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WECANet: The First Open Pan-European Network for Marine Renewable Energy with a Focus on Wave Energy-COST Action CA17105

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Abstract: Growing energy demand has increased interest in marine renewable energy resources (i.e., wave energy, which is harvested through wave energy converter (WEC) arrays. However, the wave energy industry is currently at a significant juncture in its development, facing a number of challenges which require that research re-focuses on a holistic techno-economic perspective, where the economics considers the full life cycle costs of the technology. It also requires development of WECs suitable for niche markets, because in Europe there are inequalities regarding wave energy resources, wave energy companies, national programs and investments. As a result, in Europe there are leading and non-leading countries in wave energy technology. The sector also needs to increase confidence of potential investors by reducing (non-)technological risks. This can be achieved through an interdisciplinary approach by involving engineers, economists, environmental scientists, lawyers, regulators and policy experts. Consequently, the wave energy sector needs to receive the necessary attention compared to other more advanced and commercial offshore energy technologies (e.g., offshore wind). The formation of the first open pan-European network with an interdisciplinary approach will contribute to large-scale WEC array deployment by dealing with the current bottlenecks. The WECANet (Wave Energy Converter Array Network) European COST Action, introduced in September 2018 and presented in this paper, aims at a collaborative and inclusive approach, as it provides a strong networking and collaboration platform that also creates the space for dialogue between all stakeholders in wave energy. An important characteristic of the Action is that participation is open to all parties interested and active in the development of wave energy. Previous activities organised by WECANet core group members have resulted in a number of joint European projects and scientific publications. WECANet's main target is the equal research, training, networking, collaboration and funding opportunities for all researchers and professionals, regardless of age, gender and country in order to obtain understanding of the main challenges governing the development of the wave energy sector.

Keywords: marine renewable energy network; wave energy; ocean energy; wave energy converters; WECANet; European COST Action; CA17105

1. Introduction

The growing energy demand, the need to reduce greenhouse gas emissions under the pressure of climate change and the shrinking reserves of fossil fuels have all increased the interest in renewable energy. An example of a marine renewable energy resource with high potential is energy from waves, which is harvested through wave energy converters (WECs), devices that convert the kinetic and/or potential energy of waves into electricity. The potential for massive exploitation of wave energy will require deployment of large numbers of WECs at specific sea sites, arranged in WEC arrays or farms. This is already a common approach in the field of exploitation of offshore wind energy.

However, the wave energy industry is currently at a significant juncture in its development. Over the last 20 years, there has been significant investment in the development of WECs, but little concrete progress appears to have been made. Even regarding the wider ocean energy industry, in a recent global status report on renewables it is stated that government support remains critical to ongoing developments [1]. Whilst the commercial development of wave energy is not a direct research challenge, it is important that research undertaken supports the wave energy industry in reaching commercialization, otherwise wave energy is in danger of becoming irrelevant.

A number of pre-commercial or demonstration initiatives in the wave sector have invested in the deployment of almost full-scale prototypes and have had to face challenging and unexpected technical and financial issues. These issues have often also caused the failure of the initiatives. One could say that an increase in the number of initiative failures could induce social, political and investor scepticism that will result in a structural decrement of the wave energy sector. Therefore, an increase in the knowledge of technical and financial risks will pave the way to overcome these obstacles. This is; thus, the capital role of the research sector toward a sustainable future of the whole wave energy community.

A review of the current state of wave energy [2,3] indicates that a large number of researchers work on the prediction of the hydrodynamic performance of WECs, as well as on the structural loads that they are likely to experience. In addition, there is a significant amount of research supporting the optimal design and control of WECs from a power performance perspective. Nevertheless, looking at the abandonment of recent WEC prototypes [4], it was typically not the power performance that was an issue, but rather engineering details, such as the performance of structural elements of the WECs, as well as the complexity of offshore operations, which create major challenges regarding large-scale deployment. In addition, solving survivability issues of WECs that operate mainly in "hostile" high-energetic wave climates, as well as minimizing the "cost of energy", are key elements for the commercialization of wave energy. Effectively, research needs to re-focus onto a techno-economic perspective, where the economics considers the full life cycle costs of the technology [5].

