Turning the tide in the 2Seas

Tidal energy sector, supply chain analysis & recommendations for innovation & Business Development

Final report

This report closes 0 8.1 Series of Stakeholder events on certification, collaborative innovation & business development & the Deliverables D1.8.1 - D1.8.2 – D1.8.3 – D1.8.4 of the MET-CERTIFIED project;

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Abreviations	
2Seas	The counties & regions covered by the Interreg 2Seas
BOP	Balance of Plant
CB	Certification Body
CfD	Contracts for Difference
EIA	Environmental Impact Assesment
EIA	Environmental impact assessment
ETIPOcean	The European & Innovation Platform for Ocean Technology, was also entrusted by the European Commission to work on the technological aspects of its Ocean Energy Forum
iCfD	Innovation Contracts for Difference
IEC	IEC International Electrotechnical Commission
IECRE	EC International Electrotechnical Commission – Renewable Energy
iPPA	Innovation Purchase Power Agreement
KEET	Key Enabling Energy Technology
KET	Key Enabling Technology
LCOE	LCOE Levelized Cost of Energy
MRE	Marine Renewable Energy
Ocean Energy	All forms of RE (wind, tidal, wave, thermal, osmotic, biomass, PV) harvesting energy or resources to produce energy.
OTEC	Ocean Thermal Energy Conversion
OWF	OWF Offshore Wind Farm
PPA	PPA Power purchase agreement
RETL	Renewable Energy Test Laboratories (name used by IEC-RE for TF)
ROC	Renewable Obligation Certificate
SG	Salinity Gradient
SWAC	Sea Water Air Conditioning
TEC	Tidal Energy Converter
TF	Test Facilities
TRL	Technology Readiness Level
TS	Technical Standard
USP	Unique selling point
Important definitions	
Accreditation	The process in which certification of competency, authority, or credibility is presented. Organizations that issue credentials or certify third parties against official standards are themselves formally accredited by accreditation bodies; hence they are sometimes known as "accredited certification bodies". The accreditation process ensures that their certification practices are acceptable, typically meaning that they are competent to test and certify third parties, behave ethically and employ suitable quality assurance
Certification	The process or action performed by a Certification Body to attest that specific Renewable Energy equipment was fully evaluated according to a Scheme including the relevant requirements of one or more applicable Standard(s) accepted for use in e.g. the IECRE System.
Compliance	Certification or confirmation that the manufacturer or supplier of a product, meets the requirements of accepted practices or specified standards.
Conformity	If the product, service or system meets the requirements of a standard
Moderate environmental conditions	Usually occurring in sheltered locations and in mild climate. According to Douglas sea scale, adopted by World Meteorological Organization (WMO), moderate conditions correspond to a wind wave height (Hw) of 1.25 m and a swell
Standardisation	The process of implementing and developing technical standards based on the consensus of different parties that include firms, users, interest groups, standards organizations and governments.[1] Standardization can help maximize compatibility, interoperability, safety, repeatability, or quality.

1 Introduction

This report presents the lessons learned & recommendations during the business development activities performed in the activities 1.8 of the MET-CERTIFIED project.

All of these activities were originally set up to contribute to the overall **strategic** outcome of the MET-CERTIFIED project (*increase the adoption of insurable and therefore bankable marine energy projects in the 2 SEAS region through the development of internationally recognised standards and certification schemes in the sector*) mainly by 2 **tactical objectives**:

1) Engage the 2Seas (SME) supply chain in the procurements of the project
2) Stimulate innovation & SME business development for SMEs

This report does not describe the operational activities performed nor the tactical objectives achieved, but **consolidates the lessons learned and insights during the project, mainly in the following 3 themes**

1) Tidal energy sectoral analysis during the last 4 years (**chapter 2**);
2) A business inventory - supply chain mapping (**chapter 3)**
3) A set of innovation, SME business development & TF actions **(chapter 4),** that are based on
    a. adjacent activities & deliverables in the MET-CERTIFIED project (WP 2 & more specifically D 2.8 the Best Practices for Marine Test sites & case study for a multi –use TF);
    b. EU or sector wide roadmaps, but tailored as much as possible to the 2Seas region tidal energy value chain).

At the **start of the project, the tidal energy sector seemed to gain momentum** by entering peak flow at spring tide, with multiple projects & technologies under rapid & intense development, backed by interesting policy support activities, the rise of relevant Test Facilities (TF) and hot public & private money flowing in the sector. However, **this turned out to be slack tide with turbulent waters**, spinning up some technologies whilst simultaneously drowning others. The MET-CERTIFIED project and some project partners were in the midst of these vortices, to say the least.

During the project execution both internal project (partner) as well as external (sectoral) setbacks were observed. **Externally**, the tidal energy sector faced several policy support setbacks & shake outs of (leading) technology developers, whilst the drop in LCOE and industrialisation of offshore wind attracted a lot of (offshore energy) SMEs. The UK removed the tidal energy ringfencing in its ‘Contracts for Difference’ (CfD) scheme, whilst the French government delayed or even cancelled tidal energy tenders & support schemes, focussing instead on the rise in floating offshore wind. **Internally**, the original project partners Huisman, Van Oord & BlueTec withdrew between submission and the initiation phase of the project, whereby Tocardo took over the budget & project responsibilities. PTEC was unable to deploy its test site activities as originally planned. Tocardo went into administration twice during the project, which implied changing staff members & refocussing their own internal objectives twice. A third bankruptcy implied the exit of Tocardo as a project partner and initiated the quest for a new tidal energy developer to join the project (which was at the time of writing an unsettled issue).

As will be motivated later on, **keeping track of failures** (both internal and external and however they are defined) is extremely important to avoid duplication of past errors (both on technology development, project development or policy support). **Therefore the lessons learned in this context might have more relevance for future tidal energy development and cross-industry (emerging) technology development**, then if the context would be more supportive.

Just for completeness, the **operational** activities performed in the project Deliverables 1.8.1 till 1.8.4 were:

1) Inventory of business (opportunities) & recommendations for tidal energy (or in general: Marine Renewable Energy – MRE) in the 2Seas region, which is consolidated in this report;
2) B2B meetings & networking event, which are not described in this report but in the newsletters;
3) Organisation of site visits related to tidal energy, which are not described in this report but in the newsletters;
4) Facilitation of access to test sites, whereby mainly SMEs were encouraged to participate in testing in the 2Seas tidal MRE Test Facilities (TF), which were reported to the Interreg 2Seas Joint Secretary due to their confidential character.

All public deliverables can be downloaded on http://met-certified.eu/downloads.

This report does have not the intention to assess *if* tidal energy should be a key enabling energy technology in the 2seas region, as this is policy choice and thus beyond the scope of this project. **It is merely an attempt to provide recommendations & actions** so that, in the case tidal energy, is considered as a key enabling energy technology (KEET), it provides a concrete list of actions[1] to go forward, and ultimately & hopefully make tidal energy bankable.

Levelized Cost of Energy (LCOE) projections of tidal energy for 2025-2030 still face a large gap with e.g. offshore wind or PV. Of course, learning effect are important to drive down LCOE, and this only comes at scale. But competing in LCOE with these RE technologies will likely be a difficult battle to win, especially in the energy utility market. Therefore the tidal energy sector should focus primarily on its USPs: 99%[2] predictability of the resource on a very long term, combination with Sea Water Air Conditioning (SWAC), applications in remote locations (islands), combination with storage (battery & H_2) or delivering power directly to underwater dataservers. Last but not least, the combination with coastal defence infrastructure, especially at estuaries or areas with high tidal range, can be considered, however these faces the challenge of their compatibility with coastal defence itself or the incremental power production of large multi income source infrastructure projects (like eg. Swansea Bay Tidal barrage).

This report builds further on the tidal energy value chain analysis, policy support reports and roadmaps that were published before and during the MET-CERTIFIED project, and thus contains desk (literature) study. Reference is made to these reports, in order to **paint an objective, clear and coherent picture of the 2Seas tidal energy sector state of play**.

[1] Differentiated towards the MET-CERTIFIED target groups technology developers, Certification Bodies (CB), investors, insurers and TFs in mind

[2] Theoretically, 100% prediction is possible. However, some meteorological effects might have limited effects on tidal currents, especially near the surface.

2 Tidal energy sector analysis '16-19 in EU & 2S region

2.1 Looking back: turbulent waters for tidal energy

2.1.1 (Pre)commercial tidal energy projects: expectations vs achievements (installed capacity)

An objective analysis of tidal energy developments results during the last 4 years in Europe shows a mixed image. Excluding the 244 MW La Rance tidal range plant at Saint Malo (deployed in '66), the overall European ocean energy ever installed capacity is 26.8 MW, as indicated in Figure 1(OEE 2018), of which **11.9 MW were operational** late 2018 and 14.9 MW were decommissioned due to ended testing programmes. Selected projects are demonstrated in Table 1, whereby a worldwide project portfolio of wave & tidal energy projects is given in Annex. These numbers are in stark contrast with historic sectoral projections & industry expectations. 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 (Ecorys and Fraunhofer 2017). The roadmap presented by Ocean Energy Forum in 2016 had put forward a target of 850 MW by '21 (Ocean Energy Forum 2016).

TABLE 1 OVERVIEW OF INSTALLED DEMONSTRATION OR (PRE-COMMERCIAL) TIDAL ENERGY IN EUROPE. SOURCE: OCEAN ENERGY EUROPE, MET-CERTIFIED

	2000	2006	2015	2016	2017	2018	2019	Grand Total
Belgium								
Water2energy & De Meyer - Demo Antwerp BE						0,15		0,15
France								
DesignPro Renewables and Mitsubishi Electric Test in Seeneoh FR						0,025		0,025
Guinard Energies Test p66 in Brest FR						0,0035		0,0035
Sabella Ouessant Brittany Fromveur FR						1		1
EEL at Brest FR					0,01			0,01
Italy								
ADAG Kobolt - Messina Strait IT	0,05							0,05
Netherlands								
SeaQurrent							0,5	0,5
Tocardo Oosterscheldedam NL			1,25					1,25
Tocardo Afsluitdijk NL			0,3					0,3
Norway								
Norwegian Ocean Power at Gimsoystraumen NO					0,35			0,35
UK_Scotland								
Magallanes Renovables EMEC demonstration UK						2		2
Nautricity demonstration EMEC UK					0,5			0,5
Schottel Hydro - Sustainable Marine Energy Plat-I					0,28			0,28
Tocardo Interreg InToTidal UK					0,25			0,25
Andritz Pentland Firth - MeyGen phase 1A UK				4,5				4,5
Nova Innovation - Shetland tidal array UK				0,3				0,3
Orbital Marine Power Scotrenewables Tidal Power Ltd UK				2				2
SIMEC Pentland Firth - MeyGen phase 1A UK				1,5				1,5
Open Hydro scale demonstration UK		0,25						0,25
UK_Wales								
Minest0 in Holyhead Deep UK						0,5		0,5
Grand Total	**0,05**	**0,25**	**1,55**	**8,3**	**1,39**	**3,6785**	**0,5**	**15,7185**

Despite advancements by some technology developers, it still remains a challenge to get the 150 TWh of potential European tidal energy in the form of electricity to the grid. Numerous reports have analysed the ocean energy sector or root causes, reasons or interrelations of this "over promising & under delivery" dilemma. An integrated & excellent analysis report made in this context is the "*Study on Lessons for Ocean Energy Development*" (Ecorys and Fraunhofer 2017), which stated:

> *"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."*

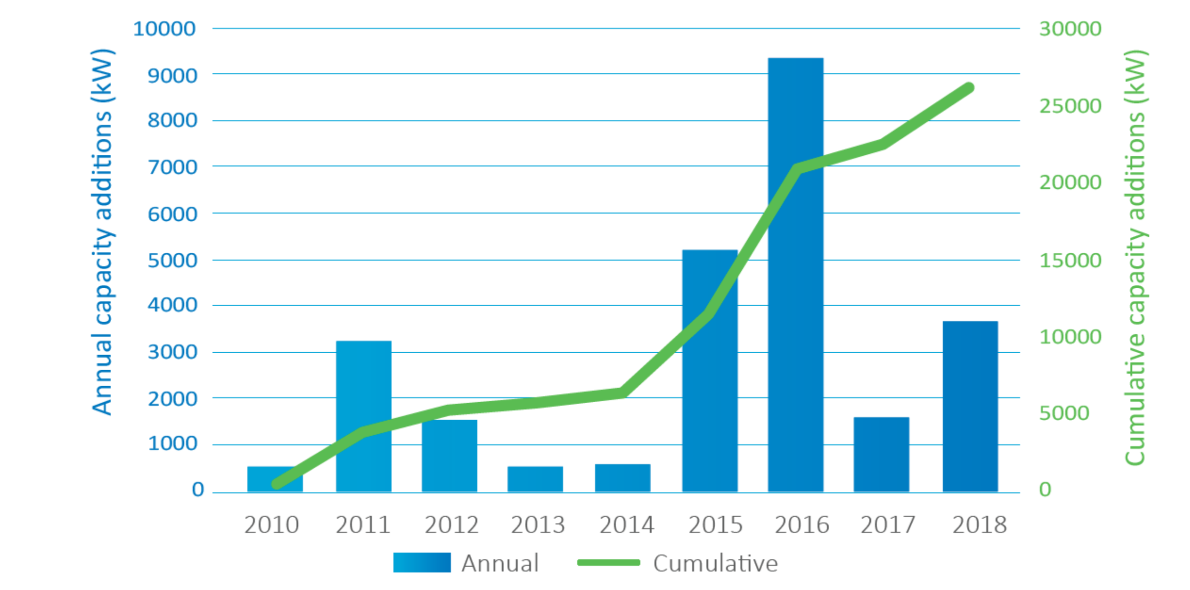


FIGURE 1: ANNUAL & CUMULATIVE TIDAL STREAM CAPACITY IN EUROPE (OEE 2018)

2.1.2 Turning against the tide: some technologies advance, but industry faces setbacks

The 2Seas MS national setbacks[2] with arguably the highest impact on individual OEMs but also the overall sector were:

1) UK: The UK ringfencing for tidal energy was removed in '17, whereby tidal energy had to compete in the Contract for Differences with, amongst others offshore wind. The differences in strikes prices were considered too big to bridge the gap, with no tidal energy projects who could secure their CfD. This resulted in the Meygen project getting stuck at phase 1A (6 MW) and not being able to proceed to 1B (32 MW). Also the tidal lagoon projects (like in Swansea Bay) were shelved. For the MET-CERTIFIED project, this also had an indirect impact on project partner PTEC, as well as on Tocardo for its UK projects (see point 3).

2) FR: The industry leader Group Naval / Naval energies decided to disinvest in the originally Irish Open Hydro technology, just 2 days after attempting to energize the new Cape Sharp Open Hydro turbine and just 6 weeks after the inauguration of the Cherbourg facility in July 2018. Naval Energies blamed a "*deterioration in the market*" and a "*lack of commercial prospects in the long term*" for its decision (Siggins 2018).

3) NL: Tocardo had to go in administration for the first time in January 2018, in order to protect its assets from the Canadian shareholder Tribute Resources. Tocardo refinanced and changed its name into Tocardo Solutions, but went bankrupt again in October 2019, whereby most investors involved still believe in the potential of tidal energy & Tocardos technology, but mentioned the inability to secure government operational support by the DEI (Demonstration Energy Innovation) (Grol 2019). In January 2020, QEDNaval & Hydrowing announced a new joint venture with Tocardo Tidal Power.

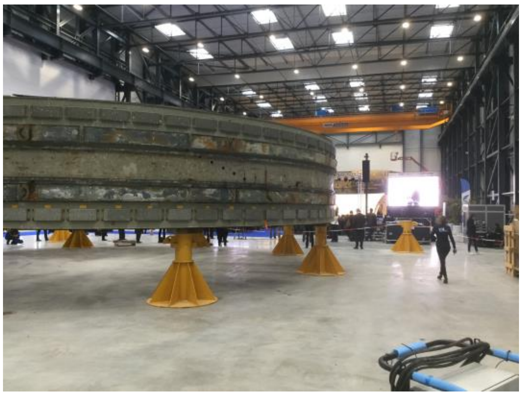


FIGURE 2: INAUGURATION OF THE CHERBOURG NAVAL ENERGIES (FORMERLY OPEN HYDRO) ASSEMBLY FACTORY, JUNE 2018, 6 WEEKS BEFORE THE DISINVESTMENT BY GROUP NAVAL.

Emerging (energy) technologies are often associated with shake-outs as a form of technology selection, but tidal energy has seen numerous shake-outs, which are presented in Figure 3 (Bluewater & Open Hydro need to be updated to “operations closed – knowledge transfer unclear”). Tocardo needs to be merged with QEDNaval & Hydrowing. A lot of lessons can be learned from Figure 3:

1) **Europe hosts a lot of tidal energy technologies**, relatively to the world. This is also confirmed by other European OEM & value chain analyses, indicating that UK (19%), France (9%) and the Netherlands (7%) are the European top players, whereby Europe is hosting 52% of the tidal energy developers worldwide, but also 70% of the ocean energy infrastructure (Magagne, Shortall et al. 2017).

2) **The shake-out is here: only a few tidal energy technologies remain**. This is not necessarily a bad thing in an emerging energy market. In offshore wind e.g. the European market is highly dominated by Siemens Gamesa (69%), MHI Vestas Offshore (24%), Senvion (5%), Bard Engineering (2%), GE Renewable Energy (1%) (WindEurope 2018). However, they currently are into a big industrialisation phase.

   The burden of proof of the tidal energy sector (pre-commercial) viability in the short term lies on the shoulders of Atlantis, Andritz, SME-Schottel, Scott Renewables (now Orbital Marine Power) & Sabella. Other technology developers should be included as well, like the joint venture between Tocardo-QEDNaval-Hydrowing or Minesto. Some of the technology leaders have shown steady progress, good availability and a good operational track record by delivering MWh (Figure 4) in the grid (Carcas, Davies et al. 2017, OES 2018, reNews 2018, OrbitalMarinePower 2020).

3) **But when knowledge gets transferred (by eg knowledge/IP or staff transfer), not all is lost**. On the contrary, avoiding errors from the past can be avoided.

4) **The ones that remain, have a long track record**. Typically they have had a steady progress along the Technology Readiness Levels (TRL), or have a long background in adjacent mature sectors like hydro power maritime propulsion or energy. But a long track record is not necessarily a guarantee for success, as entering an emerging market that yet needs to be established in term of government support, licensing & funding, comes with a high cost. Entering the market too early is detrimental for the in-house resources. Furthermore, these mature sectors typically rely heavily on industry proven technologies, instead of new start-ups, who focus too much on re-inventing a whole concept, instead of integrating as much proven technologies as possible.

5) **Investment participations by large shareholders** (technology OEMs, integrators or utilities) is not necessarily a guarantee for success.

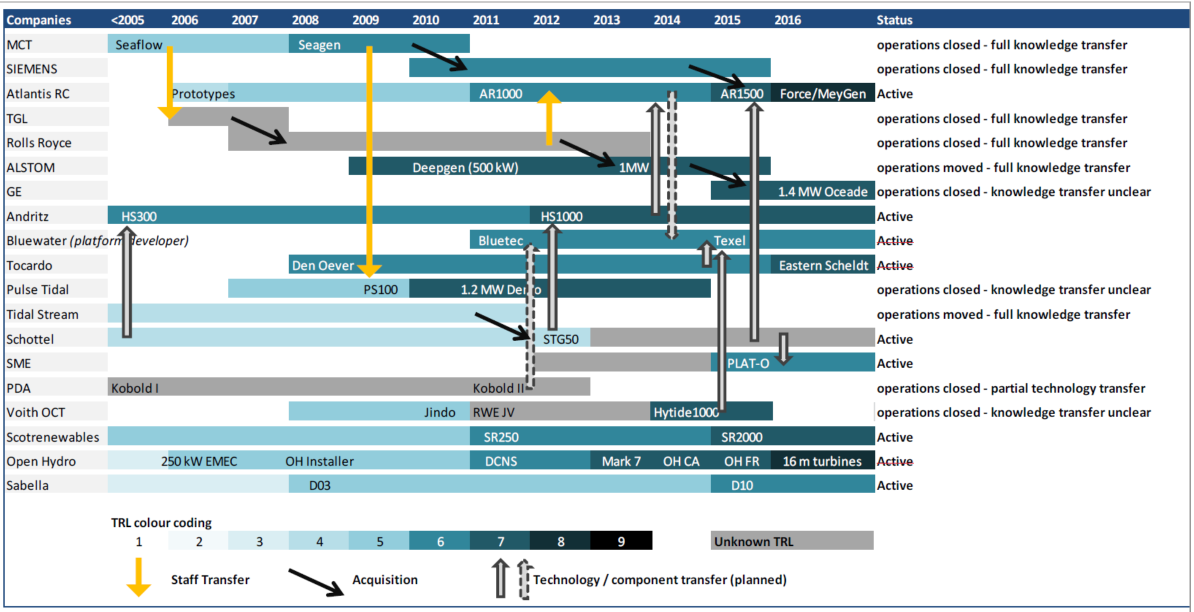


Figure 3: Schematic overview of chronologic development of the tidal energy sector (Ecorys and Fraunhofer 2017).

