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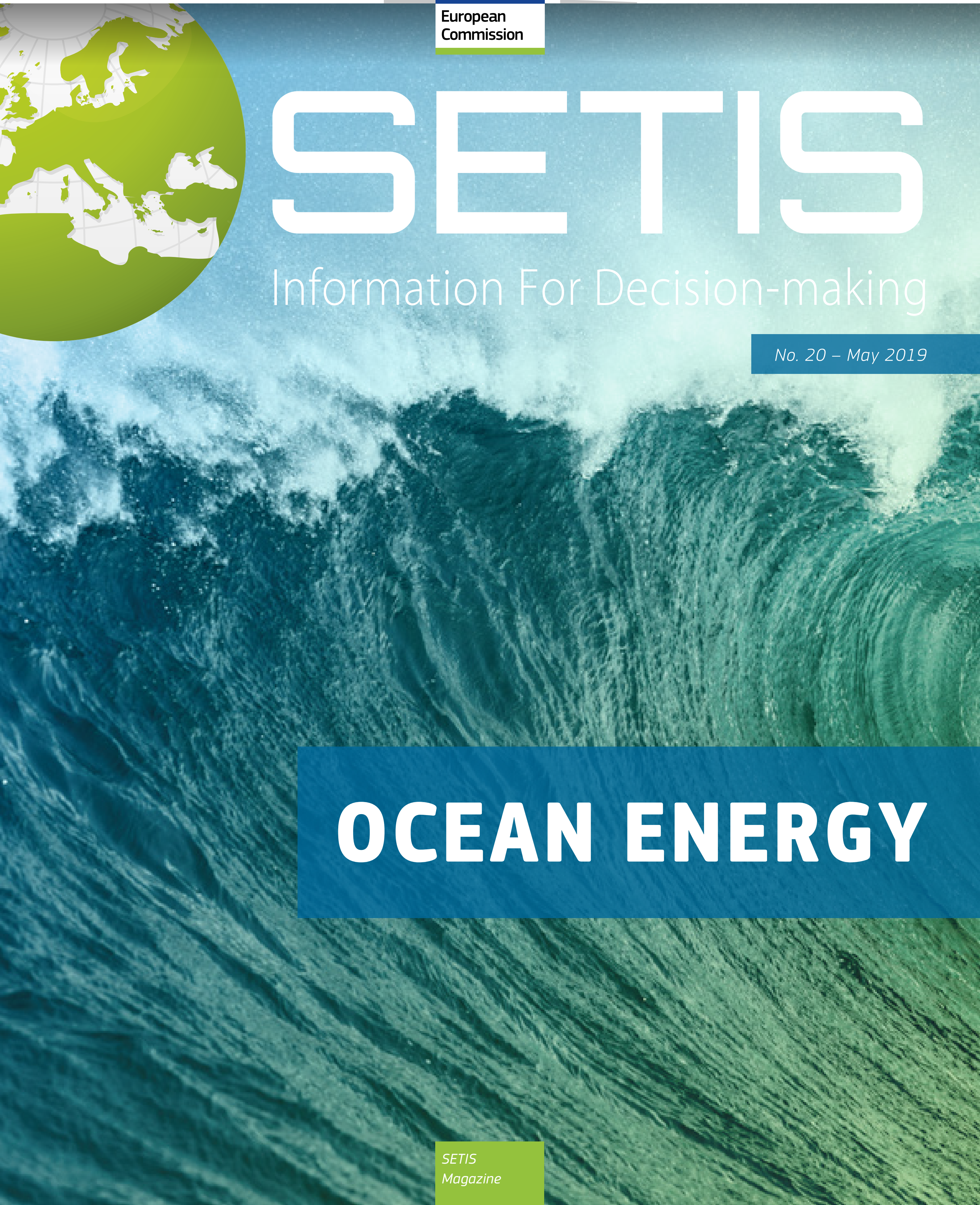
No. 20 – May 2019



OCEAN ENERGY

SETIS Magazine

SETIS Magazine

Ocean energy
No. 20 - May 2019

Jobs and skills in the energy transition
No. 19 - December 2018

The relevance of the water-energy nexus for EU policies
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Looking back 10 years of forward thinking SET Plan
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EDITORIAL

Ocean energy is one of the few sources of renewable energy which remains **untapped**[1]. Europe's rich natural resources and conditions mean that 10 % of EU electricity demand could be met by ocean energy by 2050. It is therefore well placed to contribute to key objectives in the **Energy Union Strategy**[2] in terms of decarbonisation of the energy system and increased security of supply, and to the goals of the **Blue Growth Strategy**[3] in terms of economic impacts and employment creation in coastal regions.

Ocean energy represents an area of leadership for Europe, which hosts the majority of tidal and wave energy developers[4], 78 % of global installed capacity is deployed in European waters. But further development is needed to make ocean energy technologies a key player in the transformation of the energy system, and to exploit their potential for growth and job creation in the EU.

The European Commission has laid out a number of policy initiatives to support the deployment of new ocean energy technologies, building on current industrial leadership and providing a route to market. The **SET Plan Implementation Plan**[5] for ocean energy provides 11 Research and Innovation activities to drive the sector towards commercialisation, whilst the recent **DG MARE market study**[6] investigates ways to create market support systems for it.

This edition of SETIS Magazine takes a closer look at the development of ocean energy technologies in Europe and worldwide. It examines the current policy drivers at European and International level, and looks at innovation in the sector.

Renowned experts from the wider research and policy community assess the state of the art of ocean energy from various angles: technological, financial and environmental. Routes to market are also explored, including the role of ocean energy in powering islands and remote communities in low-resource areas. International examples provide further insight into the long-term benefits of ocean energy, and on alternative policy approaches for driving its development.

1 https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_en.pdf
2 https://ec.europa.eu/commission/priorities/energy-union-and-climate_en
3 https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en
4 EU companies hold 66% of tidal stream patents and 44% of wave energy patents globally. Source: Ocean Energy Europe, IRENA
5 https://setis.ec.europa.eu/system/files/set_plan_ocean_implementation_plan.pdf
6 https://ec.europa.eu/maritimeaffairs/content/market-study-ocean-energy_en

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NEWS

The European Strategic Energy Technology Plan (SET Plan) aims to transform the way we produce and use energy in the EU, achieving EU leadership in the development of technological solutions to reach the 2030 energy and climate goals.

The SET Plan, supported by its Strategic Energy Technologies Information System (SETIS), is the key implementing instrument of the European Commission's Energy Union Research and Innovation (R&I) Strategy.

The 11th SET Plan Conference took place in Vienna on 20-21 November 2018, and took stock of progress on the SET Plan actions, following endorsement of the relevant Implementation Plans (IPs)[1]. DG ENER's Director General, Dominique Ristori, presented the 2018 progress report, *SET Plan delivering results*[2], jointly prepared by the JRC, DG ENER and DG RTD. You can revisit the highlights of #SETPlan18 on the conference website[3].

A meeting of the SET Plan Steering Group (SG addressed the challenges of developing partnerships between public and private actors to accelerate the EU's energy transition. Discussion focused on 1) the future of the Joint Action Working Group under the Horizon Europe Framework Programme; 2) indicators for tracking progress on executing IPs; 3) interaction between the SET Plan SG, EERA, ETIPs and other relevant stakeholder structures; and 4) the research, innovation and competitiveness dimension in the *Governance of the Energy Union Regulation*[4]. The main outcome was the endorsement of the *Energy Efficiency Solutions for Buildings*[1] and *Smart Solutions for Energy Consumers*[1] IP.

A further SET Plan SG meeting took place in February 2019, focusing on 1) the latest developments of the R&I dimension of *A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy*[5]; 2) the status of current Horizon 2020 Energy ERA-NET co-funds actions; and 3) inter-institutional discussion on the rules for partnerships in Horizon Europe.

One of the co-chairs of the Temporary Working Group on Action 10 for *'Maintaining a high level of safety of nuclear reactors and associated fuel cycles during operation and decommissioning, while improving their efficiency'*, presented its Implementation Plan. Only interested SET Plan countries[6] will participate, on a voluntary basis, in the activities presented[7].

At the SET Plan SG meeting in April the chairs of four Implemen–tation bodies reported on their status and governance structures. Commission represented by SETIS presented its views on the most suitable methodology to monitor the progress towards the Implementation of the SET Plan.

Two SET Plan Conferences will take place this year. The first, in Bucharest[8] on 12-14 June, will focus on regional and local issues. The second will take place in Helsinki on 14-15 November, and will focus on the industry sector. SG meetings will occur under each Presidency of the Council of the EU.

1 https://setis.ec.europa.eu/actions-towards-implementing-integrated-set-plan/implementation-plans
2 https://setis.ec.europa.eu/set-plan-delivering-results
3 http://www.setplan2018.at/
4 EC communication (2016) 759: *Proposal for a Regulation on the Governance of the Energy Union*
5 EC Communication (2018) 773: *A Clean Planet for all – A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy*
6 Formal notification of endorsement of Implementation Plan received from: BE, CH, CZ, ES, FI, FR, HR, IT, LT, NL, PL, RO, SI, PL, TR & UK
7 Fission-related R&I actions are expected to be supported primarily through the national programmes of interested countries and by industry. Financial support (if any) via the Euratom Research and Training Programme will continue to be restricted to research addressing safety, radioactive waste/spent fuel management, radiation protection and education and training, in accordance with the underlying legal framework Council Regulation (EURATOM)
8 http://setplan2019.ro/

FOREWORD

Europe is the world's undisputed ocean energy leader. Let's benefit from this first-mover advantage!

KARMENU VELLA

Karmenu Vella is the European Commissioner for Environment, Fisheries and Maritime Affairs. He was born in Malta on June 1950. Mr Vella graduated in Architecture and Civil Engineering, and later obtained a Master of Science in Tourism Management from University of Sheffield. He was first elected to Parliament in 1976 and continued to be re-elected in the elections that followed for nine consecutive times. During his political career he has been appointed Minister for Public Works, Minister for Industry and Minister for Tourism twice. Mr Vella had also held various senior posts in the private sector.

Europe is committed that renewables should make up at least 32 % of the European Union total energy consumption by 2030. And the Commission has gone a step further. Last November we presented our *strategic long-term vision for a prosperous, modern, competitive and climate-neutral economy by 2050 – A Clean Planet for All*.

A climate-neutral European economy would mean a massive increase of our clean electricity production, including from the ocean. In addition to offshore wind, it is clear that new generations of renewables – and ocean energy in particular – will have a big role to play in the years and decades to come.

Ocean energy could offer stability and complementarity in our energy mix. For wave and tidal energy technologies, the industry sees a potential installed capacity of 100 GW in Europe and creating up to 400 000 jobs by 2050. Thermal energy from the sea is another interesting option to explore.

Thanks to its investment in research and development, Europe is today the clear global leader in wave and tidal energy technologies. EU waters offer favourable natural conditions to harvest renewable energy offshore. We have the engineering abilities and skills. In the context of the SET Plan Ocean, Member States and the Commission have set ambitious but reachable cost-reduction targets for the next decade.

The deployment of these technologies and the building up of a manufacturing and maintenance industry could boost economic development well beyond coastal areas. The operation and supply chain is already pan-European and involves many Member States, with innovative SMEs and large manufacturers, benefitting from its links with other mature industries, such as the offshore, mechanics, shipping or aerospace business where Europe has leading companies. European companies are already exploring export potential.

It might not be possible for one Member State alone to build the critical mass and the economies of scale that will bring ocean energy technologies to market. However, when we put all the projects in Europe together, we can jointly build the home market that European businesses need to grow.

In the coming years, the European Commission wants to direct funding and financial instruments even more strongly towards promising low-carbon technologies like ocean energy. But we also need cooperation. Between different parts of national administrations. Between Member States. And between the national and the European level.

Policy predictability is key. Because we know that ocean energy investors and developers need visibility and certainty in public policy – for instance through targeted support measures and objectives to open up a business perspective. To anticipate and de-risk future consenting process, we will continue our support for projects that monitor the interaction of ocean energy devices with marine life.

Over the past years, I have met many passionate entrepreneurs in the ocean energy sector. They have demonstrated incredible innovation and made remarkable progress.

When I look at the future of this sector, I see a stable and reliable supply of clean energy. I see new jobs and investments in coastal regions and beyond. This requires strong and continuous political leadership. The European Commission will continue to pursue a strong European ambition and global leadership in ocean energy.

ARTICLE

Europe: a hub of innovation for ocean energy

There is clearly a tremendous amount of energy in the oceans, and harnessing it for our energy system would be ideal. But how? Along the coastline of Europe, you can see that this question has long inspired innovation, with a host of ideas born and tested to make use of waves and tides. The Joint Research Centre of the European Commission has been watching the sector for years, and its analysis shows the parts of the EU in which developers are active, and in which the ocean energy supply chain is developing. Most of the activity, predictably, takes place in coastal areas, but there are inland regions which are also engaged.

