar to Pelamis' developments, characterised by too high ambitions and a race through technology readiness levels, rather than actual technological performance. The cause or final push towards the company's bankruptcy, however, was simply human error. Irreparable damage was suffered because a valve was not opened during installation. Besides obvious lessons on careful preparation of deployment procedures, it shows the importance of spreading risk, especially in a context where both offshore operations and individual devices themselves are (still) very expensive. It suggests that centring too much of any sector's hope on one project is risky, as any project could fall victim to bad luck and/or human error.

Some stakeholders comment that certain developers have been trying to go *too fast with the wrong concept*. They expect that more radical steps are needed, such as going back to first principles to identify promising technologies. The future development of wave energy technology should build on the lessons learned but also try to open up to a wider industry base and make more use of innovations from other industries.

Text box 3.3. Pelamis' unsuccessful race through the TRL scales

Table 2.2 in chapter 2 provides a descriptive overview of Pelamis Wave Power's development. Having been unable to attract more funding in 2014, PWP went into administration. Lack of funding was only the symptom - a closer analysis reveals that a range of root causes underlie the failed development of this attenuator concept.

Getting the technological performance of the device to the right level was often mentioned as the critical barrier. More specifically, the reliability of the device was an issue, due to pressure on the hinges. Solving this issue moved the device back on the technological readiness scale. Later in the development process, the control system affected performance significantly. The prototypes only produced a third of the potential power output. Addressing this would also have required the developers to take a few steps back, as a lot of the engineering was built around the underperforming control system. Finally, in hindsight, serious doubts have been raised on whether the attenuator concept as a whole is not too complex. This would suggest that the root causes for failure were mostly technological in nature.

However, several sources also point to other root causes which were equally if not more important:

- PWP's founder and CEO identified the transition from the inventor (enthusiastic, strong ideas and opinions, but lack of knowledge and experience) to executives (shareholder objectives as the primary goal) as one of the causes why the wave energy sector over-promised and under-delivered.[34] It seems that this transition was also an issue with PWP, where executive expertise from outside the company did not manage to stay on for a long time. PWP has seen a period of several external 'C-level' staff members who did not hold the position for long stretches of time, after which the original founder again became the CEO;[35]
- One other cause raised by PWP's founder in his general reflections on the sector is impatient capital, resulting in wrong incentives. Specifically in the case of PWP, others have pointed out that efforts weren't concentrated on the right things, most notably on improving the control system. It was suggested that more technological advancements could have been made with a better working relationship between the funders and the developer. The resulting lack of trust may well have been more important than PWP's technological challenges;
- PWP initially went through a procedure of scaled development (e.g. testing of scale models followed by full-scale testing of hinges and other components before, finally, testing of a full scale device) but

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[34] Presentation during ICOE 2016, C11 Quoceant Ltd.

[35] http://subseaworldnews.com/2013/06/04/uk-pelamis-founder-richard-yemm-appointed-as-ceo/;
http://www.rechargenews.com/news/policy_market/article1294033.ece;
http://www.theedinburghreporter.co.uk/2010/10/exclusive-pelamis-wave-power-loses-ceo-and-cfo/.

didn't repeat this process when moving onto new versions of the device (e.g. the P2 device) and went straight to full scale;

- A more efficient spending of resources could have bought PWP the time it needed to improve performance. An important observation is that, at an early stage of development, three identical machines were put in the water, all of which were, essentially, still prototypes.

This suggests that managerial issues trumped the technological challenges faced by PWP. Irrespective of the 'who-question', stakeholders agree that key issues were sector-wide inflated expectations and a race through the TRL scales which have ultimately led to an insufficiently scaled technology development, inefficient spending of resources and serious damage to the wave sector's credibility.

Stakeholders suggest that sufficient checks and balances would have reduced the likelihood of failed developments. Additionally, a more evenly spread support may well have reduced the desensitisation of developers towards these checks and balances.

Technological barriers also become visible through the very high LCOE (levelized cost of energy). At the level of single device demonstration, *very high installation & maintenance costs occur.* One reason is that the current fleet of service vessels is designed for the huge dimensions of offshore oil & gas. Therefore, they are not always suited to more delicate, and much smaller scale, ocean energy operations – a barrier which can also be seen as a supply chain barrier. One possible solution to reduce O&M cost could be to share ownership of dedicated installation and O&M vessels between project developers.

Further technical barriers which were raised address the availability of adequate materials – strong and cheap – in order to achieve a design with a high survivability at affordable cost and satisfying performance.

Text box 3.4. The Wave Dragon and long-term prospective for cost reduction

The Wave Dragon forms a floating overtopping device which absorbs large wave fronts by use of widely spread collector arms. This concentrates the waves to a ramp so that water overtops the ramp edge and fills a water basin at a higher level than the surrounding sea surface. The resulting height head difference is converted into electricity by means of a water turbine. A 1:50 scale and, in the end, a 1:4.5 scale prototype was tested. It never got round to testing a full scale model due to difficulties in securing funding. Stakeholders argued that the root cause was the ratio between power output and the volume / weight of required materials. This ratio was so low that it would be very difficult to become cost-competitive, even considering performance improvement and economies of scale.

In general, stakeholders address the role of innovation as a key element to cost reduction and improving reliability but there is little consensus what e.g. the way forward is for wave energy or how a cost effective supply chain can be created.

Tidal

Unlike most wave technologies, which still need to get on the curve, many tidal devices are already moving down the learning curve. The technology has converged in the basic design, so no major barriers are lying here anymore. The current challenge has consequently shifted towards the supply chain development and the introduction of new products that enable cost reduction. Tidal energy technology is currently moving from single device demonstrators to array installations which adds new challenges e.g. with regard to the grid connection and inter array cabling.

Reliability of tidal devices is still a major challenge, although at a different level than for wave energy. In particular, this is the case for blades and suitable materials, where the designs from wind energy cannot be transferred directly. *Exposure to maintenance costs* is, furthermore, high, as reliability standards and maintenance intervals are much more critical for tidal devices compared to wave energy devices. Put in another way, even a small component failure can bring a tidal turbine to a halt, and it can become expensive to intervene in between scheduled maintenance sessions (because of e.g. lack of vessels or poor meteorological conditions). The main issue is that a balance needs to be struck between simplicity and weight on the one hand and reliability and ease of maintenance on the other.

The *installation of the support structure* on the seabed, with uncertain and highly variable seabed morphologies, remains a significant technological and, therefore, also a cost challenge. Each project requires tailoring to adapt to the subsoil conditions. Techniques from the offshore oil and gas sector require considerable adaptation before they will provide viable solutions for tidal installations. One needs to bear in mind that such structures are to be installed at locations on the sea-bed that have, by definition, very high current speeds (up to 20 m/second), with only short intervals when the tide is turning (typically 30 minutes), as well as challenging meteorological, geographic and wave conditions.

The barriers described above currently have a strong impact on cost – LCOE as well as total cost of ownership. The *required offshore supply chain* to drive down the cost will only materialise if there is a clear market visible. In comparison, in offshore wind the availability of installation vessels became an issue when the number of turbine deployments really started to grow fast. Having access to related dedicated vessels, and at affordable prices, would help a lot to bring costs down for the tidal sector. However, such important investments can only be justified if there is enough critical mass and market to recoup such costs. Another impact of the technical barriers is *delays in the time to market.* A number of investors backed out of ocean energy after they realised that the progress towards commercial development and return on investment was slower than expected. These observations show clear characteristics of a circular ‘chicken-and-egg’ problem.

The barriers and challenges addressed during the stakeholder consultation largely match with the results from the analysis of the technology and chronology of the sector (Chapter 2). There are however still fairly different views amongst the stakeholders of the sector about the relevance and criticality of these technical barriers. In the past, some device developers, in need of funding, have been overoptimistic with their development plans. While investors were attracted, they pulled out again once they realised that the time to market turned out to be significantly longer than expected. Some of the judgment on the current status and future challenges might be influenced by this history.

3.3.2. Critical mass and supply chains

Building on the above technological considerations, private stakeholders (developers, industry) pointed repeatedly to the crucial role of critical mass, economies of scale and operational supply chains – all needed to drive costs down. In this respect, tidal has made important progress, but wave has still a long way to go.

Tidal

During the last few years, a European value chain for tidal stream has emerged. Whereas ambitions have been (and sometimes still are) to build these at national levels primarily, it has become clear that cooperation between European players is essential in order to provide the required reliability and cost-competitiveness. Component manufacturers, testing, installation, operating and maintenance now all take place in different locations across Europe. A sufficient choice of components is now available for tidal stream. An increasing amount of knowledge and experience is shared along the value chain, as people move around in the sector, although employees cannot apply designs from the previous employer because of IP issues, they will have experience with what works and what doesn’t. A good example is how former Pelamis staff now provide consultancy services within the sector. Intra-sector personnel exchange arises from take-overs, mergers, bankruptcies, etc.

Text Box 3.5. Tocardo Turbines – signs of supply chain diversification and economies of scale

Tocardo is a spin-off of Teamwork technology, established in 2000. From 2000-2007 several tidal technologies were tested. Among lessons learnt were that several of them failed because of, either too fragile structures (= high O&M costs) or too high investment costs (CAPEX). From 2005 blades were tested for their hydrodynamic behaviour (at a test site in the Dutch Afsluitdijk) and in 2008 the first turbines were installed. This proved to be a turning point for Tocardo and its technology. The system has now been operational for 8 years. Also in 2008, Tocardo became independent.

Since then, the company has delivered its turbines for several sites in the Netherlands, including an extension of the Afsluitdijk array at the Den Oever site, a new installation at Kornwerderzand (east side of the Afsluitdijk), in the Oosterschelde storm surge barrier, and as a participant in the BlueTEC offshore floating platform project near Texel. Internationally, Tocardo has provided turbines for a demonstration project in a fast flowing river in Nepal.

Critical for Tocardo's business model has been its choice for small size turbines instead of scaling up to larger devices. Tocardo chose to scale up by developing arrays of smaller individual units, which help lower the risk of the system as a whole -; if one turbine fails, the rest of the system can continue making it more reliable in dealing with the high under water forces.

Nevertheless, a range of barriers still exist - limiting the sector in going fast forward, to upscale, bring in economies of scale and scope, reduce costs and mobilise sufficient finance.

Regarding the resource issue, the *availability and development of sufficient sites* is crucial, as also explained in more detail under section 4.1 above, i.e. precise information about the currents, as well as the seabed and sub-seabed conditions, requiring large amounts of data and precision. Such information is not available from existing data and needs to be carefully collected by contractors. It has been difficult to conduct site development and technology development at the same time. Some interviewees question whether the overall resource availability of tidal stream will be sufficient to deliver sufficient economies of scale, required to bring prices down.

Installation and grid connectivity have been, and remain, an important barrier. Clearly, the ocean environment itself is an (exogenous) barrier: testing onshore like with offshore wind systems is not possible, and testing offshore is very expensive. So there is need for cooperation to get devices in the water, and a need to accept that it can take a lot of time. Indeed, the operational difficulties involved in the installation of devices at extremely harsh locations cannot be overestimated. The limited time window available to sink turbines and installations in areas with strong tidal currents (as little as 30 minutes), combined with tough meteorological conditions is a major cost and risk factor as well as an important factor behind delays. Indeed, installation difficulties are a mix of exogenous, technological and supply chain barriers – and it is difficult to pin these down.

Text box 3.6. Grid integration at tidal sites

Many of the tidal energy projects have faced challenges in grid connectivity, due to the specificity of the connections themselves, as well as the remoteness of the locations from markets. Interviewees pointed in this context to:

- Cabling has been developed and deployed for offshore wind, and there is need to adapt these technologies, as well as addressing connectivity between the various machines – from above-water line to under-water line;
- Orkney/Pentland Firth is the best UK site for tidal, but the available grid connection on Orkney is of too low capacity;
- A main challenge is to stabilise the technology to bring the electricity from the turbines to the land. There are still different views on the way to sub-connect – even though GE is providing this technology to several (competing) actors.

Some interviewees have pointed to the *contractual risks* at play – when different project developers and OEM manufacturers are involved. Such contractual risks are crucial, particularly while technologies are not sufficiently robust and reliable. Developers often underestimate the legal costs of a project (contracting). In early demonstration stages, a lot of developments are done in-house and that keeps sub-contracting to a minimum. However, these changes in the (pre-) commercial stage, where much more subcontracting is required (environmental, offshore operations, vessel hire, cabling, …). Contract management can take a long time too. Furthermore, there is not enough knowledge about the marine environment in the legal sector. Legal councillors need to spend a lot of time to get to know the risks. This will naturally improve as there are more projects. One UK interviewee said: "*I don't think lawyers are represented in the sector. I hardly see* *them at conferences. They don't fully understand the sector at this moment*".[36] Adding to this, legal costs are particularly high when production and installation volumes are low. Again, the management of a range of supply chain companies requires large projects and volumes – which in turn requires sufficient resource potential.

Wave

The situation is quite different for wave technology, as a supply chain is effectively not yet in place. Contrary to tidal, it is felt that there is still a *lack of original equipment manufacturer (OEM) involvement* in the wave sector, even in Scotland. The fact that a range of very different wave technology concepts and technologies are still being developed is not helpful at all. As a consequence, wave developers still tend to do a lot in-house, stretching their field of expertise, and, therefore, producing suboptimal solutions.

With regard to *knowledge management*, several interviewees, notably from Ireland, point to the weaknesses surrounding the current "do it alone" approach, where there is not enough sharing, or open source research. This means that the same mistakes are being made repeatedly, and the progress of developments undertaken in isolation is slower. Failures and their reasons are simply not shared enough. A Spanish interviewee added to this that there are almost 1000 patents in marine energy technologies. However, there is only limited sharing of the underlying knowledge between developers – and much less so than in other industries. In wave technology, developers have not been able, or willing, to transmit experiences to each other (positive and negative one's). A need is felt to learn from other industries, where there is a bigger convergence, both in the concept they are looking for and also in wider collaboration among the different actors.