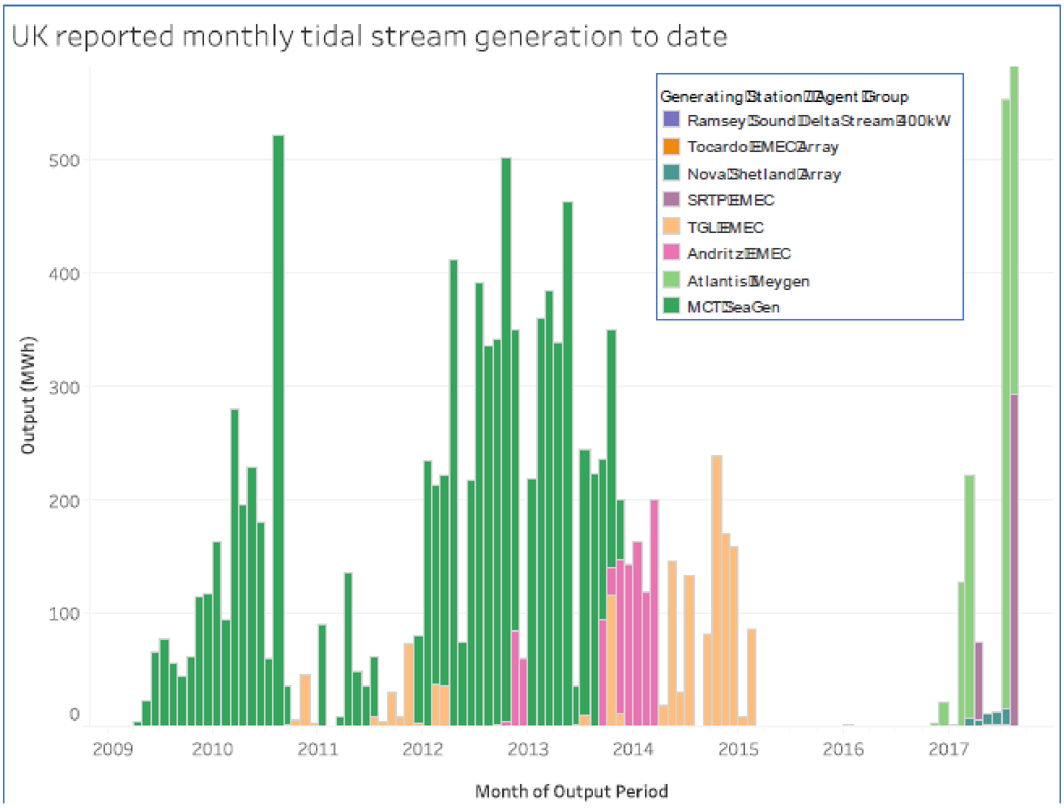


Figure 4: Tidal stream generation reported to OFGEM UK (Carcas, Davies et al. 2017)

2.1.3 EU, MS & regions (public) funding activities: TRL 8

In the framework of the SET Ocean implementation plan (SET 2018), an aggregated analysis was made of the public funding by the EU (FP6, FP7, H2020), national and regional programmes known to JRC for the period 2007-2019, including the ones who were granted for 2018 & 2019 and were known at the time of the analysis (Feb 2018, so the Interreg La Manche Tiger project of € 46 mio budget/ 28 mio funding was not yet incorporated in this analysis).

Key take-aways from this analysis are (Table 2):

1) This funding has contributed to a **project portfolio of a total of 1.36 b €** with 776 m € public funding (Table 2).
2) **470 m € of these funds were allocated to tidal energy**, 270 m € to wave energy.
3) The **TRL 8 tidal projects received approximately 170m** (Figure 5, right). Demonstration is important, but as will be motivated in § 4.6.6, doing so without a stage-gate approach, is a sub-optimal use of (public) investment.
4) From '14 onwards, the tidal energy sector secured funding in numerous projects between TRL 5-8, clearly demonstrating the public funding priority by the EU for **demonstration projects in tidal energy** (§ 2.1.3).

TABLE 2: OVERVIEW OF PUBLIC FUNDING TO THE OCEAN ENERGY SECTOR DURING 2007-2018(SETPLAN 2018).

Program	Total project costs	Funding contribution
OceanERA-NET	€ 11,984,284	€ 8,000,000
ERDF	€ 264,941,103	€ 209,509,646
EU	€ 657,529,725	€ 363,731,270
National	€ 436,629,384	€ 199,288,780
Total	**€ 1,364,908,496**	**€ 776,382,084**

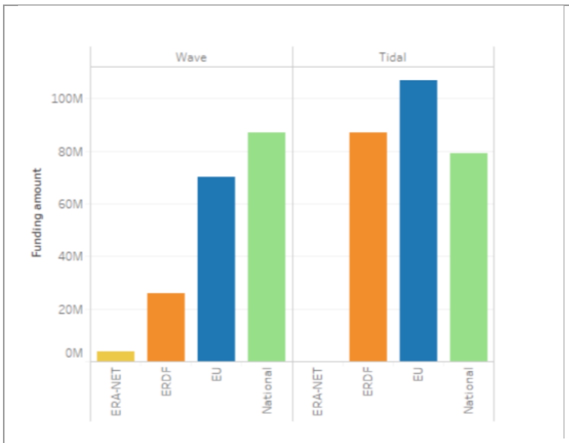


Figure 5: Funding directed to wave and tidal energy technology for the period 2007-2019. Projects or programmes directed to ocean energy in general are not taken into account in this graph.

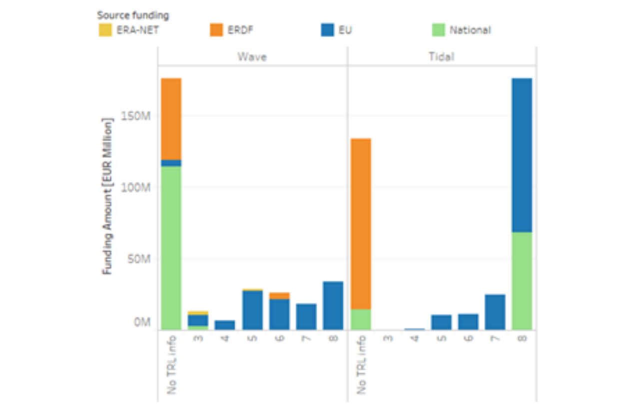


Figure 6: Funding directed to ocean energy per TRL for the period 2004-2019. Project of programmes where no specific TRL information could be retrieved are categorised under no TRL info. Programmes directed to ocean energy R&D without further details are omitted from the analysis.

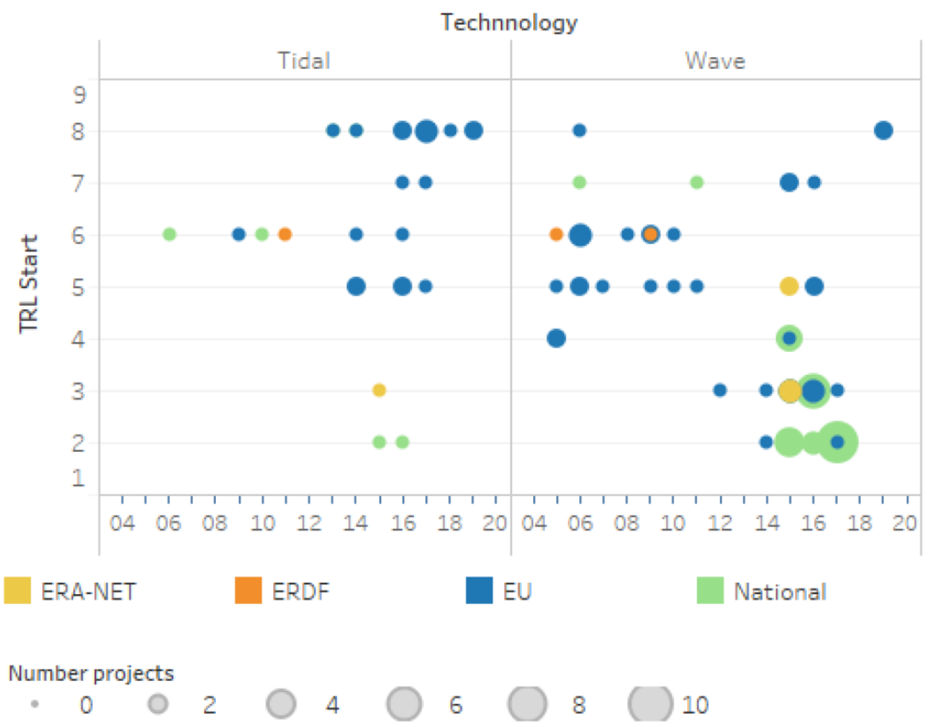


Figure 7: Assessment of the phase of development (TRL) for each project/funding stream. The size of the dots refers to the number of projects awarded

An overview of (selected) European (publically funded) ocean energy projects is presented in Annex.

2.1.4 Leading tidal energy technologies: standards & certification

In the context of the MET-CERTIFIED project, the *communicated* standards used or certification strategy used by the leading companies (excluding Tocardo) is worthwhile mentioning. Internally they might be using more standards or certifications, but some have a different external communication strategy w.r.t. to standards.

The Atlantis AR-1500 turbine of Meygen 1 indicated the use of the following guidelines, standards or certificates (Thake 2018) :

1) IEC-TS 62600-200: Power curve/Power performance assessment
2) IEC-TS 62600-201: Tidal Energy Resource assessment
3) Statement of Feasibility DNVGL - SE -0163
4) DNV-GL-ST-0164 Tidal Turbines - Rules and standards
5) DNV-GL-SE-0163 Certification on tidal turbines & arrays
6) IEC 61400 Wind Turbine systems, various parts
7) General ISO EN BS standards (not specified in detail)
8) Regulations
    a. CDM 2015, UK H&S executive
    b. EC Machinery Directive 2006/42/EC - UK Supply of machinery safety regulations 2008

Orbital Marine Power focusses a lot on the achieved operational hours and MWh delivered, but relatively little on the used standards or certifications. As indicated in the introduction, this does not necessarily mean that they are not used. In its project description to the Marine Warranty Surveyor (OrbitalMarinePower 2018), which can be considered as a reference document to outline 3rd party certification (although mainly focused on the general safety of the marine operations, not on e.g. Power performance), is stated:

The Orbital O2 structural components are designed for a 25-year operational lifetime though certain components within the device will have a shorter lifetime. The design & construction of the structure adheres to a number of DNV-GL and other relevant offshore design standards. The structure is designed *to survive rare extreme environmental conditions that occur with a very low probability, such as a 1 in 100-year wave.*

DNV-OS-E301 is the only one mentioned for mooring in particular. Indeed, loss of mooring can have quite catastrophic consequences, as was the anecdotal case with Oceanlinx wave generator (Figure 8), that lost mooring and drifted to the breakwaters of Port Kembla in Australia, in May 2010 only 3 months after deployment, making a 5 mio AUD asset in a salvage liability, resulting in Oceanlinx bankruptcy in '14. The salvage was only solved 7 years later by Polaris Marine, who refloated it, towed it to deep waters and eventually sank it into the abyss (PolarisMarine 2017).

FIGURE 8 :AUSTRALIAN OCEANLINX (WAVE ENERGY – OSCILLATING WATER COLUMN), IN OPERATION, DURING THE MOORING LOSS IN 2010, 3 MONTHS AFTER DEPLOYMENT DURING A STORM & AS A STRANDED LIABILITY (HASHAM 2010, GRAYDIVINGSERVICES 2020)

Nova Innovation does not mention any specific use of standards or certifications on its website. In the H2020 EnFait project, a roadmap to certification for Nova Innovation was outlined Figure 9. It was however emphasized that the EnFAIT project will not in and of itself result in a certified tidal energy converter. However, the certification processes and procedures outlined allow for a framework to be established for **future** certification of the Nova Innovation M100 tidal energy converter (MacGillivray 2018).

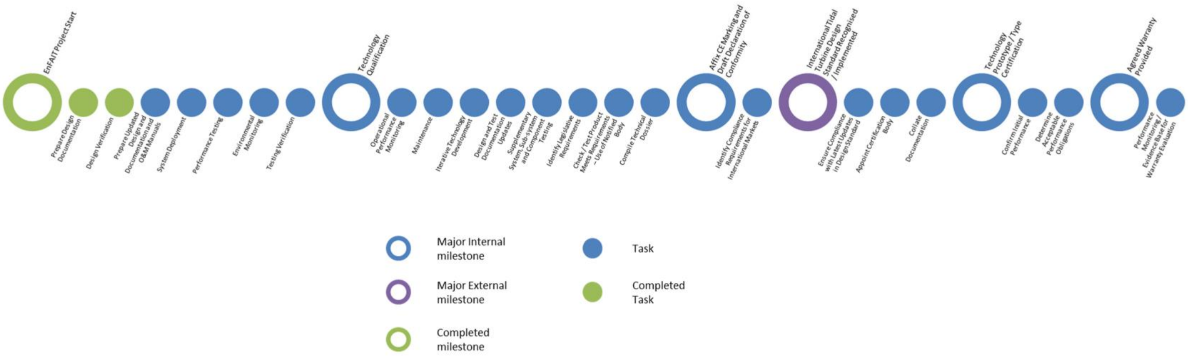


FIGURE 9: NOVA INNOVATION PATHWAY TO CERTIFICATION

Minesto outlined its certification and standardization strategy in the EU H2020 Powerkite project (Westre, Bergvall et al. 2018), whereby they state,

> *That identifying which standards and guidelines to implement and follow, and ultimately be reviewed and assessed against is a balancing act for an emerging industry…. There are several organizations and companies that are interested in having their guidelines and standards being used, as this means growing market shares as well as other opportunities*

Minesto continues to focus, not just on the choice of guidelines and standards to follow, but also on the choice of the CB.

> *It is important to find the right level standards as well as review parties (CB). By aiming too high, costs for such reviews may constitute a hurdle in its own right, while aiming too low may introduce undesirable risk to the development projects.*

After which Minesto state that, in the long run, they most likely will pursue a type certificate (Type Approval), most likely against DNVGL ST-0164. They then state why they have selected DNVGL as their CB for a third party verification of Minestos tether design: DNVGL currently owns the governing standard, DNVGL actively engaged in the sector early on (resulting in an impressive reference list) and last but not least, due to the sheer size, DNVGL has critical mass in terms of ocean energy or marine warranty surveyors.

Minesto considers some of the Technical Standards (TS) IEC 62600 tidal series (-200, -201, -10, -2) too rigid for ocean energy as they originate from the Oil & Gas, which is characterized not only by a difference in balance sheets, but also in much higher impacts (loss of life, loss of infrastructure or environmental impact than the O&G sector). They do however base their view on the applicability of TS IEC 62600-200 & -201 to their tidal energy "kite" concept, contrarily to the 3-bladed horizontal axis tidal energy turbines.

An interesting example of a recent successful deployment in the wave energy sector is **AW-Energy**, who installed its 350 kW Waverolle in Peniche in Portugal. Waveroller has had a very clear and strong focus on its certification strategy, resulting in its certification by Lloyd's Register (LR) for its WaveRoller® device. It has been awarded following previous certifications by LR through the Technology Qualification certificate process laid out in DNV-OSS-312 Certification of Tidal and Wave Energy Converters (AW-Energy 2020). This strategy seems to lead to a success, although it is yet to be seen if Waverollers power performance and operational availability is on par with expectations. Not surprisingly, Waverollers CEO, Christopher Ridgewell, formerly worked at Lloyds Register, and thus knows the certification case & industry.

Although this overview is anecdotal, and is not a multivariate critical success factor analysis for pre-commercial deployment, it seems that the use of standards & 3rd party certification is a good indicator for success in the deployment of a first prototype. However, DNVGL DNV-GL-SE-0163 & DNV-GL-ST-0164 seem to be considered as the most common used and governing benchmarks, instead of the IEC-RE schemes.

2.1.5 Case UK: Electricity produced by tidal energy in UK

The UK electricity produced from tidal energy can be derived from the OFGEM reported Renewable Obligation certificates from Figure 4 but only comes from 3 producers: Meygen fase 1A (Atlantis), Scotrenewables (now Marine Orbital Power) & Nova Innovation.

However, the amount needs to be placed in the context of all producing Renewable Energy technologies. **Tidal power only accounted for 0.003% of the ROCs issued on UK basis and 0.016% on a Scottish basis, even though tidal power receives the highest amount of ROCs/MWh: 5 if under 30 MW project size (DECC 2012)**. The 5 ROCs for wave and tidal energy are a clear policy choice with the intent to support early commercial wave & tidal energy projects, and clearly showed the UK government willingness to issue operational (generation side) support, but it only comes into play in pre-commercial TRL8-9 stage.

This clearly shows that currently tidal energy, even in the UK, is neglectable in terms of commercial electricity generation. This does not imply any consequence as such for its potential though.

TABLE 3: UK OFGEM ROCS ISSUES PER TECHNOLOGY FOR 2018 (OFGEM 2019)

Technology/Region	England	Scotland	Wales	Northern Ireland	Total	UK %	Scotland %
Offshore wind	33016581	1210107	4697301	0	38923989	38,7%	5,5%
Onshore wind	6312659	15902691	2192309	3338796	27746455	27,6%	72,8%
Fuelled	13855343	2133747	463098	1132570	17584758	17,5%	9,8%
Solar PV	8367550	54367	727193	450786	9599896	9,5%	0,2%
Landfill gas	3104244	357384	102803	68724	3633155	3,6%	1,6%
Hydro	53388	2111918	156263	42427	2363996	2,4%	9,7%
Sewage gas	626929	32949	34116	0	693994	0,7%	0,2%
Tidal power	**0**	**3506**	**0**	**0**	**3506**	**0,003%**	**0,016%**
Total	65336694	21838223	8373083	5033303	100581303		

2.1.6 Trend: crowdfunding as new source of income for tidal energy

Several tidal energy developers have launched successful crowdfunding campaigns:

1) Nova Innovation with Seedrs.com: 500.000£ in order to "fast-track its technology and accelerate growth across Europe & North America" (in November 2019).

2) Marine Orbital Power with Abundance Investment: 30 month secured debentures, raising £7 mio (average of 2278 individual investors with approximately 3000£ investment) in January 2019 (OrbitalMarinePower 2019, OrbitalMarinePower 2020).

3) Tocardo Tidal energy (Tocardo 2016) with DuurzaamInvesteren.NL (2016): 850.000 € collected in one day for the "Oosterschelde Tidal Power 2 B.V." Oosterschelde Getijdenstroomcentrale. The memorandum mentioned to increase its equity, in order to pursue further developments and that it was outside the supervision of Netherlands Authority for the Financial Markets (Tocardo 2016).

The success of these crowdfunding actions are remarkably, and could be interpreted as a proxy for the public support that tidal energy currently has. This is important for the large scale (array) deployment of tidal energy. Marine Orbital Power stands out and the press release mentions the high share of local (Scottish) investors.

However caution is recommended. These investments are currently not comparable to investing in Renewable Energy Cooperations or Energy Saving Companies (ESCO), who are investing in fully commercial energy production or efficiency solutions, with a relatively stable and risk-free dividend when managed well. Individual (non-accredited) investors should be clearly warned about the risks in the memorandum or prospectus. Crowdfunding investors anno 2020 are clearly supporting this technology, but if their investment sinks, they might become opponents.

2.2 Current status: slack tide for tidal energy policy support

This section describes the scattered policy support in EU & of the4 MS of the 2Seas region, including its impact on the current status of the supply chains in the 4 countries. In the last section, some innovations are mentioned that arose from the tidal energy sector.

1. National support policies are relatively limited (France & UK) or absent (BE-Netherlands), or subject to decreased (not increased) ambitions (UK CfD ringfencing removed).
2. Offshore wind was & is gaining momentum (industrial scaling, currently over 20GW), with decreased LCOE and attracting a lot of the maritime – offshore energy - supply chain.
3. Some leading technologies remain in the water, delivering MWhs in the grid & collecting operational hours, but some technologies are stuck in the valley of death, resulting in withdrawals of large scale investors.
4. LCOE projections of the tidal energy sector itself still face a large gap with e.g. offshore wind or PV. Therefore the tidal energy sector should focus on its USPs: 99% predictability, combination with SWAC, applications in remote locations (islands), combination with storage (battery & H2), delivering power directly to dataservers.

2.2.1 Scattered policy initiatives instead of stage-gate support in the 2Seas

Tidal energy (current, low head estuaries or low head tidal lagoons) currently did not yield full potential. However there is little doubt that the tidal energy technology potential and business case is still strong, in the long term. The failure of the sector to grow at an industrial scale, has many root causes.

In this section, the focus lies on the scattered policy support on a EU basis Table 4. Of course some funding schemes explicitly want to increase cross- EU collaboration, like Interreg, OCEAN-ERA net and others.

Typically government support is high on demonstration type projects (TRL 8-9), as was demonstrated in § 2.1.3, which is also expected in the so-called "valley of death" funding paradox. But in essence there is little coherences amongst different funding schemes (Table 4).

Furthermore, stage-gate approaches are not the standard good practice, but rather an exception. A Feed In Tariff (FIT) is of no use for TRL4-5 technologies, and might be even counterproductive, by pushing technology developers to advance too fast and cut corners in their development strategies. **In order to counteract, a stage-gate approach is recommended (see § 4.6.6**). An overview of these MS incentives relative to the deployment in scale is presented in Figure 10.