Some concepts didn't survive; others were more successful and have now advanced to full-scale testing. Expectations were and are very high, along with the pressure to deliver quickly. But you cannot rush science and technology development. This takes time, but can be more effective when developers build on the experience and knowledge of their peers, taking care not to repeat past mistakes. Knowledge exchange and (cross-sectorial) cooperation is therefore very important.

The European Commission has always supported this cooperation in Europe, via R&D framework programmes such as FP7 and Horizon 2020. The Horizon 2020 programme has several sub-programmes. The SME programme focuses on the stimulation of innovation, helping SMEs to bring new technologies to the market. Cost-reduction of ocean energy technologies is one of the main goals of the Horizon 2020 Energy programme. One of its criteria is that each consortium includes beneficiaries from three different EU Member States or associated countries. This criterion has led small networks of ocean energy innovators to be set up. The Commission also gives financial support to ocean energy, via support programmes such as InnovFin EDP (a loan facility executed by the European Investment Bank) and NER 300 (a funding programme for innovative, low-carbon energy demonstration projects).

> *‘ Europe is the birthplace to innovative ideas which have the potential to reach the market, but knowledge exchange and cooperation are crucial to progress. ’*

Between 2007 and 2018, the European Commission supported a range of ocean energy projects through various financial instruments, making a total investment of EUR 864 million. The European Commission currently funds 18 projects via the Horizon 2020 programme. These 18 projects might better be described as ocean energy innovation hubs, through which networks of ocean energy developers are created. Developers from industry are working together in consortia with researchers and scientists. Innovative solutions are proposed and tested. New knowledge is built up.

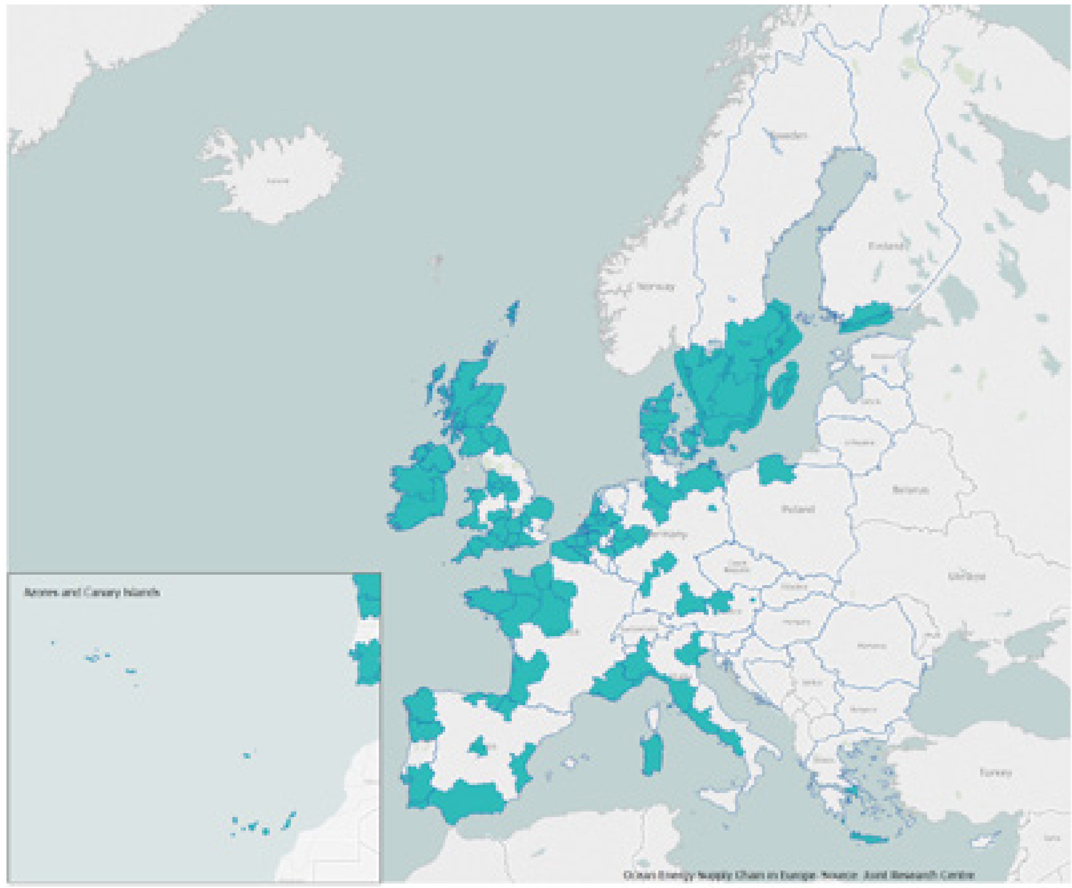


Figure 1: EU regions where the ocean energy supply chain is developing. Source: JRC snapshot 2019 on ocean energy, to be published 2019.

Not all EU projects are focused on the development of new designs and concepts. For instance, in MaRINET2, almost 40 partners provide support to technology developers to test their devices in research facilities and in real sea conditions, improving the quality, robustness and accuracy of testing practices. MARINERG-I, a network of 13 universities/research institutes, is developing a plan for an integrated European Research Infrastructure: an independent legal entity, designed to facilitate the future growth and development of the offshore renewable energy sector.

The sector is also encouraged to discuss and develop a common vision of what is needed for the future. The European Technology and Innovation Platform on Ocean Energy, a network of stakeholders in Europe, recently produced a strategy document for the whole sector: *Powering Homes Today, Powering Nations Tomorrow: Policy Solutions to Deliver Ocean Energy Industrial Roll-Out.*

Europe is the birthplace to innovative ideas which have the potential to reach the market, but knowledge exchange and cooperation are crucial to progress. Networks of ocean energy developers and researchers are essential, and European hubs have therefore been created to make this a reality. These hubs are not working in isolation: there are many crossovers. Europe has become, as a result, one large hub of innovation and knowledge for ocean energy.

Wave Energy Transition to Future by Evolution of Engineering and Technology. The WETFEET project focused on the development and integration of two different wave energy converters. The project considered cross-cutting aspects such as logistics and supply chain, as well as environmental and socio-economic issues.

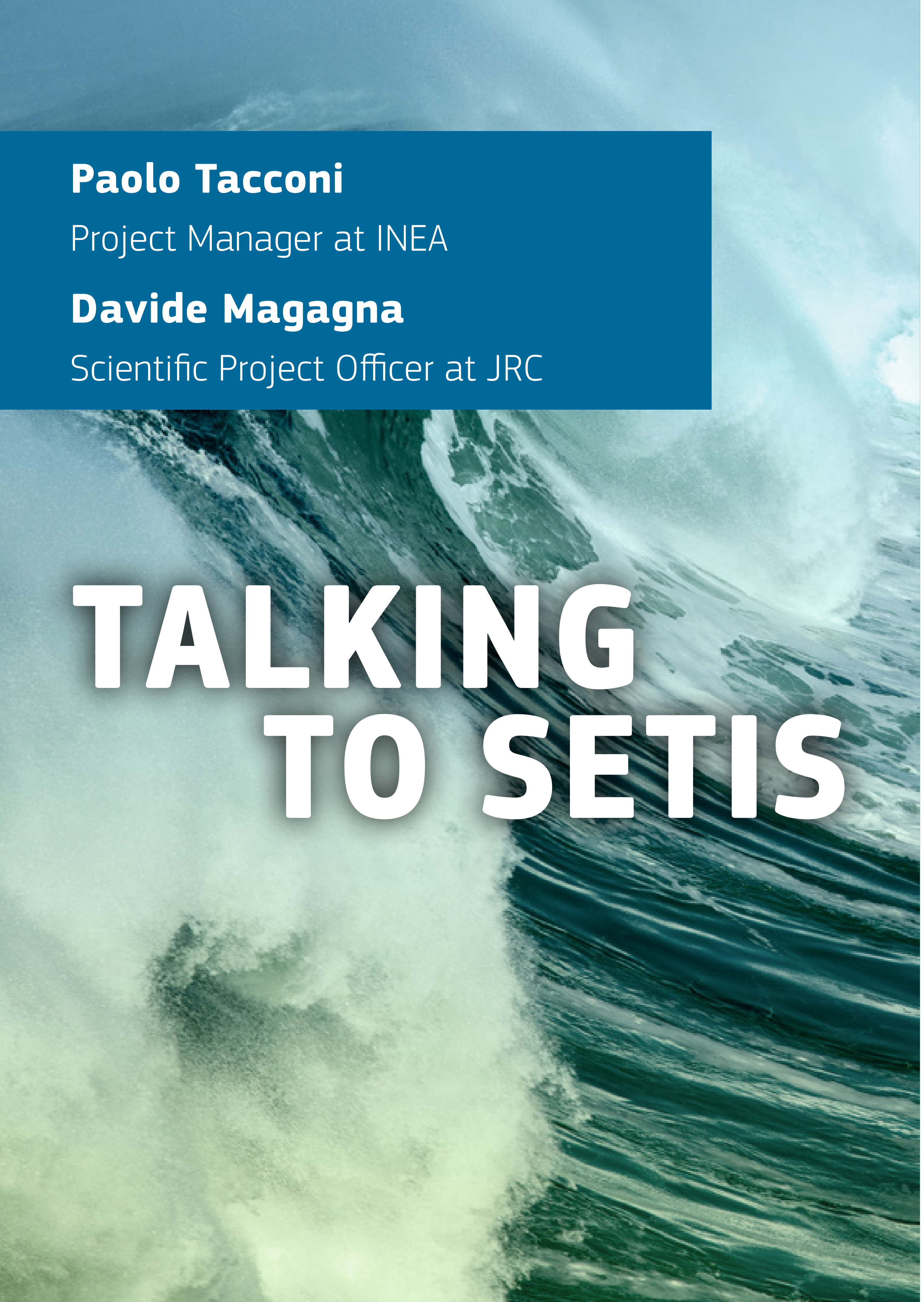
12 partners coming from PT, IT, FR, UK, NL, AT

6 partners from industry, 5 universities and 1 research institute

EU contribution EUR 3 456 883

MATTHIJS SOEDE

Dr. Ir. Matthijs Soede has a PhD in Chemical Engineering from Delft University of Technology. He began his career at SenterNovem, an agency of the Ministry of Economic Affairs in the Netherlands, advising companies, research organisations and universities on European programmes for research and development. In 2008, he was seconded to the European Commission, where he joined the Industrial Technologies directorate in DG RTD. In 2012, he joined the European Commission as Research Programme Officer for Ocean Energy in the Energy Directorate of DG Research and Innovation.



Paolo Tacconi

Project Manager at INEA

Davide Magagna

Scientific Project Officer at JRC

TALKING TO SETIS

ABOUT COST-REDUCTION OF OCEAN ENERGY: LESSONS FROM HORIZON 2020

Ocean energy comprises five distinct technologies: wave energy, tidal stream energy, tidal range energy, ocean energy thermal conversion and salinity gradient. EU policies focus primarily on tidal stream and wave energy development because of their market and resource potential in the EU. The sector is growing again, thanks to progress in technology and successful demonstration projects. The EU hosts 78 % of global wave and tidal energy capacity, which has itself doubled between 2017 and 2018.

The European ocean energy industry is making significant steps forward, and plans now to expand manufacturing facilities. The supply chain spans 16 EU countries, with a significant presence also in landlocked countries and regions, who provide valuable expertise for the production of components and sub-components (Figure 1).