Whilst some of this research may be done in the laboratory or using computer modelling, it will also require the deployment of prototypes, both to help identify the key issues as well as to investigate potential solutions. It is suggested that for practical and economic reasons these prototypes should be relatively small, but necessarily, fully-operational devices. This means the research focus, at least in the short- to medium-term needs to move from large-scale wave energy exploitation (and thus mainstream technologies developed for areas of more energetic wave conditions, which pursue device commonality through design consensus) to the challenge of developing WECs and tailored practices suitable for niche markets. However, in Europe, wave technologies and companies operating in the sector often come from the countries which are currently considered as leaders in ocean technology, namely the United Kingdom (especially Scotland), Denmark, Norway, Sweden, Ireland, Finland and Portugal [6]. In terms of national programmes or investments, the same countries are leading. It can be observed that countries along the Atlantic Arc are those with a larger market or energy resource or investments since the European seas (e.g., the Mediterranean) offer less of a resource. For many decades, the higher availability of wave power in specific areas has been the main driver for developing wave energy project ideas at a certain location or country. Yet, the higher technological challenges (e.g., WEC survivability) associated with locations of much higher wave energy potential has resulted in the direction of developing WEC concepts that are suitable for niche markets (e.g., WECs designed to operate in mild wave conditions). Hence, there is a need for a focus on the research and technological challenges that take into account the wave energy potential inequalities between European countries bordering open high-energetic oceans and those bordering smaller low(er)-energetic seas (Figures 1 and 2). This has the potential to become an interesting niche position for the local industries of these countries. This is not to argue that research should be defined by commercial requirements, but recognizes that if wave energy can be demonstrated for small niche technologies then this can progress to the development and deployment of larger and more powerful devices suitable for large-scale energy production.