Table 1. High level mapping of current Ocean Energy activities in MS and Regions and indicative available support

	Is there a national Ocean Energy Policy outlined?	Is there an assigned Ministry/ Department owner at Government Level?	Is there operational responsbillity for the delivery of the Ocean Energy porgrammes	National PRIORITY ACTIONS - TECHNICAL	PRIORITY ACTIONS - ENVIRON	PRIORITY ACTIONS - FINANCE	PRIORITY ACTIONS - OTHER	2016 - Amount (€M) spent on Ocean Energy by MS	2017 budget planned	Estimated Budget allocation from 2018-2020 (note this is not considered as commitment only an indicative estimate of possible allocation of budget to 2020)
IE	YES	YES	YES	YES	YES	YES	YES	4M EUR	5M EUR	Yes - Under the OREDP the Government committed 30M EUR up to 2020
BE	NO*	YES	NO				YES	0.6M EUR		
CY		YES	NO	YES	YES	YES	YES	99M EUR	20M EUR	
DE										
ES	NO *	YES	YES	YES			YES	1M EUR	TBC	
ES (Basque)	YES	YES	YES	YES		YES		2.5M EUR	2.5M EUR	Demonstration programme: 5M EUR
ES (Cantabria Region)		YES	YES	YES			YES	6.0M EUR		
FR	YES	YES	YES							
FR (Normandy)	YES	YES	YES	YES			YES			
PT	YES	YES	YES	YES	YES	YES	YES	0.44M EUR	18.9M EUR	23.15M EUR
IT	YES	YES	YES	YES	YES	YES	YES	1M EUR	0,5M EUR	Yes - approximately 6M EUR up to 2020 through competitive national projects
SE	No *	YES	YES	YES	YES	YES	YES	4.3M EUR	2.7M EUR	3.9M EUR allocated so far (from Swedish Energy Agency). NB: most likely more funding will be allocated
UK (NI)	YES	YES	YES	YES	YES	YES	YES	No	No	N/A
UK(Wales)	YES	YES	YES	YES	YES	YES	YES	3M EUR	8M EUR	45M EUR
UK (Scotland)	YES	YES	YES	YES	YES	YES	YES	15 M EUR	15 M EUR	45M EUR
UK (BEIS)										

Table 4: High level mapping of current ocean energy activities in MS & Regions and indicative available support (SET 2018)

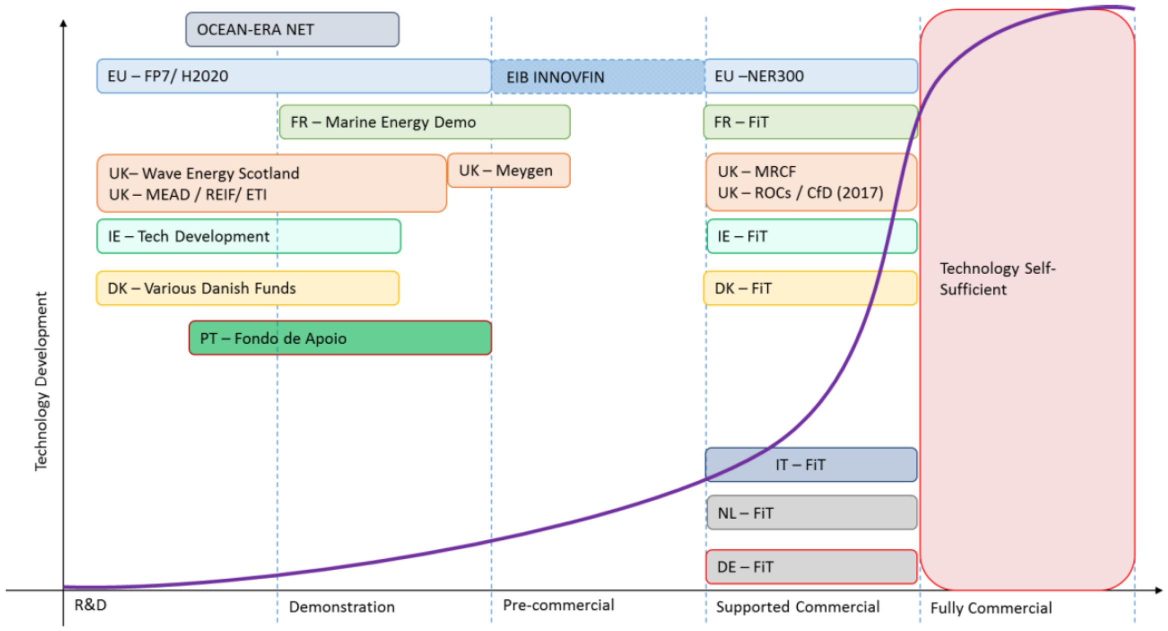


Figure 22. Summary of market push and pull mechanisms for ocean energy in the EU based on Carbon Trust deployment scenarios [Vantoch-Wood 2016]. Supported commercial indicates technologies that have a market but receive support such as FITs, whilst the term fully commercial refers to energy technologies (not necessarily RES) that do not require FITs or other support schemes, and are thus self-sufficient.

FIGURE 10 SUMMARY OF MARKET PUSH & PULL MECHANISMS FOR OCEAN ENERGY IN THE EU BASED ON CARBON TRUST DEPLOYMENT SCENARIO'S (MAGAGNE, MONFARDINI ET AL. 2016).

2.2.2 Financial & political support UK

The UK Energy Act 2013 introduced the Contract for Difference CfDs scheme. This scheme is at the basis of UK energy concession auctioning, but to date, not a single tidal energy technology or project was able to secure CfD funding, as the bridge between other technologies is considered too high. Furthermore, the LCOE price drop of offshore wind is however very successful for CfD allocation. In september '19, CfD prices for offshore wind of 39-41 £/MWh were amongst the winning tenders (Figure 15).

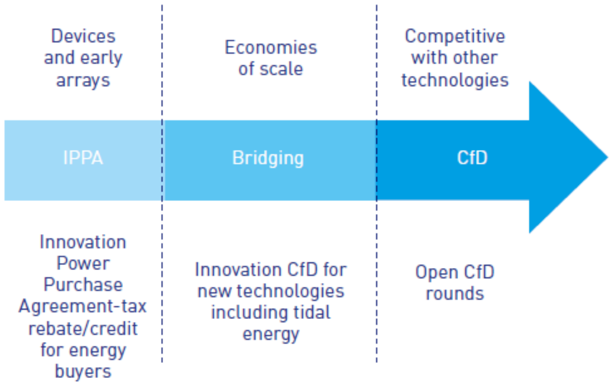
There was no CfD auction in 2018. The third round of auctions, worth £60m, opened in May 2019. These are shown in the table below, compared with the 2019 draft strike prices for other generation technologies in the "less established" category and the 2017 CfD second round of auction results. **Despite defining strike prices for wave and tidal of £281/MWh for wave and £225/MWh for tidal stream** (were quoted for projects due to deploy in 2023/24 in the BEIS 2017 Draft Allocation Framework), without a ring-fenced budget for these technologies, tidal energy was not able to secure its CfD support, as anticipated (OES 2018, OFGEM 2019, OWC 2019).

UK Contracts for Difference for less established technologies: Draft strike prices and Auction results (£/MWh)

Technology	Draft strike prices		2017 Auction results	
	2023/24	2024/25	2021/22	2022/23
Offshore wind	56	53	74.75	57.50
Advanced conversion technologies (with or without CHP)	113	111	74.75	40
Anaerobic digestion (with or without CHP, >5MW)	122	121	-	-
Dedicated biomass with CHP	121	121	74.75	-
Wave	281	268	-	-
Tidal stream	225	217	-	-
Geothermal	129	127	-	-

FIGURE 11: UK STRIKE PRICES AND AUCTION RESULTS FOR LESS ESTABLISHED TECHNOLOGIES (£/MWH)

The Marine Energy Council (UKMEC) was formed in 2018, intended to be the unified voice of the sector to engage with Government to secure support. In order to bridge the gap with the traditional CfDs, new incentives are proposed like:



1) **the Innovation Power Purchase Agreement (IPPA)** can be used to support technology developers to deliver projects of up to 5MW whilst protecting consumers from costs by providing off-takers a tax rebate when buying marine energy (based on the first 120 MW tidal energy deployed). This would allow marine projects to sell their power over the market rate, with the off-takers reclaiming excess costs against tax, with this cost declining over time (UKMEC 2019).
2) **Innovation Contract for Difference (iCfD)** is a bridging mechanism that enables utility scale projects to commercially (for an installed capacity between 120-920MW) advance to a level where they can compete with the current CfD auctioning. This would allow for a new 'pot' within the CfD framework for all new technologies such as wave, tidal stream, and Advanced Combustion Technologies to complete among themselves.

However, this industry proposal is not yet implemented by the policy side. A further motivation of this scheme, with the UK socio-economic benefits and the exact proposed mechanisms can be found in the Marine Energy Councils position paper (UKMEC 2019).

Besides tidal current or river stream energy, the developments of the ultra-low head tidal lagoon energy & storage projects are worthwhile mentioning in this context (Hendry 2016). The 2017 UK Government strategic review of tidal lagoons established that the 320 MW Swansea Bay tidal lagoon would serve as a "pathfinder" project for the sector subject to value for money for the UK taxpayer. The project was seeking a 35-year power price contract plus significant investment by the Welsh Government. In 2018, the UK Government concluded that this represented poor value for money, the costs believed to be much higher than alternative sources of low carbon power, so would not agree to these terms.

As for the **UK supply chain** the following observations & recommendations are made in cross industry value chain analysis (BVGassociates 2019). Given the important tidal resources in the UK, the numerous companies involved in tidal energy as well as a mature offshore wind supply chain, the **UK should take the opportunity of becoming a leader not only locally but also in European projects.** It is therefore also important that R&D and funding efforts from governmental organisations and institutions continue. In addition to this, there is a gap in the supply chain of **dynamic subsea cables** which could be closed by British companies. Moreover, British tidal developers could benefit from the experience acquired in the development of offshore wind projects.

2.2.3 Financial & political France

France implemented the Energy Act (*Loi de Transition Energétique pour la Croissance Verte*), adopted in August 2015, which defines an aim of 40% renewable energy in the electricity mix by 2030. The application decree called for a "Pluri-annual Energy Policy". However, for ocean energies, the mention is limited to the availability of public incentives for prototypes and pilot farms of converters until the LCOE of these technologies is demonstrated to be commercially competitive with respect to other renewable sources of energy. An estimated cumulative budget of this overall support for ocean energy in 2018 is €88 million, which includes 6 large completed or ongoing projects for two high-energy tidal zones which have already been identified (Raz Blanchard and the Fromveur Strait in Brittany), a major part of the selection criteria will rely on the assessed price per MWh. However, the present LCOE of tidal energy is considered too high in order to enable such a call (OES 2018).

As for the **French supply chain** the following observations & recommendations are made in cross industry value chain analysis (BVGassociates 2019). Given the good tidal resources in France as well as the numerous companies involved in tidal energy, France should take the opportunity of becoming a big player not only in French but also other European projects. It is therefore also important that R&D and funding efforts from governmental organisations and institutions continue. In addition, the gap in supply chain for support structures for tidal energy could be closed by French companies. Furthermore, since offshore and floating wind are also about to take off, the local tidal supply chain could benefit from this.

2.2.4 Financial & political support NL

The Netherlands does not have a national strategy for ocean energy and nor are there specific targets. The marine spatial planning is focused on offshore wind, special areas have been appointed for offshore wind (3500 MW). There are no commercial offshore ocean energy projects planned yet. For 2019, the generic national subsidy scheme (SDE, stimulating renewable energy), has also been opened for tidal current, wave energy and free flow energy. The maximum subsidy for renewables has been reduced to €0,13/kWh, due to the decreased costs of offshore wind, which is considered as the benchmark (OES 2018).

In June 2019 the Dutch government presented its Climate Plan (RVO 2019), referring explicitly to the "Routekaart windenergie op zee 2030" (Wiebes 2018) and beyond. However, energy from water (like tidal energy) was not mentioned, prompting the Dutch sector organisation Energie uit Water to request to a similar "Routekaart energie uit water" based on a position paper (EWA, Ackermans et al. 2019), which was discussed in September 2019 by the Dutch House of Representatives (Second Chamber). As of the writing of this report, it was unclear how the Dutch government will further implement this.

As for the **Netherlands supply chain** the following observations & recommendations are made in cross industry value chain analysis (BVGassociates 2019). Dutch companies, helped by governmental organisations and institutions, should focus on developing and being involved in projects outside of the Netherlands, where the tidal resources are more important, as is already the case for a number of companies. In addition, the gap in the supply chain for project development for tidal projects could be closed by Dutch companies. Furthermore, Dutch companies could benefit from the experience acquired in the development of offshore wind projects.

2.2.5 Financial & political support BE

The Belgian government has not put any policy objectives forward regarding ocean energy in specific, but does have a generic framework to extend the offshore renewable capacity up to 4 GW by 2030 (NEKP 2019), including a 2nd zone for offshore renewable energy in the new Marine Spatial Plan (BS 2019). Although other forms than offshore wind are possible, it is expected that offshore wind will be the preferred technology, as the resource for wave & tidal on the Belgian Part of the North Sea is too low to be economically feasible with current technologies (Mathys 2012). The 478 MW Seamade offshore wind project is currently under construction. In the original grant agreement of ’12 contained a condition to develop wave energy. However, this site only has 6,5 kW/m of wave energy, depths of 35-40m and no available (wave) technology exists yet (OES 2018).

As for the **Belgium supply chain** the following observations & recommendations are made a cross industry value chain analysis (BVGassociates 2019). Belgian companies are virtually absent from the tidal energy supply chain. There are however governmental institutes and enabling bodies involved in tidal energy and this could enable the creation and insertion of Belgian companies in this technology, preferably in other countries where the tidal resources are more important. In addition, Belgian companies could benefit from the experience acquired in the development of offshore wind projects.

2.3 Looking forward: turning the tide

2.3.1 beyond LCOE

As argumented before, the success and aggressive LCOE drop of offshore wind has had a negative impact on the development of tidal energy (projects, technologies & supply chain), when solely using LCOE as a benchmark. Indeed numerous LCOE prospections have been put forward by the tidal energy sector.

In the EU SET Plan quantitative targets were set for the LCOE of tidal stream and wave energy, which should be reduced to at least 150 €/MWh in 2025 and 100€/MWh in 2030 (SETPlan 2018).

The European Commission Joint Research Centre observed prices for tidal energy projects between 340-380 €/MWh (based on own calculations of restricted data of funded project, assuming a relatively high learning rate of 12% and a discount rate of 12%). In 2015, 600 €/MWh was observed, indicating a sharp increase (Setis 2019).

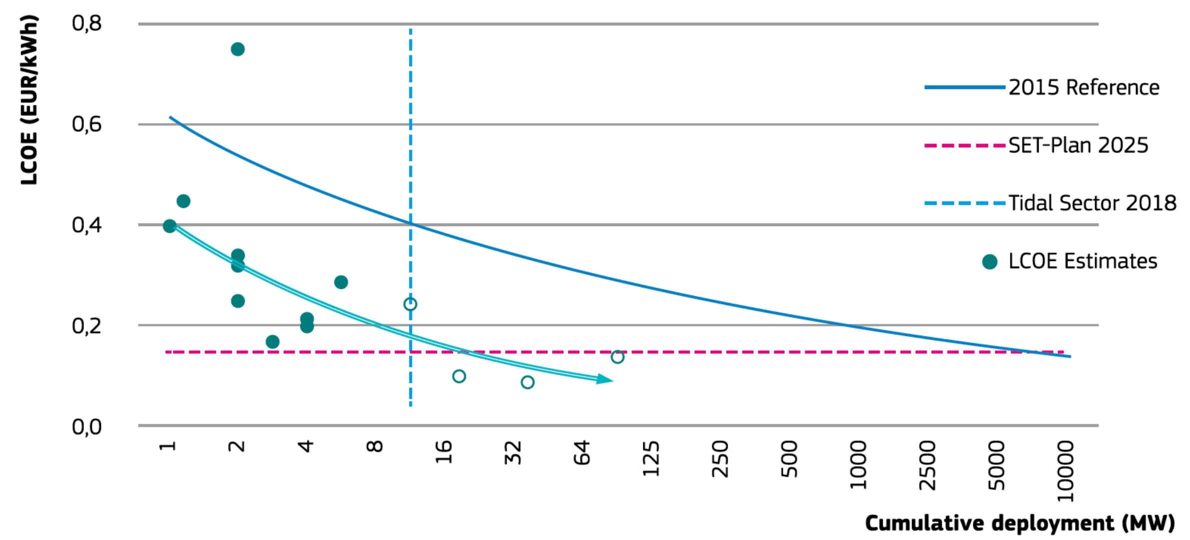


Figure 2: Cost-reduction curves for tidal energy and LCOE estimates from ongoing projects. Solid dots represent data from ongoing demonstration projects, while hollow dots indicate developers' estimates on the basis of technology improvements and increased deployment. Source: Joint Research Centre

FIGURE 12: COST-REDUCTION CURVES FOR TIDAL ENERGY & LCOE ESTIMATES FROM ONGOING PROJECT. SOLID DOTS REPRESENT DATA FROM ONGOING DEMONSTRATION PROJECTS, WHILE HOLLOW DOTS INDICATE DEVELOPERS ESTIMATES ON THE BASIS OF THE TECHNOLOGY IMPROVEMENTS & INCREASED DEPLOYMENT BY JOINT RESEARCH CENTRE (SETIS 2019)

ORE Catapult UK stated that tidal energy will have to bridge the 100-150 £/MWh (Smart and Noonan 2018):

> *“With 10MW currently deployed, we estimate the LCOE for tidal stream energy being deployed in the UK today to be approximately £300 per MWh. Based on our analysis and industry engagement, we see that significant cost reduction is possible in the immediate term and that ongoing reductions will be*

> *achieved over a relatively modest volume of deployment. **We forecast LCOE of £150 by 100MW installed, £130 by 200MW and £90 by 1GW**."*

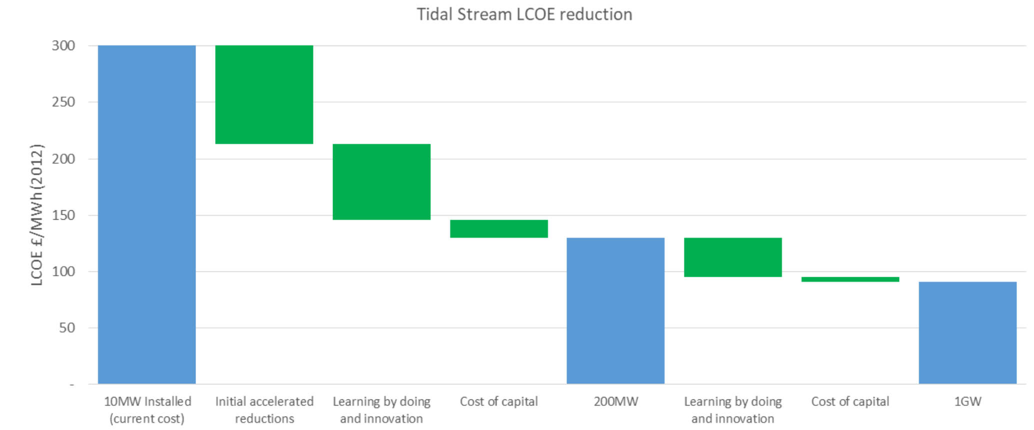


Figure 13: Tidal stream LCOE cost reduction pathway (Smart and Noonan 2018)

However, ORE catapult UK also made LCOE projections for offshore wind, indicating an offshore wind LCOE of 53£/MWh by 2025 (Noonan 2019).

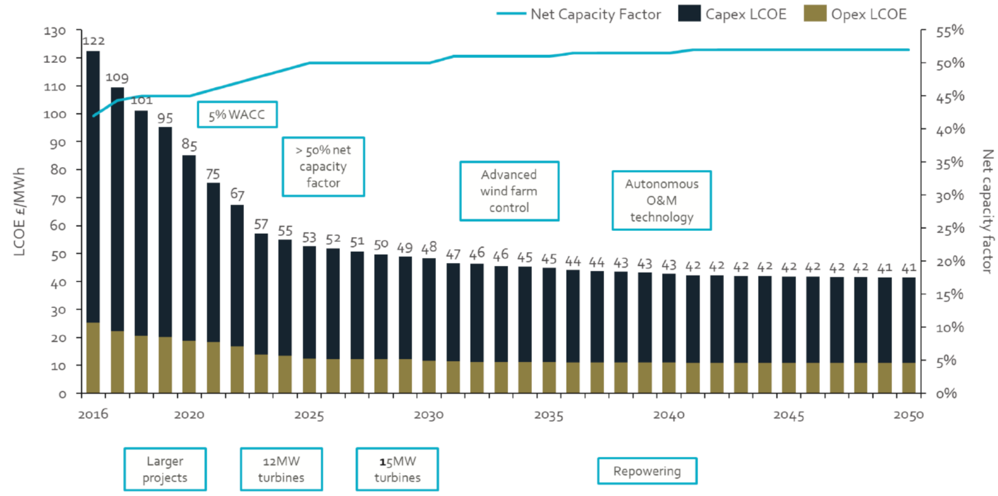


Figure 4: LCoE reduction pathway

FIGURE 14: OFFSHORE WIND LCOE COST REDUCTION (NOONAN 2019)

This report was published in June 2019, whereas the CfD round 3 results were announced in September 2019, with lower LCOE prices than expected for offshore wind (Figure 15), but no CfDs were secured for the tidal energy sector. Carbon Trust commented on these results as following (CarbonTrust 2019):

> *"The Carbon Trust welcomes the announcement of the Contracts for Difference (CfD) Round 3 strike prices, demonstrating the massive cost reductions that have been achieved in UK offshore wind over the last decade. The strike prices of £39.65/MWh and £41.61 (2023/24 and 2024/25 delivery years) have shown the rapid cost reduction journey that has continued from CfD Round 2. **Offshore wind is now lower than the Government Reference Prices, and very likely to be close to future wholesale electricity prices**.*
>
> *We are now in **a market where developers are no longer receiving subsidy payments from government, but they are given revenue certainty**. The CfD regime has shown to provide vital long-term revenue certainty for developers, which is essential for a project's bankability."*

Offshore wind is now at the point where project developers are willing to accept the full merchant risk of wholesale electricity market prices (instead of a combination of fixed government subsidies per MWh & the wholesale price), which is a clear indicator of a maturing technology.