Technology	2025	2030
Tidal energy	0.15 EUR/kWh	0.10 EUR/kWh
Wave energy	0.20 EUR/kWh	0.15 EUR/kWh

Table 1: Ocean energy SET Plan Targets. Source: SET Plan Declaration of Intent on Ocean energy

Cost targets for ocean energy were established in the *SET Plan Declaration of Intent on Ocean Energy*[1] (Table 1). These targets are ambitious and indicate that the levelised cost of electricity (LCOE) of ocean energy technologies needs to fall by 70-80 % from the 2015 level[2]. The SET Plan Implementation Plan for Ocean Energy proposed 11 actions in order to meet the targets. Amongst other measures, it calls for an increase in the number of demonstration projects to

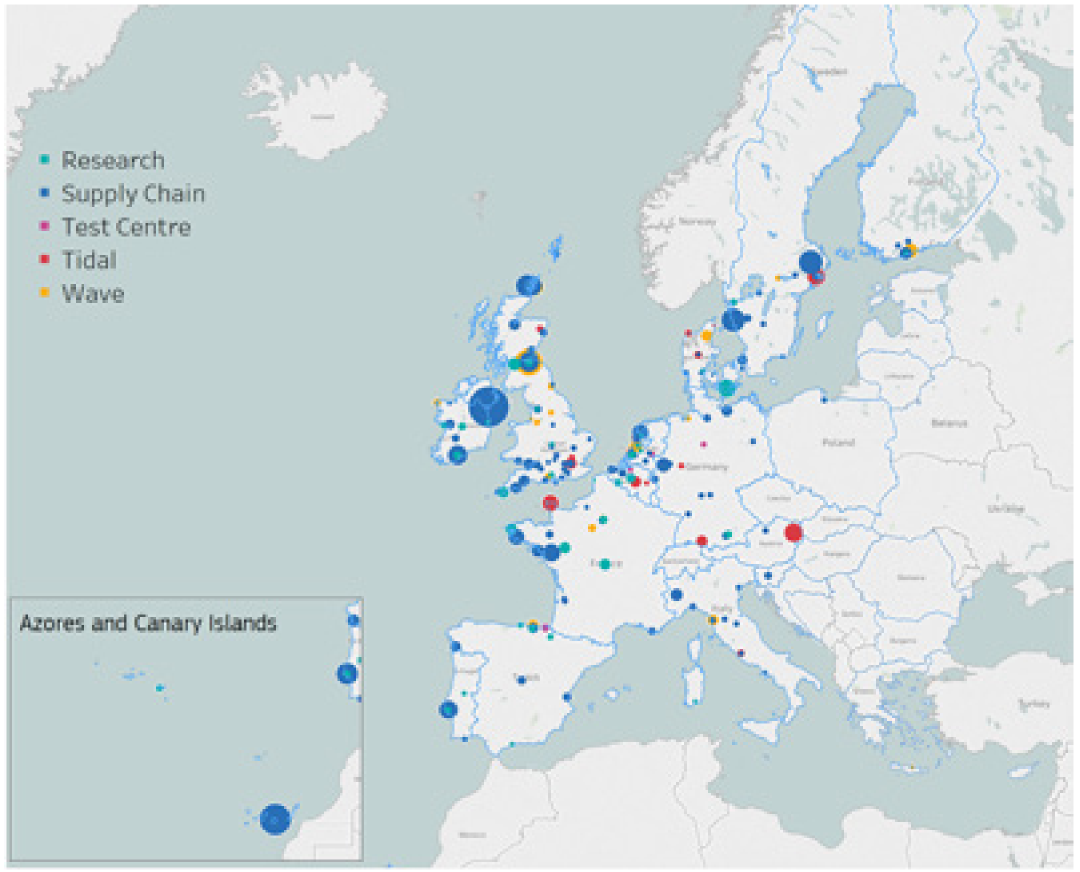


Figure 1: Ocean energy supply chain in Europe. Source: Joint Research Centre

1 https://setis.ec.europa.eu/system/files/set_plan_ocean_implementation_plan.pdf
2 *JRC Ocean Energy Status report 2016 update*

PAOLO TACCONI

Paolo Tacconi has a Master's Degree in Mechanical Engineering from the University of Florence, Italy. He has worked as Project Manager in the H1 Energy Research unit of the Horizon2020 department of the Innovation and Networks Executive Agency (INEA) of the European Commission since March 2018. He is in charge of several H2020 Wind Energy and Ocean Energy Research and Innovation Actions (RIA) and Innovation Actions (IA). He previously worked in the wind energy sector in Denmark, as Structural Engineer at LM Wind Power (2011-2014), and in the additive manufacturing sector in Belgium, as Sales Engineer and Project Manager at Materialise (2016-2018).

DAVIDE MAGAGNA

Davide Magagna has a PhD in Ocean Energy from the University of Southampton, United Kingdom. He currently works as a Scientific Project Officer in the Knowledge for the Energy Union unit of the European Commission's Joint Research Centre. He has been working on ocean energy for over 10 years. His works focuses on the techno-economic and societal assessment of marine renewable energy technologies, including trends of future emerging technologies. He represents the European Commission in the International Energy Agency TCP on Ocean Energy Systems. He also works on the interaction between water and the energy systems in the WEFE Nexus.

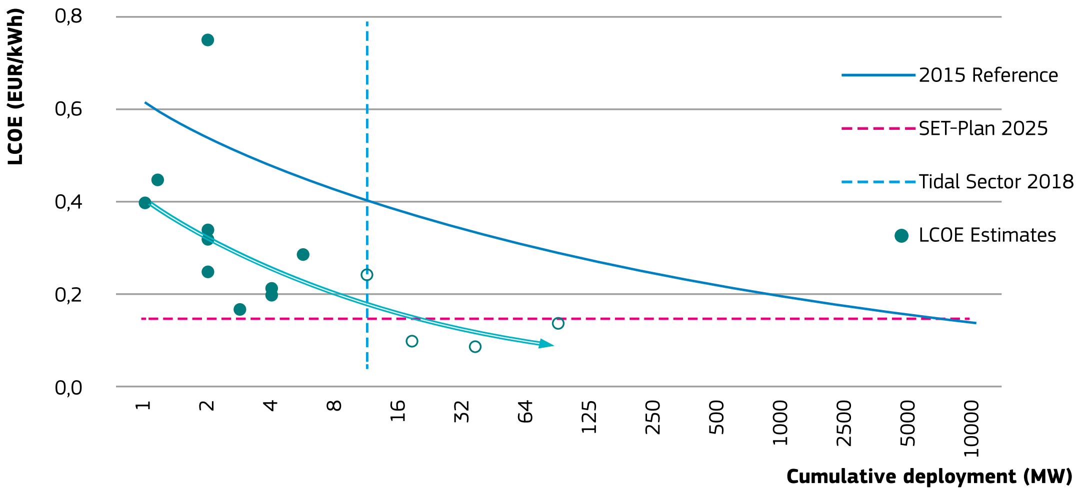


Figure 2: Cost-reduction curves for tidal energy and LCOE estimates from ongoing projects. Solid dots represent data from ongoing demonstration projects, while hollow dots indicate developers' estimates on the basis of technology improvements and increased deployment. Source: Joint Research Centre

mitigate the risks faced by developers. Indications from ongoing demonstration projects show that steep cost-reduction is happening, and that meeting the targets is feasible.

The European Commission supports 18 projects through Horizon 2020, focusing on research, development and deployment of ocean energy technologies. Many developers have been able to deploy their technologies and test them in operational conditions, obtaining information about performances and cost-reduction.

Tidal Energy

At the end of 2018, in Europe 18 MW of ocean energy capacity was operational, with tidal energy accounting for 12 MW of this. Data from the projects indicate that the LCOE of tidal energy technology ranges between 0.34 and 38 EUR/kWh (Figure 2)[3], down from 0.60 EUR/kWh in 2015. This corresponds to a reduction of more than 40 % in three years.

The current value is below the 2015 reference cost-reduction curve[4], which indicated that LCOE would reach 0.40 EUR/kWh with the current deployed capacity.

These high cost-reductions are related to the increasing reliability of the devices deployed in first-of-a-kind demonstration projects. Technologies are still in pre-commercial phase and operational strategies being implemented, tested and optimised. Ongoing demonstration projects show that electricity can be generated continuously, and that capacity factors of 37 % or higher are achievable.

Capital expenditures are decreasing, thanks to the know-how acquired, e.g. more efficient installation techniques. Learning-by-doing, operational improvement, economies of scale, and technology innovations are driving tidal technologies towards commercialisation.

Wave Energy, the role of Horizon 2020

Most EU-funded wave energy projects have a strong focus on R&D, especially on improving the performance of wave energy generators. Compared to tidal energy, less information is currently available, especially in terms of electricity generated. Thanks to the contribution of Horizon 2020[5], wave energy developers are optimising the design of their devices, and of critical components such as power take-off and moorings. Through these technological advances, developers have identified ways to reduce costs.

Future outlook

The expectation is that ongoing demonstration projects and R&D activities can further reduce the LCOE of ocean energy. For tidal energy, the 2025 SET Plan targets could be reached sooner than previously expected, provided that the current cost-reduction trajectory holds and that announced deployments become operational. By 2021, 160 MW of tidal capacity could be deployed and a further 1.5 GW is planned to be installed by 2025. Continued support in Horizon 2020 and Horizon Europe can help generate similar cost-reductions for wave energy.

Ongoing Horizon 2020 projects show that cost-reduction is taking place, and are underpinning the path to market uptake. However, further deployment is needed to exploit the full potential of the ocean energy sector. The creation of an Investment Support Fund, and of an EU Insurance and Guarantee Fund, as foreseen in the SET Plan Implementation Plan, can facilitate the deployment of ocean energy demonstration and pre-commercial farms. These and other actions are designed to reduce the risks faced by technology and project developers and to pave the way to commercialisation.

3 JRC Calculation based on EC restricted data. Assumption: 12 % learning rate and 12 % discount rate
4 Tsiropoulos, I., Tarvydas, D. and Zucker, A., *Cost development of low carbon energy technologies. Scenario-based cost trajectories to 2050*, 2017
5 https://ec.europa.eu/inea/en/horizon-2020/h2020-energy/projects-by-field/874

ARTICLE

Ocean energy employment: the potential for ocean energy in EU Coastal Regions

Including ocean energy (OE) generators in the local energy mix can be beneficial at various levels: they are fully carbon-free; they complement other renewable energy sources when space onshore is scarce; wave and tidal power resources are abundant; and although intermittent, they are highly predictable. For decision makers, the assessment of the number of jobs related to the development of the ocean energy sector is of utmost importance. This information would help to motivate governments, corporations and agencies to further support the sector by providing them with credible and unbiased information on the sensitive issue of job creation. Various roadmaps have advanced figures for the 2025, 2030 and even 2050 horizons, but in the time since, numerous ocean energy technologies have been designed and tested, and even implemented in pilot farms. In the Orkney Islands, which hosts the European Marine Energy Centre for plug-and-play sea testing and the validation of new devices at sea, a fair percentage of the working community is now employed by the sector and its value chain (more than 200 out of 14 000 inhabitants). But this promising example cannot necessarily be extrapolated. The time has come to assess an accurate total number of existing jobs directly related to the sector. It is also time to validate an approach to assess job creation in the sector and to update projections for the 2030/2050 horizons.

This issue has been studied, among other countries, in France, where a questionnaire was sent to all OE stakeholders in the various regions. This yearly study, financed by the French Maritime Cluster (CMF), the French Syndicate for Renewable Energies (SER), and the French Trade Association for Wind Energy (FEE), encompasses offshore wind and OE, but the global figures can be broken down to show that 400 and 477 FTE were in existence in the OE sector at the end of 2016 and 2017 respectively, in tidal, OTEC and wave technologies[1]. The consulting company responsible for the study, Observatoire des Energies Marines, followed a thorough methodology in order to extract and verify the raw data collected by the questionnaire.

Another way to evaluate job creation is by using economic models, which nevertheless require adequate input data. The US Department of Energy has developed the JEDI model for renewable energies[2], which relies on parameters to be tuned by sector and by country. This fine tuning has proved successful in, for example, the merging of river and marine hydrokinetic technologies,

1 http://merenergies.fr/
2 https://www.nrel.gov/analysis/jedi/

YANN-HERVÉ DE ROECK

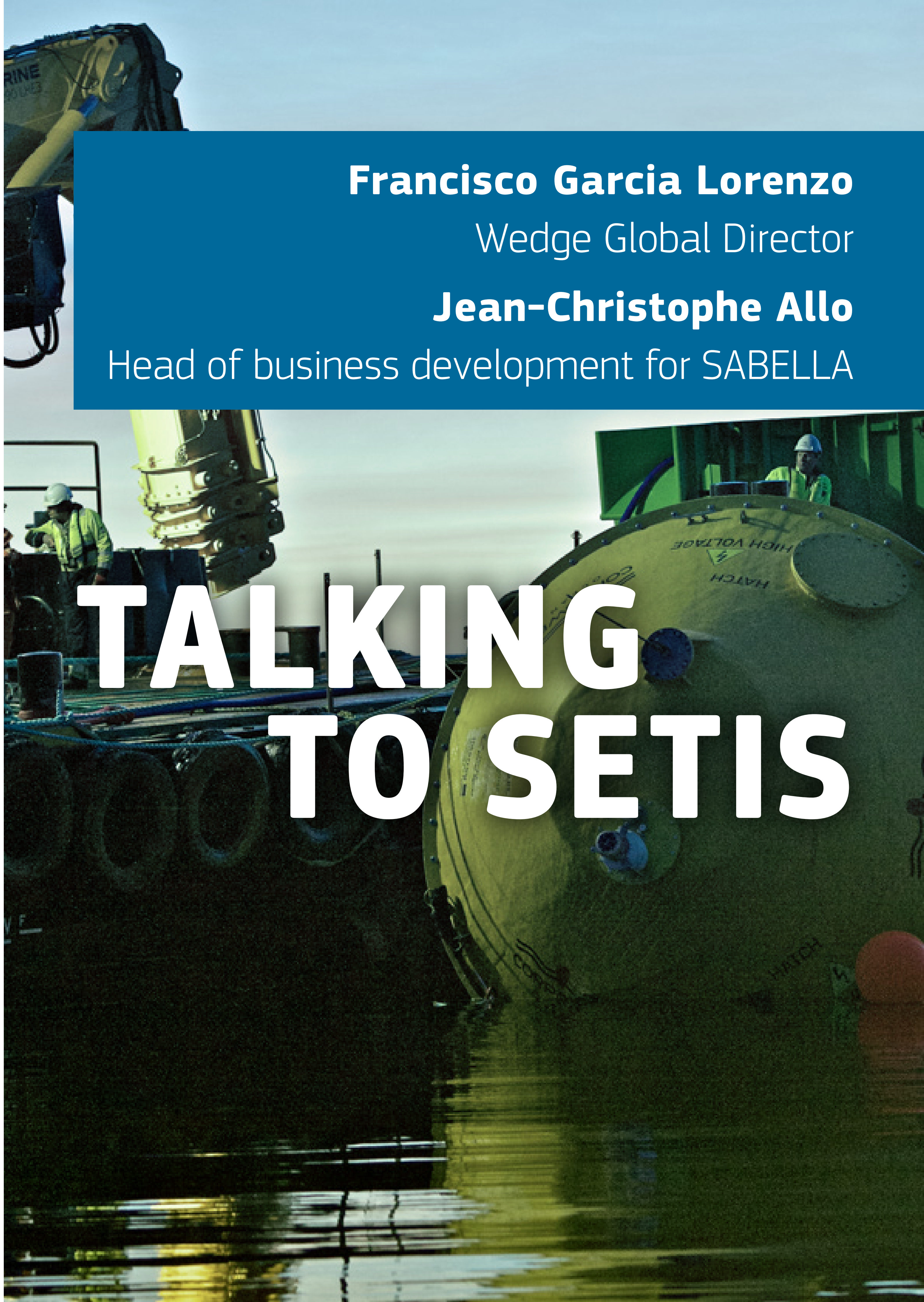
Dr. De Roeck trained in France as a civil engineer (Ecole Polytechnique, ENPC) and applied mathematician (PhD, University Paris-Dauphine). In 1991 he joined Ifremer, contributing to numerical modelling programmes from composite materials for marine usage to geophysics and coastal oceanography. His experience comprises: operational oceanography, environmental monitoring programme, and contribution to data policy at European level (MODEG expert for EMODNET). Since 2012, as Executive Director of France Energies Marines, he leads a public-private research institute fully dedicated to marine renewables. He is the French delegate and vice-chair of the Ocean Energy Systems Program of the IEA.