However, there is also a different view regarding knowledge management, namely that it is not such a critical issue – and that one cannot expect private companies to share lessons or experiences they have paid for themselves. One developer stated, in this context, that IP may block sharing of a specific type of technology, but the supply chain still knows what worked and what didn't work. This experience can be used to guide developers in the future. Another observer pointed to the fact that collaboration does not necessarily take place more in other sectors. Perhaps there is already more collaboration in ocean energy than in oil & gas or offshore wind, where cooperation is purely project-based but where competition is fierce on revenue support. There is a need for a good understanding about aim of collaboration, including an informed view on the benefits that can be gained by all. Experience shows that this is not always achievable.

A specific role is played by educational programmes, which is illustrated in the textbox below.

Text Box 3.7. Role of educational programmes in knowledge sharing

In the initial development phase of ocean energy, based largely on academic research and innovation at low TRLs, most of the technical expertise has naturally built on existing know how in offshore wind, hydropower, oceanography, naval architecture and offshore oil and gas. As ocean energy moves out of the labs and wave tanks further towards full scale installations, demonstration and commercial projects a greater variety of skills are required. Capacity building and training therefore becomes a challenge for an emerging sector since the time required for education and training throughout all EQF levels can be critical to the capacity- building required at the phase of entering the market.

The recent Ocean Energy Forum "Ocean energy strategic roadmap" provides a vision of building a European OE Industry. It does not detail the aspects of training and education, human resources or capacity building. In contrast, the "Strategic Energy Technology (SET) Plan Roadmap on Education and Training" published by JRC in 2014 proposes master programmes on ocean energy with the objective to "develop and implement advanced courses at bachelor level, joint-degree programmes at master and doctoral level, as well as part-time programmes at advanced academic level. The relevant topics identified cover wave and tidal energy technology, engineering and management, fluid dynamics, wave and wind energy floating platforms, ocean energy systems, offshore operations and maintenance and environmental impact and regulations. It is recommended that access to existing prototypes is provided. The relevant EQF levels identified are 5-8.

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[36] Actually, a number of UK law firms (e.g. Shepperd Wedderburn) are actively involved in marine energy.

Another activity proposed in this roadmap is a "European Programme for Access to Research and Pilot Facilities for Higher Level Education and Training in Wind and Ocean Energy" in which activities should also build on and expand further education and training activities at other relevant research infrastructures such as WindScanner and MARINET. The „Marine Renewables Infrastructure Network for Emerging Energy Technologies " (MARINET) provided specific training on experimental testing and numerical modelling.

The first European research training network in the sector was started in 2004 under a RTN funding scheme of the FP6 Marie Curie actions: "WAVETRAIN - European Research Training Network For Competitive Wave Energy". With a focus on wave energy, 11 partners from 8 different countries, including the 7 universities involved, provided training mainly through 6 special topic short courses between 2005 and 2007. 17 candidates were contracted to work in the test facilities, such as wave tanks, in cooperation with device developers with the effect that almost all of them where hired by wave energy companies.

A follow - up initiative of similar scale, Wavetrain 2, started in 2008 with funding from the FP7 Marie Curie Action "Networks for Initial Training". As in the previous project, the focus was put again on "a hands-on practical training in leading wave energy institutions, complemented by courses which ranged across all the relevant topics (from the technical to non-technical ones)". In addition site visits and a conference were organized. In total, 22 early stage researchers were contracted by the 13 partner institutions. Collaboration with the young researchers network organization INORE (International Network on Offshore Renewable Energy) was established.

Finally, the ongoing OceaNET project was established in 2013 under funding from FP7. It addresses floating offshore wind and ocean energy and provides 9 short courses of 1-2 weeks covering topics such as wind and wave energy resource, site selection, wave energy technology, Innovation management and entrepreneurship, fixed and floating offshore wind technology, experimental and numerical modelling of wave energy, offshore renewable energy farms, social and economic impacts, environmental impact and monitoring. The project involves 6 universities plus 3 further R&D organisations and will train 13 early stage researchers until 2017.

Other training on ocean energy provided by universities across Europe is mainly integrated into existing bachelor and master courses such as the EUREC master on Renewable Energy, masters on sustainable/renewable energy (Porto, Edinburgh, Leeds, Groningen),Naval Architecture and Ocean Engineering (Gothenburg, ENSTA-Bretagne Brest), Maritime and Coastal Engineering (Paris, Barcelona, Copenhagen, Aalborg) and Marine Science, Marine Systems and Policies (Edinburgh), Marine Technology (Trondheim) and others. Plymouth University offers the first dedicated masters course on marine renewable energy in the UK covering topics such as Economics, Law and Policy for Marine Renewable Energy, Assessment of Coastal Resources and Impacts, Economics of the Marine Environment, Marine Planning, Mechanics of MRE Structures and Modelling of Coastal Processes.

Installation, maintenance and grid connectivity remain major barriers, according to several interviewees. A common view is that wave developers have been focusing too much on optimising the device, while neglecting offshore operations. However some observers hold precisely the contrary view. One government official stated that it is easier to get devices into the water, then design it and improve reliability. Furthermore, grid connection remains a major problem.

Text box 3.8. BlueWater and approaches to control maintenance costs

After previous projects were terminated at early stages due to, amongst other factors, partner bankruptcies (LIFE project in Italy with PDA as turbine manufacturer) or partner takeovers (Canadian project when MCT's mother company Siemens retracted from the sector, the Dutch marine service company Bluewater, which originated in the oil & gas sector, launched the Blue TEC project. For this, they had assembled a consortium of partners well known to them, in a structure with limited dependency on subsidy.

Their idea of a floating platform holding arrays of turbines is to develop structures with low operational and maintenance costs. Rather than targeting sites with the highest energy potential (e.g. Orkney with water flows of 4-5 m/s) the concept has been developed for medium velocity sites (2-3 m/s as in the test location near Texel, Netherlands. Although energy output will be lower, the sites typically are closer to shore and easier to reach, and installation is easier due to the less fierce hydrological conditions. Ultimately the optimum balance, between energy output and installation & maintenance needs, to be found. In terms of potential, the company notes that the number of sites with the highest water flows is limited and the market for lower speed applications could be larger.

3.3.3. Performance and markets

Markets can be considered in two different ways:

- Electricity markets – Ocean energy needs to be able to produce electricity in a reliable way and at competitive costs. As this prospect still lies some distance away, it has been difficult to draw in utility companies, for which ocean energy is just one of the many Renewable Energy options. In this respect, there is insufficient trading maturity because neither availability nor reliability are high enough;
- Industrial products/exports markets – for industrial players there is an opportunity to sell, in international markets, high value products, components and services for which a potentially large global market may emerge. An important consideration for industrial players is to keep Europe in the technological forefront, and prevent other global players from seizing this market.

These different perspectives can easily lead to tensions between industrial players and utility companies. After all, utilities are clients, not developers. And although they support and sometimes get involved, this is not their primary objective.

Some French observers pointed to the strategic need to keep markets open and to ensure that there will be enough *competition* and players in the market.

Some consideration needs to be paid to the *segmentation of markets* as well. For example, in the Canary islands, the cost for generating electricity is higher and therefore the price to be paid for OE generated MWh could be also higher. It makes sense to focus on proving the technology in such environments, where it is also financially interesting – a strategy pursued by Sabella for example. Another niche market could be for offshore automated aquaculture.

Text Box 3.9. Sabella – developing tidal energy for island communities

Sabella is a French engineering and project management firm in the field of marine energies, and develops tidal stream turbines. The concept is based on a prototype developed by Hydrohelix (a company still associated with Sabella) and sea-tested. The technology is a 6-blade horizontal axis, bi-directional seabed tidal turbine. The 1 MW demonstrator D10 was immersed in 2015 in the Fromveur Strait (Brittany) – and is the first grid-connected tidal turbine in France. It supplies 15% of the electricity consumed on the nearby Ushant island.

Another market consideration is that for *energy prices overall*, including oil prices. It is often stated that the current oil price (far below $ 100 / barrel) is an important barrier, since it does not arouse the interest of investors' funds, nor of big players that are critical for the support of developers. However, the low oil prices do bring advantages as well, notably in the form of the increased access to support infrastructure (e.g. offshore vessels).

3.4. Support conditions

3.4.1. Research support

A number of barriers in the area of research support were identified. Amongst these, the involvement of the right expertise and the research funding incentives were prioritised, based on the widespread number of stakeholders who expressed this view.

Throughout the field investigations, it was raised that there is a tendency for ocean energy developers to work in isolation, and that it is difficult to *involve the right technical expertise*. Respondents indicated that this has led to a situation where developers stretch their field of expertise, designing suboptimal solutions or failing to focus technology development on the most low hanging fruit. Offshore engineering was the most frequently mentioned example of a field where developer expertise is traditionally insufficient. Clearly, such fragmentation of expertise points to the need to have more cooperation.

Numerous explanations were put forward by non-developer stakeholders, including developer overconfidence, lack of awareness and a certain overprotectiveness of their developed technology (protecting one's 'golden egg'). Some developers put forward that they are constrained by both time and resources, explaining that it takes time to negotiate involvement of potential technology partners and that it is often more efficient to accept a lower performance own-design at a lower cost.

This barrier is currently relevant for both wave and tidal energy, although in a different manner. For tidal energy, the relevance primarily concerns offshore operations. For wave energy, which is characterised by higher technological complexity and lower maturity, the involvement of the right technical expertise is even required for device development.

Providing the *appropriate research funding incentives* has proven to be challenging. The interview results show a clear consensus that sector-wide objectives have long been overambitious, resulting in a race towards commercial readiness, which incentivised developers to scale up too quickly. Both public and private research funders are said to have contributed to this, most notably by incentivising the development of end products and reaching maturity levels, rather than engineering results. The focus of developers is obviously influenced by criteria for grant funding, stressing the importance of carefully designing award criteria.

A more prudent approach could have led research funders to better tailor their support. In one example, it was the research funder who tried but failed to sufficiently steer the focus of an overconfident developer. The research funder wished to focus on arriving at a stable ('frozen') design with a sufficiently promising power output, whereas the developer was focussed on maintaining a continuous experimenting process.

Irrespective of whether one or more root causes are behind it, the cutting of corners in technology development is repeatedly put forward as one the main barriers to OE technology development, notably because it has affected investor confidence. This is particularly the case for wave energy, as this technology is less mature and has suffered more development failures.

It takes time for public research funding to become available, which requires *flexibility on how public research support* can be utilised in a highly dynamic context of technology development. As an example, European funding can take up to three to four years to reach the sector, risking suboptimal use of resources. Specifically for the UK´s Marine Renewables Deployment Funds(MRDF) programme, there was a lack of flexibility once the rules had been set, and it became clear that the funds could not be utilised.

Text box 3.10: Lack of flexibility in governmental support in the UK's MRDF programme

The MRDF was a £42 million scheme officially launched in 2006, which aimed to support the construction and operation of early-stage commercial scale wave and tidal stream projects using technologies that had completed initial R&D phases. The scheme, intended to fund projects through a combination of capital grants (technology push) and revenue support (market pull), failed however to receive any suitable applications. The capital grants included payment of 25% of the net eligible costs incurred and defrayed by the company. The revenue support included payment to the company at a rate of £100/MWh of metered energy.

With the failure to spend any of the allocated money, the MRDF was criticized for its too strict qualification criteria. The scheme was intended for technologies that had previously completed pre-competitive R&D, demonstrated at least three months of continuous generation at full-scale and were ready to begin commercial operation. At the time the MRDF was launched, no device developers satisfied those criteria.

In order to help the industry advance to the point at which it was eligible to apply for the MRDF, a new Marine Renewables Proving Fund (MRPF) was subsequently introduced. The new £22m fund was designed to help the industry to progress to large scale prototype deployment and testing. It provided a total of six grants and all recipients had deployed their devices for testing at EMEC by 2012.[37]

Although numerous tank testing facilities and testing sites are available, a financial barrier to *access such testing infrastructure* has been identified.[38] The barrier was deemed relevant based on the potential to improve investor confidence through phased testing, which requires wider access to testing infrastructure, especially for small scale testing. For tank testing facilities this barrier is especially relevant for commercial facilities, according to academic stakeholders. This barrier was not prioritised by interviewed developers. It seems mostly relevant for wave energy, considering the convergence which still needs to take place for the technology to develop.

3.4.2. Project finance

Project finance has emerged as a dominant barrier for the development of both wave and tidal. Clearly, this is also a very 'visible' factor – especially when finance is terminated for running projects. The fundamental question, however, is whether (lack of) project finance is a root cause or rather a symptom, for example of unproven technologies with a (too) high risk profile, or too high cost profiles due to limited economies of scale.

As already stated above, for wave energy there are significant technological uncertainties, issues of reliability and a lack of consolidation of technologies. This creates an uncertain environment, which investors are very hesitant to operate in. In comparison, tidal energy is not only at a higher TRL level (with multiple demonstration projects and some pre-commercial projects), it has also consolidated around a set of technological solutions and a number of projects have already achieved private funding. Having said that, the technology is not yet mature and, with every project, technological issues emerge.

Frequently mentioned as a barrier are the *differences in time horizon of projects.* For many investors the pay-back period is too long to justify the investments. In particular, venture capital investors have shorter time horizons, typically a 5 year exit period, while the payback horizon for ocean energy is significantly longer. At the same time investors with an appetite for long-term infrastructure projects (with steady yields, but large initial capital investment) are not present, at the moment, in ocean energy.

The overarching finance barrier lies, however, in the *high risk levels* of ocean energy projects, which under the Solvency II and Basel III rules are not classified as investment grade and therefore unavailable to institutional investors (such as pension funds and insurance funds). It can be expected that as the risk profile for OET decreases or, alternatively, the risk/yield appetite of investors changes, this barrier is likely to be overcome.

Much like the above barrier, almost all other project finance barriers (the difficulty of attaining sufficient investments) can be traced back to the underlying issue of risk in the sector. The risks can be divided into the following categories: 1) Revenue generating risks; 2) Operational risks and 3) Lack of insurance/warranties.

Revenue generating risks are inherent to the highly regulated nature of the electricity market. The whole sector therefore relies on feed-in tariffs to price their future revenue projections. The fact that governments have been imposing retroactive cuts to the tariff has led to substantial revenue generation risks. In other words the uncertainty about changes in the electricity price (the level is viewed as less problematic) causes significant increase in risk, at times deterring investors. This uncertainty has been mentioned on multiple occasions.