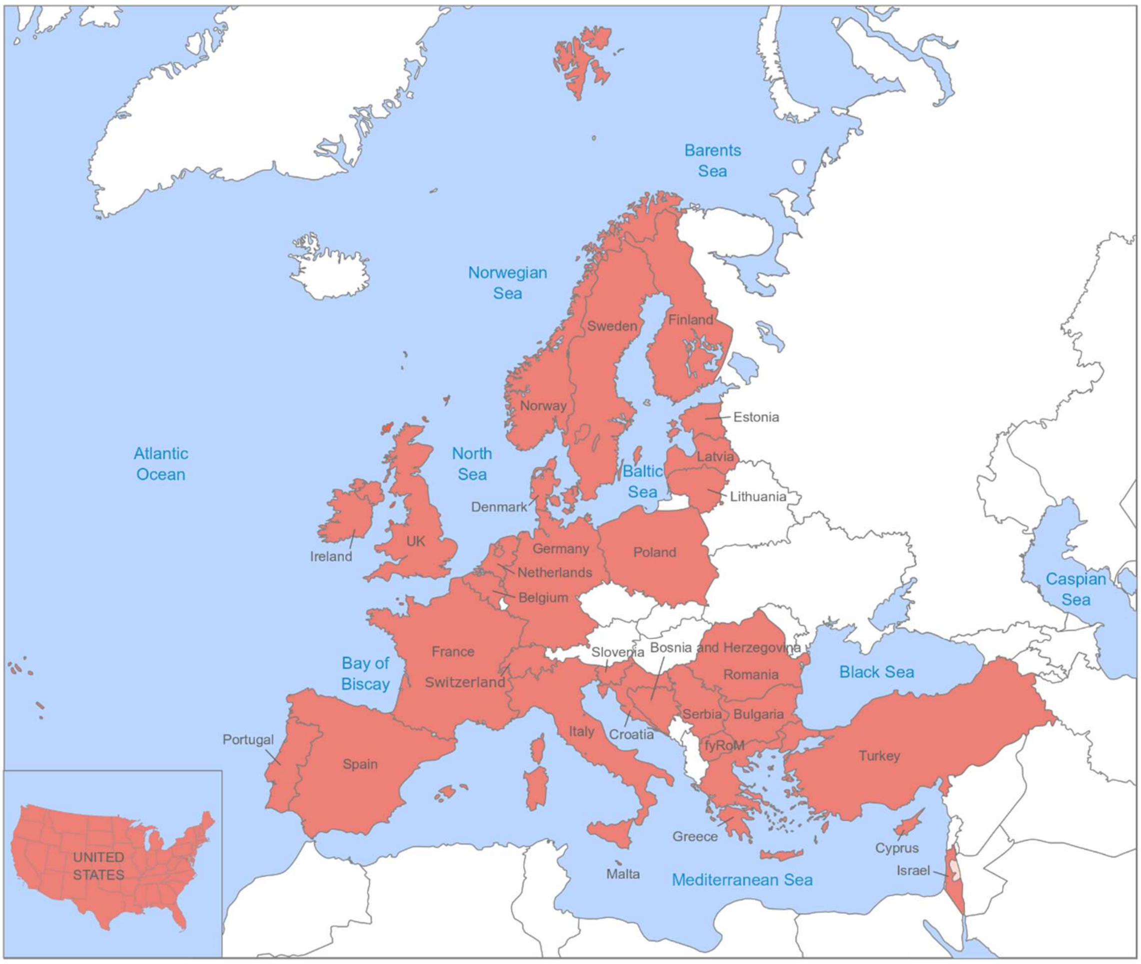

Figure 1. The WECANet COST Action represents 31 countries (in colour), which border open high-energetic oceans, and/or smaller low(er)-energetic seas. The involvement of the WECANet countries is detailed in Section 6 "Network as a whole". Exploitation of the available wave energy potential in Europe requires a tailored approach, which is the target of this WECANet COST Action.

Another major challenge is reducing the uncertainties related to the above research and technological issues, as well as mitigating possible environmental impacts, in which an interdisciplinary approach plays a significant role. In the different layers of the project design, a large number of experts are involved (from engineers to biologists and economists) and success will only be achieved with the required degree of interrelation and communication. Adopting a holistic approach and taking into account the main cost-drivers and impacts of wave energy projects, will lead to reducing risks in costs for potential investors. In other words, one of the main challenges is to increase reliability of wave energy technologies by decreasing technological and non-technological risks. This will, in its turn, boost the confidence of potential investors in wave energy projects [7,8].

An additional challenge that the wave energy sector is facing today is the comparison often made to other "marine renewable energy" sectors and, in the worst case, its inclusion to a wider-scope group of "emerging renewable energy" technologies (tidal, offshore wind, floating photovoltaics, etc.). Due to the fundamental differences between these technologies, and the challenges they are facing (as they are all emerging technologies), generalising under the common lens of "marine renewable energy" creates additional dangers for wave energy. For instance, fundamental differences between wave and tidal energy converters, including how they interact with the natural environment, as well as the different tools employed for their study, design and deployment, require separate treatment of these technologies. In other words, an "ocean energy" approach instead of a "wave energy" approach does not ensure the necessary attention and the "in-depth" analysis that is crucial for wave energy development. On the contrary, it may lead to enlarging the already existing gap between wave energy and the other technologies, rather than actually bridging it. This gap is illustrated in the recent findings by the European Environmental Agency [9] where it is clear that wave energy investments and consumption are the lowest (yet with highest future expectations), compared to other renewable energy industries, especially tidal and offshore wind. Moreover, as mentioned in the previous paragraph, for the European case there is a need to distinguish between wave energy exploitation in the ocean and the seas due to differences in the intensity of wave energy resources, as illustrated in Figure 2. This is an additional reason why the "marine renewable energy" approach is not suitable.

Another challenge, directly related to the European COST Missions and Policy [10], is dealing with bottlenecks that prevent the efficient use of human resources for European science. These bottlenecks are related to:

- Lack of efficient networking and communication. Research often does not have the expected impact on industry, policy- and decision-makers, and this creates further technological bottlenecks and research valorisation barriers. This is partly the result of lack of communication, lack of an interdisciplinary approach and of insufficient flow of information between the involved stakeholders.
- Lack of access to high-level, state-of-the-art research facilities and infrastructures (e.g., for numerical and experimental modelling of WECs) for talented and creative researchers and ECIs (early career investigators), especially from ITCs (inclusiveness target countries), from non-leading countries in wave energy, and from countries deeply affected by the recent European economic (debt) crisis that has been taking place in the European Union since the end of 2009.
- Researcher age balance. Wave energy is an emerging sector and still limited in terms of involved human resources compared to other energy sectors and thus senior researchers stand often in the spotlight. As a result, ECIs, compared to their senior colleagues, have often limited access to strategic networking opportunities where they can contact important stakeholders. This leads to fewer opportunities for collaboration with strategic international partners, which makes them and their research less attractive for future strong project consortia and for receiving national and European funding. On the other hand, achieving age balance is an important element of a network, in order to combine different levels of R&D experience and to ensure knowledge transfer between generations of researchers.
- Location, in terms of inequalities of available wave energy resources across Europe, which results in a lack of effective collaborations involving more countries than the current leaders in wave energy investments and in European and national funding (see previous paragraph on niche markets). As a result, researchers based in countries that are non-leaders in wave energy have also fewer opportunities.
- Gender, given the existing inequalities in all engineering sectors, and in particular in wave energy.