and in terms of limiting time requirements, but comes at the cost of reduced accuracy compared with traditional polling – but polls, too, exhibit ranges of uncertainty.

> *A total of 1 350 direct jobs and a range of 500 FTE in indirect jobs was found over 16 countries*

A specific study is therefore underway to estimate job creation worldwide, in the framework of the Technical Collaboration Program on Ocean Energy Systems, under the auspices of the International Energy Agency. Subsequently, these study techniques will be implemented in a combination of both approaches, exploiting finely tuned models based on the necessary preliminary field data collected from polling. A direct added value stemming from the use of models in this job creation assessment will be the increased credibility afforded extrapolations: job creation values at the 2030 and 2050 horizons will then be estimated using the validated modelling approach. The results of these studies will be aggregated by continent, thereby helping to confirm the current European leadership of this sector.

At European level, the JRC completed a case study in the *2018 Annual Economic Report on Blue Economy* by performing an assessment of the number of jobs related to ocean energy deployment. This was obtained by proportional computations on the basis of the annual turnover of the companies involved in the sector, identified due to their participation in Horizon 2020 R&D projects in ocean energy. A total of 1 350 direct jobs and a range of 500 FTE in indirect jobs was found over 16 countries. An ongoing update of this study begins with a thorough mapping of the value chain in the OE sector. The EurObserv'Er data provide the required turnover figures needed to run a numerical job estimation in the near future, based on various scenarios. The forecast exercise requires the development of hypotheses on economic trends, i.e. evolution of the Global Added Value (GVA) along the value chain (for instance, the share of R&D efforts with respect to the maturity of the sector, or the sharing of elements of the value chain between countries/continents) to be identified and input to the model.



Francisco Garcia Lorenzo

Wedge Global Director

Jean-Christophe Allo

Head of business development for SABELLA

TALKING TO SETIS

About the role of ocean energy in European islands

JEAN-CHRISTOPHE ALLO

With a degree in engineering management and energy projects, and a postmasters in ocean energy, Jean-Christophe Allo has been involved in tidal energy since 2010. He joined SABELLA in 2012 to manage the D10 project and increase the profile of the company both in France and abroad. He then moved to business development, strategy and public relations. Today, Jean-Christophe is head of business development for SABELLA, promoting tidal energy solutions worldwide. He is also involved in the company's long-term roadmap and represents SABELLA in several organisations, including OEE, AMET, SER and CMF.

What are the benefits of developing ocean energy in island communities?

JCA: Island communities are the perfect match for the development of ocean energy from several points of view. First, the predictability of the tidal resource, relying on astronomical phenomena, unlike the meteorological variables to which solar and wind energy are vulnerable. This is hugely helpful for the process of energy transition in weak and off-grid networks, making it easier to manage integration of renewable energies, in terms of meeting consumer demand and deploying associated energy storage systems.

Most island communities have an energy mix that depends almost exclusively on diesel generators. This leads to significant greenhouse gas emissions and very high energy costs, both for the purchase of fuel and for logistics (transport, storage, etc.). Ocean energy is an emerging and promising market, but still at the beginning of its economy. As a consequence, cost is not yet competitive compared to mature, renewable energy power plants. But in such a niche market, this first-stage economy can be achieved in a self-sufficient way.

> *2019 is a milestone year for the ocean energy sector and islands across Europe are leading the way to success*

Last but not least, island communities are a microcosm of global systems. The success of a project in these places demonstrates the acceptance and appropriation of tidal energy while demonstrating the replicability of this type of project on a larger scale.

FGL: The main benefits of ocean energy development on the islands are an improvement in sustainable land management, an increase in installed capacity from renewable sources and a boost to economic activity in the marine and maritime sector.

The integration of renewable energies in island areas is currently limited by territorial and environmental restrictions. It is, however, essential to expand the energy mix of renewable energies in the insular territories to help reduce dependence on fossil fuels. While some types of renewable energy, such as solar photovoltaic and wind, present problems, ocean energy is the obvious solution, integrating renewables while complementing sustainable land management.

Increasing installed capacity with marine renewable energies has the direct benefit of reducing emissions and complying with the energy policy agenda of member states. Increased activity in the marine-maritime sector also creates employment in island areas, consolidating an already productive sector. The direct relationship between the technological development of ocean energy generation systems and port environments is evident. The islands already offer specialised companies in this sector that can facilitate the phases of manufacture, testing, operation and maintenance of this type of technology. The integration of ocean energy would therefore offer a welcome boost for this existing sector.

When can we expect islands to benefit from ocean energy as a key energy source in their mix?

FGL: The main pilot projects and technological development in ocean energy are being carried out on islands. The insular territories are therefore the first to benefit from ocean energy.

Within the energy policy agendas of the outermost regions of Europe, marine renewable energies are a key element of forecasts for 2030. In Spain's Integrated Energy and Climate Plan, for example, ocean energy capacity is expected to increase from zero today to 50 MW in 2030. The majority is expected to be installed in island territories.

JCA: In June 2015, SABELLA[1] deployed a device for the first time in the Fromveur Passage and connected it to the grid on Ushant island in France. After a year, the turbine was retrieved for a full check-up and to run several optimisations, largely to allow for the production of a clean electric signal, suitable for the grid. The turbine was redeployed in 2018 for a further three-year campaign. The final stage on Ushant will be reached in 2022 with the PHARES project, led by AKUO Energy: the commercial deployment of a hybrid energy mix with solar panels, one wind turbine and two tidal turbines, together with battery storage. This project will prove the competitiveness of renewable energy production with ocean energy baseload, compared with existing diesel generators.

It is realistic to plan a significant deployment of similar projects in three to five years from now, in several islands

1 SABELLA has been at the forefront of the ocean energy industry since the early 2000s, testing the D03-30 prototype in 2008, and the D10-1000 in 2015. SABELLA promotes ocean energies in islands; this niche market has specificities which are perfectly suited for ocean energy. This mutually beneficial relationship between islands and ocean energy can form the basis for a new industry sector in the European Union, while bringing resilience to these remote territories.

Figure 1: Deployment of D10-1000 turbine in the Fromveur Passage in October 2018. Source: SABELLA / Balao

all over Europe and abroad, at a cheaper cost than existing fossil fuels. Depending on tidal currents, target costs range from EUR 150 to EUR 250 per MWh.

Who, and how, will benefit from it?

JCA: The primary beneficiaries of these projects are island communities. Such projects will create jobs and also a sense of ownership and pride. This is based on two pillars: the creation of new activities for the implementation of the project and its follow-up operation on the one hand, and the development of the attractiveness of the territory beneficial to tourism on the other.

> *Ocean energies are a real opportunity to create value for European islands and a chance for these territories to recover their maritime history*

Moreover, on a regional scale, significant local input will be required to set up ocean energy power plant, spreading the economic benefits over a broader area. If the island doesn't have its own port facilities or the naval means to support industrial and offshore operations, the closest port will enjoy a substantial positive impact of its own.

FGL: Those who will benefit include the business and port services sectors, government and society.

Ocean energy, and the activities derived from its management and maintenance, will create significant demand for companies providing services such as mooring, environmental engineering, electricity and electronics, logistics, and diving. These specialised companies are key to the development of ocean energies, and employment in the islands will benefit as a result.

Public administration will also benefit, in terms of energy demands in key island infrastructure, such as those related to water. The water-energy binomial is very present in the insular territories; most of the demand for potable water is met by the desalination of sea water. Associating wave energy facilities with the production of desalinated water is an option worth exploring.

How will this initiative be implemented?

FGL: In order to achieve the 2030 goal to integrate ocean energy into our electrical systems, RD&I projects are being developed to devise technologies, and strategies for their integration, complying with the requirements established in the electrical network codes.

At the same time, if these initiatives are to be implemented, we need to develop administrative procedures to facilitate the connection of this type of technology to the network and to improve existing energy transport lines in the insular territories.

JCA: SABELLA intends to promote a Fuel Free Island energy model tailored for far-flung communities. Building on the success of the project in Ushant, SABELLA will have the opportunity to propose a hybrid solution based on ocean energy, in line with the European Commission's ambitions in the Clean Energy for EU islands initiative, launched in Valletta, Malta, in May 2017.

FRANCISCO GARCIA LORENZO

Francisco Garcia Lorenzo is an industrial engineer (ICAI, Madrid) with an MBA (MIT Sloan). He has worked in the renewable energy sector for 20 years, in both public and private positions. He is currently Wedge Global Director, and Advisory Member of the Office of the Secretary of State for Energy of Spain. He has also been involved in the International Energy Agency (2006-2008) as Spanish Delegate to the Renewable Energy Working Party on Renewable Energy Technologies (REWP-RET) as well as Observer in the Ocean Energy Systems Implementing Agreement (OES-IEA). He is an Ocean Energy Europe OEE board member, APPA Marina (Marine Renewable Industry of Spain) Chairman, and Renewable Energy Master Director at EOI Business School.

ARTICLE

Delivering ocean energy in Europe: which technological priorities?

Europe needs ocean energy

In 2050, Europe's energy landscape will look very different from today's. Moving towards an electrified, carbon-neutral system means a significant increase in the uptake of renewable energy, with 80-100 % of future electricity supply set to come from renewable energy sources.

> *Europe is sitting on a rich resource of clean, predictable ocean energy – and it will be needed, as the energy transition accelerates*

Tidal energy is fully predictable – even years into the future. Wave energy devices capture the energy transferred from the wind to the sea, with swells continuing to provide power even after the wind has disappeared. Europe is sitting on a rich resource of clean, predictable ocean energy – and it will be needed, as the energy transition accelerates. It is estimated that 100 GW[1] of wave and tidal energy capacity can be deployed in Europe by 2050, which would meet around 10 % of current electricity consumption.

To achieve these ambitious goals, ocean energy research and innovation (R&I) needs to improve the reliability and survivability of ocean energy devices, reduce the perceived risk of these new technologies and lower their costs. The European Technology and Innovation Platform for Ocean Energy (ETIP Ocean) has laid out a list of priority areas for ocean energy R&I in its Strategic Research Agenda.

The three highest technological priorities for ocean energy are the deployment of demonstration devices, the improvement of power take-off performances and the development of effective control systems.

Deploying prototypes and demonstration projects

Single devices and arrays need to be deployed in real sea conditions. Through accumulation of operating hours, performance can be determined and optimised. This will allow for technology certification as well as the creation and validation of high definition models necessary for designing the next generation of ocean energy projects.

1 *Ocean Energy Roadmap, Ocean Energy Forum*, November 2016

To enable commercial investment in future ocean energy projects, data is needed from full-scale demonstrations in real sea conditions. As with the development of other technologies, several projects may be necessary – from full-scale prototype to pre-commercial farms – before commercial investors will feel sufficiently confident.

However, building and testing a full-scale prototype is costly. As such, it is imperative that data from demonstration devices is available and widely shared within the industry to accelerate technology development. Various EU-funded projects such as MaRINET2, Bluegift, FORESEA and Ocean DEMO are already addressing this challenge by supporting access to European, world-leading ocean energy test centres.