Text box 3.11. WaveBob's inability to find financing

WaveBob's floating platform concept aimed at minimising operational risks and technical risks associated with wave size variation (that caused technical failures in the Pelamis project). The project was installed in Galaway test site. In 2008 WaveBob secured €5 million of private capital investments. However five years later in 2013, WaveBob went into administration when it failed to secure around €10 million to move the technology towards demonstration.

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[37] https://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/1624/162408.htm.

[38] State aid rules for free access to test sites have been discussed – this issue remains to be unresolved in Ireland, while other regions have apparently overcome this.

> The environment around the year 2012 was becoming unstable, with national support withering, resulting in a rather complex and challenging funding mix as well as private investors becoming risk averse because of the global economic crisis. This combination has meant that the revenue generating risks were significant at a time when WaveBob was in need of the next financial round. In addition the technology, and the wider sector, was not moving towards full commercialisation as previously expected (with other notable bankruptcies such as Pelamis). Finally, WaveBob pursued a great variety of investors, each with their own timelines and reporting requirements. Such a combination of conditions proved WaveBob to be an overly risky investment, with uncertain and perhaps limited returns and, consequently, the company failed to persuade increasingly risk adverse investors to keep the project afloat.

Furthermore, given the youth of the sector and the novelty of projects, it is unsurprising that there is lack of sufficient understanding of full *operational risks*, especially in the later stages of a project's lifetime. For example the full cost of installation and maintenance as well as later decommissioning operations are little understood. This means that either a large contingency budget needs to be kept (bringing down returns and thus putting off investors), or the project is evaluated as highly risky. For tidal energy the full costs are understood to a greater extent, due to past experiences. However detailed cost data are rarely shared and the lack of understanding remains limited. For wave energy the sector is at an earlier stage of development and, therefore, the level of cost knowledge is even lower.

As a consequence of the lack of understanding of total costs and technological reliability, the sector currently has *hardly any access to insurance or warranties*. Other renewable energy sectors, such as solar or wind, do not suffer from such issues. This has resulted in private companies moving in to insure and provide hedging to all sorts of risks (including bad weather insurance to level out revenue generating capabilities). Several interviewees stressed the importance of this barrier to secure secondary financing rounds. Calls have been made to therefore fund more research to tackle, in particular, the operational risks and to provide public support, or direct insurance products.

3.4.3. Framework and regulatory conditions

Among the regulatory barriers collected in the field investigation, the lack of consistency in public policy towards renewable energy, in contrast to industry & competition policies) is considered the most important one. The fact that public policy is perceived to be unstable raises concerns, as it has a bearing on future demand, and hence the willingness of investors to fund the necessary developments in the sector. The barriers mentioned under this category have a strong link to financing (feed in tariffs, subsidies) and to research support (R&D funding, access to testing infrastructure).

Above all, interviewees raise the *lack of long-term government ambitions* as a barrier. They argue that if no bold aims on where the sector should move are set, there are no targets to work towards and it is much more difficult to push for action than if there were. Suggestions related to this barrier also include the subsequent need for a development strategy or road map, including long term support, funding and access to infrastructure (refer again to section 4.5).

Interviewees point to the need for *consistency and alignment of policies* within and across government levels, and to have consistent ambitions (e.g. EU vs Setplan, but also national vs regional/local governments). They report conflicting viewpoints from different government agencies. For example, on the one hand energy/climate support policies through e.g. subsidies that are then countered by strict state aid/competition rules from another part of government. As already noted in some Member States, ocean energy policies can be supported both from an energy policy as well as from an industrial policy perspective, and both angles can lead to different approaches.

As for other renewable energies, such as wind, *continuity of support* is essential (see also section 4.3 on research support above). It is seen as a barrier that such schemes, if they exist, are more often than not defined only for a limited number of years, leaving uncertainty for the time afterwards. Reportedly, there are no feed-in tariffs for OE in the UK before 2021. This is a fundamental problem, as investments need to be made with a much longer time frame in mind.

Text Box 3.12. Wavestar: Feed-in-tariffs and the struggles with mid-term investor outlooks

The operations of Wavestar went into hibernation at the end of 2016. Before the closure, they built an 110kW prototype in Poland and installed it in Denmark, in the context of a large (€ 13 m) FP6 project. The prototype stayed in operation for four years, providing the following learning on designs, optimisation and PTO's. It also indicates the timeframe for development and optimisation of demonstrators:

- It took one full year to stabilize the process of energy production. The main barrier was optimizing the control system, stabilizing the interaction with the hydraulic PTO, the susceptibility towards waves of different intensities, and automated stopping and starting to handle extreme loads (during storms);
- Over a period of four years, they managed to improve the control system, going from an efficiency of 5% to 60%. The mechanical changes made during this period were fairly limited, showing how long it can take to optimize just the control system. A main challenge is getting a system which is able to manage different forces and consistently harvest energy from these forces in an efficient way;
- The efforts produced a lot of data, which have been used to copy the wave conditions from the sea into the simulator at Aalborg University. This data was presented at conferences and is available through the website of Wavestar.

Despite this progress, Wavestar failed to attract sufficient investors for the next step, the development of a 1MW device. Although they received funding from the European Commission and commitment from one external investor, this was not sufficient. A major barrier was that investors were not provided an outlook for a return on investment, because a tailored Feed-in-Tariff would was not in place.

Another root cause behind the failure may be been the design of the structure, which might have been too large and heavy. Calculations based on projections made by installation companies suggested that a minimum of 20MW arrays (of 1 MW modules) was needed to be competitive. Nevertheless, the required capital expenditure for the structure was very high, which could, of course, be seen as a technical design failure.

Indeed, the *position of ocean energy within the overall Feed-in-Tariff structure* is crucial. Such FiTs are often absent, or not specific for ocean energy. Where policies and regulatory regimes are applied at an aggregate level, the less developed ocean energy sector cannot compete with e.g. offshore wind. In relation to this, the field investigations point to the notion that tidal and wave each are at different stages of development and would therefore need different models of (financial) support and/or FiT rates. The rigidity of existing programme subsidies is reported and a call for more flexible adaptation to changing conditions is made. (e.g. replacing a partner or a technology). How can private investments which require a pay-back period of 20 years be justified if demand from FiT is secured only for a fraction of that time, or even not that?

A call for support schemes that target tidal/wave, separately from other RES, was made, and applied in France through the ADEME calls for the Raz Blanchard. Especially for wave energy, developers could benefit from different forms of *pre-commercial procurement*, to help overcome the so-called 'valley of death' (gap between low and high TRL levels). Positive feedback on the model chosen by Wave Energy Scotland is repeatedly given. In both the case of France and Scotland, the scheme aims to trigger convergence, while spreading support to sustain competition.

As part of the project application and start-up phase, administrative procedures have also been raised as a barrier. This concerns general issues like the (perceived) long time that is needed for approval of licenses or applications (at national level as well as EU level and, in reported cases, driven by local public consultation procedures), as well as specific barriers such as consenting and the need for pre-project environmental research. Whether this is still a major barrier everywhere is, however, debatable. Other interviewees refer to cases in both Scotland and Canada where environmental monitoring, although it is considered important, is organised as part of the project monitoring rather than a pre-project go/no go condition. Various interviewees mentioned that principles of environmental consenting procedures are thus being challenged. While recognising the precautionary principle, many stakeholders argue that the environmental value of the ocean energy project itself should also be weighed as part of the assessment.

4. PROMOTING INNOVATION, COLLABORATION AND KNOWLEDGE SHARING

4.1. Introduction

Following the detailed review of root causes behind barriers in chapter 3, this chapter elaborates means with which these root causes can be addressed.

Concerns have been raised regarding the large number of devices under development, budgetary limitations in relation to current market size and the very limited exchange of lessons learnt and best practices. Nevertheless, a wide range of academics, developers and industry are active in the sector. The JRC reports that in 2011, the sector employed some 700 people within R&D organisations and around 1000 directly within the industry.[39]

Regarding the extent of knowledge exchange, the following functioning mechanisms of exchange have been identified throughout the study:

- Academics and public research institutions work together in research consortia across Europe;
- Industrial actors, both developers, OEM's, utilities and suppliers work together and share information within the context of consortia;
- Business, academia and government actors share together in geographically confined spaces, notably through clusters;
- In addition (not studied here), industrial actors and developers as well as academia exchange at the level of industry associations (e.g. Ocean Energy Europe).

Despite this apparent cooperation in the sector, there are clear signals that there is much scope to further promote innovation, collaboration and knowledge sharing. When reflecting on, one can take multiple angles. Four main aspects on collaboration and cooperation within the sector have been explored and discussed in the 4 focus groups organised in Ireland, France, Spain and Portugal (minutes of these focus groups are provided in Annex):

- Procurement of technological innovation (Section 4.2);
- Smart approaches to offshore installation and maintenance costs (Section 4.3);
- Intellectual property, knowledge sharing and testing centres (Section 4.4);
- Ocean Energy Clusters, a tool for knowledge sharing (Section 4.5).

Each section starts with a description of the challenge, followed by a number of key observations, then followed by concluding remarks. Implications for EU and Member State support are drawn in the concluding section (Section 4.6).

4.2. Procurement of Technological Innovation

The challenge

A suboptimal or even counterproductive effect of incentives from funders - both private and public - to developers was frequently raised as a root cause behind failures. Consciously or unconsciously, developers have been inclined to overpromise. This phenomenon is even more prevalent in a (perceived) winners-takes-all race to commercialisation, incentivising funders to overly push for technological advancement. The challenge is therefore to take a more prudent approach in order to avoid cutting corners and to incentivise the desired progress with the right indicators.

The variety and especially the prevalence of non-design related root causes behind failures shows that any project can fail, even ones where the technology has potential. This seems to suggest that public support should be spread out. Conversely, a strong call for convergence has been recorded during the research, and a focus of public support is suggested to achieve this.

An emerging question is what role well-designed procurement mechanisms can take and how they can be tailored so as to incentivise the necessary technological steps without triggering deviation, overambitious steps or the wrong emphasis.

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[39] Corsatea, T.D., Magagna, D. (2013) Overview of European innovation activities in marine energy.

Overview of public procurement practices

Public support to Ocean Energy Technology is important in light of the limited presence (even virtual absence) of private funding or other support schemes. This may relate to the low TRL levels that the sector is still at, but is also due to the absence of a clear future market outlook.

However, public support for Ocean Energy technology development is piecemeal. For example, the Spanish national government has no R&D programme to support ocean energy. In the past there was, but the economic and financial crisis has led to budget shortages and such programmes have been abandoned. Apart from that, more general R&D public procurement initiatives are very complex due to administrative rules, and therefore used with only limited success. Currently offshore floating wind is generating increased (public) interest, reducing the chances for wave energy to benefit from the (limited) R&D budget.

As discussed during the focus group in Bilbao, the regional support schemes of EVE (Basque Energy Agency) as well as the *Basque Development Agency* are important funding sources. In their programming (see also theme 3 clusters), they try to target wave energy separately from other (offshore) energy segments. Since there are no funding mechanisms fitting the whole TRL development line, continuity of funding is a real problem for developers.

The 2013 French calls for projects (selecting the Normandie Hydro and Nepthyd projects) provided a substantial push to the industry. It is not only the investment support but also support to operating costs which have made the difference – this leads to a very different perception of risks. Of course there is a need to find a balance between public and private investments, and public investments can never give a ‘carte blanche’ without appropriate co-investments. As part of such a deal, experience and information achieved in the development needs to be shared as well – even though the dilemma about intellectual property rights is real.

Much reference, for example in the Irish as well as Spanish focus groups, is made in the sector to *Wave Energy Scotland*, through which the public sector funds a series of procurement calls, aimed at encouraging collaboration between device developers, researchers and large engineering firms. The projects must aim to develop new knowledge that is useful to the wider wave sector and there must be wide dissemination of research results on a non-exclusive and non-discriminatory basis. A model for handling intellectual property rights is also being developed as part of a detailed business plan. In consultation with a range of stakeholders, including device developers, project developers, supply chain companies, academia and utilities, Wave Energy Scotland has identified the optimal areas for research and innovation. Criteria for support are:

- allow accelerated progression towards successful wave technology development and demonstration;
- provide opportunities for generating intellectual property;
- allow development of technology that is potentially transferrable to other sectors (tidal, floating offshore wind etc.);
- provide the opportunity to deliver disruptive technology that can have a major impact on device cost and/or performance; and
- generate economic and community benefit.[40]

Some participants in the focus groups noted that the WES initiative is exclusively public, and that it allows hardly any private investment. This is in line with the WES approach, which applies high levels of funding at low TRLs with the obligation to share at least some of the IP in order to support the development of wave energy technology in general.

When moving towards higher TRLs through a well-defined staged process, fewer technologies are funded and ultimately moved forward towards demonstration “at full scale”. At that point, either a higher industry involvement could be required or the public procurement continues with the benefit of sharing more of the results and experiences. How this develops remains to be seen – WES has not yet published details on that development phase. Therefore, in the current set-up, the scheme appears more applicable to lower TRL levels only.

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[40] http://www.gov.scot/Resource/0046/00464410.pdf.

Promoting innovation and technological progress through public procurement

The French view, as expressed during the focus group in Paris, was that public support can be justified, as long as a sector continues to make (technological) progress and that market perspectives exist (whether in France, Europe or outside). In this respect, more could be done to promote the deployment and testing of European technologies globally (e.g. through European development aid mechanisms as has been done for CCS). This could be also a way to overcome the market potential barrier. However, public support needs to digress with TRL levels increasing. It is only from TRL 9 onwards that a sector is expected to 'stand on its own feet'. A related problem, however, is that the sector has a tendency to inflate the TRL levels, both for EU and national programmes. A need was therefore discerned for standardisation and certifying, and to bring these as requirements into the procurement schemes.

In this context, the French state has recently introduced the *competitive dialogue* as an alternative to calls for proposals for offshore windpark developments. This alternative public procurement mechanism (in line with the EU Public Procurement Directive) allows the state to remain in dialogue with a limited number of pre-selected bidders simultaneously. The French renewable industry association (SER) welcomed this procedure for offshore wind as it addressed a number of issues related to tendering, with a reduced risk premium amongst its prime advantages.