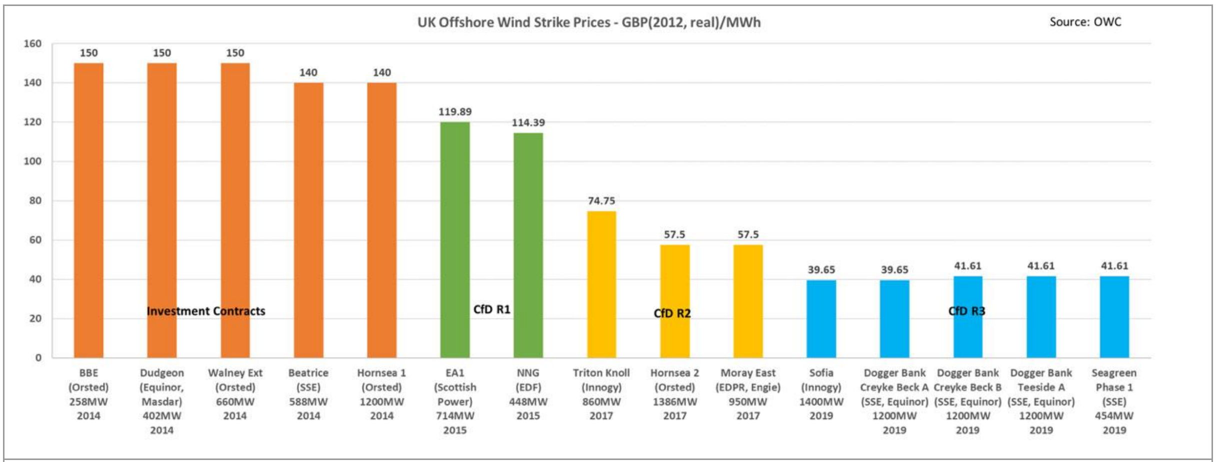


FIGURE 15 STRIKE/CFD PRICE (CHECKEN) (OWC 2019)

To conclude: solely based on LCOE tidal energy is extremely unlikely to compete with the LCOE of offshore wind. Therefore, tidal energy should on the one hand try to duplicate the offshore wind (supply chain) development, but on the other hand focus on other tidal energy characteristics instead of just claiming "*cheap & abundant energy*".

2.3.2 Innovation in tidal energy

Although the technology seems to converge to horizontal, 3-bladed turbines, some interesting innovations are recently being performed by the tidal energy sector (BVGassociates 2019):

1. *Some innovations involving contra-rotating turbines (e.g. Nautricity), wet-gap turbines (e.g. ORPC) and turbines with variable pitch and flapping blades (e.g. CarBine) have emerged and could lead to significant increase in production, notably reducing losses in the energy conversion. Moreover, innovations involving direct-drive power take-off systems are being tested and developed in the context of projects (TAOIDE, TiPA (Nova Innovation)).*
2. *For the balance of plant there have been advancements in the field of floating tidal devices (e.g. Orbital Marine Power, Sustainable Marine Energy) and sea bed connection systems (e.g. Sustainable Marine Energy's RAPTOR anchor, which is capable of enduring higher loads or Vryhof's anchor bag). In addition, different companies and projects have been developing dynamic power cables, which allow a higher bending capacity (e.g. NSW, HDPC4FMEC (MaRINET2)) which is critical for floating tidal projects.*
3. *Regarding installation, different new installation concepts (e.g. towing of floating structures, new anchoring and mooring solutions) have emerged in offshore and floating wind, and tidal technology could draw from this.*
4. *Finally, when it comes to OMS, there have been some design innovations as well (e.g. floating structures/platforms, direct drive power take-off systems, new mooring and anti-corrosion solutions).*

It is emphasized that an emerging technology should find the **right balance of innovation and combining off the shelf technologies, with interfaces and manufacturability in mind**.

2.3.3 Technology recommendations for tidal energy (BVGassociates 2019)

Within the Interreg NWE OPIN project, BVGA formulated the following technology recommendations, which are applicable for the EU wide as for the 2Seas region:

1. *Tidal energy is technologically proven, with devices in the water generating electricity. Learning from many industries has contributed to this progress. A notable example is offshore wind, which explains much of the industry convergence to a horizontal axis device type.*

2. *While there are two competing schools of thought,* ***floating vs bottom-fixed devices****, they capture different parts of the water column and so might be able to* ***co-exist*** *at some locations.*

3. *The main challenge for tidal stream now is* ***cost reduction and getting wider market acceptance****. The industry needs to bring costs down to align with other renewables. There is learning to be had by getting devices into the water, but this can be costly for SMEs. The vessels required will depend on the technology, for example bottom-fixed projects might require* ***more costly jack-up vessels*** *(as was the case for the Meygen Project Phase 1A) which will drive up cost.*

4. *Floating tidal devices share challenges with* ***floating offshore wind, including dynamic cables, mooring system design and installation****, device connection and operation and maintenance.*

5. *Tidal devices are needed which can exploit the energy in* ***slower tidal flows than the earlier generation devices****. High velocity tidal flows only occur in a few locations, whereas lower velocity flows are much more widespread. Developing cost efficient devices for these lower flows will unlock much more global potential. Such devices are likely to be smaller and lighter, except for the rotors, which will need to cover more area. This could be achieved in part by* ***larger (hydro-elastic) diameter rotors and in part by multi-rotor-generator systems****.*

6. *While tidal stream is highly predictable, the resource might not always coincide with demand (and higher electricity price) and so energy storage is an interesting prospect. UK based company Nova Innovation are trialing a Tesla battery with their small scale tidal technology, and such projects could gain increasing interest as tidal and energy storage costs both fall.*

3 Business inventory

3.1 Scope & Objectives

The main objective is to make an inventory and map the value chain of tidal energy (and by extension the whole Marine Renewable Energy – MRE sector) in the 2Seas region. This inventory was combined with the insights obtained during the MET-CERTIFIED project, in order to make a SWOT of the 2Seas region. Lastly, this inventory will be disclosed on the MET-CERTIFIED website through a searchable map interface (google maps implementation).

Weblink BETA: https://www.google.com/maps/d/u/0/viewer?mid=1Fm56DeEquGJAJhBrRwJMfucjl0kmo9sO&ll=19.158467059782467%2C-2.166505500000085&z=2

3.2 Tidal Energy developpers tier 1 value chain

Table 5 gives an overview of tier 1 supply chain for tidal energy convertors. Generators are typically in-house developments, blades are typically outsourced. For other components, typical larger technology industry wide suppliers are chosen, due to their wide range of product lines (SKF, Siemens, ABB). In the balance of plant or electrical connection, we see a wider range of suppliers, which most likely can be performed (currently) more local in e.g. harbour yards.

3.3 Typical investment cost breakdown along the supply chain

Table 6 provides a typical breakdown of investment costs for an <10 MW tidal energy project, with 2 MW devices, whereby the source is not disclosed due to confidentiality (BVGassociates 2019). For reference, the investment costs of tidal and the rapidly maturing floating wind are also given. Lastly, this table gives insights in the possibilities of cross-sectoral interchange.

Large synergies are expected in the project development, generator supply chain (as the technology of a 3-bladed horizontal axis is in essence the same), balance of plant (especially dynamic cables – umbilicals), but not in installation & some O&M strategies due to the size differences. Jack-up installation vessels are considered expensive now, but some are no longer able to install offshore wind, such as the Neptune of DEME, who jacked up at la Raz Blanchard during high currents.

3.4 Tidal energy value chain

3.4.1 Inventory of the current tidal energy value chain

An inventory of **current** active tidal energy developers is given in Table 7. France & UK are clearly leading, followed by the Netherlands. Belgium has very little supply chain engagement.

Europe hosts 52% of tidal energy developers, with UK 19%, France 9% & the Netherlands 7% (Figure 16). Key technology developers in the sector are Atlantis Resources Limited, which has developed the 6 MW Meygen array, AndritzHydro Hammerfest (deployed 3 x 1.5 MW turbines at Meygen), OpenHydro (deployed 2x0.5MW turbines in France, and 1 x 2 MW turbine in Canada), Tocardo (deployed 3 MW in Netherlands), Scotrenewables (2 MW converter in Scotland), Schottel (German developer producing 62kW turbines), NovaInnovation (deployed 1st tidal farm with power rating of 300 kW), Sabella (1 MW turbine). European leadership is also strengthened by the availability of 70% of the ocean energy infrastructure (Magagne, Shortall et al. 2017).

Tocardo (acquired by QED Naval & Hydrowing) is however the only with HQ in the 2Seas region. At the time of writing the impact about Tocardo's new investors (QEDnaval & Hydrowing) was unsure.

EU is also not only strongly represented as a technology developer in tidal energy, but also in different supporting roles like marine contracting, see Figure 17.

TABLE 5 SUPPLY CHAIN TIER 1 FOR TIDAL ENERGY CONVERTORS (TOCARDO 2016, MAGAGNE, SHORTALL ET AL. 2017)

Developer	Blades	Bearings	Brakes	Shaft	Gearbox	Control	Generator	Electrical	BOP	Engineering & project development	EIA/MetOcean
Andritz Hydro/ Hammerfest	AEL			Schottel		In-house	In-house	Convertem			
Atlantis Resource Limited	Norco ltd.	NKE	Altra Industrial	Schottel							
Invo-Tech	David Brown	Schottel	ATB Morley	ABB							
Nova Innovation	Shetland composites	SKF			Siemens		Siemens			Wood Group	
OpenHydro	Norco Ltd.						In-house				
Schottel		Wolfgang Preinfalk					In-house				
Scot-Renewables Marine Orbital	Designcraft A C Marine & Composites (ACMC)	SKF		SKF	Siemens	MacArtney	In-house	ABB	TEXO Faun Tracway		
Tocardo	Airborne Marine						In-house	Istemewa	Huisman Hillebrand Strukton	Mammoet Van der Straaten Leask Marine	
Minesto				SSPA	SSPA	SSPA	SSPA	Laborelec	Moorlink - Vryhof UW-Elast AB	Midroc Project Management	Queens University Belfast Chalmers University

Table 6: Typical Early stage cost breakdown of tidal, wave & floating wind, with indication of potential synergies between tidal & offshore wind (BVGassociates 2019)

Package	Subtask -cost or activity	Tidal (€/MW unless noted otherwise)	% of total	Key synergies tidal energy with offshore wind	Wave	Floating wind
Development & project management	Development & consenting services and expenditure incurred by lost projects	220	4,5%	Large synergy, some factors uncertain, eg mammals - turbine interaction, stiff & stubby blades, erosion & fouling different	250	175
	Professional & enabling service	30	0,6%		50	25
Generating device supply	Rotor	500	10,3%	Convergence similar (3-bladed horizontal axis) Volume too low, some learning experience, like Bosch Rexroth-Wavepod	5000	375
	Nacelle	1250	25,8%			875
	Tower	250	5,2%			250
Balance of Plant foundation, array & electrical transmission	Support structure	450	9,3%	Large synergies fixed bottom, off the shelf foundations (GBF) Maritime supply chain: aquaculture & shipbuilding Mooring Combining Junction boxes Dynamic cables & umbilicals!	1150	1400
	Sea bed connection	500	10,3%			100
	Subsea cables	200	4,1%		250	200
	Onshore electrical	100	2,1%		100	50

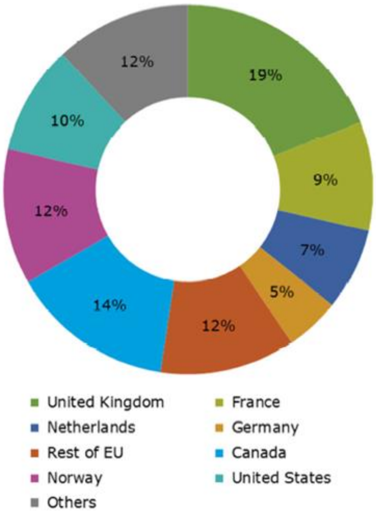
Installation	Turbine installation	200	4,1%	Jack-up vessels contested (Note: DEME Neptune jacked at la Ranche Blanchard) Slack tide means short installation vessels, but smaller boats might work Combination with aquaculture vessels Highly dependent on adjacent ports	450	140
	Support structure	175	3,6%		400	
	Cable installation	100	2,1%		100	185
	Professional & enabling service	25	0,5%		50	15
Contingency	Contingency	400	8,2%		850	380
OMS (€/MW/year)	Maintenance & service	85	1,8%	Little room for synergies expected, some existing software tools might help ForeCoast (JBA), Mermaid (James Fisher), EOWIN (Systems Navigator))	225	75
	Operations	45	0,9%		125	35
	Professional & enabling service	20	0,4%		50	15
Decommissioning		300	6,2%		650	225
Total		4850	100%		9700	4520
Assumptions						
Device type	Bottom-fixed horizontal axis				Bottom-fixed point absorber	Semi-sub floating platform

Device rating	2 MW	1 MW	8 MW
Farm size	<10 MW	<5	<40
Year of FID (Financial Investment Decision)	2020	2020	2020
Data source	Derived from confidential data source	Academic literature	BVGA cost model

Table 7: Supply Chain in the 2SEAS countries, strengths, gaps, Large, Medium, Small Enterprises & others (BVGassociates 2019)

Country	Strengths	Gaps & Opportunities	Large Enterprises	SMEs	Others
BE	• Good tidal resource levels and large area (English Channel and Atlantic Coast) • Several companies and organisations involved in tidal energy • Existing test sites	• Low tidal resource levels • Limited area • Limited number of companies involved in tidal energy • No projects	DEME	De Meyer, Com&Sens	De Blauwe Cluster, Ghent University, IBN Offshore Energy Cluster, IDETA, POM West Flanders, Sirris, VLAIO
FR	• Good tidal resource levels and large area (English Channel and Atlantic Coast) • Several companies and organisations involved in tidal energy • Existing test sites	• Limited experience in marine renewable energy	Akuo Energy, Constructions Mécaniques de Normandie, EDF Énergies Nouvelles, INNOSEA, BESSÉ, Bureau Veritas France, Cetim, RTE	Sabella, Blue Shark Power System, Guinard Energies, Hydro-Gen, HydroQuest, EEL Energy, JIFMAR, Principia, Allia, Tidalys, Valorem (including subsidiary Valemo), Above All, Akrocean, Atlantique Scaphandre, CETEAL, Charier, D-ICE ENGINEERING, EISIS, ELWAVE, Europe Technologies, FMGC, Fonderie BOUHYER, Garos Capteurs, Géotec, Genie Wind, In Situ, INNO'ENERGY,	WEAMEC, Centrale Nantes, Université de Nantes, Cluster Maritime Français, France Énergies Marines, GICAN, IFP Energies Nouvelles, Ifremer, Syndicat des Énergies Renouvelables, Agence Régionale des Pays de la Loire, CEA Tech, Centre de droit maritime et océanique (CDMO), GIE Albatros, ICAM, IFSTTAR,

				KEOPS, MELTEMUS SAS, NEREIS Environnement, Ocean Zoom, Productys Solutions, Sogebras, SubAirTech, Kopadia, Loiretech, Meteodyn, Neodyme, Nextflow Software, SEENEOH, Doris Engineering	IRT Jules Verne, Neopolia, PASCA, Pôle EMC2, Pôle Mer Bretagne Atlantique, Atlanpole, Pôle S2E2, THeoREM,
NL	• Companies involved in tidal projects outside of the Netherlands • Some offshore wind experience from which tidal industry can draw	• Average tidal resource levels and limited area • No projects in planning	Bluewater, Fugro, Royal HaskoningDHV	BT Projects, Deepwater Energy, SeaQurrent, Tocardo, Vryhof, Water2Energy	Deltares, Dutch Marine Energy Center, Hogeschool Zeeland, IRO, MARIN, Netherlands Maritime Technology, NIOZ, TU Delft, Wageningen University and Research
UK	• Highest tidal resource levels in Europe (10GW, 50% of Europe's tidal energy resources); large area • Large number of companies and organisations involved in tidal energy • Well developed offshore wind industry from which tidal industry can draw • Demonstration projects operational and existing large-scale projects under development/construction	• Could develop local supply chain in synergy with offshore wind sector • Could become European leader in tidal energy (also outside of the UK)	Arup, Atkins, APB Marine, BVG, Balfour Beatty, Associates, Briggs Marine, Current2Current, EC-Cable and OG, Free Flow 69, Pipe LayGreen Marine, GoBe, SolutionsHydro Group, Leask (SparrowMarine, Mainstay MarineGroup),Solutions, MarineSpace,Intertek JNautricity, Nova Murphy & Innovation, Oceanflow Sons, James Energy, Orbital Marine, Fisher JBA Offshore Wind Consulting, Consultants, Partrac, JDR Cable Perpetuus Energy, Pure Systems,Marine, QED Naval, Lloyd's SIMEC Atlantis Energy, Register, LOC SMD Hydrovision, Renewables, Sustainable Marine Mott Energy / Schottel Hydro, Macdonald, Saunders Energy, NaturalTension Technology Power, RPS, International (TTI), SLR, Subsea Wave Hub, 7, Wood, Xi Engineering, Xodus	APB Marine, BVG Associates, Current2Current, EC-OG, Free Flow 69, Green Marine, GoBe, Hydro Group, Leask Marine, Mainstay Marine Solutions, MarineSpace, Nautricity, Nova Innovation, Oceanflow Energy, Orbital Marine, Offshore Wind Consultants, Partrac, Perpetuus Energy, Pure Marine, QED Naval, SIMEC Atlantis Energy, SMD Hydrovision, Sustainable Marine Energy / Schottel Hydro, Saunders Energy, Tension Technology International (TTI), Wave Hub, Waves Group	AREG, Bangor University, British Hydropower Association, Cranfield University, EEEGR, EMEC, Heriot-Watt University, Highlands and Islands Enterprise, Imperial College London, Innovate UK, INORE, Lancaster University, Loughborough University, Marine Energy Wales, NOF, ORE Catapult, RenewableUK, Scottish Enterprise, Scottish Renewables, University of Edinburgh, University of Exeter, University of Manchester, University of Oxford, University of Plymouth, University of Southampton, University of Strathclyde



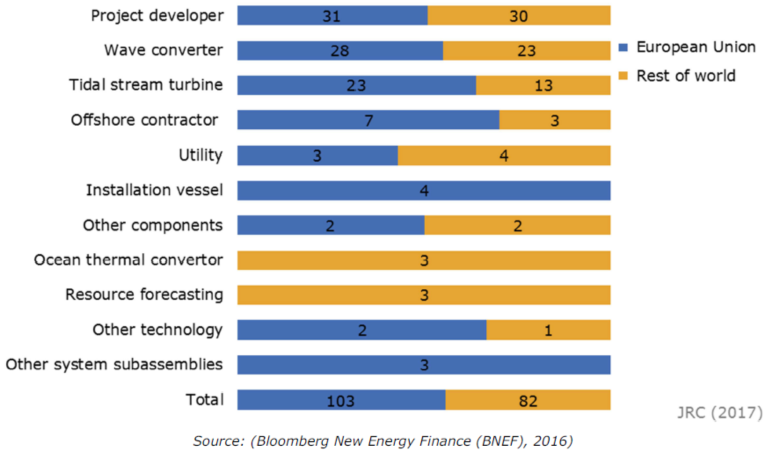


FIGURE 16: SHARE OF TIDAL ENERGY DEVELOPERS PER COUNTRY IN 2017 (MAGAGNE, SHORTALL ET AL. 2017)

FIGURE 17 SHARE OF ORGANIZATION IN THE OCEAN ENERGY SECTOR, CLASSIFIED PER ACTIVITY (MAGAGNE, SHORTALL ET AL. 2017)

3.4.2 Geographical opportunities for the 2SEAS value chain

Tekstueel nog aan te vullen.

TABLE 8: GEOGRAPHICAL OPPORTUNITIES OF THE 2SEAS SUPPLY CHAIN

	2Seas region	MS forming the 2S region	EU & Worldwide – Export potential
Domestic production	Localised to Dutch Delta Region & Ilse of Wight	UK & France have high potential Netherlands limited Belgium none	Canada, Japan
Value Chain, OEM	Limited OEMs in 2Seas region, most often still TRL 6-7 Only Tocardo-QEDNaval-Hydrowing above TRL 8 Ultra low head, bi-directional technologies (sluice gates, tidal lagoon?)	Hotspots in Scotland, Brittany, Normandy, Pays de La Loire In NL spread over the country In BE absent Large EU OEMs seem to withdraw/loose interest (GE, Energies Navals, Rolls Royce), exception: Andritz See Table 5 & Table 7	Europe hosts 52% of the tidal energy OEMS
Value Chain, Expertise & project development	Very high & relevant Belgium & UK are leading, followed by the Netherlands. Soon France	Experienced & relevant	See Annex: Develop Marine Energy Projects worldwide Example: Halagonia 9 MW Canada, **530 €/MWh FIT** for 15 year
Value Chain Suppliers	Tier 1 most often large or medium sized enterprise (Table 5)	Table 7	Currently limited
Certification?	See § 2.1.4 for analysis & 4.6.4 for recommendations, mainly focussed on stage gate approach & TF		No adaption of the IECRE accreditation and certification yet. DNV-GL is currently leading and owner of the governing guidelines.