Increasing yield with improved Power Take-Off

The power take-off (PTO) for ocean energy devices is the mechanism which extracts energy from the resource. The PTO is not a component in itself, but a system composed of several components. There is a multitude of PTO designs for use in different resources.

The PTO system needs to be reliable, as any failure directly impacts power production. PTO performance, survivability and reliability are crucial to the economics of any ocean energy project.

Many PTOs developed for tidal energy have been demonstrated in real sea conditions and had their design successfully validated. Simplifying those designs by reducing the number of moving parts will increase reliability and bring down costs.

A number of different designs exists, though further convergence is likely. Multiple angles and variables affect the interactions of waves with devices. This makes understanding the resource and optimising PTO design particularly important. Next steps for improving the reliability and performance of wave PTOs include short-term power storage solutions, array layout modelling and peak power management systems.

Increasing reliability and survivability with control systems

Ocean energy devices face extreme weather conditions. They need to be designed to resist occasional heavy loads over short periods of time. The cumulative effects of stresses, tensions, cyclic and extreme loadings, corrosion and biofouling increase material fatigue on the devices' components.

Control systems allow components to react and adapt when faced with specific conditions. They can be used to mitigate fatigue and damage created by waves or currents, but also to improve performance. For instance, a control system may 'pitch' tidal turbine blades – rotate them on their axis – to maximise energy capture, or adjust the mooring lines of a floating device to match sea level.

Real time monitoring and forecasting of the resource is necessary to determine the control strategies that will increase performance and operability of ocean energy projects. This requires accurate resource measurement and forecasting as well as real-time transmission and specific analysis tools.

Horizon 2020 and other EU schemes have done much to enable the industry to focus on those priorities. More RD&I will be needed in the coming years to bring these nascent technologies to industrial development.

RÉMI GRUET

Rémi Gruet joined the European trade body for ocean energy in 2013. After six years in the private sector, he has spent the last 15 years influencing the European political agenda, working both inside and outside EU institutions – notably the European Parliament and European Wind Energy Association. He is a leading authority on renewable energies and climate and environmental policy, and has authored and co-authored numerous reports, such as the recent *Ocean Energy Forum Roadmap, the SI Ocean Market Deployment Strategy and the Wind energy and Climate policy report*[1]. He is a visiting lecturer on EU energy policy at the University for Political Science in Lille, France.

Jonathan Hodges

Senior Innovation Engineer at Wave Energy Scotland

TALKING TO SETIS

About delivering innovation: stage gate metrics for ocean energy

Many in the sector refer to stage gate metrics: what is their potential for an emerging sector such as ocean energy?

We are really learning from other industries here, both developing and mature, where stage gates are used to manage new product development and standardise the activities carried out at each stage. During stage gates, industries commonly apply metrics, or evaluation criteria, to compare technologies, helping developers, funders and investors to make the right decisions – after all, technology that can satisfy the evaluation criteria will have a higher chance of commercial success.

> *Stage gate metrics bring crucial structure and consistency to the emerging ocean energy sector, ensuring that the most promising and high-performing technologies receive public funding and that developers can provide coherent evidence of their potential*

Stage gate metrics bring crucial structure and consistency to the emerging ocean energy sector, ensuring that the most promising and high-performing technologies receive public funding and that developers can provide coherent evidence of their potential.

This comes at an important time for wave energy, which is progressing well but without consolidation of technology types. We are unlikely to see the kind of consolidation that exists for offshore wind on three-bladed turbines, but this underlines the importance of consistent assessments that help investors to see past the differences and gain confidence in promising investment opportunities. This all supports us towards commercialisation, which will allow us to exploit the economic growth and low-carbon energy contribution that the ocean energy sector offers.

Based on WES experience, what's the impact of stage gate metrics on technology development?

We can see clear impacts in the WES programme and the wider sector. WES runs a research, development and innovation programme, using pre-commercial procurement to create competition between technologies. By applying stage gate metrics, we have driven an ever-improving standard of well-conceived, appropriately scoped projects, and allocated over EUR 45 million to 86 projects since 2014. Only projects which demonstrate clear potential against the metrics move to the next stage, and the process has allowed us to select the most promising technologies, which are starting to attract investment interest.

> *The European Commission is leading a task to build global consensus on stage gate metrics (or evaluation criteria) for ocean energy*

The European Commission is leading a task to build global consensus on stage gate metrics (or evaluation criteria) for ocean energy, on behalf of the International Energy Agency's Ocean Energy Systems (IEA-OES) committee. The chosen metrics mirror the key challenges, pushing technology developers to align their activities and outputs with investors' expectations. This drives up the overall quality of proposals, meaning more successful projects and accelerated sector progress.

What's the opinion of technology developers on the process?

Developers of credible technologies see real benefits. The majority are seeking future investment and all of them need to demonstrate positive results and trajectories. This becomes easier if the targets are widely accepted, framing the conversation around metrics which test the fundamental characteristics of a technology. These range from technical details to higher-level evaluations which are meaningful to investors, such as Levelised Cost of Energy, and Return on Investment.

Investors can also find wave technology difficult to understand - lots of yellow things bobbing up and down in the ocean! As an outsider, it all looks quite similar, but if you focus, the differences are huge. Imposing a standardised structure onto the process supports the conversation between developers and investors; it's an essential step to attracting investment. Developers understand that stage gate metrics can help them to distinguish themselves from the competition.

When do you expect to see commercial results for ocean energy technology?

The timelines differ for various sectors, but progress is becoming ever more convincing. The tidal stream sector is demonstrating consistent electricity generation over increasingly long-term deployments and is building innovative financial packages to support the scale-up of projects. Wave technologies are a few years behind but are making good progress. Participants in the WES programme will deploy scale devices in Scotland in 2020, bringing an opportunity to integrate proven subsystems and other supporting technologies with novel wave energy converters. We are showcasing a coherent development path and enjoying exciting results. This pedigree breeds confidence and subsequently investment, putting both sectors in a strong position to achieve utility-scale cost-competitiveness and a maturing commercial product by 2030. Aquaculture, island communities and underwater autonomous vehicle charging also offer valuable markets and potential scale-up routes.

Would you say the ocean energy sector would have experienced fewer failures if we had had stage gate metrics 15 years ago?

Ocean energy technologies are still maturing, so research, development and demonstration activity are inevitably risky. If we didn't experience failure, we wouldn't be trying hard enough, but the nature of the failures would have been different with a structured stage gate metrics process.

This consistent assessment process focuses funding more rapidly into technologies with the required characteristics, so issues are identified sooner, at a smaller scale, and can be fixed or avoided before financial cost and impact on the sector grows too large. The previous failures contributed valuable knowledge to the development of metrics and we must use them to avoid repetition and to take sensible scale-up steps.

> *By combining metrics with consistent funding, enforcement mechanisms and common assessment tools, we are setting the ocean energy sector on track for the technology consolidation and maturation process that investors seek*

To be effective, stage gate metrics require an effective enforcement mechanism and an adequate funding stream. Programmes like WES and the European Commission's upcoming pre-commercial procurement scheme provide both, and are increasingly supported by shared assessment tools and methods, such as those being developed by the Horizon 2020-funded DTOceanPlus project. By bringing this all together, we are setting the ocean energy sector on track for the technology consolidation and maturation process that investors seek.

JONATHAN HODGES

Following an early career in the aerospace industry, developing and testing Rolls-Royce turbofan engines, Jonathan Hodges moved to the ocean energy sector where he gathered experience in innovation, resource assessment and techno-economic analysis. In his role as Senior Innovation Engineer at Wave Energy Scotland (WES), he aims to identify innovation opportunities and develop WES funding calls to help the sector deliver cost-competitive wave energy technologies. Jonathan is involved in global collaboration activities to develop technology assessment tools and processes, deliver consensus on stage gate metrics, and seek technology transfer opportunities to advance the sector towards commercialisation.

ARTICLE

Understanding the environmental effects of ocean energy: experiences and challenges and the role of the WESE project

The nascent status of the marine renewable energy sector, particularly ocean wave energy, yields many unknowns about potential environmental pressures and impacts, some still far from being well understood. The operation of wave energy converters (WECs) in the marine environment is still perceived by regulators and other stakeholders as risky, particularly for some groups of species and habitat. In many instances, this perception of risk is due to the high degree of uncertainty caused by a paucity of data collected in the ocean. However, the possibility of real risk to marine organisms or habitats cannot be ignored; the lack of data continues to confound our ability to differentiate between real and perceived risks. De-risking environmental consent for wave energy projects has therefore been identified as a key challenge in fostering development of the sector[1]. Human activity in the marine environment is expected to increase in the future, producing greater pressure on marine ecosystems, as well as competition and conflict among users. This presents challenges in terms of consent processes for commercial-scale development. Time-consuming procedures linked to uncertainty about environmental impacts, the need to consult with numerous stakeholders and potential conflicts with other marine users appear to be the main obstacles to issuing consent for ocean wave energy projects. These non-technological barriers could hinder the development of one of the main pillars of the *EU Blue Growth strategy*.

Funded by the European Maritime and Fisheries Fund (EMFF) and launched in November 2018, Wave Energy in Southern Europe (the WESE project) aims to improve knowledge of the potential environmental effects and risks of wave energy, to inform decision makers and managers and to reduce uncertainty as regards environmental consent. The WESE Consortium, led by the RD&I Basque centre AZTI, includes a multidisciplinary team of partners, bringing together technology device developers (bimep, IDOM, AW Energy), consultants and researchers (WavEC, CTN, AZTI) and data managers (Hidromod). It aims to involve the wider community of ocean energy stakeholders from across Portugal and Spain. The project will run until October 2021 and specific details can be found on the project website[2].

The project aims to overcome the non-technological barriers discussed above, and activities include the collection, processing, analysis and sharing of

1 Ocean Energy Forum, 2016
2 http://wese-project.eu/

JUAN BALD

Juan Bald has a PhD in Biology from the University of Navarra (Spain) and a Masters in Environmental Sciences specialising in Oceanology, from the University of Bordeaux (France). He started his career in 1997 as a marine biologist in the Marine Research Division of AZTI (Spain). He is currently principal researcher and Head of the Marine and Coastal Environmental Management Unit in AZTI. He has worked on the development of indicators for ICZM and European Directives and marine protection; marine and estuarine monitoring, pollution and water quality, environmental impact assessment (EIA), shellfish resource management and ecological modelisation.

TERESA SIMAS

Teresa Simas started her career in 1996 as an associate researcher at the New University of Lisbon, where she completed her MSc and PhD on Marine Ecology and Environmental Engineering. She went on to work as a consultant on the implementation of the Water Framework Directive in Portugal and on marine project EIAs. She joined WavEC in 2008 as head of department, and has been involved in several R&D projects and services on marine technology environmental assessment. She lectures on ocean habitats and EIA for the European Masters in Renewable Energy (EUREC) at IST University of Lisbon.

environmental data around wave energy devices currently operating at sea: Mutriku OWC plant, Marmok-A installed at Bimep in Spain, and WaveRoller installed at Peniche, Portugal. This data collection and analysis will improve our knowledge of environmental effects in the priority research areas identified by the OES-IEA Annex IV team, in their *State of Science report, 2016*. These are: 1) risk to marine animals from sound generated by wave devices; 2) changes in physical systems (energy removal); and 3) effects of Electromagnetic Fields (EMF) emitted by energy transfer cables.

The WESE project will identify specific knowledge gaps and appropriate monitoring methodologies in these priority research areas, and prepare and implement standardised monitoring plans on the sites under study.