The dominant view from the participants at the focus group in Bilbao was that procurement schemes alone are not the solution for technological progress. More public R&D money alone will in any case be insufficient to compensate for the lack of private funds. Therefore, what is needed is generating the interest of private companies including utilities, which can only succeed if there is a clear view on a future market, which is not the case for wave energy at the moment. Therefore, rather than developing procurement schemes, the need for providing a market outlook is highlighted. It is noted that Spain does not apply Feed-in-tariffs (FIT) for wave energy and this would be a prime driver for investors to procure further innovation steps. Obviously, the level of such a FIT should be sufficiently high to deliver feasible business cases (reference is made to the solar sector where, only 8 years ago, feed-in-tariffs in the range of €400/MWh were paid, which helped growth in the sector but which have since gone down to around €40/MWh.[41]

A recurring comment from the focus group in Lisbon was that, for wave energy, as an immature technology, it is difficult to directly compete for R&D funding with more mature technologies. If wave energy is to be taken seriously, it cannot be assessed by the same criteria as other renewables. The identified advantages of spreading support among different technologies are spreading of risks and diversifying production profiles in the renewable energy mix. This implies that for procurement of innovation support, one size does not fit all. One needs Key Performance Indicators (KPIs) that are adapted to the technology at hand. Importantly, LCOE is currently not seen as an appropriate KPI for wave energy but should rather be about reliability and survivability. One participant put it that immediate cost effectiveness is not the KPI to go for. Of course, it is needed to convincingly show the route to lower LCOE, and reliability and survivability affect LCOE through the operation and maintenance costs, but not as a direct KPI. We provide more details on KPIs per technology maturity stage in chapter 5.

Tailoring public procurement to wave and tidal

All focus group sessions held concluded that while both the French and the Scottish experiences have their merits in promoting innovation in ocean energy, they appear to be catering towards different sectors (tidal versus wave), with different Technological Readiness Levels. The French support is more investment support, whilst the Scottish model appears more appropriate to lower TRL levels.

Beyond public procurement, another possibility of public investment would be to provide *public equity*, as currently discussed in Brittany, where a Regional Investment Scheme for the maritime sector is being considered. It would seek to obtain minority shares (20-30%) into e.g. specific ocean energy companies for duration of 5-8 years. This would strengthen the capital basis of companies that do not yet command sufficient market confidence and who are affected by the Valley of Death (typically TRL 7). It would also allow the public sector to have a return on investment, and could operate as a revolving fund.

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[41] Statement/figures to be checked.

Participants in the Lisbon focus group pointed to the importance of involving *utility companies* as important players in their role as end-users of the technologies. The advantage of involving utilities, compared to the supply chain, is that they are not focused on selling their product (components), but rather producing the final product (electricity). One challenge in this respect is to make sure that utilities work together rather than compete to develop technological concepts, for which a strategy is needed.

Specifically regarding triggering of convergence, the participants identified that *forcing convergence can be highly risky*, at different levels. In general, a broad starting point was considered key, to not rule out potential breakthrough technologies or block creativity (although interestingly, one participant suggested that the wave energy sector has too much creativity). Moreover, the participants were sceptical on whether the decision makers would have the right expertise to make this type of choice. The participants broadly agreed that technological convergence should be an organic process.

In that sense, public support should apply a *funnel of restrictiveness*, becoming more strict when a concept reaches a higher TRL. Convergence can then be realised by searching for common elements in competing concepts, and concentrating on the essential common elements. The right set of KPI's should narrow down alternatives as technologies progress. The main challenge is to find the right set of KPI's, where it was again stressed that LCOE is an inappropriate KPI for low TRL technologies.

How can synergy between EU-wide and Member State or region-specific schemes be obtained?

The focus group results point to marked differences in the relationships between European, Member State and regional schemes. The differences between EU countries become clearly visible here. Whereas France has a strong national programme for (tidal) ocean energy, the Spanish national government does not support the sector at all. At regional level, the Basque Region is very supportive, as is the Canaries, and several other regions in the North (Galicia, Cantabria, Asturias) are also becoming active. So far, each region focuses on R&D within its own region, demanding that tests are done within their region or that certain research centres are to be involved. However, as the cooperation with neighbouring regions increases, such requirements may become more relaxed (that however remains to be seen and also depends on factors such as politics).

The Bilbao focus group discussion concluded that the current EU funding scheme *Horizon2020* mainly promotes international rather than inter-regional collaboration ("we already have a Spanish partner") with the result that, as part of H2020 consortia, things that could be done locally (e.g. testing at a test tank) are done at a distance. Confronted with the example of the FORESEA project (Interreg North Sea), in which various test centres cooperate, it was asked whether this programme would become more open to research activities now, as in the past it was mainly seen as a regional cooperation mechanism. Therefore, if there were EU mechanisms that could support the inter-regional cooperation within Spain, that might further advance a cooperation model and create synergies. Such a task is currently not taken by the Spanish national government, or at least not sufficiently, according to the participants.

According to views recorded in France, H2020 is still a complex programme from an administrative perspective, and competition for the funds is severe. It is important to justify the support requested in the best possible way. Horizon 2020 is seen by many as too complex and it remains too far removed from what the industry wants. Industries, according to one stakeholder from the business sector, want to test and develop, and they wish to remain focused on just that. Indeed, many SMES do not know Horizon 2020 or NER300 well. In France, national funding is – at least from an administrative perspective - easier to obtain, and often more convenient/appropriate. However, researchers do recognise that rewards from winning H2020 projects can be substantial, as it allows research and innovation staff to be fully dedicated to their projects for a longer period of time, and to do so in the context of larger European networks.

In the Lisbon focus group, the role of *Structural Funds* was underlined as a means to geographically differentiate / spread support. In themselves, such funds could be sufficient as an instrument, however they are typically too broad with regard to valid application, implying that wave energy would be in a difficult situation to compete. Furthermore, an additional challenge when using the Structural Funds, according to at least one French interviewee, is that the Structural Funds tend to have only limited strategic focus; the ERDF funds are typically spread too thinly, and there is always an element of regional politicians wishing to please as many voters as possible. Therefore, dedicated calls for ocean energy should be implemented if the sector is to benefit more from this type of funding.

Towards alignment of EU, MS and regional support mechanisms?

The relation between EU (H2020, NER300, Structural Funds, Juncker investment funds), Member State funds as well as regional funds (including again Structural Funds) is complex and diverse across Europe. The key question is, therefore, how such funds can be mutually supportive, and jointly promote particular ocean energy technologies in specific places? Several principles can thereto be applied to achieve such an alignment: the use of technological readiness as key indicator or co-financing schemes mixing the funds mentioned are the main ones identified.

Building on the principle of stage-gate funding, a subsidiarity between regional, national and EU funding, suggested by the French focus group participants, would be based on *technology readiness.* As a rule of thumb, in advancing every TRL-step, a 5-fold budget increase is required. Regional authorities could focus on the lower TRL's, national governments on the middle tier, and the EU could focus on the highest TRL's – e.g. through schemes such as NER 300 and/or the EFSI Investment Package. However, a possible downside of such a scheme would be that many countries or regions could engage and support projects which are not sufficiently promising from the start. Another complexity exists when national and EU priorities are not the same. For example, confidence in wave technology is currently low and public support provided is limited. Therefore, French actors in wave are drawn by default to EU programmes. Furthermore, the justification for a European programme focusing on research and innovation (H2020) would be somewhat undermined.

An alternative alignment mechanism could therefore be obtained by introducing a *co-finance mechanism* (similar to the European Structural Funds); this could be applied by, for example, linking the French Programme for Future Investment to the EFSI Juncker Investment Plan.[42] Along the same lines, existing initiatives already exist, notably the OCEANERA-NET – which works towards joint calls for collaborative research. It includes a number of key actors from Scotland, Ireland and the French regions of Brittany and Pays de la Loire. From the start, several regions participate and the EC tops this up. It would be good to more strongly include knowledge sharing as an element as well.

4.3. Smart approaches for reducing offshore installation and maintenance costs

The challenge

Throughout the study, the high share of offshore installation and maintenance cost, including grid integration, in the total LCOE has been raised repeatedly. Several approaches towards decreasing these costs have been identified, although these in part have contradictory implications for the technology's design and the resource regime for which it is tailored. There are ongoing research projects (e. g. the FP7 project LEANWIND, GA-No. 614020) which investigate the application of "lean" approaches to all phases of an offshore energy generation array (see text boxes below for examples).

Supply chain readiness is obviously a crucial element for these cost reductions. Moreover, synergies with other offshore sectors may be found, although this will depend on the technology's design. In their Ocean Energy Strategic Roadmap, the European Ocean Energy Forum highlights "Installation and logistics" as one of the priority areas for technological progress. While "*a significant scope for utilising existing infrastructure (such as harbours, vessels, power cables, grid connection) and processes (including training, health and safety) from other marine industries*" is identified there is also the need for "*a new generation of waterborne and sub-sea solutions … to match the specificities of ocean energy devices and reach the targeted costs per kWh*". An offshore supply chain including all project phases including pre-installation, installation, operation and decommissioning, covers a wide variety of technical aspects. How to install, maintain or repair a device, or component elements, has to be designed into the device and therefore varies considerably from device to device. Even in tidal energy, the foundation and installation methods are fairly different. Further technological convergence would be needed to use similar installation methods and equipment, vessels etc. On top of that designs would need to be fixed (in particular foundations) and deployment plans would have to be robust for the offshore supply chain to develop reliable business plans. The experience from offshore wind shows that this process takes a long time and can cost first movers a lot of money, if they did not predict the market correctly. This explains some reluctance in developing an OE supply chain and to invest large amounts of

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[42] to be further explored in the validation workshop.

money e.g. in specialised vessels. However, e.g. dedicated installation vessels etc. are required to bring cost down and make cost more reliable and independent of other markets.

A critical deployment mass, as it can be expected in a regional OE cluster, will be a very significant facilitator for the development of a dedicated supply chain. The involvement of the supply chain at an early stage of a project will de-risk later installation and operation phases. Test centres such as EMEC, Bimep and others can be seen as a nucleus for a cluster development and a small-scale blue print on how the supply chain can be rolled out effectively. This could include the provision of local vessels at favourable cost, joined planning and sharing of grid connections, sharing environmental data generation and monitoring efforts, standardisation of foundations, and station keeping in accordance with local seabed and Metocean requirements.

The boxes further below cover recent and ongoing EU-wide activities, addressing knowledge fragmentation as well as optimisation methods within an array project, to minimise cost. However, a wide range of technical innovations are needed once the deployment of OE arrays are implemented at larger scales.

What can be done to strengthen existing supply chains?

In some EU regions e.g. within the Basque country and neighbouring regions, the entire offshore supply chain required to realise OE array projects can be covered. The Spanish cluster "Energia" is a tool to promote cooperation across the supply chain.

An improvement that would help in reducing O&M costs, and which raises durability is to involve stakeholders from across the supply chain from the very beginning of the design process. Typically this is not done, as developers often keep the development process in their hands and only involve others at a more advanced stage, where it is more difficult to modify designs.

Important aspects in the stimulation of an offshore supply chain lie in the project risks, which are, in most cases, covered by the (device) developers. Suppliers act as subcontractors, providing only a small part of the supply chain and are, therefore, not prepared to take the risk involved in their own contribution. The model of EPIC contracts (Engineering, Procurement, Installation and Commissioning) delivers a turn-key service, where a single provider takes all the risk. This increases the cost of a project substantially for the client since the EPIC contract provider needs to factor in the financial and technical risk into the project cost. Another aspect of the supply chain business is the IP generated within the process. Many device and project developers want to keep IP to themselves whereby the development and sharing of good practice and lessons learned is hindered. To overcome this situation, the supply chain would need to take more risk and contribute to the development of innovative solutions at their own cost. A prerequisite would however be, that robust business models can be developed and markets are stable over a longer period.

The French focus group made reference to the fact that both main French consortia make use of an estimated 300 suppliers, whether first-tier (directly working with the OEM), second-tier or third tier (working indirectly with the OEM). Several of these suppliers are working for more than one consortium. Following the Marine South East (UK) example, SMEs in the region could be helped to enter the supply chain – perhaps not at first tier but at least as second-tier or third-tier providers. This is typical work for a cluster organisation. Recent developments in Ireland, a country with an ambitious OE programme, but a relatively underdeveloped marine industry sector, include the establishment of an Irish Marine Industries Network and a dedicated Marine Development Team, supporting the early cluster development at e.g. IMERC in Cork. Generally, there is an understanding of the need to build European-level supply chains – if the industry wishes to stay competitive in the future.

Text Box 4.1. The DTOcean project (GA608597)

The DTOcean project brought together an integrated suite of Work Packages to address the challenges that have been highlighted, as the sector progresses from single devices to arrays. The Work Packages formed core elements of progression beyond current state-of-the-art knowledge. Within each work package there has been a significant focus on the economic, environmental and reliability challenges. This ensured that each step of the design process considered the overall impact of individual Work Package decisions. As a result, a suite of open source design tool modules for the ocean energy sector has been produced, covered by a user friendly graphical user interface.

The main aspect for this study is the cost optimisation abilities of the DTOcean tool. The tool produces cost optimised array layouts, cable routing schemes and mooring/foundation concepts. These costs are dynamically calculated from the user- proposed array configuration and the devices to be used.

Costs for installation and O&M are calculated based on the resulting optimised array layout, using data base information. The data cover costs for several types of vessels (crew transport, offshore construction, cable laying, etc.), personnel, spare parts, etc. Where detailed data for this calculations could not be found the basic cost distribution was estimated according to the figure below:

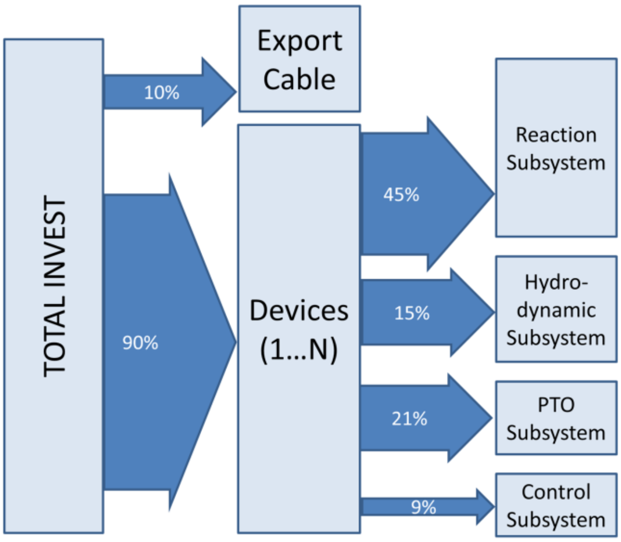


Figure 4.1 Cost break down for marine energy array projects

Other costs (e. g. hourly rates for specialists and technicians) have also been estimated, since industrial players in the sector were very reluctant to communicate real world prices. But at least the estimated costs used in DTOcean have been verified and confirmed to be in the correct range by several industrial partners within the project.