3.4.3 Building a 2Seas tidal energy supply chain: tapping on the maritime supply chain, boosted by the offshore wind supply chain

Offshore Wind is booming in Europe, whereby Belgium & UK were already early on in the market, followed by the Netherlands. In the Netherlands & France, the results of the 3-4 policy support & project development materializes in an impressive pipeline of projects. Belgium currently finalizes i's last Seamade windpark (going to 2,2 GW), The Netherlands is ramping up Borssele 1-2-3-4, Hollandse Kust Zuid & Noord, France is developing several parks and the UK set forward a 32 GW offshore wind deal. On top of that WindEurope put forward a 450 GW target by 2050. In order to optimally roll out this ambitious 450 GW, WindEurope (through consultancy firm BVG) performed a high level multi-criteria spatial analyse, resulting in an qualitative map of LCOE ranges under different spatial exclusion zones, like shipping routes (Noonan 2019, WindEurope 2019). Interestingly enough, the 2Seas area is amongst the relatively low LCOE zones (WindEurope 2019), with The Belgian-Netherlands coast, in France Seine-Maritime, La Manche, Brittany & Pays de La Loire as relatively low LCOEs

When comparing these maps with the tidal energy resource (Figure 19) or occurrence of tidal currents between 1,5 – 3 m/s (Figure 20), an interesting pattern emerges (Noveltis 2020). For a complete discussion, the tidal range is given in Figure 21 (this indicates good zones for tidal barrage or lagoon, but does not necessarily coincide with high tidal energy currents). When interpreting these maps, the following considerations need to be taken into account:

1) The tidal energy map is averaged out on a course grid, whereby very high, local, tidal energy currents are averaged out. An example is the Figure 22, whereby a fine grid can show (local) tidal energy densities of 15 kW/m² for the La Manche region, whereas the coarse grid averages out the density to approximately 5 kW/m².

2) This resource is mainly driven by the tides, and not as such the discharging in estuaries, implying that the resource at these estuaries might be underestimated, which is relevant specifically for the Dutch Delta.

Indeed the tidal energy test sites or demonstration projects belong to the high tidal energetic zones. Examples are Fromveur, Paimpol-Brehat, Channel Islands (Aldernay), Ilse of Wight (PTEC), Seine-Maritime, Channel area and the Dutch Delta. Tidal range is high at Saint-Malo but also the Severn Estuary (Swansea-Bristol).

The following conclusions can be made from this comparison:

1) **The 2Seas region has not got the best tidal energy resource potential** (exceptions are the Dutch Deltas & UK Ilse of Wight), but it does however have a very interesting offshore wind & maritime supply chain ramping up in these areas.

2) From a 2Seas perspective, a case could be made to **cluster tidal energy activities with zones outside the 2Seas, such as Sommerset-South-West** (for tidal range in Severn) and definitely co-develop projects with the **La Manche** region (cfr Tiger project).

3) Last but not least: offshore wind projects are currently in development at zones relative nearby tidal energy hotspots (but not coinciding, as high tidal currents impose high costs for installation, scour & cable exposure). **This might indicate that especially in France, an opportunity arises to co-develop both offshore wind & tidal energy supply chains, although on different time scale**. For the French west coast, the wave energy might benefit as well from the experience build by the (in chronological order) established maritime (including shipping, aquaculture, defence), developing offshore wind & emerging tidal energy supply chain.

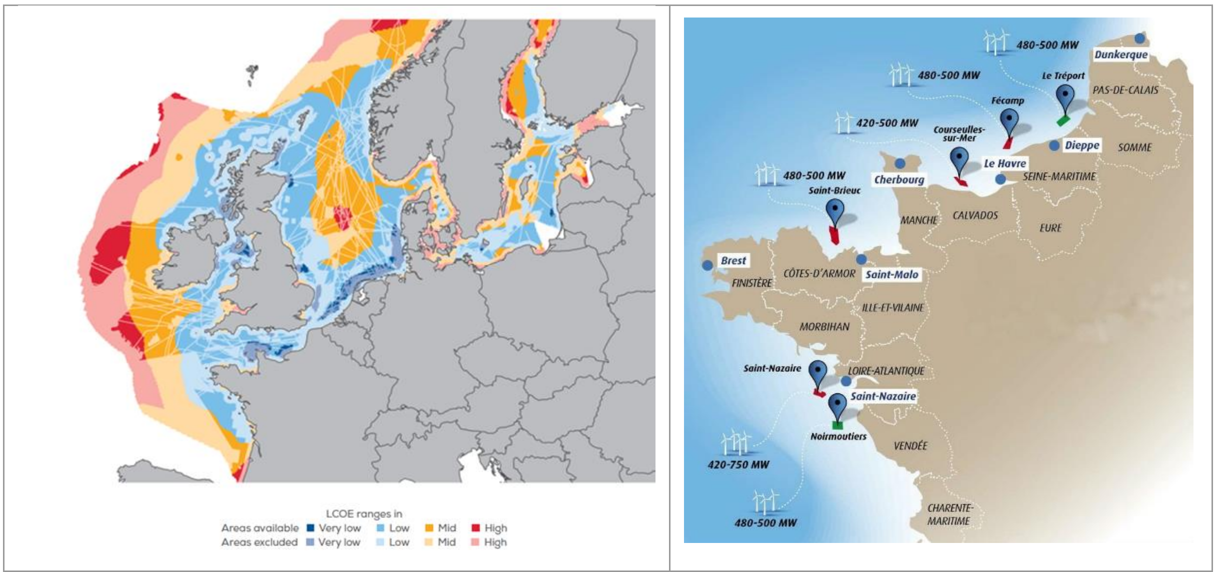


Figure 18: Relative LCOE ranges of Offshore Wind in 2Seas Region & Europe (WindEurope 2019), left and the round 2 French offshore wind farms.

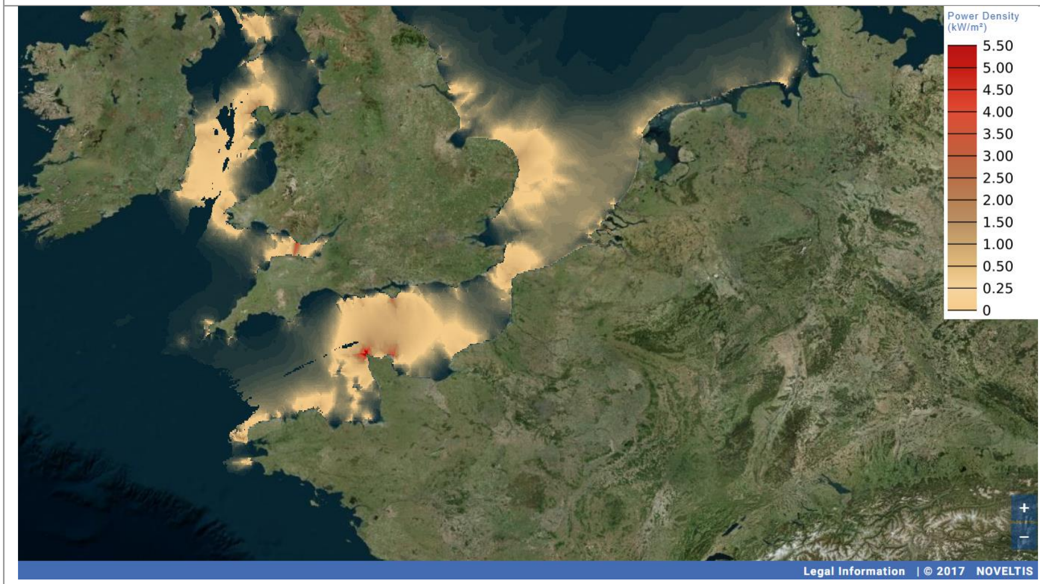


Figure 19: Course grid Tidal Energy power Density (kW/m²), indicating the high resource zones in the 2SEAS region (Noveltis 2020).

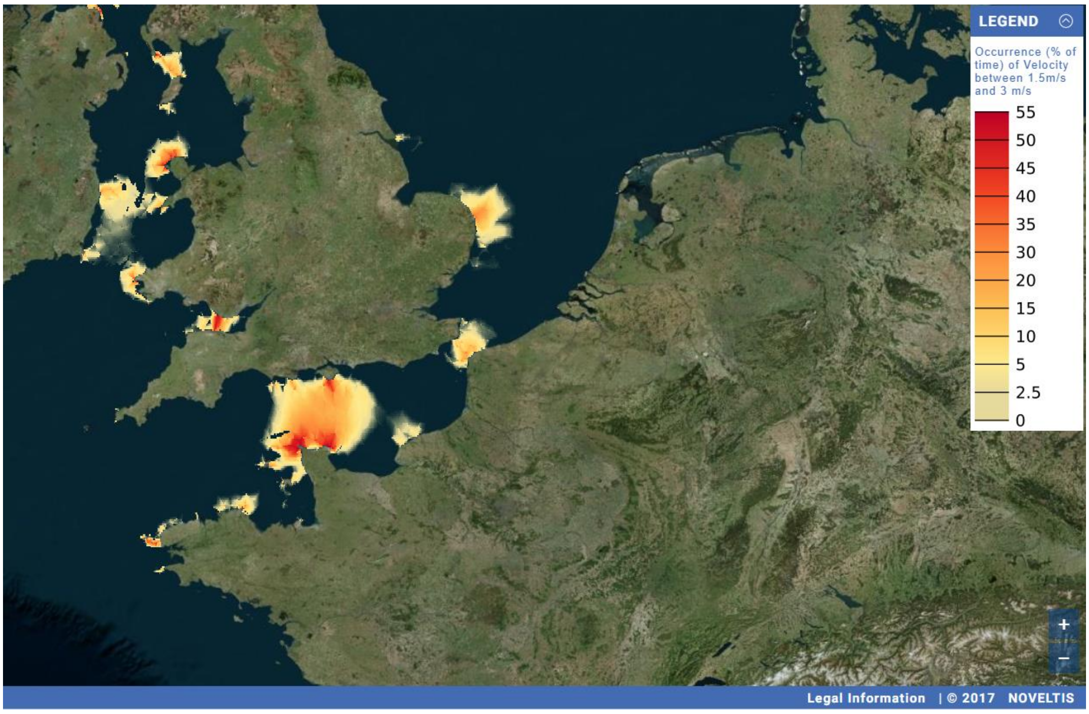


FIGURE 20: OCCURRENCE OF TIME (%) WHEREBY THE TIDAL CURRENT IS BETWEEN 1.5 – 3 M/S, WHICH IS A GOOD INDICATOR FOR THE BEST DEPLOYMENT ZONES (NOVELTIS 2020).

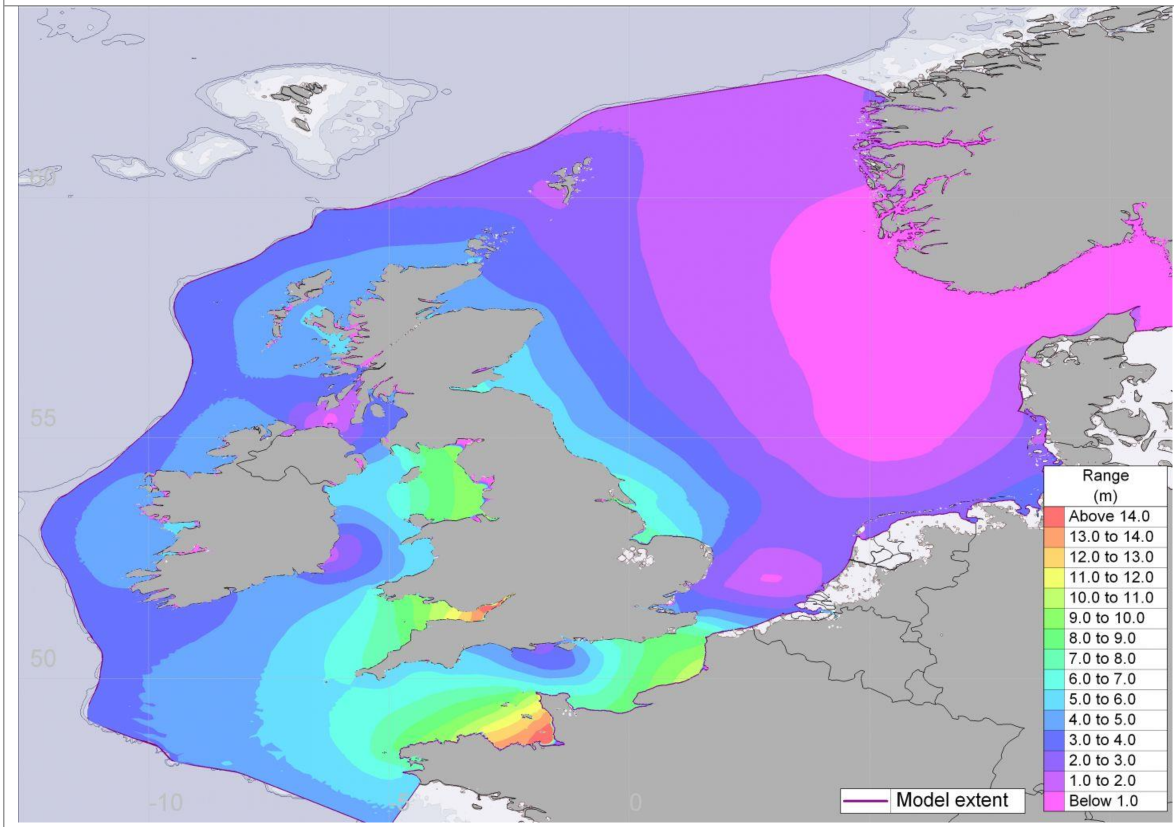


Figure 21: Tidal RANGE in the 2Seas & EU basin (Smartide 2013).

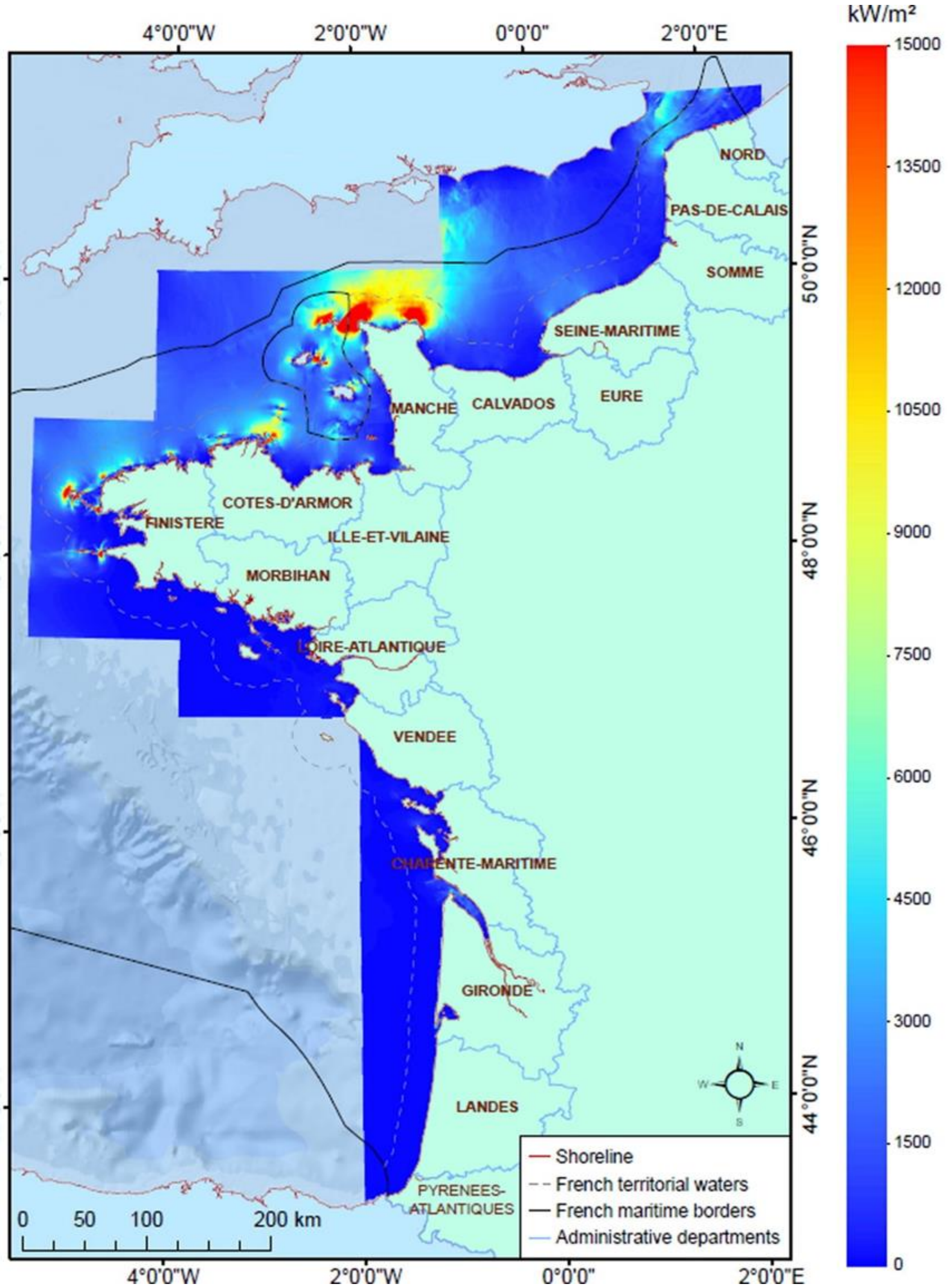


Figure 22: Fine grid tidal power energy resource (note that the dimension are in W/m², not kW/m²) along the French coast (Campbell, Martinez et al. 2017).

4 Innovation, SME business development & Test Facility actions in the 2Seas region

4.1 Summary of the Best Practices Marine Test sites report (D2.8.1)

4.1.1 Recommendations:

The study (METCERTIFIED 2018) shows that marine test facilities face challenges in securing both public and private financing for early phase projects, especially those with significant technology risk and capital intensity. An early-stage clean energy company may be able to secure funding for initial pilot or bench-scale demonstrations, however, finance for larger scale testing campaign is often available only for proven technologies with a low-risk profile. This gap in commercial-scale financing limits the ability of test facilities to take project developers from TRL 4 to TRL9 and effectively commercialize advanced energy technologies. In order to address the challenge it is recommended to:

1) Raise awareness and educate technology developers to foresee **sufficient budgets for testing in early design phase** (See also recommended action § 4.6.6).
2) Facilitate public investment in new test facilities and **simplify permit procedure** (See also rrecommended action §4.6.7)
3) Unlock new sources of capital and foster **more effective investment models** to scale innovative clean energy companies (See also recommended action § 2.2.2).
4) Catalyse the formation of **long-term marine funds for technology testing and development**. **Standardisation and certification** offer both the opportunity of further market development and the threat of additional administrative work for the companies within the sector (See also recommended action § 4.6.4).
5) Facilitate matchmaking between early-stage companies and potential investors and marine test facilities. Increas the **role of clusters in value chain** (See also 3.4.3).
6) Address the **needs of customers from early R&D development** phase followed by marine testing and even assisting to launch developed technology to the market. The business model of a test facility shall be initially positioned towards the specific target market but gradually expanded to serviceable and total available market at an international level (See also recommended action § 4.6.2).
7) Increase the level **of service from testing to consultancy and even certification** (See also recommended action § 4.6.4).
8) Make test facilities available to a **wider market of blue economy sector** (See also recommended action § 4.6.2).

4.2 Summary of the case study for the case study for multi-use TF in Belgium (D 2.8.2)

In D2.8.2, a comparative analysis & strategic recommendations for a new multidisciplinary maritime test infrastructure, namely the Blue Accelerator in Ostend, was described. This TF was also positioned relative to the other TF in the 2Seas region (METCERTIFIED, Caporaso et al. 2020).

Some interesting conclusions can be drawn from this report. The 2Seas TFs are quite complementary in terms of the:

1) Risk character: low risk (high innovation) vs high risk (low innovation), see also Figure 23;
2) Iterative character: iterative vs steady, large scale & focussing on long term availability (eg. operational hours & MWh inject).

EMEC & PTEC are best suited for well developed, high TRL 8-9 devices which need to prove pre-commercial feasibility, due to their relative remoteness and high energetic character. On the contrary, Blue Accelerator is more suited for “iterative” testing, whereby more frequent interventions are easily facilitated to the proximity factor.