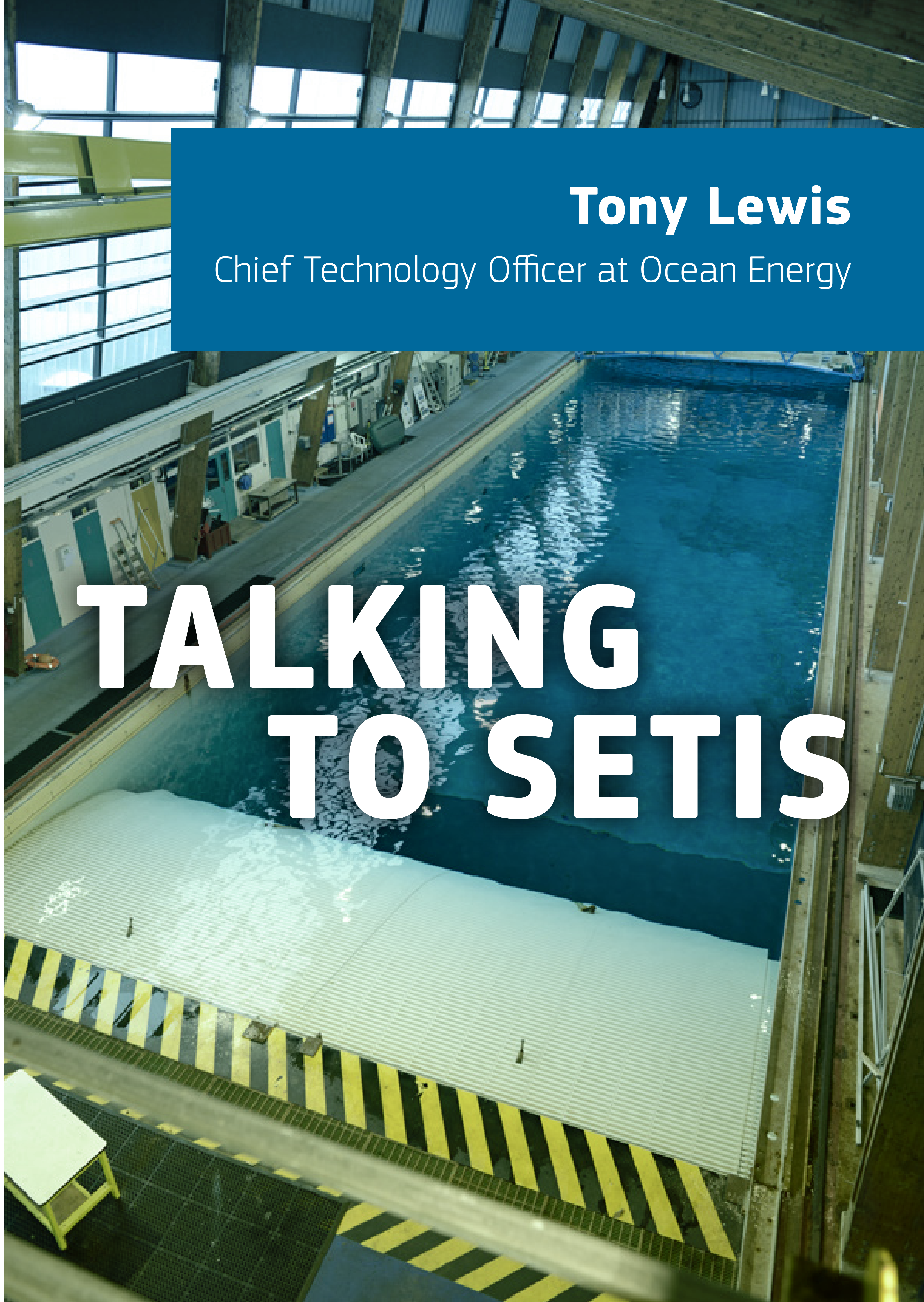
The resulting data will be used to apply and improve existing modelling tools, to contribute to overall understanding of the potential cumulative impacts of future larger scale wave energy deployments and to propose effective mitigation measures.

Country-specific licensing guidance will be developed, including recommendations on good practice for streamlining procedures and for identifying omissions, and/or procedures that may require simplification, to improve management and integration. The application of an adaptive, risk-based approach to the consent process of wave energy projects will be studied for both Portugal and Spain. Reports will be produced in close collaboration with regulators and key stakeholders in each country, and with the technology developers in the project consortium, to support the decision-making of authorities around impacts evaluation, monitoring plans and monitoring data analysis.

> *All data, tools and guidance reports will be made available through a data platform to serve data providers, developers and regulators*

The WESE work plan also involves the development and implementation of decision support tools for maritime spatial planning (MSP) on site selection, contributing to the identification and selection of suitable areas for wave energy development for promoters and investors. The tools will also support decision makers during the licensing process, with integrated, evidence-based decision-making as an essential basis for sustainable, effective and efficient MSP.

All data, tools and guidance reports will be made available through a data platform to serve data providers, developers and regulators. The findings from this project will enhance awareness of relevant ocean energy environmental effects, and increase knowledge of their evaluation and assessment, to support planning regimes and to contribute to the sector's development.

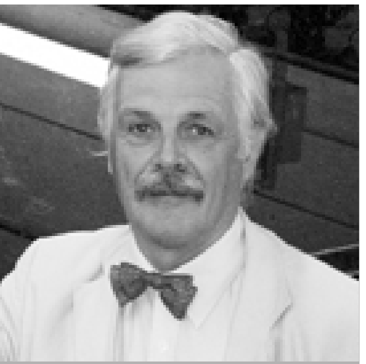


Tony Lewis

Chief Technology Officer at Ocean Energy

TALKING TO SETIS

About Marinet and Marinerg-i: supporting research and collaboration



TONY LEWIS

Professor Tony Lewis is Emeritus Beaufort Professor, University College Cork (UCC), Ireland, and Principal Investigator in UCC's Centre for Marine and Renewable Energy. He is also CTO of Ocean Energy, a technology company developing floating wave energy devices. From 1975 to 2013 he was Inaugural Professor of Energy Engineering at UCC. He has special competence in ocean energy development, offshore engineering, maritime civil engineering, laboratory tank testing and measurements in the marine environment. He was Coordinating Lead Author for the Ocean Energy chapter in the Special Report on Renewable Energy for the Intergovernmental Panel on Climate Change (IPCC 2011).

Ocean energy conversion is an emerging technology at a pre-commercial stage of development. It is estimated that the energy resource in the seas around the European coasts, in the form of ocean waves and tidal streams, exceeds present levels of electricity consumption. Ocean Energy Europe expects that around 100 GW of conversion systems will be deployed by 2050, meeting around 10 % of Europe's electricity demand at that time.

> *MARINET has accelerated technological development, particularly among SMEs; and MARINERG-i will build and consolidate a stronger, more accessible network of European testing facilities*

Some technology companies are at an advanced stage of development. These are mainly in tidal stream technology, with a number of wave energy developers progressing towards larger demonstration projects. There is reasonable convergence in tidal stream technologies (which are about five years ahead of their wave energy counterparts), with horizontal axis rotors mounted on a fixed or floating structure, but the cost of electricity is still high. There are various operating principles used in wave energy technologies, but a fully optimised, lower-cost concept has yet to be developed. Most companies in this area are SMEs with limited funds for development.

Can you briefly describe the Marinet and Marinerg-I experience?

MARINET (Marine Renewables Infrastructure Network) is essential to research and innovation for offshore renewable energy development. Funded by Horizon 2020, its second phase will run until 2021. There are 38 partners with 57 infrastructures suitable for testing wave and tidal stream energy converters, along with floating offshore wind systems and cross-cutting aspects like material and moorings behaviour, electrical power take-off and grid integration. There are also three e-infrastructures offering access to extensive datasets. Access is free of charge, with the proviso that projects are transnational and testing outcomes are published. During the first phase of MARINET, up to 2016, there were 700 weeks of access to 48 infrastructures, valued at EUR 4.3 million: comprising 300 projects and 800 users, mostly SMEs. In MARINET2 there have been three calls to date, and a total of 349 weeks of access, valued at EUR 3.8 million, have been awarded to 106 projects.

Many MARINET projects have accelerated technology development, allowing SMEs to move up through technology readiness levels (TRLs) towards commercial rollout. Without first successfully testing in MARINET infrastructures, these groups would not be able to progress to ocean deployment.

The success of the first phase of MARINET and continued funding for MARINET2 encouraged the European Commission to award funding to create a network of distributed Research Infrastructures with a coherent operational model. This will allow sustained support for research and innovation in all aspects of the offshore renewable energy sector, to help maintain Europe as a global leader in this emerging industry.

The MARINERG-i consortium has 14 partners from 12 countries and will run until mid-2019. In its first phase, MARINERG-i will establish a modern, efficient, high-quality, state-of-the-art ecosystem of members and stakeholders for cutting-edge research and innovation. MARINERG-i members will develop a formal partnership of testing facilities with clear foundational objectives and cooperation models.

If MARINERG-i is successful in its bid for inclusion in the European Strategy Forum on Research Infrastructures (ESFRI) roadmap, additional EU funding can be accessed to realise its full objectives over the next seven to eight years. In the interim there will still be a need for projects like MARINET.

How close is the collaboration with technology developers?

MARINET has seen in-depth collaboration between researchers and developers during both of its phases. The majority of its users have been developers – mostly SMEs. Some of these have progressed from testing at small-scale concept level to deploying kW-level devices at larger test facilities in the ocean, helped by MARINET to overcome their budgetary limitations.

Are developers interested in learning from your previous experiences?

The programme allows developers to learn from past experience. Prior to the submission of testing projects, there is close consultation between infrastructure managers and developers, optimising the tests to be carried out and transferring knowledge accumulated in the infrastructure's experience.

> *Channelling financial assistance towards building a stronger, more accessible network of European testing facilities will provide much-needed support for developers at all TRLs*

Short courses are also offered on a no-fee basis, based on the experience of researchers involved, together with invited experts. There were eight such specialised courses offered in MARINET phase 1, with a total of 200 attendees. In the second phase, there have been two short courses to date, with around 50 attendees.

What need is there for infrastructure now that technology is becoming commercially viable?

The SET Plan Working Group for Ocean Energy published the *Ocean Energy Implementation Plan* in 2018, identifying in Action 1.5 that *'Test facilities and laboratories are also key enablers to allow innovation to happen. Ensuring there is good access to offshore and onshore testing facilities across Europe that meets the needs of developers requires continued support. Channelling financial assistance towards building a stronger, more accessible network of European testing facilities will provide much-needed support for developers at all TRLs.'*

There is much left to do to get ocean energy technologies from idea to market readiness. MARINET has accelerated technological development, particularly among SMEs; and MARINERG-i will build and consolidate a stronger, more accessible network of European testing facilities that is vital to this emerging sector.

ARTICLE

Design tools for ocean energy farms: the importance of optimising farm layout to minimise costs

Experiences from DTOcean, DTOceanPlus and OPERA

The FP7-funded DTOcean[1] project produced a first generation of freely available, open-source design tools for wave and tidal energy arrays. These tools have been used on leading tidal and wave energy projects, including the recently installed four-turbine 6 MW MeyGen tidal array in the UK, and a wave energy application by Sandia National Laboratories in the USA. The software tools enable the user to design the balance of plant (i.e. array layouts, electrical infrastructure, moorings and foundations, installation procedures and operations and maintenance plans) required to put an array of ocean energy converters into operation.

The Horizon 2020-funded DTOceanPlus[2] project, which began recently, is extending the functionality of this integrated suite of design tools for ocean energy technologies, including sub-systems, energy capture devices and arrays. This second generation of design tools will support the entire technology innovation process from concept through to development and deployment. More specifically, the farm layout will model the hydrodynamic interactions between the resource (waves, tides) and the device(s), achieving a workable compromise between computational speed and accuracy.

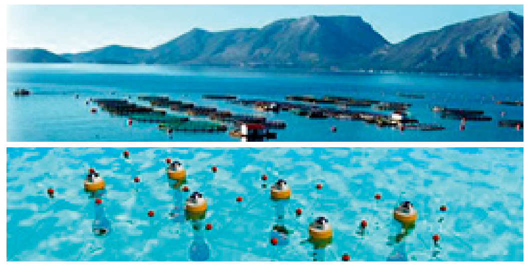


Figure 1: Photograph of shared mooring for aquaculture in Korea and illustration of application to wave energy in the OPERA project.Source: OPERA

On the other hand, the Horizon 2020-funded OPERA[3] project has collected more than two years of operating data and experience at sea, to validate and de-risk four industrial innovations for wave energy, paving the way for long-term cost-reduction of ocean energy technologies. One of these innovations is a shared mooring configuration which provides a clustered array layout of wave energy converters, as demonstrated in aquaculture. This integrated mooring system can make better use of ocean space, while at the same time reducing mooring costs.

The three projects above show that the layout of wave and tidal arrays is an area in which new developments must take place. While individual devices are progressing through the stages of commissioning and at-sea testing, the hydrodynamic interaction between individual devices within an array as well as the relationship between the overall resource and neighbouring devices are not yet fully understood. Moreover, the experience of DTOcean shows that while hydrodynamic interactions certainly impact upon the final revenue of the ocean energy array, only a holistic view of all the subsystems (i.e. energy capture and delivery, station-keeping, lifecycle logistics and operations) can lead to the optimisation of lifetime costs for the final array layout.

In DTOcean, the hydrodynamic modelling of array interactions for ocean energy converters (OEC) has been solved through an exact algebraic method (for wave) and parametric modelling (for tidal). An optimal farm layout in terms of captured energy is obtained using different evolutionary optimisation algorithms. The cost function maximises the annual energy production (AEP) of the farm, while holding the average q-factor of the array above a user specified threshold. The q-factor is an energy loss index due to the modification of the absorbed energy caused by the hydrodynamic interaction between bodies. It is calculated as the AEP of the array (AEP_{array}) over the AEP of the same array without considering the interaction. Where AEP_{OEC} is the energy production of the OEC at the same location, but without interaction with other devices, and N_{OEC} is the number of devices installed in the array.

$$q = AEP_{array} / (AEP_{OEC} \times N_{OEC})$$

The optimisation parameter space is defined by the array parameters, such as device inter-distance and row and column angles. The optimum search is constrained by the following variables: the no-go areas, the minimum distance between devices, the maximum number of devices and the q-factor.

A no-go area identifies a zone of the lease area where the installation of the device is not possible due to reasons such as unfeasible water depth or environmental impact. No-go areas are specified by the user, if known a priori, or internally calculated based on site and machine specification.