The DTOcean tool includes several cost optimisation functionalities and, in addition allows a performance analysis (e. g. device downtimes) and a ranking of the environmental life cycle impact of the generated marine energy array configurations. Since the functionality of the tool is very complex, please refer to the DTOcean (www.dtocean.eu) website to find detailed information and the access link to the tool’s installation package.

What cost reduction approaches are most promising and most easily transferred throughout the sector?

Arising from the interviews, reduction of O&M cost is seen as a key element for cost reduction. This would however require some longer term operation of devices in the open sea e.g. in the case of demonstration projects, much longer than the usual 12 months of operation. Such projects would need to incorporate extensive knowledge sharing which, in order to be attractive, should be incentivised in the funding scheme.

Other key aspects address the development of technical standards in general. Like in other technologies, standards reduce technical and financial risks. Despite the leading role of the EU in the OE sector, the contribution to standardisation is limited due to the incoherent support at Member State level e.g. to the national IEC mirror committees. The French focus group recommended, in this context, that It would be very useful for the EC to support Member States in their efforts to contribute to the definition of standards.

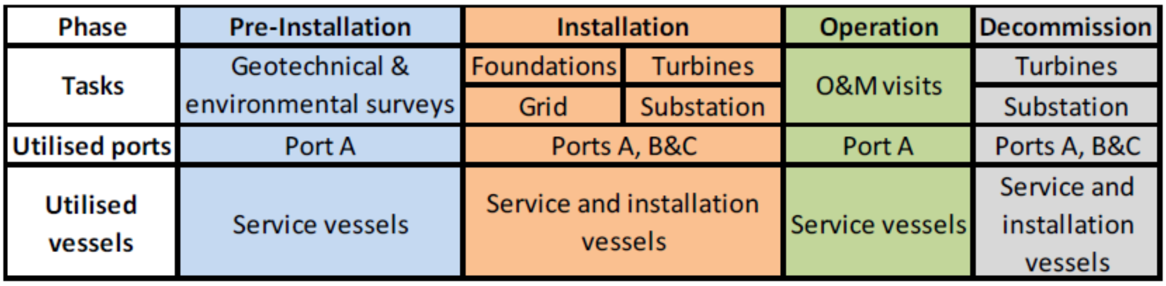
Text Box 4.2. The LEANWIND project (GA614020)

So far, LEANWIND has produced cost estimation tools for the entire logistics (incl. land transport of components, harbour costs, etc.) and for cost optimised component health monitoring approaches. Other economic aspects are under investigation. Those aspects will analyse the economic benefits of new concepts for installation and O&M vessels, which are close to completion.

A major issue in LEANWIND is the setup of simulator training sessions (developed by Kongsberg Maritime / Maersk Training Svendborg for installation, and FORCE Technology for O&M) for the new vessel designs mentioned above. The simulator training sessions will be used to verify the benefits of the new concepts and will allow training of crew and specialists on the new concepts. This will lead to both a time/cost optimised performance of the offshore activities and the health and safety of personnel, equipment and vessels. Detailed information about the actual status and intermediate results can be found on the LEANWIND web site (www.leanwind.eu).

Text box 4.3 ORECCA (Off-shore Renewable Energy Conversion platforms – Coordination Action, 2011-12)

Table: Life cycle phases of an offshore renewable energy farm



Phase	Pre-Installation	Installation		Operation	Decommission
Tasks	Geotechnical & environmental surveys	Foundations	Turbines	O&M visits	Turbines
		Grid	Substation		Substation
Utilised ports	Port A	Ports A, B&C		Port A	Ports A, B&C
Utilised vessels	Service vessels	Service and installation vessels		Service vessels	Service and installation vessels

The different tasks to be carried out during the above phases require ports with certain properties and facilities as well as the utilisation of a variety of vessels with certain abilities and features. E.g. Port A is a small local port that is used by small service vessels and to realise the service crew transfer to and from the farm. In contrast, ports B and C provide infrastructure for installation and assembly of foundations, energy conversion devices, substations etc. and might be much further away from the farm site. The report "Offshore Infrastructure: Ports and Vessels" presents the classes of ports and vessels, with their specifications, required during the installation and operation phase, utilisation strategies and market potential forecasts concerning both ports and vessels. Furthermore port and vessel requirements regarding ocean energy farms are covered.

The technical aspect of the grid connection and grid integration of offshore RE farms are described and analysed in the report "Technologies state of the art: Grid integration aspects". This includes the use of flexible cables and subsea switchgears as they are planned to be used in the first pilot ocean energy installations. Recent grid integration studies for offshore wind energy, realized in a number of European countries, such as Ireland, UK, Denmark, Netherlands, Germany, were reviewed and conclusions were developed for the ORECCA roadmap. Grid integration strategies in progress in the US and Canada were also utilised.

The electrical infrastructure of offshore wind energy and other ocean energy systems differ significantly in this stage of development, but will converge as ocean energy production units and farms reach the same power levels. Cross-fertilisation will help both developments. (www.orecca.eu)

4.4. Intellectual property, knowledge sharing and testing centres.

The challenge

From the interviews there has been an emphasis on knowledge sharing, while recognising the need to protect intellectual property as core assets for business cases. These two contrary aims have been pulling in opposite directions and, as a result, limited formalised[43] knowledge sharing is taking place. There has also been little agreement on what are the key areas where knowledge sharing is crucial, under what conditions and structures should formalised knowledge sharing take place and what are the underlying motivations for business to engage.

Given that the aim of the sector and policy makers is to develop a fully commercial sector, it is overly simplistic to say that "sharing more is better" – rather a fine balance should be found. It is fair to say that the willingness to share knowledge decreases as TRL's increase. This is logical and justified, as the stakes are higher, and as the concern that ideas are being copied increases exponentially. Therefore, it is not correct to ask the most advanced players to 'put all their cards on the table'. In this respect, universities have a stronger willingness to share – which goes with their involvement in international research networks.

In this section we, therefore, look at some of the different knowledge sharing schemes that exist and are worth learning form, the areas that our stakeholders have said would most benefit from increased knowledge sharing and then what could the EU actively do in this respect. We finish with implication for a way forward.

Different knowledge sharing schemes and their level of IP protection sharing

France Energies Marines (FEM) is active in the sharing of experiences between very different actors (regions, clusters, other actors in the system) and has also presented a roadmap including the R&I subjects that lend themselves to cooperation. To this end, FEM has set up a Technology Platform that can stimulate the market. This experience would be worth sharing internationally. Another example from offshore wind is the anonymous online database SPARTA, where information is shared on operational performance of wind turbines.[44]

Stakeholders are fully aware that the sector's "do it alone" attitude to project development causes many mistakes to be repeated and many already solved solutions to not be used. However, online knowledge sharing platforms[45] remain little used in this industry so far, largely due to the diversity of concepts and sites and, as some stakeholders suggested, one's IP being used without their knowledge or permission. One stakeholder has suggested that improving sharing experiences through online platforms could become more widely used if they were financially incentivised.

Several stakeholders have pointed to the network of testing sites as an efficient source for distributing results and findings. However, these tend to be very sensitive in terms of their IP protection, too. That is why reportings tends to remain rather higher level, to combine their findings into aggregated reports[46], or by forming working groups[47]. The agreement of testing centres, in the context of the FORESEA project[48], is a chance to build on the knowledge and knowledge- sharing potential of these centres.

In Scotland, WES makes several detailed IP documents availably, in a licence agreement, to projects that aim to enhance WES's objectives. These are: [49]

- Patents;
- Pelamis reports on hydraulic PTO;
- Laboratory and full scale machine test data;
- Wave and other environmental data;

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[43] Knowledge transfer still takes place as experts move between projects and jobs.

[44] https://ore.catapult.org.uk/our-knowledge-areas/operations-maintenance/operations-maintenance-projects/sparta/.

[45] Many platforms such as github.com mainly provide place for teams to cooperate, rather as a depository of past experiences. Alternatively they are the industry association's own knowledge sharing that has limited outreach and level of detail (such as http://www.irena.org/Menu/index.aspx?PriMenuID=13&mnu=Pri or http://www.wavetidalenergynetwork.co.uk/).

[46] Such as http://oceanenergyireland.com/PublicationGallery/Publications.

[47] Such as http://www.emec.org.uk/research/.

[48] a €11 million project bringing together leading ocean energy test facilities to help demonstration of tidal, wave and offshore wind energy technologies in real-sea conditions.

[49] http://www.hie.co.uk/growth-sectors/energy/wave-energy-scotland/wave-energy-scotland-ip-availability.html.

- PELS Computer model;
- Selection of test equipment;
- Schematics and circuit diagrams.

In order to acquire and publish the knowledge, WES remunerated the failed Pelamis company to write a paper on what went wrong and lessons learnt. Some of the stakeholders participated in a WES project about lessons learnt. They reported, however, that the actual knowledge exchanged was at a high level of aggregation, and that the real knowledge was protected.

As in any industry there is staff movement, mergers and acquisitions, internal knowledge sharing within larger companies, as well as purchasing specific knowledge from experts/research institutes/universities. Such exchanges respect IP issues, but are restricted to individual companies, often at the expense of their competitors. The stakeholders in Bilbao suggested a more commercial approach by research institutes, whereby they would sell important findings to a wider number of companies. In this way access to knowledge would be provided, while addressing IP issues and financing of the research at the same time.

One stakeholder in France has mentioned that much knowledge sharing takes place through the use of suppliers, which work with multiple clients. Even though they will be discrete and not be referring explicitly to what competing clients do, the insights obtained will be passed on in their product or service offer. Indeed, geographic proximity between users and producers is helpful, e.g. in the form of clusters.

Key areas for knowledge sharing

The stakeholders interviewed and taking part in focus groups have identified several key areas that could in particularly be well suited towards initiatives to encourage knowledge sharing:

1. Site characterisation: The survey and exploration of sites is a common activity for all who want to operate, or consider operating in the waters. Therefore pooling of resources, or sharing findings is a beneficial activity for all;
2. Environmental impacts: The whole industry has to show the environmental impacts of their system. Many of the impacts remain common for all (alien bodies in marine environments) and would benefit from a joint approach in studying the impacts;
3. Test sites: The whole industry needs high quality test sites in order to validate their concepts and test technologies. Given that the basic infrastructure is common for all, a sharing of facilities, resources and investment would benefit the industry as a whole;
4. Grids: High quality and accessible grid connections are a pre-requirement for a successful commercial ocean energy sector. Therefore sharing knowledge and resources in improving grid is very important;
5. Installation and maintenance: Some of the highest costs to any projects is the I&M, therefore bringing down costs is in the interest of the whole industry.

Repeatedly the stakeholders highlighted that, in particular, failures should be the focus of knowledge exchange. Attention should be paid to reasons why things did not work. Such an approach would prevent the same mistakes happening over again, while at the same time not revealing the solutions to overcome the problems, which becomes part of companies' IP.

However, key areas that the stakeholders have identified, that do not lend themselves much to cooperation, are optimisation of converters and turbine – power take-off (PTO).

4.5. Ocean Energy Clusters, a tool for knowledge sharing

The challenge

The analysis of barriers points to a number of interlinked factors that need to be overcome, such as critical mass, supply chain development, building trust, exchanging knowledge, making use of skills and competencies, and building support and alignment with framework conditions. Clusters are a powerful concept to address such factors and create platforms for informal exchange and knowledge sharing. The cluster approach has, therefore, been applied in the maritime domain as well. More specifically, ocean energy developments appear to concentrate, in large part, in specific places and regions, such as Scotland, Normandy, Basque country. The question is, therefore, how the cluster concept can be deployed to promote ocean energy and further enhance informal ways of sharing knowledge and experiences.

Whereas the other themes (procurement, IP & knowledge sharing, to a lesser extent supply chain integration) are areas where governments can promote actions to enhance their effectiveness, clusters are themselves a means to address cooperation barriers. Moreover, typically clusters are a response strategy taken by the industry itself rather than by 'external' parties like governments.

Clusters versus cluster organisations

According to theory (Porter), clusters are geographic concentrations of interconnected companies and institutions in a particular field.[50] They do not have to have formal cooperation relations other than normal supply or trade partnerships (purchases, service contracts, etc.) but by doing so, they typically also exchange knowledge, skills, or technologies, or share common inputs. The boundaries of a cluster may be fluid. In ocean energy, concentrations of companies working together are found across Europe, mostly near promising pilot and deployment sites, or near test centres such as EMEC, Bimep, Wavec.

When talking about clusters in practice, however, a cluster is often meant as a cluster organisation, being a legal entity set-up by companies that are part of the cluster in the sense of the Porter definition that should serve as the body to organise the cooperation, exchange and promotion of the cluster activities. Examples of such cluster organisations are found across Europe in all kinds of sectors and industries. Mostly these are small organisations (only a few staff) paid either by contributions of their members and/or by forms of public support. Active organisations providing cluster advantages include:

- Basque Energy Cluster (Spain) – focused on wave energy;
- Marine South East (UK) – covering broad maritime sectors, privately run;
- Pôle Mer Bretagne-Atlantique & Pôle Mer Méditerranée (France) – covering range of maritime sectors with strong government backing;
- Normandy (around Cherbourg);
- IMERC – the Irish Maritime and Energy Research Cluster, Cork, Ireland.

In addition, most of these local/regional clusters take part in international cluster organisations like Ocean Energy Europe, the Ocean Energy Forum and ETIP Ocean and other international groups (OES-IA, IEC-TC114). ETIP Ocean will build on the work of the Ocean Energy Forum, which produced a Roadmap as a final product in November 2016. Separate reference is made to INORE (International Network of young Ocean Energy researchers) – although this is a network of individuals rather than organisations. Apart from formalised clusters also informal clusters are found, such as the network of wave energy players in Portugal, brought together by Wavec.