The BA priorities are set out in Figure 24:

1) **Fast/easy consenting & readiness:** in order to accommodate & facilitate fast testing, a Rochdale envelope approach for EIA could be requested. See also Recommended action § 4.6.7 Government: Implement adaptive management respecting the precautionary principle for array demonstration.
2) **Join Funding programmes:** joining networks like ForeSea, DEMOOcean allow for optimized use of testing time. However, a state-gated approach is strongly recommended, and not mentioned in this context. See Recommended action § 4.6.6 The stage-gated approach also in Interreg (2Seas).
3) **Partnership with Coastal & Ocean Basin:** see Recommended action § 4.6.1 TF: rescale the open water hydrodynamic conditions in TRL 5-6 TF to the TRL 3-4 TF.
4) **Increasing monitoring activities:** open data access, environmental monitoring is too be considered a generic, which should be shared easily, technological power performance is more sensitive. See Recommended action § 4.6.5 TF & Gov: cascaded open data policy, metadata & labelling
5) **Availability of information:** Focused on good quality documentation of the TF, see Recommended action § 4.6.5 TF & Gov: cascaded open data policy, metadata & labelling
6) **Installing a power cable with optical fibre integrated**
7) **Expand offered Services,** see Recommended action § 4.6.2 TF: Diversify in sectors, from day one on

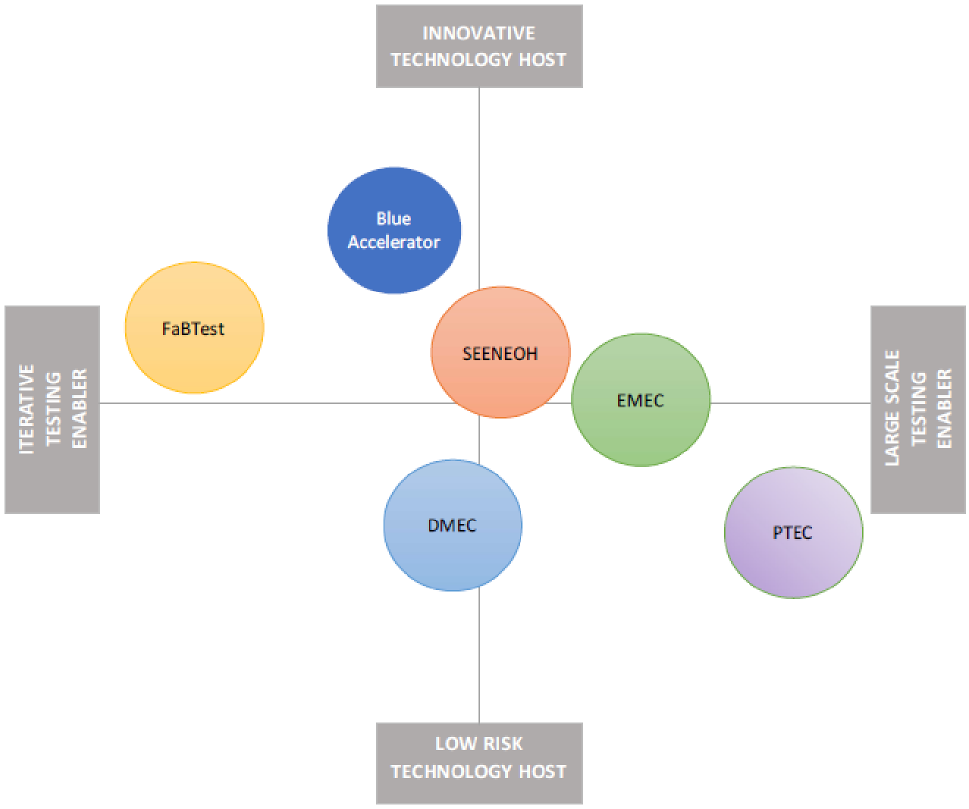


Figure 3-2 Percentual map: current positioning of the analysed test sites

Figure 23: 2Seas TF positioning mapped out to risk & iterative character

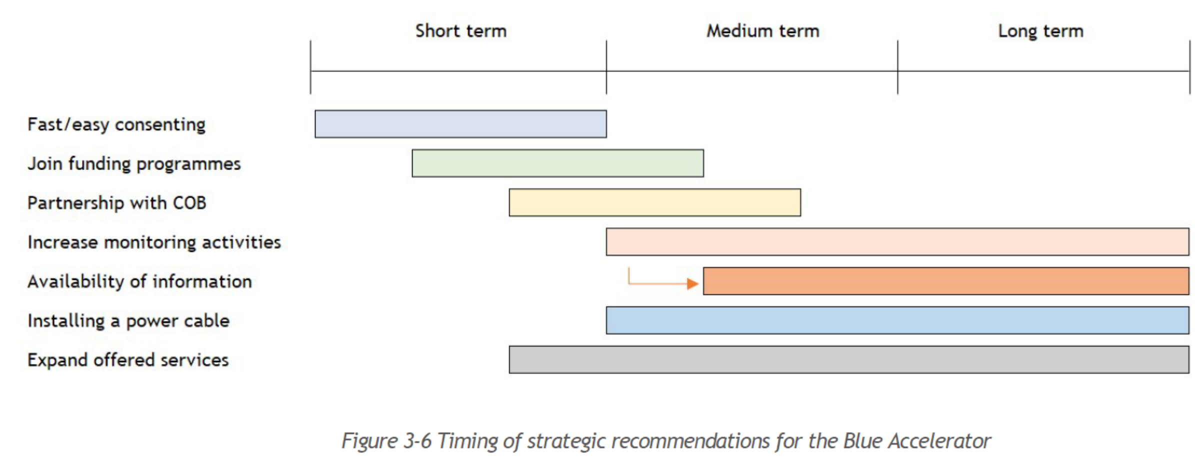


Figure 24: Time priorities of strategic recommendations for the Blue Accelerator

4.3 TFs in a global perspective

UK, France & the Netherlands host several TFs, and especially EMEC is being considered as the leading TF for the industry, now diversifying its activities and services amongs TF worldwide, which are shown on Figure 25. In Europe we have important TF in Portugal (including Azores), Spain (Basque Country), and to a lesser extent, Norway, Denmark & Sweden. Internationally Canada (eg. Force at Nova Scotia), and the numerous mainland & overseas US TF (most often with support by the US Department of Energy). In Azia, China, Korea, Singapore have developed MRE TFs.

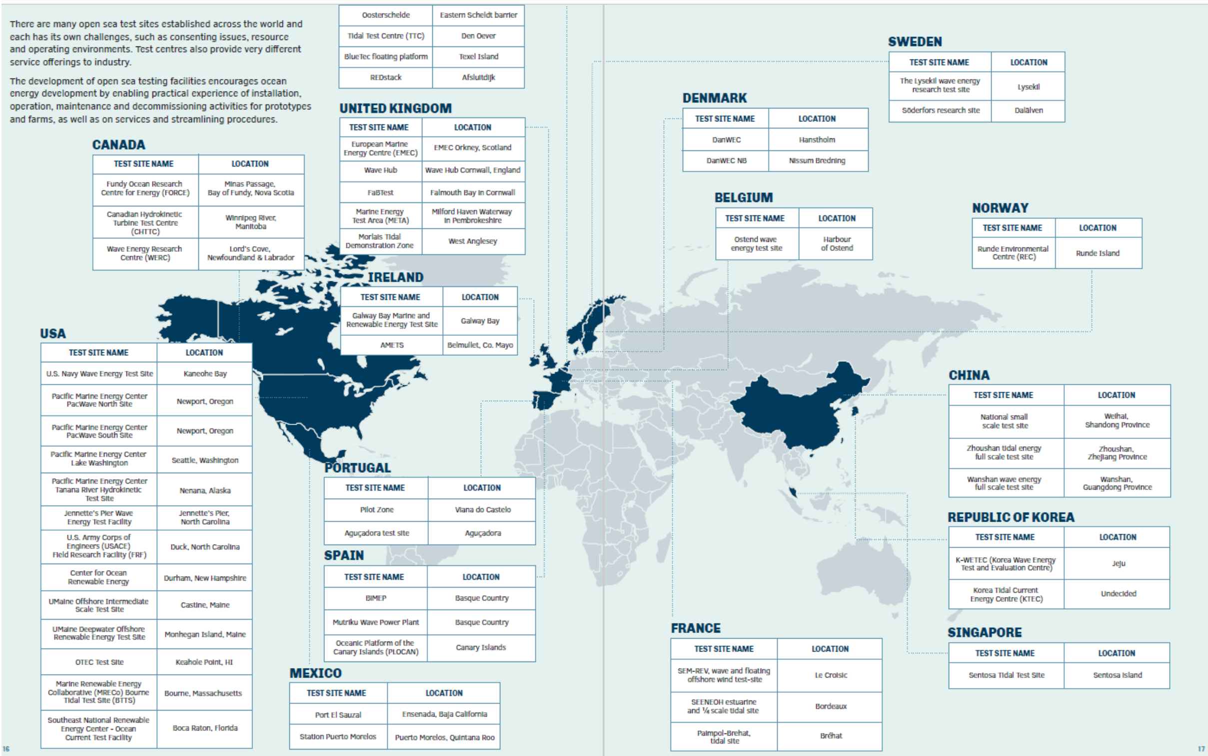


FIGURE 25: GLOBAL OCEAN ENERGY TEST FACILITIES (OES 2018)

4.4 Principles of setting up a 2S action list (roadmap)

Setting a roadmap for an emerging energy technology in a rapidly changing energy landscape for an Interreg region with 4 different national MS policies (not the mention the Brexit), local government policies superposed, requires a coherent approach. Furthermore there are differences in both existing domestic resource potential and the already available supply chain.

Therefore the following principles were used to set up this roadmap:

Implement the existing international, European & sectoral roadmaps where possible, and adapt to local 2Seas interests. Therefore, a (desktop) analysis of the existing roadmaps was made, in order to identify aggregated trends.

1) **Focus on the common denominator between the Interreg2Seas regions**, instead of just making the sum of the individual MS roadmaps. Therefore, the aggregated trends were screened for their applicability, relevance & potential impact in the 2Seas region.
2) **Prefer on no-regret activities,** meaning that the recommendations in the roadmap are also relevant for other sectors **(like shipping, offshore wind, coastal engineering**,…) mainly due to the difficult market development in the last years.
3) Lastly, due to the scoping of the project, recommendations and action points w.r.t. to MRE test facilities & certification were emphasized.

4.5 EU MRE Roadmaps overview

The European ocean energy sector released numerous new **European roadmaps**, of which the most relevant in this context are:

1) Ocean Energy Forum (Ocean Energy Forum 2016);
2) The strategic research & innovation agenda (SRIA) in preparation of the Horizon Europe Programme (ETIPOcean 2019);
3) “Powering Homes Today, Powering Nations Tomorrow” report by the sector federation Ocean Energy Europe (OEE) (Cagney, Gruet et al. 2019)

Most of the recommendations are described high-level to be universally valid, and to make sure the main principles do not get lost in operational actions tied to those principles. For instance, the “Powering Homes Today, Powering Nations Tomorrow” (Cagney, Gruet et al. 2019) emphasizes the importance of the **stage-gated approac**h (see also XX) and has put forward an **integrated strategy based on 4 main actions**:

1) **Action 1- R&D and Prototype: Finalise an EU-wide stage-gate programme while keeping grant funding**: *a truly European stage-gate approach, channeling 100% public funding via pre-commercial procurement, is an essential step to deliver an ocean energy sector. Wave Energy Scotland has demonstrated the value of this approach*. Note that the SRIA by ETIPOcean (ETIPocean 2019) formulates very concrete actions and prioritisations for the R&D activities itself.
2) **Action 2 - Demonstration and Pre-commercial farms**: A blend of grant & financial instruments for projects to reach financial close.
3) **Action 3 - From Demonstration to Industrial roll-out**: revenue support at the national level specifically for ocean energy as the only way to fully finance projects. Here the impact of the 2Seas regions is considered limited in terms of policy or decision making, but potentially high for certain regions to provide their respective national governments with regional success cases.
4) **Action 4 - A set of initiatives to generate data and best practice for licensing and consenting**
    a. Task 1- Launch further calls to fund the cross-border collection and sharing of environmental impact data. Calls should allow the monitoring of multiple ocean energy projects, using the same methodologies to measure the same environmental impacts.
    b. Task 2 - Adopt an ‘Adaptive Management’ approach for licensing and consenting decisions.

On a **national level** the ORE Catapult report “TIDAL STREAM AND WAVE ENERGY COST REDUCTION AND INDUSTRIAL BENEFIT Summary Analysis” (Smart and Noonan 2018) caused a technology wide debate in the **UK** and in the **Netherlands** a position paper was released by the Dutch Energy from Water sector (Schaffmeister and Scheijgrond 2019), in response to the fact that ocean energy was not mentioned in the Dutch National climate and energy plan (RVO 2019). No specific roadmap or sectoral policy initiatives from **Belgium** and **France** are released.

For some other reports, sector analyses are being used or often refer to the European roadmaps or they present a regional roadmap of one (2Seas) region, like the one for Cornwall and the Isles of Scilly (Pomfret 2014, SIOcean 2014, Magagne 2015, Magagne, Monfardini et al. 2016, Scheijgrond 2016, TPOcean 2016, Magagne, Marghertini et al. 2018, Mare 2018, OES 2018, Segura 2018, Tasse 2018, OCEANSET 2019, Setis 2019).

Lastly, the insights obtained during the MET-CERTIFIED project or projects executed at the same time (like H2020 Opera, Marinerg-i) were used to blend in with the roadmaps, in order to define actions.

Regarding the potential consequences of Brexit on joint EU initiatives or projects, it was assumed that both the UK Government and the Commission will negotiate a framework to allow projects, like H2020 for R&D.

4.6 Recommended actions for the 2Seas region

4.6.1 TF: rescale the open water hydrodynamic conditions in TRL 5-6 TF to the TRL 3-4 TF

TRL 3-4 laboratories should rescale the wave & current conditions of preferred TRL 5-6 TF, in order to obtain a daisy chain of TF with high predictive value in the low TRL testing for what is supposed to happen in TRL 5-6.

This daisy chaining is a logical consequence of the industry wide supported **stage-gated** approach. If successfully applied, the TRL 4 TF can detect early on fundamental problems, that otherwise would become only apparent in the (more expensive) TRL 5-7 open water TF.

Within the 2Seas region we can find interesting examples within MS regions:

1) The Coastal & Ocean Basin (TRL4) in Ostend combined with the Blue Accelerator (outside the harbour of Ostend). See D 2.8.2 for a much more exhaustive analysis (METCERTIFIED, Caporaso et al. 2020).
2) Ifremers Boulogne-sur-Mer could focus on the hydrodynamic conditions in eg. the La Manche region, or the Seeneoh test site.
3) TTC-Grevelingendam is to be a considered a very special case stretching the TRL 4-6 spectrum, depending on the application.

But also transnational collaboration is possible if TFs in the region are aligned. An example could be a device which is tested – at eg. 1/10 scale - in TRL 4 in Ifremer, which consequently is being tested in TTC Grevelingendam at TRL 5-6 at full scale (eg. for full scale power performance assessment) to then be validated at the PTEC site. **This daisy chaining of potential TF development is not just a one-way conveyor band, advancing individual technologies to a higher TRL level. Indeed, hind-cast analysis of the full scale results at TRL5-7 with the scaled results in the historically older TRL 4 results, might yield interesting new insights & R&D opportunities**.

There are however a lot of conditions to be met in order to establish this potentially successful feedback loop:

1) **An open data policy** (with quality control, exchangeable data formats & good metadata), at least amongst the TFs & technology developers involved;
2) Stimulate the publishing of dynamic data and the uptake of Application Programme Interfaces (APIs), as stipulated in the Commissions 'Open Data Directive'.

   Optionally, AI will provide interesting R&D opportunities, but they require good labelling of events by a human operator, so that the semantic AI engines can correctly interpret the data.
3) **A pipeline of multiple developments**: this methodology is potentially scalable, but the first 1 to 3 implementations will be time-consuming and thus costly, whereby the benefits differ amongst the actors.
4) **A clear consecutive project plan,** describing the conditions at the interfaces (technical, practical but certainly also IP wise).

Robin round testing (whereby a single test object is tested in different TF to determine variance in test results obtained from different TFs) is useful for regional collaboration & quality control.

As a last note, physical modelling & rescaling always implies a trade-off in either geometric, structural and hydrodynamic similitude. More specifically, more insights in the trade-offs for the latter in viscous (expressed by the Reynolds number) and gravitational forces (expressed by the Froude number) is key for this daisy chaining of relevant TFs. Due to the rise of cheap & readily available parallelized high performance computing the last 10 years, some expected that physical modelling would become less relevant. However the last years, a renewed interest in physical modelling was observed in hydrodynamic engineering.

4.6.2 TF: Diversify in sectors, from day one on

How TFs should orientate themselves towards sectors or type of clients is an important initial question and strongly depends on the funding structure and business model.

There are 2 major approaches: high focus towards a niche vs. broad focus and accommodating a wide spectrum of R&D or demonstration.

FabLab in Cornwall is a clear example of high (successful) focus towards wave energy demonstration, as also described in Deliverable 2.8.2 (METCERTIFIED, Caporaso et al. 2020). Their order book can be filled with international clients from all over the world, whereby the marginal travel cost of mobilisation or travelling to a relatively remote location within the 2Seas region like Cornwall is small.

Interestingly, both the COB & BA in Belgium have chosen for a wide spectrum approach. The main reason is 2-fold: as being a small Member state, regional or federal funding does not allow to have multiple TFs, but also the proximity factor allows to target the maritime (& offshore energy) industry as a whole. Nevertheless, these TFs are new ('19 & ''20) respectively, so this orientation needs to be validated as being a right strategic choice in the upcoming years.

NL Grevelingendam TTC can both be used for testing turbines, but is in essence a current flume, which also could be used as e.g. scouring testing for e.g. monopile foundations, although with less controlled hydrodynamic conditions like the big flumes of TUdelft/Deltares or Hamburg/Hannover, albeit on a very large scale, thus advantageous w.r.t. scaling laws.

But the main reason to choose for a diversification strategy (especially for a TF with high fixed costs) is the **economic developments within the sector, clearly indicating a relatively vulnerable emerging energy technology**. In the case where clients are missing (as was the case in WaveHub but also the DMEC test facility), there is no incentive to e.g. maintain or repair the grid connection, which is (or was) one of the biggest USP of these TFs (METCERTIFIED, Caporaso et al. 2020).

To conclude: being early as a TF in an emerging (energy technology) sector, without a diversification strategy (either sector, technology, geographically, type of services) **can imply the risk for a 2Seas TF turning from an "asset" into a "stranded asset" with mainly liabilities instead of opportunities**.

4.6.3 The proximity factor: location & proximity is paramount

There is no doubt that **EMEC** is the undisputed & pioneering worldwide test location for high energetic wave & tidal energy. But its remoteness is a 2-edged sword: it provides a huge highly technological boost to Orkney whilst simultaneously demonstrating the potential of ocean energy for remote (typically with low interconnection to the transmission grid) locations like islands. But the mobilisation and travel cost is high as well, whereby the travel cost from e.g. the EU mainland easily implies 2 days of travelling and 1000 € just to get there, which is a big (opportunity) cost for early technology developers with a weak balance sheet.

The high energetic zones (like the Billia Croo) site clearly show the forces of nature in play and the most relevant operational hours and MWhs produced by tidal energy, are coming indeed from Scotland, with most often a very important and sometimes a critical role for EMEC. But it only is relevant when achieved a TRL 8 phase at least.

The 2Seas has a clear advantage in that respect w.r.t. **proximity**, in several ways:

1) On **land** (with Belgium & Netherlands having a highly dense population & mobility network), including the proximity of research institutions, as well as the tier 1-2 supply chain, etc.
2) At **harbours**, playing a very important role for demonstration of ocean energy devices, with e.g. shipping yards or workshops for assembly or O&M, and of course the booming activities for offshore wind, now also taking of in France or accelerating (the Netherlands & UK), whereas in Belgium the 2nd wave of offshore wind installation is expected not before '24-'26;
3) And of course, the deployment locations around islands (like Aldernay Race, Paimpol-Brehat, Isle of Wight), estuaries (mainly in the Dutch Deltas), river (bypass) or sluice gates (Scheldt, Thames).

This proximity factor is a big advantage in the development of emerging technologies, as it inherently requires more (frequent & intensive) intervention on site. Ease of access both onshore & offshore is paramount. TTC-

Grevelingendam or Brouwersdam are readily available with simple trucks or land based cranes. Simultaneously, the Blue Accelerator is readily accessible, with only a 10 min sailing to the site with readily available towing tugs, RIBs (eg. from Flanders Marine Institute) or Crew Transfer Vessels from the offshore. A last, often neglected, advantage is to take e.g. EU or national policy influencers on site. Demonstrating tangible energy infrastructure is always a good strategy.

One thing to note though is that the Interreg La Manche Region specifically can be considered as a sibling for the Interreg 2Seas w.r.t. tidal energy. Herein lies an opportunity to have a joint strategy for the La Manche – Southern North Sea region. The Interreg La Manche Tiger project is a unique (flagship) project in many ways.

4.6.4 TF: Accreditation strategy for TF

All TF in the 2Seas Region should at least implement early accreditation strategies, in order to accommodate accreditation and thus the ability to deliver certified test reports. This is not necessarily to say that they should put high priority or urgency to obtain IEC-RE accreditation as such (to our knowledge, no TF is accredited as such), but at least that they develop strategies & implement test protocols & procedures based on TS or guidelines asap, so, that if the demand for accredited TF increases, the 2Seas TFs can relatively easy obtain accreditation.

This basically raises the question: what is the most optimal approach regarding standardisation, accreditation & certification, depending on the TRL level, stage-gated? This question can be answered by European Commission's internal Low Carbon Energy Observatory (LCEO) project, whereby industry wide consultations were held for the identification of future emerging technologies in the ocean energy sector (Magagne, Marghertini et al. 2018). Within this workshop, an applied checklist for ocean energy per TRL level was drafted and handed over to the Commission. An overview of selected criteria within this context can be found in Table 9. The full criteria checklist can be found in Annex. This checklist only explicitly mentions certification starting at “TRL 6”.

TABLE 9: OVERVIEW OF *SELECTED* TF ACCREDITATION OR CERTIFICATION TRL CRITERIA (MAGAGNE, MARGHERTINI ET AL. 2018) AND THE RELATIVE IMPORTANCE FOR THE TARGET GROUPS (MET-CERTIFIED)

TRL	Description	Relevance MC target groups				
		TF	Tech Dev	CB	Gov	Fin/Insurer
3	Preliminary Risk mitigation analysis		++	+		
4	Survival load cases	++	+++	+		
5	Operational environment: all the main aspects are represented in the lab, including not only the conditions influencing the power production level, but also those relevant for all the other sub-systems of the whole device.	+++	+++	+		
6	**Certification** and insurance requirements, licensing and permitting challenges are satisfied	+++	++	++		+
7	A **certification** roadmap is defined			++		++
8	Power matrix/function can be fully extracted according to **IEC standards**		++	+++		+++
9	Business case for commercial technology sales				+	+++

This accreditation strategy can be approach by a **stage-gated approach** (in line with the TS approach itself & the strategic guidelines from the industry roadmaps itself, see section) from low to high engagement within e.g. the project teams who are making or updating these TS:

1) Aware of these TS, but not yet implementing them in their testing procedures;
2) Aware of these TS, implementing them in their testing procedures, but without a short-term accreditation ambition;
3) Aware of these TS, implementing them in their testing procedures & with a short-term accreditation ambition.