The minimum distance between devices is constrained by physical limitations, such as vessel operation, or by theoretical limitations of the numerical model. For example, for an array of wave energy converters, the minimum distance between devices should be at least the diameter of the inscribing cylinder, while devices placed at distances greater than 8-10 times the device diameter have not shown significant hydrodynamic interactions.

Besides, DTOcean offers the possibility of carrying out multi-variable sensitivity analyses to explore further options for layout optimisation, not only from a hydrodynamic perspective, but also accounting for other variables which directly or indirectly impact lifetime costs, such as design constraints, exclusion zones, length of export cable, shared components in mooring systems, internal cable routes and vessel routes.

Lastly, experience in OPERA has revealed that a shared mooring system configuration of two rows and up to four columns can be feasible. Cell distances around 40-50 m for a heaving floating point absorber of 5 m diameter have a compatible q-factor whilst facilitating vessel access for installation and maintenance.

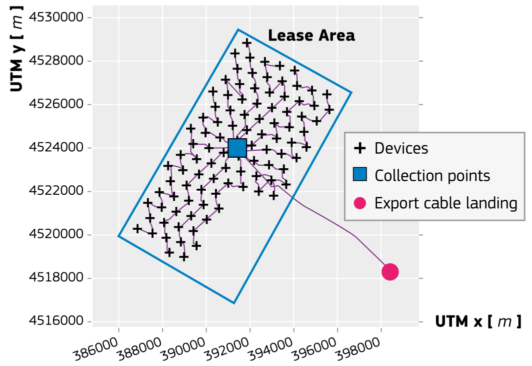


Figure 2: Optimised farm layout. Source: Data Only Greater (https://www.dataonlygreater.com)

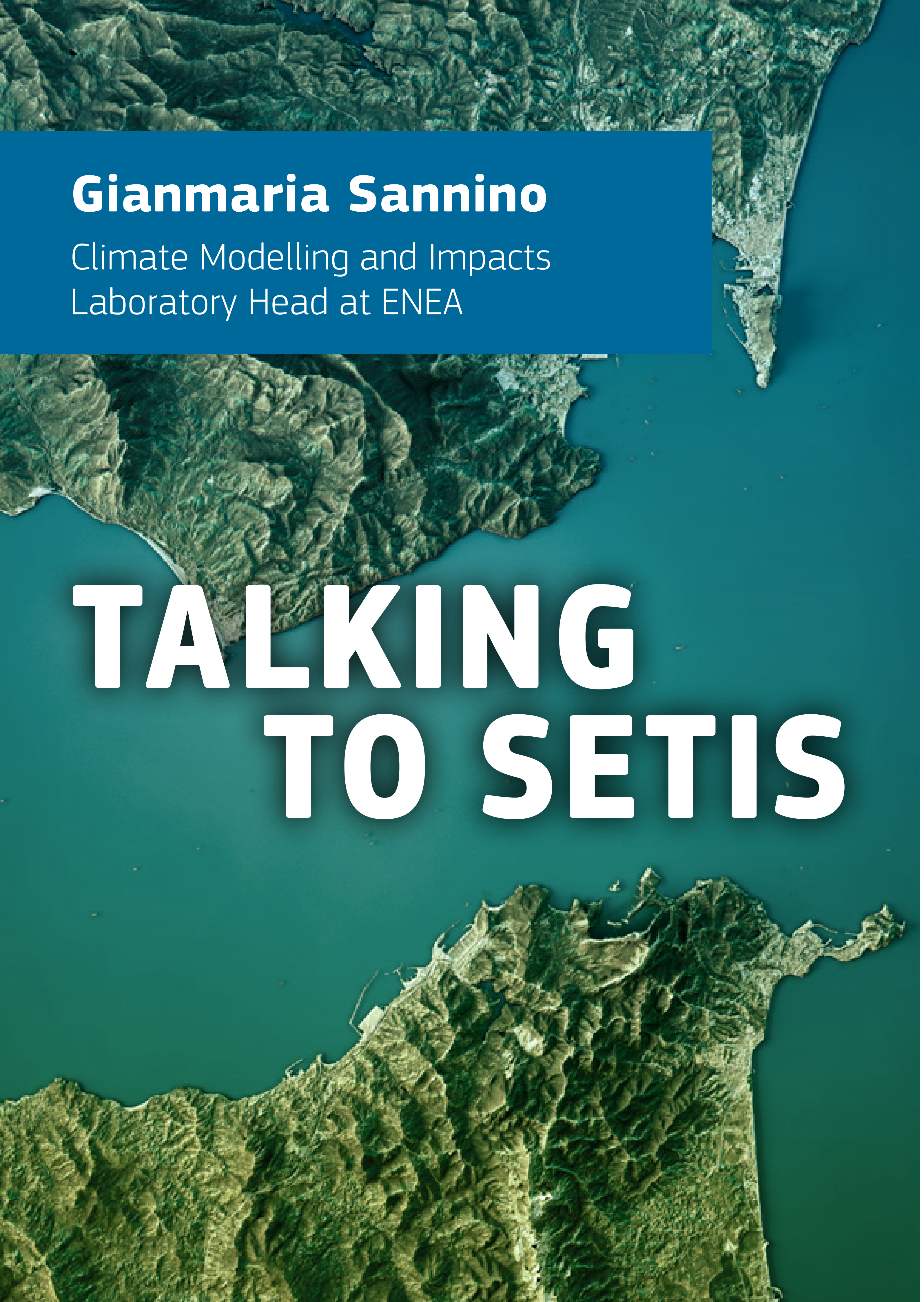
VINCENZO NAVA

Vincenzo Nava, PhD in Ocean Engineering, is currently Senior Researcher at TECNALIA where he has been involved in several ocean and offshore wind energy projects at local, national and international level. He has co-authored several peer-reviewed journal papers and contributions to international conferences, as well as book chapters and other publications. He has 14 years' experience as a professional civil engineer, and his fields of particular expertise are hydrodynamics and marine structure design.

PABLO RUIZ-MINGUELA

Pablo Ruiz-Minguela is Head of Wave Energy at TECNALIA, where he leads R&D activities related to the development of wave energy technologies at both national and international level. He offers 26 years of experience in R&D (13 of them in wave energy), has managed over 30 research projects, and is author or co-author of five patents for marine energy, 14 publications and 23 conference communications. MSc in Industrial Engineering at the University of Basque Country (Spain), MSc in Advanced Manufacturing Technology (1992) at the University of Manchester (UK), and MBA (2012) at the Business School ESEUNE (Spain).

1 https://www.dtoceanplus.eu/About-DTOceanPlus/History
2 https://www.dtoceanplus.eu/
3 http://opera-h2020.eu/



Gianmaria Sannino

Climate Modelling and Impacts Laboratory Head at ENEA

TALKING TO SETIS

ABOUT MARINE ENERGY IN THE MEDITERRANEAN: PROSPECTS, CHALLENGES AND NEXT STEPS

When speaking about marine energy, many in Europe think about the Atlantic coast and North Sea. What's the potential in the Mediterranean for blue energy?

Although the availability of marine energy resources in Europe is higher along the Atlantic and Nordic coasts, considerable resources are also available in the Mediterranean, offering new prospects for sustainable energy production in coastal areas and for economic development in southern Europe.

There is significant offshore wind resource in the Gulf of Lion, with an average annual power density of 1 050 W/m², and in the Centreal Aegean Sea of 890 W/m². High offshore wind resources are also found in the areas east and west of the island of Crete, east of the Strait of Gibraltar, in the Western Ligurian Sea, in the Strait of Sicily and in the Southern Adriatic.

In terms of wave energy availability, the western coasts of Sardinia and Corsica, together with the Sicilian Channel and the Algerian and Tunisian coasts, are the most productive areas in the whole Mediterranean, with an average flow of energy per crest unit of 10 to 13 kW/m.

> *As existing tidal turbines require a current velocity of at least 1.5-2 m/s to operate effectively, tidal energy can be harvested from the Strait of Gibraltar and Messina*

As existing tidal turbines require a current velocity of at least 1.5-2 m/s to operate effectively, tidal energy can be harvested from the Strait of Gibraltar and Messina. The latter is the most promising site in the Mediterranean for this type of renewable energy, with currents characterised by a speed exceeding 3 m/s. A recent evaluation indicates that annual energy production in the Strait of Messina could reach 125 GWh/year.

Do you see an advantage in developing MRE technologies for the Mediterranean?

The implementation of marine energy converters in the Mediterranean will stimulate significant technological innovation, due to low local energy levels which place stricter constraints on device efficiency and environmental compatibility. The milder climate also allows for concepts and prototypes to be tested in the natural environment at more affordable costs, reducing capital risk for new and innovative SMEs.

> *The vulnerability of the Mediterranean environment also demands innovative solutions to support the energy independence and sustainability of particularly exposed habitats, ecosystems and social communities*

The vulnerability of the Mediterranean environment also demands innovative solutions to support the energy independence and sustainability of particularly exposed habitats, ecosystems and social communities, such as those located in small isolated islands. These local innovations will contribute new options to the global effort to adapt to and mitigate climate change.

Some technologies have already been deployed in the Mediterranean. How do you see further technology development taking place? Can it help to deliver SET Plan targets?

Mediterranean countries have made substantial progress in marine energy over the last 10 years, now boasting a high number of qualified developers from research centres, university spin-offs, SMEs and large enterprises.

Efforts have concentrated on wave and tidal energy converters, which are best suited for Mediterranean conditions, and for which various technical solutions have been developed. Many prototypes and pre-commercial devices are now completing their technological readiness level (TRL) path and enhancing their visibility on the international stage.

GIANMARIA SANNINO

Gianmaria Sannino has been a staff scientist at ENEA since 2000, where he leads the Climate Modelling and Impacts Laboratory. He has a PhD in Marine Science and Engineering from the University Federico II in Naples. His research activities are focused on climate and ocean modelling, and the exploitation of ocean energy potential. He is a member of the scientific committee of the National Technological cluster, Blue Italian Growth, the Joint Programmes on Ocean Energy of the European Energy Research Alliance, the European Climate Research Alliance, and the Med-CORDEX initiative promoted by the World Climate Research Programme. He is also a member of the EU Implementation Group, Ocean Energy, for SET Plan.

The main advantage offered by such technologies is that, by being specifically projected for the low-energy Mediterranean environment, they must address the issue of efficiency. But to export them to the global market, their survivability must be demonstrated in more severe sea conditions, as must the feasibility of upscaling.

Research institutions and industrial players in Mediterranean countries have already taken up these challenges. The region has the potential to strengthen the European industrial technological base, thereby creating economic growth and new jobs, and allowing Europe to maintain and consolidate its leading position in the MRE sector, thereby meeting SET Plan targets.

Two Interreg MED projects are focusing on MRE – Maestrale and Pelagos; what are the lessons learned from these?

In 2016, the EU Interreg MED Programme launched the horizontal project, InnoBlueGrowth, to create cohesive stakeholder communities in strategic investment areas. PELAGOS and MAESTRALE are two projects dedicated specifically to marine energy.

PELAGOS has established a permanent Mediterranean Cluster of stakeholders to sustain macro-regional strategies and connect key actors (technology and service providers, large enterprises, power distributors, financial operators, policymakers, NGOs and citizens), thus enhancing trans-national cooperation in the development of new marine renewable energy (MRE) devices.

PELAGOS will also implement pilot actions at regional, national and transnational level, to illustrate and provide services, tools and methods tailored to the needs of SMEs and to help highlight the obstacles and limitations facing the MRE sector. At the same time they will identify joint opportunities in key market sectors such as tourism and leisure, aquaculture and shipbuilding.

MAESTRALE aims to create the basis for an MRE deployment strategy in the Mediterranean, connecting partners from Italy, Spain, Croatia, Greece, Cyprus, Portugal, Slovenia, and Malta. Its main output is the creation of blue energy labs (BEL), including local enterprises, public authorities, knowledge institutions and citizens. In the coming months, these will outlive the project to support future blue energy policies and plan concrete strategies for growth. Pilot actions have already been implemented to raise awareness among local stakeholders, to increase social acceptance and to reduce the inherent uncertainties in impact assessments.

The first positive results of these initiatives are already tangible. Dozens of SMEs are starting to collaborate and exchange knowledge, and the number is expected to increase when the Mediterranean Cluster and blue energy labs are fully operational by the end of 2019.

ARTICLE

An international vision for ocean energy: decarbonisation and economic benefits

The potential exists, worldwide, to develop 300 GW of wave and tidal current energy by 2050, according to forecasts by the International Energy Agency collaboration programme for Ocean Energy Systems (IEA OES). The benefits promise to be substantial, with the creation of 680 000 direct jobs, 500 million tonnes of carbon savings, and EUR 29.6 billion[1] investment in 2050.