The main roles that cluster organisations play, as observed by a range of interviewees and also confirmed in the focus group meetings, are:

- Act as a platform for soft knowledge exchange;
- Providing networking opportunities for its members;
- A channel for raising trust among its members;
- Creating opportunities for supply chain links;
- Acting as one voice of the cluster towards governments.

Text Box 4.4: Roles of the Basque Energy Cluster[51]

In the Basque Country, the creation of the Energy cluster has been a major help for getting to know each other within the supply chain. The Cluster Energia has set up working groups, one of which is specifically focused on wave energy. It organises meetings every 3 months or so, in which participants present their activities and progress, as well as their future plans, and where contacts are established and refreshed. Furthermore the cluster has organised knowledge exchange trips to other countries, notably Scotland and Ireland. Participants to the focus group confirmed that this clustering has helped them to optimise the use of the locally available supply chain, simply by bringing them in contact with people from different sectors behind the wave energy initiative.

For the public sector, the cluster has been an effective liaison mechanism with the industry, supportive to maintaining public commitment, and raising understanding among public authorities.

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[51] Source: Focus Group meeting.

> So far, there is a common feeling of complementarity, rather than competition. These forms of knowledge sharing have, however, mainly been of an informal character. It has turned out to be difficult for competing companies to share knowledge without compromising the core business of the companies.
>
> On the other hand, as no company earns money from wave energy yet, the joint need for moving up the TRL level is considered an incentive to share knowledge, more than if the sector was in a more mature stage. Clustering has helped to feed the belief that a future market is possible because a large number of stakeholders are working together for it, and, when it comes close to commercial sensitivity, a more closed approach will be followed through bilateral relations between industry players and individual research centres.

From the focus group meetings in France, UK and Ireland, messages obtained in Spain, especially on the role of clusters, in growing trust among stakeholders, are generally confirmed, although local differences do play out. In France, for instance, large companies act as concentration points to connect supply chain partners, thus leading to more supply chain interaction beyond the level of knowledge sharing alone. In other places like Portugal, the fruitful cluster models observed in for example Spain are considered a promising approach towards addressing critical mass and informal knowledge sharing barriers in the sector, and as a way to foster and attract employment.

What can be improved?

Areas identified where the effectiveness of clusters can be strengthened are:

- How to link remote players that are not, or only weakly, linked to a cluster;
- Embedding Ocean energy in broader maritime clusters present across Europe (for instance connected to other broader offshore energy clusters, or to maritime or port clusters with relevant supply chain partners);
- How to go beyond regions? For example across regions within a country, but also across countries (attempts to create links between Spain and Scotland, or between Portugal and Finland have been observed). And how to avoid competition between neighbours/regional clusters? This indicates a need to promote inter-cluster cooperation;
- In relation to the previous, how to create effective connections between clusters at regional and at national level. An example is the model for the maritime cluster in the Netherlands, which is organised as a national cluster, but dominated by industries in the region of Rotterdam port. In the north of the country, however, a regional sub-cluster is set-up, which has led to successful cooperation models within the northern region but at the same time maintaining strong connections to the national cluster partners located elsewhere in the country.

The focus group results point to differences in the role of clusters between wave and tidal energy. Because of the more mature stage of tidal energy, with larger industry players involved and at more advanced TRL levels in which higher investments amounts are taken, the sector attracts more suppliers and results in stronger supply chain ties, driven by the large investor or OEM. The role of the cluster organisation evolves according to the evolution of the sector, targeting more mature sector needs. As such, wave energy clusters can benefit from lessons learnt and models developed in the tidal sector.

In parallel, ocean energy clusters, whether wave or tidal focused, may benefit from stronger ties to broader energy clusters and/or broader maritime clusters. While the former can be a vehicle to integrate ocean energy services into the broader energy supply sector (where utilities are the main organisers), the latter can create access to broader groups of suppliers and create entries to wider knowledge networks.

Entering these wider networks/clusters may, however, be challenging for OE clusters/companies. Most countries have ‘maritime cluster’ organisations where OE would be a minor player and the vested interests of mature sectors will prevail. In some places, however, this has been addressed though establishing thematic working groups for OE.

4.6. Summary: implications for EU and Member State support

The above overview clearly presents the various approaches that can be taken towards promoting innovation, collaboration and knowledge management. These are not mutually exclusive, but rather complementary, and have the potential to reinforce each other. All of the above approaches demonstrate that innovation requires collaboration within industry, between industry and research, between research and government as well as between industry and government – the so-called ‘triple helix’ at work.

In the area of *public procurement*, there is need for clarification about the relation between EU funds (H2020, NER300, Structural Funds, Juncker investment funds), Member State funds and regional funds (including again Structural Funds). The question needs to be addressed as to whether such funds can be mutually supportive, and jointly promote particular ocean energy technologies in specific places? Several principles can thereto be applied to achieve such an alignment: the use of technological readiness as key indicator or co-financing schemes mixing the funds mentioned are the main ones identified.

In the area of *supply chain optimisation*, the EU as well as Member States can promote technical standards. It would be very useful for the EC to support Member States in their efforts to contribute to the definition of standards, notably through IEA mirror groups.

In the area of *knowledge sharing and IP*, the EU as well as national funding mechanisms can:

1. Introduce time slots for discussing failures and best practices in ocean energy conferences;
2. Support a significant prize award for knowledge sharing reports that are detailed and “provide insights for the development of the industry”, with a condition that IP is given up when collecting the prize, thus encouraging entry while reserving giving up IP with the cash prize. This was done in the UK e.g. for offshore wind platforms;
3. Consider a similar system as WES, where there is a remuneration to the person disseminating knowledge and experiences. Having said that the execution of the WES model, with the detail of the reports and the licencing implications, should be closely scrutinised and potentially made more open sourced and detailed;
4. Encourage a “secondary market for knowledge”, whereby knowledge and experiences can be bought and sold between companies. This possible initiative would make a commercial case for knowledge sharing from the companies point of view (essentially they would get paid to share their experiences, often of what did not work), while at the same time distributing knowledge across the industry allowing others not to make similar mistakes, or get inspired by certain steps;
5. The EU could provide the initial investment in setting up a privately run (for profit) e-commerce platform (like e-bay), where such knowledge/findings could be bought and sold and subsequently to help with the publicity;
6. With regard to test centres, these are also bound by intellectual property and confidentiality, which limits their ability to share. There should, however, be an obligation to publish and to share. In this context it will be instructive to follow the development of the FORESEA project as well as exploring further the role of MARINET;
7. An idea emerging during the discussion was the development of systematic and impartial monitoring of ocean energy projects, allowing the sector as a whole (including public funders) to track progress and to capitalise on investments and experiences already made.

In the area of *clusters*, the EU as well as national funding mechanisms can:

- (co-)fund cluster organisations, at EU level as well as, perhaps, through project-based cooperation between various regional cluster organisations;
- Promote the support of clusters among member states, perhaps through existing DG GROW & DG MARE cluster support mechanisms;
- Apply Interreg as a tool for Blue Economy (/ocean energy) cooperation support;
- Expand the Blue Growth and Smart Specialisation strategy policies to include a focus on ocean energy and links between this and other blue growth sectors.

5. CONCLUSIONS, RECOMMENDATIONS AND THE WAY FORWARD

5.1. Conclusions: towards an integrated approach to OET development

The State of Play in Ocean Energy: the cup is half full and half empty

The Ocean energy sector is relatively young and still emerging. It has benefited from EU support (about € 200 m. in the past 30 years) and has innovated and moved forward, although at different speeds. The sector remains promising, especially when niche markets (e.g. islands, remote locations) and export potential are accounted for. Although its potential is more confined, the tidal segment is currently more consolidated and advanced than the wave segment which remains rather fragmented. Overall, technological progress and development of the sector has been slower than expected a decade ago, and the focus of this study has been on the analysis of the underlying reasons for this.

A range of critical factors have held the sector back – and these are often interconnected

Both technological and non-technological factors have played a role. Exogenous factors are important: the metocean conditions are extremely harsh. A range of factors are endogenous to the industry: technological convergence, reliability & maintenance costs, offshore operations such as installation, supply chains and costs. Support conditions have been critical too: involvement of the right expertise, project finance and framework conditions & political support. But non-technological barriers are crucial as well. Failures have often been driven by managerial influences and overconfidence (cutting corners), human error (simple installation mistakes which bankrupt the developer), but also purely technical (ratio of weight to electricity outputs). It suggests that sufficient phasing and checks and balances are required when supporting technologies. However, the most important implication is that not one, but a range of barriers hold back development, and these barriers are all very closely interlinked – which is inherent to emerging industries. Part of the challenge in public support schemes is the constant competition with other more mature renewable energy technologies.

Interconnected problems call for an integrated approach and solutions

The findings point towards a strong need for an integrated approach: remaining firmly focused on technological development and robustness, whilst having a clear eye on the longer term goal to drive costs down, e.g. by bringing in economies of scale and building out a supply chain including full attention to installation, maintenance and grid connectivity. These tasks – together with the key challenge to restore investor confidence – are beyond the scope of small device developers. It requires the involvement of larger companies, advanced cooperation mechanisms, consortia, and a conducive, consistent and stable policy framework which provides specific and targeted support to tidal and wave through a consistent and coherent set of support measures.

5.2. Recommendations: a framework for an integrated approach

An integrated approach also implies that private and public sector actions are aligned. It requires that private sector actions are complemented by a coherent and stable policy framework.

Overleaf is a visual presentation of such a framework for an integrated approach to Ocean Energy Technology development.

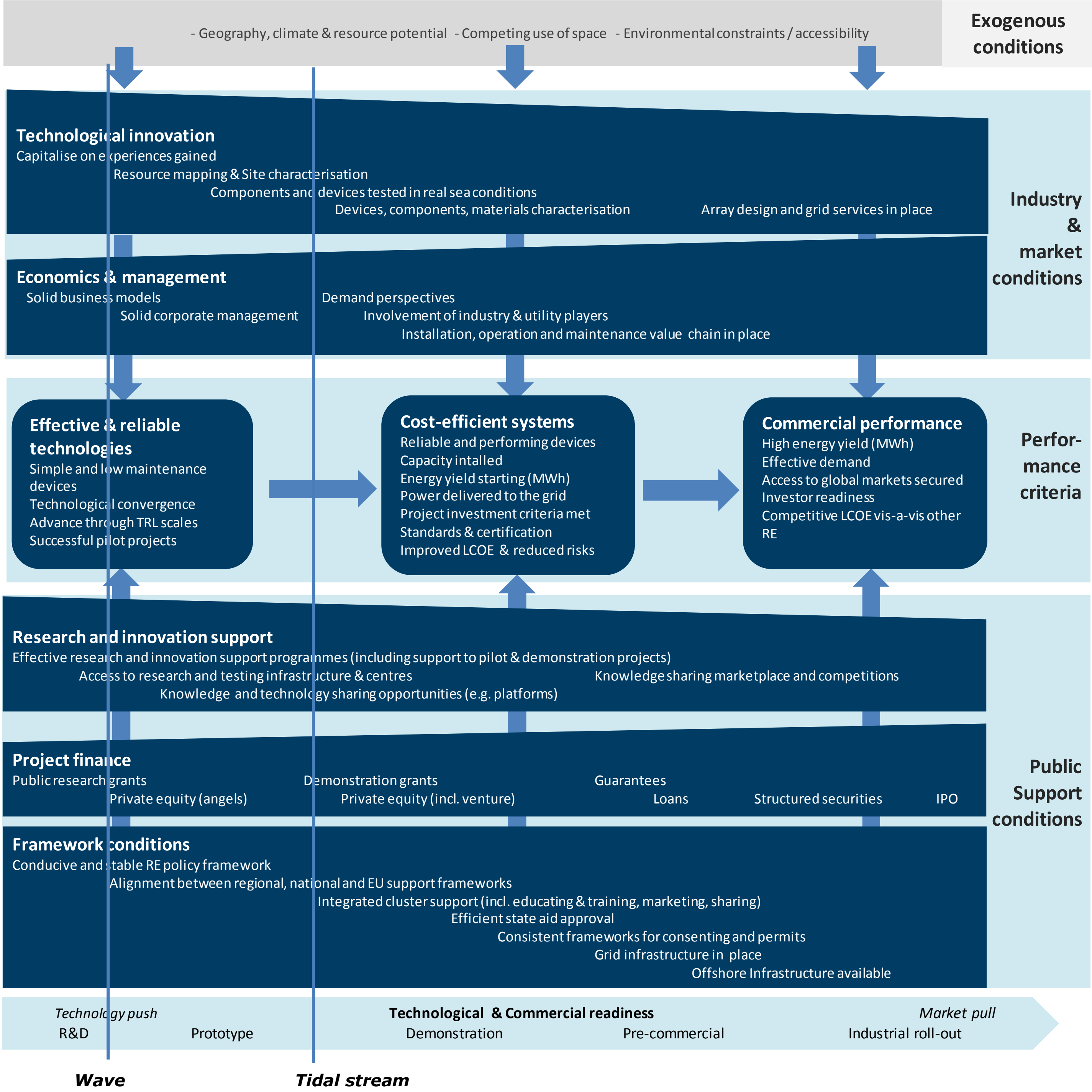

Figure 5.1 Framework for an integrated approach to Ocean Energy Technology development

The figure shows, from left to right, how the importance of types of conditions (Exogenous. Industry & Market and Public Support) shifts as technologies mature. Industry & Market conditions are further broken down into Technological Innovation and Economics & Management, while Public Support Conditions are broken down into Research and innovation support, Project finance and Framework conditions. The block on Performance Criteria identifies criteria relevant for each stage of technological and commercial maturity, which first focus on developing Effective & reliable technologies, followed by Cost-efficient systems and Commercial performance.

The framework points clearly to the fact that performance can only be achieved by a combination of both industry & market conditions, joined up by public support conditions. The framework also points to the fact that performance criteria evolve throughout development stages, from an initial focus on effective and reliable technologies, through cost-efficient systems and commercial performance.

Within this framework, tidal and wave energy are positioned differently. The emerging view, and as portrayed by the framework, is that in wave (the left bar in the framework), technology development suffers, above all, from a divergence of technologies and concepts. It requires technology push instruments, e.g. access to public research funding and testing infrastructure and appropriate procurement mechanisms, to trigger convergence. This will in turn require a more realistic evaluation of the state of play and a wider collaboration, across the value chain as well as across technologies and projects.