4) Accredited TF, delivering high quality control & 3rd party audited or certified testing reports to their clients.

5) Active accreditation, standardization & certification TF "ambassador" for the whole industry, both in terms of the ocean energy sector, as well as the broader TF sector.

MET-CERTIFIED has held activities to increase engagement within e.g. the Project Teams (PT) or Maintenance Teams (MT) by actively raising awareness over the different activities, presentations and workshops.

For TRL 4 TF such as Ifremer Boulogne, Coastal & Ocean Basin Ostend, Coastal Ocean Laboratory Plymouth, this should be focussed on the respective wave technical specifications (TS) 62600-103 ed. 1.0 (TC-114 2018) & the TS 62600-202, to which the MET-CERTIFIED project actively contributed(TC-114 2020).

For TRL 5-6-7 (the open water test sites) these are outlined in figure, depending on the application (wave, tidal, river-stream respectively starting with -1, -2, -3) and the topic addressed (performance, resource or rescaling to a 2nd location stage-gated approach).

In this context, the H2020 Equimar project is worthwhile mentioning (FP7 that ran from April '08 to April '11). This project has, in retrospect, played an important role in the clustering of TF expertise, and formed the nucleus of the EU collaboration for e.g. the project teams within TC-114 (and the resulting TS 62600-103 wave energy scaling standard) and the resulting TS-103 wave energy scaling standard. This project however did not focus on the demonstration itself (like MET-CERTIFIED does), but had solely (desktop & research) related work packages related to the combination of experience and the lessons learned from each project partner (Kofoed 2019).

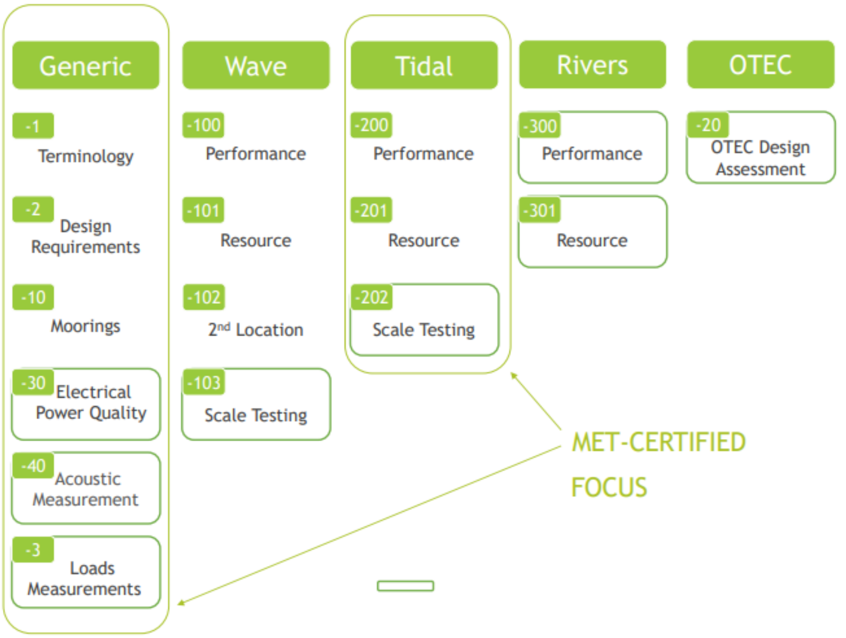


FIGURE 26 OVERVIEW OF THE IEC-TS 62600

If an accreditation strategy is in place early on within a TF, it can easily implement an official accreditation under the IECRE, once the market conditions are favourable enough to pursue this accreditation. The requirements from the IECRE to be considered as an accredited TF (note that IECRE uses the terminology Renewable Energy Test Laboratory or "RETLs"), are:

1. Be endorsed by the Member Body in the IECRE participating country;
2. Pay annual membership fees to IECRE;
3. A review of a sample of historic test reports issued for the competence area. If this is not available, a representative test report which may contain fictitious data can be a substitute;
4. A review of results of a proficiency test for the competence area;
5. A review of the candidate RETL's own processes and procedures related to the specific competence area;
6. Accreditation against ISO/IEC 17025 for the specific competence area;

7. Reassessment every 3 years;
8. Pay fees of peer assessment and accreditation;
9. An on-site peer assessment of a test and the related documentation.

Within this strategy a TF should also take into account the **costs** to become an accredited RETL (Renewable Energy Test Facility) under the IECRE, namely:

1. IECRE Membership; CHF 2.000 (one-off);
2. One-off Participation fee for marine energy sector: CHF 1.000;
3. Annual Membership for ME Sector: CHF 500 per annum
4. Peer Assessment cost: see IECRE OD 001 Ed 3.0 2017
5. Fee per Test Report or conformity assessment issued under IECRE: CHF 500/1.000 (under vote)

So the direct (external) total costs involved for the first 5 years are in the order of CHF 5.500 + peer assessment (estimated at 10-15k€). Of course, internal resources need to be spent to obtain these criteria, but is important to note that most of them (like ISO-17025) contains "*General requirements for the competence of testing and calibration laboratories*" and is basically good practice for any TF or Test laboratory, to perform credible and auditable test reports.

4.6.5 TF & Gov: cascaded open data policy, metadata & labelling

Non-disclosure & confidentialities are key in executing R&D & performing business, **but TFs & Governments (subsidizing actors in specific) can have a much more pro-active role in disclosing testing data, especially if the testing has been partially (sometimes almost fully) funded with public money.**

Open data should not just be considered as open to all, for any reason whatsoever, as soon as they become available. This data could be opened to affiliations clearly contributing to advancing the ocean energy sector. The Creative Commons licenses all require attribution, but make a distinction in share-alike, non-commercial or derivative rights. Last but not least, a balanced staged moratorium for data (e.g. 2 years only metadata disclosure, 4 years processed data, 8 years raw data) could allow matching the commercial requirements with public disclosure needs, assuring that test results of non-successful technologies are at least accessible. Of course the successful test results leading to commercial development should be protected.

The ORE Catapult datapod initiative clearly shows this is possible, even on an voluntary commercial basis, like Equinor, who opened up its data of the mooring lines of the offshore wind Hywind Tampen project. This initiative is neither to be considered solely as a PR initiative nor as an altruistic action by Equinor. It clearly indicates that, Equinor, through open data, is willing to facilitate open innovation for a problem (like offshore wind mooring) that is relevant to the wide industry.

EU collaboration offering access to TFs like Marinet2, Marinergi, ForSea, DemoOcean,… should be the first to facilitate operational open data policies. For new projects, this should be a condition sine qua non for funding. The new EU "Open Data Policy" (COM 2019) mentions explicitly "*energy consumption and satellite images (earth observation and environment), in situ data from instruments and weather forecasts (meteorological)*". These are directly relevant to (open-water) test facilities.

Furthermore, a call to open up retro-actively previously obtained data should be a sector wide opportunity. Of course, this would require an extensive analysis of the NDA agreements that were signed, but at the same time one can argue that test results from e.g. 5 years ago could be released, at least in an aggregated or high level form.

The common interest in doing so might be much bigger than continuing a business as usual strategy, as the tidal energy sector definitely needs to credibly demonstrate its commercial viability not just as a singled out technology, but also as a whole sector.

4.6.6 The stage-gated approach also in Interreg (2Seas)

The stage-gated approach developed by Wave Energy Scotland (Figure 27) is considered unanimously by the ocean energy sector federation, academia & the Joint Research Centre of the Commission to be an effective and efficient use of public money, by gradually de-risking subcomponents in order to integrate them later in integrated technologies (Magagne, Marghertini et al. 2018, Cagney, Gruet et al. 2019, ETIPocean 2019). Together with a concrete and applied checklist to determine the TRL levels for ocean energy (Magagne, Marghertini et al. 2018), a coordinated and aligned staged-gated R&D & demonstration trajectory for the tidal energy sector could be established (see also Annex).

The "*Ocean Energy Development Monitor*" in Table 10 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.

Within the framework of the **DTOcean+, a new staged-gated development tool/interface** will be launched in Q1 2020 (DTOcean+ 2019).

To conclude: there is a remarkably large consensus from all stakeholders (developers, policy, supply chain) that the stage-gate approach is the way forward for future policy support mechanisms, instead of rushing to TRL 8 demonstration projects, as was shown in § 2.1.3. The Interreg programs (2Seas, but also North-West-Europe, La Manche, Atlantic with maritime activities) could be aligned both internally as well externally with the stage-gate approach.

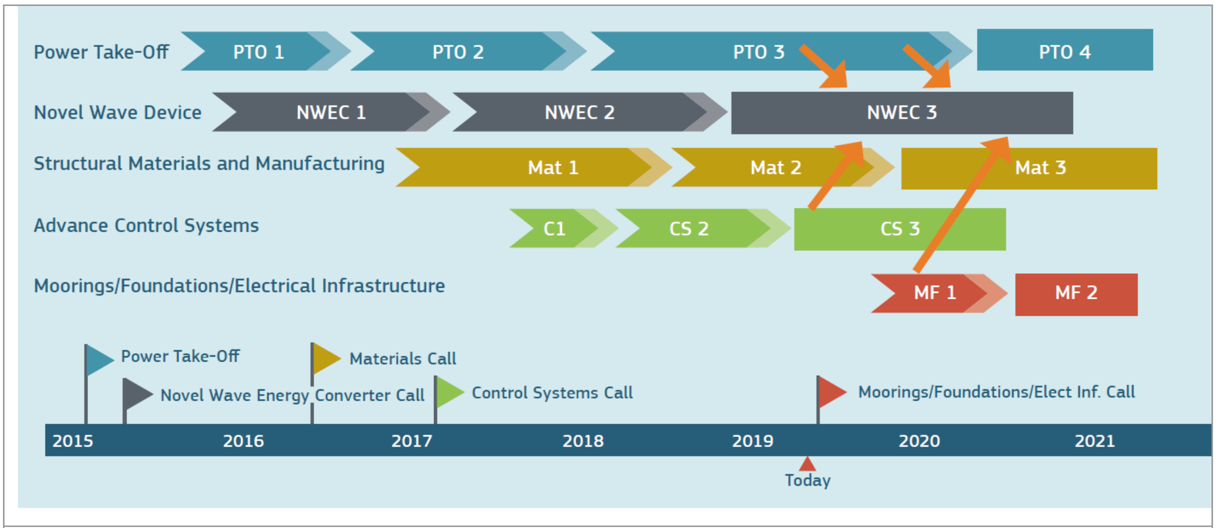


FIGURE 27: WAVE ENERGY SCOTLAND (WES) STAGE-GATED APPROACH FOR DE-RISKING OF SUBCOMPONENTS (CAGNEY, GRUET ET AL. 2019)

Table 10: Ocean Energy Technology Monitoring framework (Ecorys and Fraunhofer 2017)

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	Unknow n
	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

4.6.7 Government: Implement adaptive management respecting the precautionary principle for array demonstration

The **precautionary principle** is deeply embedded in international maritime law like the OSPAR convention. The burden of proof lies with the proponent of the activity and explicitly requires an 'informed and democratic' process. This implies that this burden of proof lies with the technology developer of tidal energy (like, but certainly not limited to e.g. fish friendliness). Furthermore, it needs to be open & transparent.

The historic context of these conventions and its interpretations date back to MARPOL (1973), the Rio Declaration (1192), OPSPAR (1998) and its preceding North Sea Conferences in response to, a.o., protection of fishing stock, the (deliberate) dumping in or incineration of polluting substances at sea, shipping & the oil & gas infrastructure. Whilst this principle was and certainly still is an important defence mechanism for the marine environment, it does not take into account possible benefits (e.g. local ecological impact vs global climate change impact). Especially the burden of proof is hard for the demonstration of a new technology, like tidal energy.

It is clear that the 2Seas regions cannot change international (maritime) law nor the national legislation equivalent, but it could facilitate the environmental impact knowledge about tidal energy. The following actions might help to at least:

1) Establish **a "best available technologies" baseline** for the most critical environmental impact (eg. fish or porpoises) impact.
2) Implement strategies like **Adaptive Management**, whereby a continuous monitoring obligation is used to adapt the human activities in order to minimize its impact on the environment, such as Adaptive Management as implemented in the US Department of Interior (DOI 2009), as also suggested by Ocean Europe Energy (Cagney, Gruet et al. 2019)[3].
3) Rochdale envelope for (first) tidal energy arrays. The UK Rochdale envelope approach under the planning Act 2008 defines a "technological" envelope under which a project can be developed, allowing some flexibility to new industry trends. Typically, bandwidths are defined in e.g. total capacity, turbine capacity (in the original case: onshore, later also offshore wind) and number of turbines. This allowed Environmental Impact Assessment to be made for an "envelope" of technological conditions, whereby the ecological impact differences within these conditions are considered small.

Those 3 actions are nevertheless not a "golden bullet" solution, as the precautionary principle within international maritime law is not expected to be changed.

4.6.8 Government: Lowest LCOE or highest local content, choose wisely

One of the benefits of ocean energy cited often by policy makers is the local opportunities for harbours and the supply chain. Whilst this might be true in early one-off and relatively small scale projects, this does not necessarily remains the case if the (tidal) energy sector would industrially scale, as we are currently seeing in the offshore wind. Large (utility) developers like Ørsted are having to ask politicians whether they want the cheapest possible offshore wind, or to prioritise other spin-off benefits such as job creation. Christina Aboo, director R&D of Ørsted, has put the following statement forward:.

> *"Right now, it's 'we want both'. But honestly, as an industry we are stepping up and saying simply, 'guys, you cannot have it. To accommodate all the extra requirements would be adding cost, potentially decreasing quality and increasing project risk, but not reducing the price of energy. The focus should be on planning regionally rather than "state by state or even city by city sometimes"*

Although this quote is anecdotal, it contains 2 main messages: in order to achieve minimum LCOE, the least restrictions on the supply chain should be put forward in tendering or auctioning, but is also is call for so called "functional or regional collaboration", with collaboration hubs crossing boundaries. Examples in the 2Seas region could be Dunkirk-Ostend harbours for the XX windfarm, Ostend-Flushing for the Belgian & Borssele wind farm cluster, or even the Greater Gabbard-Seamade OWF (Offshore Wind Farms).

It is expected that tidal energy, if commercial breakthrough is achieved, similar installation, O&M or even decommissioning hubs will arise. For tidal energy, the La Manche region hub could be considered as a functional hub. But in this case, the potential for combined offshore wind – tidal energy hubs could be explored. The same goes for e.g. installation jack-up vessels like DEMEs' Neptune, who is too small to install the new double digit MW wind turbines, but is fit-for-purpose as a tidal energy (turbine or foundation) vessel, as demonstrated by the jacking at Raz Blanchard at 4 m/s (which was previously considered not possible) or the installation of the ballasting blocks at the foundation at the Meygen 1A project.

4.6.9 Technology developpers: Modularity & serial production from eg automotive

In tidal energy technology development, a first iteration is not a "**minimum viable product**" like the consumer or retail market, but over designed due to the (expensive) nature of offshore & maritime logistics, whereby a fast iteration cycle is not optimal. So first iterations of tidal energy are typically over designed (use of safety margins) and ideally heavily instrumented, in order to eg. monitor loads or interaction with marine life.

[3] Note however that OSPAR is not applicable to US' seas, and Although the United States now recognizes the UNCLOS as a codification of customary international law, it has not ratified it.

Technology Qualifications are a first recommended and good practice, mainly to verify if the solutions used are proven in other or often contexts.

However, design for **serial production** is often not considered to be a priority at this stage. Therefore lessons from other industries can be learned from industries like automotive[4] & offshore wind (foundations & turbines). Note that **shipping is most often not a serial production activity**. From the automotive, several different mass production can provide inspiration in early phases of the design & development.

Modular platforms, like eg. Volkswagens automotive Modularer Querbaukasten MQB platform or more recently the Modulare E-Antriebs-Baukasten (EV) platform provide good examples. Same principle is applied to eg. the gearboxes of ZF Wind Power, which is a contractor for a.o. MHI Vestas offshore wind. The market request here is to effectively increase torque density (in weight & volume) for wind turbines. ZFs platform is called Shift, whereby the first iteration covers a torque range of 2,100-3,000kNm and is already commercially available. Further platform development is already able to deliver gearboxes of up to 12-15 MW: "*Our largest differential-type medium-speed gearbox is well scalable to the input torque and gearbox step-up ratio required for 15MW, by retaining the current three-metre gearbox outer diameter*." (Windpower 2018). Tidal energy convertors should also be developed to be produced by a modular platform approach. **Here the 2Seas area could implement automotive or (wind) gearbox (downsized) modularity strategies (eg. from Germany) to make domestic production cost competitive.**

5 Conclusion

This report analysed the current status of the tidal energy sector, mapped the current & potential supply chain & provided a set of recommendations in order to build a tidal energy supply chain in the 2Seas. This analysis was based on a desktop study & on the experiences obtained during the MET-CERTIFIED project.

At the start of the project, the tidal energy sector seemed to gain momentum. However, this turned out to be **slack tide** with turbulent waters, spinning up some technologies whilst simultaneously drowning others. The MET-CERTIFIED project and some project partners were in the midst of these vortices, to say the least.

This report did have not the intention to assess *if* tidal energy should be a key enabling energy technology in the 2Seas region. It is merely an attempt to provide recommendations & actions so that, in the case tidal energy is considered as a key enabling energy technology (KEET), it provides a concrete list of actions to go forward, and ultimately & hopefully make tidal energy bankable.

The tidal sector analysis showed that only 26.8 MW of tidal energy projects was deployed in the EU, with 11.9MW currently operational, the other decommissioned (mostly after their test period). This is in stark contrast with the anticipated capacity of the tidal energy sectoral roadmap. The causes of were both internal and external.

Public (EU from several programs) and private money found its way to the sector through numerous projects, but a stage gated approach was rather the exception than the norm, resulting in a relatively high budget spent on TRL 8 demonstration projects. Policy & subsidy support is rather scattered amongst the EU member states. Arguably, the total amount of project grants of 1.36 bio € in the period '07-'18 in the whole tidal energy sector should have been sufficient[5] to demonstrate the tidal energy sectors' viability, but at this stage, the viability demonstration is somehow anecdotal and limited to a few developers/OEMs.

Project developers (currently also very coinciding with technology developers) complained about insufficient policy support for early tidal energy demonstration (array) projects. The removal of the ringfencing for tidal energy in the UK CfD auctioning schemes might be the best example, despite the relative high strike price & 5 ROCs. In France, the expected *appel d'offres* (tenders) of the French government were delayed or cancelled. And in the Netherlands, Rijkswaterstaat/RVO still is doubtful about the integration of energy production in coastal & storm flood protection. Of course, Brexit didn't help supporting investor confidence, but the impact so far of Brexit seemed limited. Assessing the potential impact of Brexit in the future was beyond the scope of this report.

At the same time, offshore wind has accumulated 20 GW of installed capacity, with LCOE dropping to levels comparable to the wholesale electricity price, as has been seen in the latest UK CfD round 3. This presents an opportunity cost for the supply chain, who can more easily make its turnover from high volume markets. The current value chain of tidal energy is somehow scattered, although Test Facilities & demonstration projects show the importance of local supply chain, certainly for remote & island locations and certainly for tier 2-3 players or tier-1 players like marine contractors. However, this might shift as the industry grows.

[4] Lessons from automotive are only relevant for the construction site, as the end-user market of retail vs energy utility is completely different.

[5] If allocated both effective & efficient.

The *potential* value chain is clustered around areas with strong supply chains in offshore wind, maritime & shipping (latter including defence/Navy). Furthermore these value chain clusters are most often in the proximity of offshore wind development zones, indicating an interesting potential that the nucleus of the future tidal energy value chain lies at the current offshore wind & maritime value chain.

The analysis clearly shows that it is better to consider the Interreg La Manche & Interreg 2Seas region as one functional geographical zone, both for the resource as well as the supply chain.

The 2Seas areas has several TF for MRE. Some of them faced setbacks, like PTEC, Wavehub, Marsdiep, others recently became available (Blue Accelerator in Ostend) or will become available very soon (Coastal & Ocean Basin in Ostend, Grevelingendam Tidal Testing Centre).

The most important recommendation for all type of the MET-CERTIFIED target groups[6] is to implement a *coordinated stage gated* (public) funding policy in *all* EU & MS programs, in combination with open data policy (especially for failed projects). This also involves the 2Seas.

The additional recommendations for **TFs** are:

1) Daisy chain of test facilities: rescale the hydrodynamic conditions of the TRL5-8 TF to the TRL4 TF. Collaborative (follow-up) EU projects like eg. Marinet & Foresea can further.
2) Diversification for TFs in order to target different markets & provide transferable (cross industry) services & expertise.
3) Develop an accreditation strategy early on, in order to implement it when market conditions ask for it.

The additional recommendations for **Government/regulators** are:

1) Facilitate demonstration projects with tools like adaptive management or Rochdale envelope consenting.
2) Use the proximity factor in your advantage, whereby lower energetic zones are chosen as TFs, to gain operational hours in the water & MWh in the grid.
3) Cascaded open data policies should be imposed on projects with public funding.
4) Lowest LCOE or highest local content, choose wisely

The additional recommendation for **Tidal energy developer/OEMs** is:

1) Design & develop for manufacturability & mass production, including modularity.