To meet these forecasts, the sector needs to make significant progress through international collaboration and cooperation. There have been great strides forward in recent times, with several tidal projects achieving extensive operating hours, and multi-GWhs generated globally. Wave energy technology has also moved forward, with a number of successful large-scale laboratory and offshore tests. Complementing this progress, Wave Energy Scotland and the US Department of Energy (DoE) are leading international collaboration on the development of stage gate metrics for ocean energy, providing a robust and standardised approach to the management of innovation and technological progress.

Public and private investors around the world have continued to make significant investment. In 2018, the US Department of Energy announced funding of EUR 21.2 million[2] to support 12 next-generation marine energy technologies, along with enabling projects. In the UK, Orbital Marine Power concluded testing on their 2 MW turbine, and raised EUR 7.9 million[3] from 2 300 individual investors for a next generation device. Wave Energy Scotland selected two devices for real-sea testing in 2020, with funding of EUR 8.7 million[4].

> *To assist sector development, OES is engaged in a range of international collaborations across its 25 member countries*

At policy level, ocean energy is finding its place within a global energy market subject to considerable change. The drivers for renewable energy continue to strengthen, while declining prospects for nuclear energy in key ocean energy markets make headroom for low-carbon

1 Converted from USD 35 billion
2 Converted from USD 25 million; exchange rate 0.8476
3 Converted from GBP 7 million; exchange rate 1.1304
4 Converted from GBP 7.7 million; exchange rate 1.1304

HENRY JEFFREY

Henry Jeffrey is a specialist in marine energy roadmaps, action plans and strategies. He is responsible for dissemination and internationalisation within the UK Supergen Marine programme. He is Strategy and Internationalisation Officer for Wave Energy Scotland, and chairs the European Energy Research Alliance (EERA) and the IEA OES group for Ocean Energy. His international collaboration on the production of marine roadmaps and research strategies includes Canada, the US, Chile and Mexico. He has also coordinated several European marine energy projects, including DTOcean, which developed design tools for arrays of wave and tidal devices.

technologies. However, globally, ocean energy projects are still waiting for clear market signals, which are vital if the industry is to progress towards commercialisation.

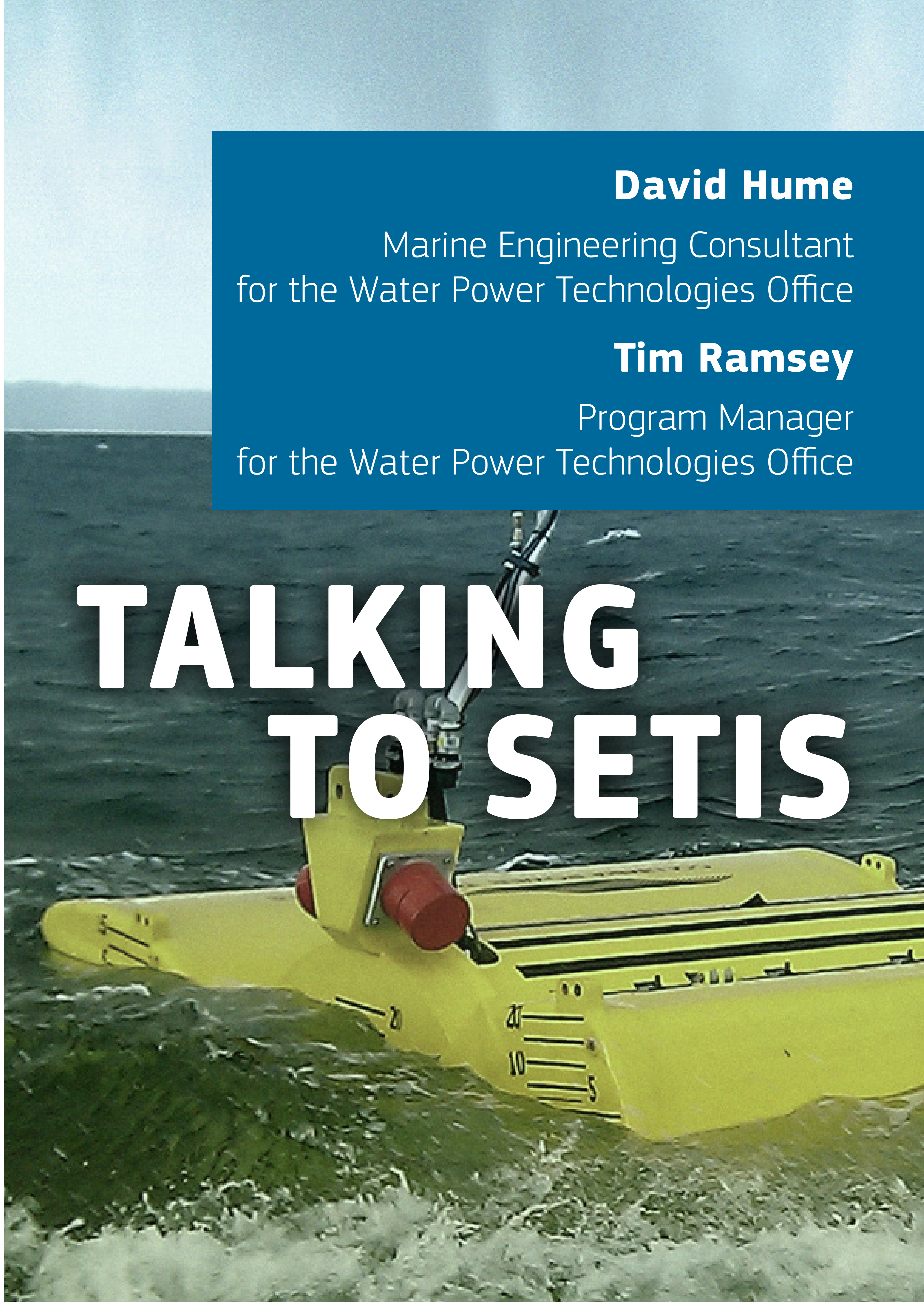
> *OES's most recent task has been to develop a framework for international performance evaluation of ocean energy technologies*

To assist sector development, OES is engaged in a range of international collaborations across its 25 member countries. These include the Environmental Issues project led by the US DoE, which has developed a means for retiring the environmental risks that slow down consent processes and the development of marine energies. A new study led by Tecnalia in Spain monitors the evolution of ocean energy costs and assesses the impact of various drivers on the levelised cost of energy (LCOE), taking into account historical trends, future development and differences in technologies and countries.

OES also carries out tasks dedicated to modelling verification and validation: one for wave energy, led by Ramboll in Demark; and another for tidal energy, led by the Energy Research Institute at Nanyang Technological University in Singapore. These groups have been engaging with experts from international research institutions and the business sector, comparing results among different numerical codes. A group of member countries – Japan, India, China, Korea, France and the Netherlands – have been working together on Ocean Thermal Energy Conversion (OTEC), to assess its potential around the world and to discuss the status of existing and planned OTEC projects.

OES's most recent task has been to develop a framework for international performance evaluation of ocean energy technologies. With strong inputs from the European Commission, the US DoE, and Wave Energy Scotland, it aims to produce a fully defined set of metrics and success thresholds for wave energy technologies, developing an internationally accepted approach.

In summary, there is clearly huge global potential in ocean energy, with significant benefits for carbon savings, security of supply, and jobs creation. The challenges might be robust, but by collaborating internationally, we can develop efficient and effective ways to accelerate the deployment of ocean energy technologies, and thereby reap substantial rewards.



David Hume

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TALKING TO SETIS

About lesson from outside the EU: alternative markets for ocean energy growth

DAVID HUME

David's work experience covers numerous sectors within the Blue Economy, including defence, ocean observation, tourism, marine robotics, offshore energy, and fisheries. Currently, he supports the US Department of Energy's Water Power Technologies Office on marine renewable energy research and development, leading efforts on market research and technical analysis. He holds a BS in Marine Engineering Systems from the US Merchant Marine Academy, an MS in mechanical engineering from the MIT School of Engineering, and an MBA from the MIT Sloan School of Management with a focus on energy and sustainability.

What other uses for marine energy are there?

Marine energy has utility beyond producing electrons for the grid. Over the past two years, the US Department of Energy's Water Power Technologies Office (WPTO) has systematically investigated these potential non-grid uses for marine energy, and the opportunities are promising.

> *The Water Power Technologies Office recognizes marine energy's unique potential to serve distributed maritime markets where finding reliable sources of energy at sea is a major constraint*

The use cases considered fall naturally within two thematic areas: Power at Sea and Resilient Coastal Communities. Power at Sea refers to the provision of power to applications that are off-grid and offshore, such as marine aquaculture, ocean observation, and charging underwater vehicles. Resilient Coastal Communities considers the energy and water needs of remote, island, and rural communities on or close to land, and includes applications like seawater desalination and isolated coastal microgrids.

WPTO has created a new R&D initiative to investigate these applications in more depth under the *Powering the Blue Economy™ initiative*[1]. After a year of research and review, we have just released a report of the same name, which explores each of these applications in detail.

Why explore these different applications?

Working in the ocean is difficult. Rapid corrosion, foundation scouring, biological growth, and extreme weather events are just a few of the challenges facing marine technology developers. The expectation for grid-compatible marine energy systems is that they will last years or decades in this hostile environment while providing reliable and cost-competitive energy for customers on shore. For those developers pursuing grid-scale power generation, a combination of technological efficiencies, economics, and risk mitigation have led them to link large machines together into wave farms or tidal arrays. Testing these large systems in such an unforgiving environment requires long, expensive, and onerous design cycles before they are sufficiently de-risked for the commercial sector. Progress is being made, but technologies have been slow to mature.

The marine energy sector must find new ways to get more devices into the water and attract new sources of funding to accelerate development.

What would the benefits be of these different applications?

Powering the Blue Economy™ is not only about advancing marine energy – it is also about understanding and enabling new markets.

> *Removing power constraints and addressing the needs of other coastal and ocean energy end users could accelerate growth in the blue economy and create new opportunities for sustained economic development. Marine renewable energy presents a novel and innovative suite of technologies that could help remove some of these constraints*

In ocean observation, for example, energy limitations restrict data collection both temporally and spatially. Consider unmanned underwater vehicles used for sub-sea inspections. These systems are limited in their mission range and duration by the capacity of batteries, requiring that the vehicle be recovered by a surface vessel periodically for recharging. This adds significant operational cost and burden. Marine energy could provide the electrons needed to recharge vehicle batteries at sea, drastically reducing the need and expense of a support vessel.

1 https://www.energy.gov/eere/water/powering-blue-economy-exploring-opportunities-marine-renewable-energy-maritime-markets

Marine aquaculture is migrating further offshore as economies of scale encourage larger farms which need more space. These facilities use energy for feed and waste dispersal, or even forced circulation. However, as farms migrate away from the coast, providing energy becomes a challenge. Marine energy systems could be co-located or even integrated with offshore aquaculture facilities, to mitigate this constraint and allow expansion further from shore.

Is the development time positively affected by this approach or would it delay the market uptake in the energy system?

By pursuing these alternative applications, technology development and market uptake should accelerate. In many of the non-grid applications considered, WPTO found no other viable means of power generation other than marine energy, and in those that did have an incumbent energy technology, it was often a limit to growth. These conditions should create a strong market pull.

Many of these potential markets have power needs far lower than that required for the grid; that means smaller devices, fewer regulatory restrictions, lower capital costs, and more suitable testing sites. New markets also mean new stakeholders, which could bring in a greater diversity of funding opportunities and investors. Pursuing these applications requires designing to a new set of user requirements, but many of the lessons learned and technologies developed will benefit grid-compatible systems as well.

Time will tell whether *Powering the Blue Economy™* has a significant impact on technological development and market uptake, but WPTO is confident and excited about the opportunities that await.

TIM RAMSEY

Tim Ramsey has been with the US Department of Energy (DOE) since 2005 and currently serves as the Program Manager for the Water Power Technologies Office's Marine Energy Program. In this role, he leads the Program's efforts to conduct early-stage R&D specific to marine energy applications, supporting the development of new, cutting-edge technologies and the establishment of a strong and competitive marine energy industry in the United States. The Program provides substantial financial support to researchers at a wide range of organisations, to focus on solutions to high priority challenges broadly applicable across the industry.

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SETIS Magazine

SETIS launches a new magazine quarterly, each issue is dedicated to a different low-carbon energy technology or relevant aspects of the sector. It covers the latest developments in the subject in question. Relevant personalities are invited to write articles outlining the main challenges and priorities facing their sectors, and interviews are conducted with key representatives from the related topic.

The magazines also include a SET Plan news section detailing the last developments to achieve the Integrated SET Plan objectives, and European Commission services and/or relevant organizations/institutions are invited to provide a foreword that highlights the main policy developments on the subject.

Ocean energy

This edition of SETIS Magazine takes a closer look at the development of ocean energy technologies in Europe and worldwide. It examines the current policy drivers at European and International level, and looks at innovation in the sector.
Renowned experts from the wider research and policy community assess the state of the art of ocean energy from various angles: technological, financial and environmental. Routes to market are also explored, including the role of ocean energy in powering islands and remote communities in low-resource areas. International examples provide further insight into the long-term benefits of ocean energy, and on alternative policy approaches for driving its development.

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