Tidal energy (the right bar in the framework) is currently more advanced, with technological convergence, in the design and the basic concept of the three blade rotor, providing more confidence to investors. Tidal energy technology is currently moving from single device demonstrators to array installations which adds new challenges, essentially the testing of pilot farms, with the associated need to build out the supply chain and drive costs down, paving the way for more private funding to enter the sector. This requires demonstration and market pull instruments. A longer term barrier, however, may arise from the exogenous factors – namely the resource potential: will there be enough sites (in Europe and globally) to justify the investments not only in devices and components but also in support infrastructure including dedicated vessels that, in their turn, are needed to drive down costs?

Building on the above, the challenge for both the industry and the public sector is to apply the lessons learnt from the past and to apply these key elements as presented in the above framework.

5.2.1. Key elements for Industry

Technological Innovation and Development

Across Europe, both industry and government is aware that the renewable energy industry has provided enormous opportunities that have not been availed of by all. For example, industry is aware that the UK allowed wind to slip through their fingers by not investing at the right time and the sector is aware that this may happen again. A similar sentiment has been spotted in Sweden, which saw how neighbouring Denmark was able to conquer the wind energy market. Hence a deliberate interest to join the next ‘wave’.

At the simplest level, it is crucial to *learn from mistakes*. Mistakes and failures are common in a technology which is so new. However what is essential is that actors are learning from their mistakes. For example, a highly successful company such as Open Hydro had some problems with their dedicated barges and the underwater cabling during the installation 2 years ago at Paimpol Bréhat. However, they have overcome these problems now, and that has brought about much progress in the effectiveness, efficiency and costs of installation and maintenance.

As pointed out by the chronology of developments, the more successful companies and actors in ocean energy are *building on previous experiences*. Through company take-overs, mergers and acquisitions, experience is carefully contained. In this context, a Swedish public sector representative referred to the fact that the sector continues to attract new developers who expect to bring quick solutions ‘out of the blue’, not necessarily being aware of what has been achieved before.

However, one other reason why learning is not taking place sufficiently may lie in a sense of unfounded (entrepreneurial) optimism, and thus a tendency to be *racing too fast through the TRL scales*. One UK-based interviewee expressed surprise at device engineers’ beliefs about how fast a device can progress: “The reality is that many prototypes will need to be made. One well quoted example is with the Dyson vacuum cleaner, where 5000 prototypes were built before it was commerciality feasible. There is no escaping the fact that you are going to need several prototypes”. Bear in mind that Pelamis built two prototypes, and then built three identical machines that were essentially still prototypes. And turbines now being built for purpose are different from the one-s tested at EMEC. In such situations, fundamental issues could emerge which have never been explored, issues which manifest themselves only when put into the water. But at this point, alterations are quite difficult, because a lot of supporting engineering is built around the concept. Then it is difficult to adjust and change that because the risk emerges that further optimisation will not be possible, without a total redesign.

But if the lesson is to move step-by-step along the TRL scales, then there remains in practice the pressure from the investment community to move faster. After all, it is rare to find a deep-pocketed investor who can invest in endless iterations of one machine. One will simply not get permission from funders to then build yet another new prototype.

Designing *simple and low maintenance equipment* and devices is another good practice. Intervention at sea (turbine immersion, cable laying) requires a set of meteorological and tidal conditions to be met. When it comes to both installation and maintenance, adequate conditions are found only a few times every year and can't be predicted in advance. If the project misses one given opportunity, its whole schedule of operations may very well slip by one year. Reduction of the frequency and duration of maintenance interventions is hence essential.

Critical mass and supply chains

One way to keep eyes open on all the technological and non-technological challenges is through *solid corporate management*. The role of the CEO is of course crucial in managing relations with the outside world including investor relations. Stability and continuity are key here. But other corporate functions are equally crucial. A UK view is that one certainly has to separate the CTO-type role from commercial day-day operations (COO) which prevent a focus on R&D or new product development. With a strong CTO, and project manager, other things will fall into place. Taken together, one needs strong commercial exploitation planning, and a strong emphasis on cost from day one. This is relevant, because it can be difficult to adjust design choices which limit commercial cost performance when the device is already in an advanced stage of development.

An alternative attempt to provide a holistic/integrated approach comes from tidal development in France, where the involvement of *larger industrial players* has resulted in less 'stop and go' than for example in the UK, creating more continuity. The fact that these projects are being supported by major consortia consisting of both industrial and utility players is a major advantage. Another lesson is that there is a need for good consortia where synergies can be obtained. For example, DCNS bought Open Hydro for propulsion marine technology – there is good complementarity. The same applies to the Alstom purchase of TGL – which gave them access to maritime expertise not yet available. In addition to this, there are always industrial policy considerations – which are important when taking part in important national calls for proposals such as the one's for Raz Blanchard. In this context, it is worth mentioning that Voith's cooperation with Alstom did not withstand the test of time. Was Voith perhaps not planning to bring future industrial production to France?

An area of potential gains, valid for both tidal and wave, is that of installation costs, a major barrier for demonstrations and testing. *Sharing and pooling of resources* was already identified as a challenge, and good practices seen in other ocean sectors can inspire the wave sector. An example is the Marinel project, an EU funded R&D project in which a large-scale marine transformation substation will be designed, capable of exporting around 1GW to the electricity network. The main innovation in this design lies in the fact that it will be able to float and be self-installed, which will provide huge savings in costly transportation and installation operations. It aims to promote off-shore wind power, which has huge growth potential. In addition the shared ownership of dedicated installation and O&M vessels between project developers could help lowering costs. In tidal the participation of offshore service suppliers in project consortia (such as Van Oord and Damen in the BlueTEC project) already implicitly delivers this. Public procurement strategies could possibly also be designed such that this cooperation is promoted.

Tailoring of devices and installations is key. With regard to installation and maintenance, important cost savings can be made by making use of tailor-made ships that can install/transport the devices and equipment (the current generation of ships from the oil industry being far too heavy). And the pooling of such tailor-made ships would provide even more advantages. By the same token, grids and connectivity need to be tailored to ocean energy. Dedicated submarine robotics can make a big difference too. These are all areas where EU R&D support can still make a difference.

At EU level, reference is made to mechanisms like the *Open Power Innovation Network*, which also aim to promote industry exchanges. Such models may need further tailoring to fit the wave energy sector though, as the character of companies (small size, low capital resources) may trigger fast-track development.

Another lesson to learn is that *synergies from other sectors* may seem promising, but that they do not always easily materialise in practice. Even though adjacent technologies (offshore wind, offshore oil/gas) can be helpful, they need to be adjusted to the specificities of ocean energy.

In the tidal energy industry, extensive *knowledge sharing* exists through collaborations, a (partially) common supply chain, transfer of staff and other commercial relationships. Due to the diversity of technologies in the wave energy sector such a knowledge transfer and exchange is much less applicable. However, most wave energy device developments do involve European research groups and universities and other research organisations, as well as making use of infrastructures such as wave tanks at various scales and open sea test facilities. In this way, many device developers collaborate with a limited number of research teams through R&D contracts or through joint R&D in publicly funded projects. Device developers benefit from the researchers' experience in developing and testing devices. Many detailed problems associated with measuring, testing and modelling have been solved and methods have been developed and improved that can be made available to new device concepts.

From the demonstration phase onwards, and even in a fully commercial sector, there is potential for *operational experience sharing* and/or innovation programmes. Relevant good practices exist in Offshore Oil & Gas, with anonymous reporting of material performance and failures, and also in Offshore Wind, with programming joint innovation[52] and reporting of performance data[53].

Examples of operational experience sharing also exist in the Ocean Energy sector, for instance two recent updates from OpenHydro on component reliability[54]. Delays caused by these types of problems can be costly, and simple to avoid / solve once you are aware of the problem. Especially if the problem is related to a 'common' component coming from a supplier, IP should not be a hindrance to sharing these experiences. Note that these type of news messages still require bilateral follow-up communications to obtain sufficient details to allow them to be put to use by other developers.

Performance and markets

Expectation management is key. A common problem of the sector has been to overpromise. Especially in the UK, the sector has been guilty of this. Actors have done so with good intentions, and to get the attention of governments and (private as well as public) investment – but it turned out to be not sustainable. Expectations had to be managed downward over time, which has hurt investor confidence.

5.2.2. Key elements for (public) support

Research support

Knowledge management requires open consortia. Consortia in receipt of public research support funding need to be able to quickly take on board new partners. Also the rate of exchange of information across projects would need to be improved – this might require an overarching organisation, perhaps a multi-country technology board, which would need to be independent, and include the perspective of developers, system integrators, utilities, and academia. Additionally, the mechanism should be more flexible to allow new solutions to be incorporated in the project plan without having to go through another 3-year proposal process.

A related issue is the need to find a way for *focusing research and development efforts*. Only some technologies are able to win – and this can only happen if there is sufficient bundling of resources. Bear in mind that ocean energy overall is already highly fragmented, with efforts not only being put into tidal and wave technologies, but also in salinity gradient and OTEC. Perhaps one of the reasons for recent progress in tidal is related to the fact that the number of technologies in tidal has been reduced, whilst the number of wave technologies has increased. The number of wave energy concepts is still large, and there seems no agreement yet on the technologies that should move forward – even though most interviewees seem to agree that the attenuator concept (Pelamis) was the wrong technology to support. Again, the WES initiative is a managed way to gradually bring such focus also to the wave sector.

An important role is to be given to the *test centres*, which coherently work on subsystems, components, and field installations. EMEC can be considered an excellent practice: they have been testing in a real world environment which can be validated and they have an experienced team

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[52] http://www.orjip.org.uk/.

[53] https://ore.catapult.org.uk/our-knowledge-areas/operations-maintenance/operations-maintenance-projects/sparta/.

[54] http://capesharptidal.com/component-update/; http://www.lemarin.fr/secteurs-activites/energies-marines/27184-calendrier-bouscule-pour-les-hydroliennes-de-la-zone.

which have supported devices from all over the world, allowing an overview of all possible mistakes made before. It also involves working within a community of developers - in a cluster. Testing centres allow multiple devices to be tested at the same site, not necessarily the same concepts, and can help improve all, and to select which ones to take forward. To this end, different test sites should work together more, and in more structured/streamlined ways. For instance, EMEC and PLOCAN could test similar technologies at their sites to demonstrate their performance, reliability etc. So far, however, the work of such facilities is not coordinated and all sites follow different approaches.

In this context, it is important to know that testing centres in Northwest Europe have agreed to cooperate in the context of the FORESEA project, a €11 million project bringing together leading ocean energy test facilities to help demonstration of tidal, wave and offshore wind energy technologies in real-sea conditions. The project is funded by the Interreg NWE (North-West Europe) programme, part of the ERDF (European Regional Development Fund). The project includes test facilities from EMEC (Orkney Islands, UK), SmartBay (Galway, Ireland), SEM-REV (Nantes, France) and the Tidal Testing Centre (Den Oever, Netherlands). Due to the set-up of the Interreg funding programme, only testing centres from North West Europe will be able to participate.

On a more general level, the *standardised testing opportunities* at sites like EMEC already push convergence in mooring systems and bundling grid connection supply. Similar facilities are being developed elsewhere too, so the opportunities for testing will increase. It is suggested by several interviewees that this can be further effected by strengthening alignment across testing sites in Europe.

From the outset of technology development, *collaboration between R&D organisations* has existed. Publicly funded research projects that support the exchange and secondment of young researchers, PhDs and post-docs between universities and industry have generated a strong basis for knowledge sharing across Europe, significantly reducing the fragmentation of knowhow. For wave energy, the nature of such distributed knowledge, however, is more generic than in tidal energy. It is more associated to topics such as wave energy resource characterization and analysis, methodologies for testing and modelling, designing and scaling of devices etc. rather than to device-specific technical solutions. This is consistent with the diverse nature of wave energy devices and the individual IP behind these developments.

Such R&D collaboration has a less direct impact on knowledge transfer than in the tidal sector but does, still, create an informal best practice sharing and common state of the art knowledge. The effect is amplified through information exchange at conferences, as well as through a number of National, EU and International activities and bodies such as Supergen Marine in the UK, EERA JP Ocean, ERA-NET, the Ocean Energy Forum and ETIP Ocean, INORE, the IEA and IEC. In addition, joint training activities such as Wavetrain and OceanNET, as well as other research exchange programmes, support the collaboration and information exchange.

A number of EU funded activities provide and present knowledge in a systematic way. The continued funding of such initiatives has certainly made a huge contribution to reducing fragmentation of knowledge as well as to sharing existing know how in various fields. Several examples are:

- Equimar, which delivered a set of protocols for testing and evaluating ocean energy devices;
- Marinet, providing access to and support from testing infrastructures;
- DTOcean, providing design tools for arrays and the necessary training.

Finally, maturing technologies are confronted with environmental consenting obligations. Conducting *joint research for consenting*, of which the UK's Offshore Renewables Joint Industry Programme is a good example, can speed up development.

Project finance

Many problems can be avoided by a *realistic vision of the risks*. It would help if there was a form of *standardisation*, which would also contribute to de-risking. While sector cooperation and knowledge sharing is a problem, there has been a lot of convergence in the sector. Projects are now relying more on off-the-shelf components, rather than designing everything themselves, which has been described as "an expensive way of ensuring failure". Standards for turbines and design of components would be required as part of upscaling efforts. Third party certification, and procedures for that, is also required. This may require more input from the Classification Society, in terms of people, time and skills. Moreover, designing devices to be compatible with standard components would save costs, time, and complexity and. would help accelerate the development of credible commercial devices.

Device manufacturers concentrate on their core technology, and should not have to bother about re-addressing issues concerning chains, anchorage, etc., possibly by making IP available at EU level. EMEC already helps by offering standardised connection slots. A standardised way of assessing risks is lacking as well, which makes comparison of projects difficult, especially across TRLs.

The way the MeyGen project is drawn up shows that investors now understand what the risks are in the sector. A good communication *link between the investors and the developer* has not always been present in the past*.*

It would be easier to draw money in on the basis of *loan guarantee schemes* – where governments would cap the potential losses of private investors. Overall costs to governments of such schemes would not necessarily be high.