For Investors/Insurers & Certification Bodies no additional recommendations were set. Caution is advised for crowdfunding of high risk emerging technologies, where due diligence is by definition a matter of expertise.

Lastly, it is now clear that in the very short term, tidal energy will most likely be unable to compete solely on LCOE alone with other forms of RE. This is especially true for offshore wind, whereby it is competing on all resources: money, marine space, grids, vessels, harbours, manufacturers & other supply chain enterprise. Tidal energy (developers) might emphasize more the USPs of tidal energy, like its predictability, and lack of visual hindrance.

However, even the most optimistic analysts underestimated the LCOE drop in offshore wind. If the tidal energy sector learns from its mistakes, successfully implements a sector wide stage gate approach and last but not least, can duplicate the scaling of offshore wind, **the tide can turn**.

[6] Test Facilities, Technology Developers, Government/Regulator, Insurer/Investor & Certification Bodies.

Annex : Overview of selected EU(Cordis) project in ocean energy.

Acronym	Budget	Funding	Title	Start date	End date
NEMMO	4 981 008	4 981 008	Next Evolution in Materials and Models for Ocean energy	1/04/2019	30/09/2022
EnFAIT	20 204 450	14 914 600	Enabling Future Arrays in Tidal	1/07/2017	30/06/2022
ELEMENT	4 984 623	4 984 623	Effective Lifetime Extension in the Marine Environment for Tidal Energy	1/06/2019	31/05/2022
PivotBuoy	3 960 065	3 960 065	PivotBuoy - An Advanced System for Cost-effective and Reliable Mooring, Connection, Installation & Operation of Floating Wind	1/04/2019	31/03/2022
OceanSET	1 043 745	992 029	Support to the Realisation of the Ocean Energy Implementation Plan of the SET-Plan	16/03/2019	15/03/2022
OCEANERA-NET COFUND	18 121 641	5 980 142	Ocean Energy ERA-NET Cofund	1/01/2017	31/12/2021
DGIM2	6 128 625	2 499 995	Deep Green Island Mode 2	1/08/2019	31/07/2021
DTOceanPlus	7 918 318	6 689 077	Advanced Design Tools for Ocean Energy Systems Innovation, Development and Deployment	1/05/2018	30/04/2021
BIG HIT	7 246 103	5 000 000	Building Innovative Green Hydrogen systems in an Isolated Territory: a pilot for Europe	1/05/2016	30/04/2021
FloTEC	22 044 232	9 782 380	Floating Tidal Energy Commercialisation project (FloTEC)	1/01/2016	28/02/2021
DEMOTIDE	47 999 417	20 301 150	DEMOnstration for Tidal Industry DErisking	1/01/2017	31/12/2020
RealTide	4 974 990	4 974 990	Advanced monitoring, simulation and control of tidal devices in unsteady, highly turbulent realistic tide environments	1/01/2018	31/12/2020
2DMAT4ENERGY	269 858	269 858	Stimuli-Responsive Two-Dimensional Materials for Renewable Energy	18/09/2017	17/09/2020
OCTARRAY	117 894 749	15 000 000	Scaling up to the Normandie Hydro Open-Centre Tidal Turbine Pilot Array	1/09/2017	31/08/2020
D2T2	3 214 666	2 250 266	Direct Drive Tidal Turbine (D2T2) Accelerator project	1/10/2016	31/03/2020
DP Renewables	2 927 031	1 934 657	A range of economically viable, innovative and proven HydroKinetic turbines that will enable users to exploit the huge potential of clean, predictable energy in the world's rivers, canals and estuarie	1/07/2017	31/01/2020
InToTidal	2 891 524	2 000 000	Demonstration of Integrated Solution for offshore Tocardo Tidal power plants.	1/01/2017	31/12/2019
MARINERGI	2 048 294	1 999 799	Marine Renewable Energy Research Infrastructure	1/01/2017	31/12/2019
POWDERBLADE	3 558 500	2 731 700	Commercialisation of Advanced Composite Material Technology: Carbon-Glass Hybrid in PowderEpoxy for Large (60-100m) Wind Turbine Blades	1/11/2016	31/12/2019

Acronym	Budget	Funding	Title	Start date	End date
OCEAN_2G	2 567 562	1 909 823	Second Generation technologies in ocean Energy	1/02/2017	30/11/2019
TIPA	4 401 565	4 401 565	Tidal Turbine Power Take-Off Accelerator	1/11/2016	31/10/2019
WaveBoost	3 988 744	3 988 744	Advanced Braking Module with Cyclic Energy Recovery System (CERS) for enhanced reliability and performance of Wave Energy Converters	1/11/2016	31/10/2019
OPERA	5 741 264	5 741 264	Open Sea Operating Experience to Reduce Wave Energy Cost	1/02/2016	31/07/2019
OpTiCA	148 636	148 636	Optimisation of Tidal energy Converter Arrays	1/07/2017	30/06/2019
BestRES	1 994 813	1 994 813	Best practices and implementation of innovative business models for Renewable Energy aggregatorS	1/03/2016	28/02/2019
PowerKite	5 074 364	5 074 364	PowerKite - Power Take-Off System for a Subsea Tidal Kite	1/01/2016	31/12/2018
CLEARWATER	22 798 367	7 736 317	CommerciaL Energy ARray for Widespread Acceleration of Tidal European Resources	1/01/2014	31/12/2018
OCTTIC	4 271 655	2 990 158	Open-Centre Tidal Turbine Industrial Capability	1/12/2016	30/11/2018
DG Island Mode	71 429	50 000	Deep Green Island Mode	1/08/2018	30/11/2018
WETFEET	3 456 884	3 456 884	Wave Energy Transition to Future by Evolution of Engineering and Technology	1/05/2015	30/04/2018
TIDES	13 615 045	8 002 735	Tidal Demonstration for Energy Scheme	15/04/2013	14/04/2018
EcoCurrent	71 429	50 000	Innovative water current picoturbines for the economic and sustainable exploitation of the renewable energy from rivers and estuaries	1/12/2017	31/03/2018
MARINCOMP	2 376 057	2 376 057	Novel Composite Materials and Processes for Offshore Renewable Energy	1/02/2014	31/01/2018
FFITT	71 429	50 000	Fish Flow Innovations Tidal Turbine	1/06/2017	30/11/2017
WATEC	71 429	50 000	Development of a novel wave tidal energy converter (WATEC) to lower renewable electricity generation costs.	1/05/2017	30/09/2017
SUBPORT	71 429	50 000	Subsea socket for offshore Platforms based on Tide turbines	1/06/2017	30/09/2017
MERIKA	4 406 018	3 950 000	Marine Energy Research Innovation and Knowledge Accelerator	1/02/2014	31/07/2017
TIDAL-EC	1 349 050	1 041 000	Tidal Energy Converter Cost Reduction via Power Take Off Optimisation	1/09/2014	28/02/2017
POLYWEC	2 620 590	2 059 156	New mechanisms and concepts for exploiting electroactive Polymers for Wave Energy Conversion	1/11/2012	31/01/2017
DTOCEAN	6 181 700	4 178 232	Optimal Design Tools for Ocean Energy Arrays	28/10/2013	27/10/2016
HydroKinetic-25	71 429	50 000	Commercialization of a viable and proven HydroKinetic Turbine that will harness the power of the world's rivers, canals and estuaries in a sustainable, innovative and cost-effective way.	1/03/2016	31/08/2016

Acronym	Budget	Funding	Title	Start date	End date
ACORN	1 342 124	1 036 000	Advanced Coatings for Offshore Renewable ENergy	1/11/2013	29/02/2016
HEXATERRA	1 571 697	1 198 998	The development of a modular 'stepping locomotion' system for installation on subsea trenching machines used for subsea energy cable burial	1/09/2013	30/11/2015
MARINET	11 045 266	8 999 998	Marine Renewables Infrastructure Network for Emerging Energy Technologies	1/04/2011	30/09/2015
TidalHealth	71 429	50 000	Health Condition Monitoring of Small Scale Tidal Generators Using Miniature Torque Sensors	1/03/2015	31/08/2015
Direct Drive TT	71 429	50 000	Feasibility study for an innovative direct drive tidal turbine	1/10/2014	31/03/2015
SEAMETEC	71 429	50 000	Smart Efficient Affordable Marine Energy Technology Exploitation using Composites	1/10/2014	31/03/2015
MAGNETIDE	1 457 244	1 131 700	Improved magnets for energy generation through advanced tidal technology	1/12/2012	30/11/2014
REMO	1 416 974	1 102 000	Online Remote Condition Monitoring of Tidal Stream Generators	1/12/2012	30/11/2014
FLOWENERGY	75 000	75 000	Flow energy harvesting in assemblies of vibrating solids: stability analysis and non-linear coupled dynamics	1/06/2011	31/05/2014
TidalSense Demo	2 949 380	1 621 900	Demonstration of a Condition Monitoring System for Tidal Stream Generators	1/02/2012	31/01/2014
PULSE STREAM 1200	13 937 029	8 008 936	Full scale demonstration prototype tidal stream generator	1/11/2009	31/10/2013
TIDALSENSE	1 568 205	1 145 650	Development of a condition monitoring system for tidal stream generator structures	1/09/2009	31/08/2011
ORECCA	1 797 871	1 599 033	Off-shore Renewable Energy Conversion platforms – Coordination Action	1/03/2010	31/08/2011
SNAPPER	1 391 919	988 620	The development of a novel rare-earth magnet based wave power conversion system - Snapper	1/09/2009	31/08/2011
EQUIMAR	5 482 036	3 990 024	Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact	15/04/2008	14/04/2011

Annex Marine Energy Projects worldwide (reNews 2018)

Year	Name	Location	kW	Technology	Type
2021	Simec Atlantis Energy Raz Blanchard	Normandy	200000	Atlantis AR	Tidal
2020	Blue Shark Power Bab-el-Mandeb	Djibouti	18960	Blue Shark	Tidal
2021	SBS Energi Kelautan Lombok island	Indonesia	12000	Atlantis AR	Tidal
2020	DP Energy FORCE Berth E	Canada	7500	Andritz Hydro MK1	Tidal
2020	Tidal Sails Hammerfest	Norway	4400	TackReach	Tidal
2023	Big Moon Power Minas Passage	Nova Scotia	4000	Kinetic Keel	Tidal
2019	Simec Atlantis Energy Pentland Firth	Scotland	3400	AR2000	Tidal
2019	HydroQuest Genissiat	France	2040	HydroQuest	River Tidal
2018	Cape Sharp Tidal FORCE Berth D	Canada	2000	OpenHydro	Tidal
2018	Magallanes Renovables EMEC	UK	2000	Atir	Tidal
2020	Orbital Marine Power EMEC	Scotland	2000	Orbital O2 2 MW	Tidal
2022	Sabella Ushant	Brittany	2000	D12-1000	Tidal
2020	Black Rock Tidal Power FORCE Berth B	Canada	1680	Plat-I	Tidal
2020	Bombora Wave Power META	Wales	1500	mWave	Wave
2020	Carnegie Clean Energy Albany	Australia	1500	CETO 6	Wave
2021	Marine Power Systems Wave Hub	Cornwall	1500	Wavesub	Wave
2019	Tocardo EMEC	Scotland	1350	UFS	Tidal
2021	New Energy Corporation Bay of Fundy	Nova Scotia	1250	EnviroGen	Tidal
2018	Sabella Ushant	France	1000	D10	Tidal
2019	Big Moon Power Minas Passage	Nova Scotia Canada	1000	Kinetic Keel	Tidal
2019	Deepwater Energy TTC-Grevelingendam	Netherlands	1000	Oryon Watermill	Tidal
2019	HydroQuest Paimpol-Brehat	France	1000	HydroQuest	River Tidal
2019	Pentair Fairbanks Nijhuis TTC-Grevelingendam	Netherlands	1000	Bi-Directional Turbine	Tidal
2019	Wello EMEC	Scotland	1000	Penguin WEC-2	Wave
2019	Wello EMEC	Scotland	1000	Penguin WEC-3	Wave
2020	Nova Innovation Bardsey Sound	Wales	1000	M100	Tidal
2018	Minesto Holyhead Deep	Wales UK	500	DG500	Tidal
2019	Columbia Power Technologies WETS	Hawaii USA	500	Stingray	Wave
2019	Ocean Energy WETS	Hawaii	500	OEBuoy	Wave
2019	China Shipbuilding Industry Corporation Zhoushan	Zhejiang China	450	SG500	Tidal
2019	Black Rock Tidal Power Grand Passage	Nova Scotia Canada	420	Plat-I	Tidal
2019	AW-Energy Peniche	Portugal	350	Waveroller	Wave
2020	Wavepiston Hanstholm	Denmark	350	WavePiston	Wave
2018	HydroQuest Caluire et Cuire	France	320	HydroQuest	River Tidal
2018	Crestwing Kattegat	Denmark	300	Tordenskiold	Wave

Year	Name	Location	kW	Technology	Type
2019	Blue Shark Power	LHD Zhoushan Zhejiang China	300	Blue Shark	Tidal
2020	ORPC Cobscook Bay	Maine UK	300	TidGen	Tidal
2018	Black Rock Tidal Power Grand Passage	Nova Scotia Canada	280	Plat-I	Tidal
2019	Waves4Power Runde	Norway	250	Next Generation	Wave
2020	New Energy Corporation Bay of Fundy	Nova Scotia	250	EnviroGen	Tidal
2019	Blue Shark Power Bab-el-Mandeb	Djibouti	240	Blue Shark	Tidal
2019	Hydro Air Concept Energy Blanquefort	France	200	Hace	Wave
2019	Laminaria EMEC Billia Croo	Scotland	200	Laminaria	Wave
2019	Wave Swell Energy King Island	Tasmania	200	WSE	Wave
2020	Minesto Vestmannasund Strait	Faroe Islands	200	DG100	Tidal
2018	Geps Techno Sem-Rev	France	150	IHES	Wave
2019	Guinard Energies French Guinea	French Guinea/Madagascar tbc	150	P154	Tidal
2019	Verdant Roosevelt Island	USA	105	KHPS Gen5	Tidal
2018	Big Moon Power Minas Passage	Nova Scotia Canada	100	Kinetic Keel	Tidal
2019	Instream Energy Systems EMEC	Scotland	100	Instream	Tidal
2019	Minesto Keelung	Taiwan	100	DG100	Tidal
2019	Nova Innovation Shetland	Scotland	100	M100	Tidal
2020	Nova Innovation Shetland	Scotland	100	M100	Tidal
2021	Nova Innovation Shetland	Scotland	100	Nova M100	Tidal
2019	Sinn Power Heraklion	Crete	72	Sinn Power	Wave
2018	Hydro Air Concept Energy Port of La Rochelle	France	50	HACE	Wave
2019	New Energy Corporation Bay of Fundy	Nova Scotia	50	EnviroGen	Tidal
2018	SINN Power Heraklion	Crete Greece	48	Sinn Power	Wave
2018	Fred Olsen WETS	Hawaii USA	30	Bolt Lifesaver	Wave
2018	Tecnalia Bimep	Spain 30 Marmok-A5 Wave	30	Marmok-A5	Wave
2018	40South Energy Pisa	Italy	25	H24	Wave
2018	CorPower EMEC	Scotland UK	25	S3	Wave
2018	DesignPro Seeneoh	France 25 GKinetic Tidal	25	Gkinetic	Tidal
2018	NeptuneWave Strait of Georgia	British Columbia Canada	25	Neptune	Wave
2018	New Energy Corporation Portsmouth	New Hampshire USA	25	EnviroGen	Tidal
2019	Guinard Energies Ria d'Etel	France	20	P400	Tidal
2018	Okinawa Institute of Science and Technology Graduate University	Kandooma Island Maldives	16	OIST WEC	Wave
2018	Marine Power Systems Milford Haven	Wales UK	10	Wavesub	Wave
2018	Aqua Power Technologies Clift Sound	Shetland UK	5,2	Manta	Wave
2019	Nemos Ostend	Belgium	5	Nemos	Wave
2018	Guinard Energies Amboarakely	Madagascar	4	P66	Tidal
2018	Guinard Energies Arzon	France	3,5	P66	Tidal
2019	Enel Green Power Valdivia	Chile	3	OPT Powerbuoy PB3	Wave

Annex: OCEAN energy TRL & MRL checkpoints

TRL	**TRL checklist applied to Ocean Energy Checkpoints (Magagne, Marghertini et al. 2018)**	**Manufacturing RL (Wikipedia and DoD 2019) Supply chain & Industrialisation**
1	□definition of principles underlying the technology □; □ evaluation of the benefit of the technology in comparison with other existing technologies; □ first identification of interfaces with other systems.	Basic manufacturing implications identified
2	□ Definition of application □ Identification of materials and suppliers □ Statement of interactions between technologies □ Identification of main technological and non-technological challenges □ Early consideration of commercial value of the technology. □ Operational environment: the environment is not simulated / is simulated to a limited extent	Manufacturing concepts identified
3	□ Analytical and experimental (lab scale, controlled environment) investigations of the main component/s of the device (i.e. absorber element, energy conversion elements if not available off the shelf, sub-components) □ Main energy-conversion elements manufacturability, installation, and operability analysis □ Compatibility analysis between main energy-conversion technologies □ Preliminary risk mitigation analysis □ **Scale of testing: tests are conducted in a controlled environment (lab), and only on the main component/s of the technology (not the whole integrated system)** □ Operational environment: the most relevant aspects of the environment (monochromatic wave height/frequency ranges, sea states' significant wave height and zero-crossing period for WEC, current speed and/or tidal ranges for tidal devices) are simulated in a controlled environment (lab). □ Fidelity: the main component/s of the system are reproduced and tested at a scaled level, to represent the main characteristics influencing the energy absorbed/transformed □ Confirmation of expected results estimated in the previous TRLs	Manufacturing proof of concept developed
4	□ Testing and validation at laboratory level of technology gathering separate elements □ Validation of interoperability □ Manufacturing, installation, and operation investments/costs identified □ Risk management integrated in the project □ Scale of testing: tests are conducted in a controlled environment (lab), and integrating the main elements □ Operational environment: the relevant aspects of the environment are simulated in a controlled environment (lab). □ Survival load cases should also be considered □ Fidelity: some of the component/s of the system are reproduced and tested at a scaled level □ Detailed assessment of the commercial value is produced □ Confirmation of expected results estimated in the previous TRLs	Capability to produce the technology in a laboratory environment
5	□ Testing and validation in simulated environment finished □ Control capacity towards integration at system level □ Manufacturing prototype completed □ Manufacturing strategy defined (including cost model) □ Scale of testing: tested in a relevant, but still controlled, environment. □ Operational environment: all the main aspects are represented in the lab, including not only the conditions influencing the power production level, but also those relevant for all the other sub-systems of the whole device. □ Fidelity: the scaled model configuration is similar to the full scale configuration in most relevant aspects (including balance of plant systems) □ PTO conversion efficiency (electrical) - Storm survival - identification of suppliers for TRL6 (relevant benign environment) □ Upscaling study based on test results is performed □ A refined detailed assessment of the commercial value is produced	Capability to produce prototype components in a production relevant environment.
6	□ Technology demonstrated in relevant environment □ Project management approaches are practised □ Servicing and maintenance techniques, even if at a smaller scale and for a limited amount of time, are practised □ Certification and insurance requirements, licensing and permitting challenges are satisfied □ Process and tooling mature □ Capacity of structuring information at system level □ Operational environment: the device is tested in a "benign" test natural site, i.e. the metocean conditions cannot be controlled, but these are suitable for a scaled prototype, avoiding extreme conditions □ Fidelity: the scaled model configuration is similar to the full scale configuration in all but minor aspects □ Details for intended final scale installation defined □ Design and manufacturing for intended final scale defined □ Simulation for energy production achieved □ An updated and refined detailed assessment of the commercial value is produced	Capability to produce a prototype system or subsystem in a production relevant environment

TRL	**TRL checklist applied to Ocean Energy Checkpoints (Magagne, Marghertini et al. 2018)**	**Manufacturing RL** **(Wikipedia and DoD 2019)** **Supply chain & Industrialisation**
7	□ Pilot demonstrated in field (operational environment) □ Relevant operational experience in gained □ Reliability of integrated pilot □ Manufacturing and deployment techniques are proven □ Scale of testing: a pilot system at final scale □ Operational environment: the device is tested in a natural site with representative real sea conditions □ Fidelity: the prototype configuration is virtually the same as the full scale system □ All information for a commercial proposition are available □ Environmental aspects are considered and implemented in the final scale □ A certification roadmap is defined	Capability to produce systems, subsystems or components in a production representative environment.
8	□ Technology in its final form and under expected conditions □ Readiness for low-rate production □ Integration in operational environment □ Scale of testing: a pilot system □ Operational environment: the device is tested in a natural site with representative real sea conditions □ Fidelity: the prototype configuration is virtually the same as the final scale system □ Power matrix/function can be fully extracted according to IEC standards □ Number of hours/availability are maximised □ Health and condition are monitored □ Energy production is validated to confirm the economic plan □ Environmental impacts are contained □ Commercialisation plan is fully formulated	Pilot line capability demonstrated. Ready to begin low rate production
9	□ System fully operational, including the inter-device energy grid, the substation, and the connection to the shore energy grid □ Integration of technology proven in operational environment □ Full-rate production □ system ready for commercialisation □ Scale of testing: 1:1 (final scale), an array of 3-5 (or more) devices □ Operational environment: the devices are deployed in a real commercial site, exposed to the full range of operational conditions □ Fidelity: the device is identical to the commercial product (apart from the necessary adjustments for the different location conditions) □ Failure report/log □ Farm power matrix/curve □ Business case for commercial technology sale	Low rate production demonstrated. Capability in place to begin Full Rate Production.
10		Full rate production demonstrated and lean production practices in place.

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