State aid regulations need to be overcome as they can limit, delay or even stop the funding amounts getting to the project. In this respect, the EU DG COMP authorities are now learning how to assess such projects, and state aid approval was recently granted to the Raz Blanchard NEPTHYD project.[55]

Framework and regulatory conditions

A range of framework and regulatory conditions can help to improve the conditions for performance of the sector.

It is important to ensure that some level of *competition* will remain in place between different technologies, between the current existing players as well as some which are catching up.

Cluster development is seen as a good practice to bring together key actors, build trust amongst such actors and promote knowledge exchange. For example, the Marinel project brings together 12 Basque entities, including companies, business associations, research centres and academic institutions. This initiative, in which the Basque Energy Cluster participates, is led by Iberdrola Ingeniería y Construcción and has the financial backing of the Basque Government through the Etorgai programme. Other cluster developments can be noticed in Normandy (Cherbourg) and obviously in Scotland as well as Ireland (Cork).

The sector also needs to make use of the best skills and there is a need for *good education and training*. Much of the skills required are practical: works at sea in areas with strong current are complicated and require expensive naval assets and very specific knowledge. The sector is still at the beginning of the practical realization of this kind of operation for ocean energy. The IDCORE programme (Industrial Doctoral Centre for Offshore Renewable Energy at the University of Edinburgh) is considered a good example of an innovative approach to skills development in the sector.

Good procurement is vital to support the development of the sector - the decision by the French government to initiate the pilot farms for tidal energy in France has been crucial for the development of the sector. By the same token, the WES model is seen as a successful innovation. But there are many examples of pre-commercial procurement outside the sector too, e.g. NASA has an interesting pre-commercial procurement that works well.

The *stage-gated approach* of Wave Energy Scotland serves as a good practice. First level feasibility studies of a wider number of applicants are funded after which, based on results, a convergence to two or three demonstrations and ultimately one service contract is arranged. This model could contribute to the needed consolidation, while at the same time, enabling benefit from lessons learnt of earlier stage failures. As the program is still relatively new, experience is still thin and results from practice will have to show its effectiveness, but interest expressed in the mechanism is wide and promising.

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[55] http://europa.eu/rapid/press-release_IP-16-2654_en.htm.

Issuing of permits is another important field where progress has been booked. Site development is a lengthy process. Ocean energy developers may not face the same opposition as on-shore and off-shore wind developers. Nevertheless, securing all necessary permits can take time. In France, a simplified permitting procedure was set forth in 2015, as part of the 'Loi pour la Transition Energétique' (energy transition law), with a unique license to be delivered at Departmental level. However, the one-stop-shop system, as exists in the UK, is considered the most efficient practice around.

5.3. The way forward: an OET Monitoring Framework

5.3.1. The need for a systemic approach to monitoring OET development

The 'Ocean Energy Strategy Roadmap' has been developed [56] by and for all stakeholders active in ocean energy. It presents four Action Plans - that focuses on maximising inputs by private and public actors. These are:

- Action Plan 1: R&D and Prototype: A European phase-gate technology development process for sub-systems and devices;
- Action Plan 2: Demonstration & Pre-commercial: An Investment Support Fund for ocean energy farms;
- Action Plan 3: Demonstration & Pre-commercial: An EU Insurance and Guarantee Fund to underwrite project risks;
- Action Plan 4: De-risking environmental consenting through an integrated programme of measures.

The Ocean Energy Strategy Roadmap takes into account the priority areas from the European Technology and Innovation Platform for Ocean Energy (ETIP Ocean).

Helping delivery by incorporating a number of principles

The above Roadmap has been prepared by all stakeholders concerned, and it contains a wide array of themes and topics that all deserve to be captured and emphasised. In order to help the sector move forward and to implement the Roadmap, a number of principles are suggested, which are built on lessons from the past:

1. ***Differentiation by technology***: Ocean energy technologies are in different stages – and challenges for wave are currently quite different (technology-push) from those encountered in tidal range (market-pull);
2. ***Need for an integrated approach***: Failures from the past were never caused by one critical barrier, nor were they solely technological. The overall findings point toward the need for an integrated approach – where technological/non technological areas are covered simultaneously. When moving across the Technology Readiness Levels, some domains (Technological innovation, Research and innovation support) become less important, whilst other domains (Economics & management) and Project finance become increasingly important. However, such transitions are gradual and all domains remain important across the various development stages;
3. ***Public/private alignment***: successful development of ocean energy requires good public/private alignment co-operation, and commitment from both sides is a conditions for booking progress. While public support (framework conditions) is important in all stages of development, the forms of support also need to evolve along with the TRL's. Ocean energy development has been geographically focused in a number of Member States/regions where support conditions are put in place;
4. ***A need to focus on performance:*** in addition to inputs, investments and actions, there is a need for performance and for accountability – as a basis for future inputs, investments and actions;
5. ***Performance requires measurement***: and measurement requires a systematic framework of indicators which allow monitoring of progress over time;
6. ***A need for transparency and accountability***: progress (or lack of it) needs to be monitored, which requires cooperation from all actors. This need for transparency and accountability is linked to the public support provided;

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[56] https://webgate.ec.europea.eu/maritimeforum/en/frontpage/1036.

7. ***A staged development based on milestones:*** like with mountaineering expeditions, there is a need to move from point A to B, and from B to C. This requires identification of intermediate milestones that need to be reached, prior to moving to the next level.

Ocean Energy Development Monitor			**Phase 1:** **R&D**	**Phase 2:** **Prototype**	**Phase 3:** **Demonstration**	**Phase 4:** **Pre-Commercial**	**Phase 5:** **Industrial Roll-out**
		TRL	TRL 1-4	TRL 4-5	TRL 5-6	TRL 6-8	TRL 8-9
		Average investments	1 - 5 mln	10 - 20 mln	20 - 50 mln	50 - 100 mln	Unknown
		Lead time for returns	25+ years	15 - 25 years	10 - 20 years	5 - 15 years	2 - 10 years
Objectives to advance the sector	***OEE Roadmap objectives***		*Small scale device validated in lab*	*Validation of single full-scale device in real sea conditions*	*Development of simple and low-maintenance devices*	*Demonstration of reduction in LCOE*	*Effective demand pull and export to global markets*
			Tailoring of components	*Evidence of ability to generate energy*	*Evidence of continued device performance (reliability)*	*Evidence of array scale grid connectivity*	*Competitive LCOE vis-à-vis other RETs*
	Additional objectives		*Tailoring of materials*	*Convergence of PTO, gear box and control system concepts*	*Convergence of prime mover concept*	*Standardisation of array design in place*	*Mass production of off-the-shelf components/devices*
					Convergence of foundation / cabling / mooring concept	*Full understanding and demonstration of risks*	*Full scale commercial deployment*
Conditions For risk-controlled technological development	**Exo-genous conditions**	**Resources**	☐ Positive outlook resource potential	☐ Proven site-specific resources	☐ Reality-check based on prototype's resource utilisation	☐ Sufficient resource to achieve scale-driven LCOE-reductions (affordability scope)	☐ Sufficient global demand
		Constraints	☐ Mapped	☐ Mapped and monitored	☐ Mapped, monitored and mitigated	☐ Mapped, monitored and mitigated	☐ Mapped, monitored and mitigated
	Industry and market conditions	**Technical performance**		☐ Sufficient potential energy capture and conversion and acceptability	☐ Progressive threshold met for survivability and controllability (+ previous 'abilities')	☐ Progressive threshold met for reliability, installability and maintainability (+ previous 'abilities')	☐ Progressive threshold met for affordability and manufacturability (+ previous 'abilities')
		Supply chain	☐ Involvement of relevant (marine) expertise for tailoring components	☐ Involvement of an equipment supply chain in device development	☐ Existence of an equipment supply chain (specialised suppliers > in-house)	☐ Equipment and offshore operations supply chain committed - certification in place	☐ Multiple sourcing of all types of inputs is possible across the supply chain
					☐ Existence of an offshore operations supply chain	☐ Involvement of financial, insurance and legal supply chain	☐ Bespoke risk hedging products (insurance, futures, warrants) available
		Private finance		☐ Private equity (business angels)	☐ Investor readiness (private financial participation)	☐ Private equity involvement (majority financing)	☐ Private Equity / Institutional investors (>95% private financing) and involvement of utilities
		Techno-logical convergence		☐ Approaches for tailored components outlined	☐ <3 PTO, gear box and control system concepts	☐ <3 concepts for prime mover and foundation / cabling / mooring	☐ Standardised array and grid connectivity design
		Knowledge sharing	☐ Public-private R&D collaborations	☐ Learning from mistakes: mechanisms put in place	☐ Ability to demonstrate that previous experiences are built upon	☐ Sharing of performance / results for understanding and benchmarking risks	☐ Operational experiences (e.g. equipment / material failures) are shared
		Investor confidence	☐ Solid business model thought through	☐ Solid corporate management practices in place	☐ Performance indicators agreed and managed	☐ Consistent and reliable energy produced	☐ Energy production at scale proven
	Public Support conditions	**Infra-structure**	☐ Access to testing labs	☐ Access to test sites	☐ Allocation of space secured (MSP)	☐ Initiation of grid development at scale	☐ High quality grid coverage
		Regulation	☐ Conducive and stable long-term regulatory framework provided	☐ Alignment between support frameworks (EU-MS-regional)	☐ Bespoke environ-mental and state aid consenting procedures initiated	☐ Efficient environmental and state aid consenting procedures in place	☐ All regulatory infrastructre in place
		Knowledge management	☐ Provide access to publically paid reports and data sources	☐ Support to platforms, researcher mobility	☐ Technical assistance and training	☐ Integrated cluster support	☐ Competition is triggered
		Funding	☐ Public research grants	☐ Pilot project support	☐ Demonstration facilities	☐ Equity funding	☐ Guarantees, structured securities and market pull instruments available

Figure 5.2 Ocean Energy Technology Monitoring Framework
Source: Ecorys and Fraunhofer.

This above figure outlines the conditions (bottom part) which need to be in place for investments aimed at reaching the objectives (top part) in order to achieve risk-controlled technological development. Both conditions and objectives are highly specific to the relevant phase of technological development, and become more restrictive as technology matures.

5.3.2. First steps towards an OET Monitoring Framework

To facilitate implementation, we operationalised three ingredients: 1) the Ocean Energy Strategy Roadmap; 2) the principles outlined under section 5.3.1. above; and 3) our Framework for an integrated approach (**Error! Reference source not found.**5.1) into a 1-page OET Monitoring ramework which is presented above (Figure 5.2).

The Monitor has a number of characteristics:

- It differentiates the various needs of the *development stages*: R&D, Prototype, Demonstration, Pre-Commercial and Industrial Roll-out;
- It defines *criteria* which are specific to a development stage;
- It introduces *conditionality*: An important implication of applying such measures is that public support to wave and tidal development activities in the future would be conditional upon meeting certain performance criteria;
- It introduced *timing*: although early uptake of some types of activities or support could move the sector forward, the uptake can also be premature. This risks loss of investor confidence and/or being forced to cut losses on sunken investments;
- It also acknowledges that exogenous preconditions need to be in place, which require continued *feasibility-checks* on OE Technology potential with an increasing focus on LCOE as technology matures;
- It acknowledges the role that all actors need to play, each with corresponding responsibilities, which transcend solely technical and financial commitments. One could call it *a covenant between industry and public actors*.

Benefits of implementing the OET Monitoring Framework

Before implementing such an OET Monitoring framework, further operationalisation aspects still need to be elaborate., This could be done e.g. by involving a High Level Expert Group, the JRC, or other. Implementing such an OET Monitoring Framework would present important benefits. It would help the various actors to play out their role, each with corresponding responsibilities, which transcend solely technical and financial commitments. The following benefits could be expected:

a) Better management of expectations in technology development
In hindsight, many stakeholders identified that in the past expectations have been raised that could not be met. This suggests that a more prudent approach is required in the future, and that improvement is needed in respect to the methods and metrics currently applied to due diligence and evaluation of technologies. The OET Monitoring Framework can provide these.

b) Contribute to certification, performance guarantees, standardisation and accreditation
The pilot plants that are now being rolled out should help to provide a basis for performance guarantees, certification, standardisation and accreditation. All these can professionalise the sector, bring confidence to investors, enable bankability, and bring down risk premiums and LCOE. The OET Monitoring Framework can contribute to this process of harmonization and standardization, as it promotes comparability and compatibility.

c) A strong need to align framework conditions and support activities
In parallel, a conducive and stable policy framework is essential. Currently, these are favourable only in a certain number of Member States and regions (e.g. Scotland, Ireland, France, Basque region). Alignment of public funding activities is called for, especially between several EU funds (e.g. Horizon 2020 and ERDF), and national and regional funding schemes. Initiatives such as OCEANERA-NET are useful, but further coordination within and between EU and Member State levels is vital. The OET Monitoring Framework would allow public support actors to benchmark and compare activities and their performance within a unified framework.

d) Technology development support should be based on a staged approach
Within such a conducive support framework, and building on existing experience (notably Wave Energy Scotland), it is essential to use limited funds smartly. Whilst ‘picking winners’ is unwise for a public sector which is supposed to be technology-agnostic, convergence of technologies can be accelerated by encouraging the right players and by defining the right performance criteria, that are tailored to a specific technological readiness level. In tandem with an understanding of commercial readiness levels, and other project management indicators, funding authorities should have an “industrial logic at heart”. This means, being strict about the

conditions under which to continue funding, and at what points it is better to stop. The OET Monitoring Framework provides the tool to do so.

e) Build up an 'ex ante conditionality' for more selective and targeted support
An important implication of applying the above measures is that public sector support to wave and tidal development activities in the future could be made conditional upon meeting certain performance criteria. It is proposed to include '*ex ante* conditionality' (as used in European Structural and Investment Funds) into the selection criteria for evaluating research proposals in the field of ocean energy. Criteria for fulfilment of the ex ante conditionality could be included in the description of future calls for proposals, to guarantee that the projects supported under the next EU research programme (FP9) are targeted to the most promising projects. A systematic use of the ex ante conditionality across all funding mechanisms would substantially reduce the risks of loss of sunk investments in technology development, increase the effectiveness and efficiency of public support, and further increase future investor confidence in the sector.

KI-NA-27-984-EN-N

Publications Office

doi: 10.2777/389418
ISBN 978-92-79-59747-3