2. The Genesis of an Open Network for Wave Energy

In order to deal with the wave energy bottlenecks and issues presented in the introductory part, the open pan-European network, WECANet (Wave Energy Converter Array Network), was recently introduced in 2018. WECANet is the COST Action CA17105, funded by the European COST Association (COST stands for "European cooperation in science and technology").

The WECANet consortium is an initiative comprised of participants from 30 COST member countries and one COST international partner country (USA) focusing on their direct interest in, and benefits from, this COST Action. The inclusiveness target countries (ITCs) are recognized as less research-intensive COST members. ITC's have very strong participation in WECANet (50%) which demonstrates the determination of this COST Action to support the development of research and coordination capacities in ITCs, as well as WECANet's contribution to the "*Spreading excellence and widening participation*" Horizon 2020 goal [11].

The participants represent the critical mass needed to address cross-border challenges of marine and specifically wave energy in Europe. Women represent almost one third of the participants and 50% of the network participants are early career investigators. Another unique feature of WECANet is the involvement of countries which do not have access to the sea (e.g., Switzerland and Serbia) which is due to the strong interdisciplinary character of the network: Switzerland participates currently with economy specialists, while Serbia has a very long tradition in naval engineering (both numerical and experimental modelling) and brings, through the Serbian participants, significant expertise to the network.

The WECANet participants cover the wide range of scientific and professional backgrounds necessary for the integrated approach of this COST Action, such as research centre and industrial partners, as well as experts in technology commercialization within the marine renewable energy sector. Furthermore, the current breakdown of the WECANet includes currently 82.9% partners from many fields of the "engineering world": 25.7% from civil (coastal and ocean engineering) and 12.5% from mechanical engineering; 19.6% from environmental engineering and bioengineering; 18.8% from electrical, electronic, information and computational engineering; 6.3% from naval architecture engineering, ship hydrodynamics, maritime technology, and chemical engineering. The rest (currently 17.1%) of the core expertise of the WECANet members includes: partners from the sciences of applied mathematics, physics and biology; partners from the sciences of economics and business administration, law, policy and environmental assessment, social and gender sciences; other stakeholders: wave developers and supply chain, output end-users, utilities, energy companies, financing authorities, offshore industries and service providers, policy makers, other sea users, general public communication specialists and local communities, researchers and industry. Moreover, the WECANet consortium includes not only universities and research organizations but also involves Non-Governmental Organisations (NGOs), Small and Medium-sized Enterprises (SMEs), large companies, and local governmental organizations. The current institutional distribution of this COST Action network is: 73.2% higher education; 12.5% business enterprises; 8% (inter-)governmental organisations; 5.4% private non-profit without market revenues, NGOs; 0.8% standards organisations. Note that all distribution percentages mentioned here are subject to change, as there is a constant inflow of new WECANet members, with a target to achieve a more balanced constitution throughout the next years.

As such, the network is fully capable of undertaking this transdisciplinary COST Action and integrating different types of knowledge. In the future, the goal is to further enlarge the number of non-university participants in the network. Moreover, participants from three large research organizations from the USA are involved. The benefit for the European research community is access to the COST international partner countries' expertise in marine wave renewable energy, while the partners from the USA learn about the European approach to wave energy issues, and especially the differences related to geographical distribution of wave energy resources. As such, the academic exchange of cross-continental perspectives is mutually beneficial.

The management structures and procedures of the WECANet are organized mainly through the activities of the management committee (MC), the core group (CG) and the working groups (WGs), who are responsible for the development of the COST Action structures and strategies.

3. Relevance and Timeliness of WECANet

Addressing climate change requires a globally-coordinated, long-term response across all involved sectors. The 2015 Paris Agreement provides the framework for limiting global warming. Article 194 of the Lisbon Treaty on the Functioning of the European Union (*EU energy policy is aimed at promoting the development of new and renewable forms of energy*) is the legal basis and sets objectives of Renewable Energy in the European Union. The existing Renewable Energy Directive (Directive 2009/28/EC, repealing Directives 2001/77/EC and 2003/30/EC [12]), established that a mandatory 20% share of European energy consumption must come from renewable energy sources by 2020. Looking towards the future, Europe has started preparing for the period beyond 2020, in order to provide early policy clarity on the post-2020 regime for investors. Renewable energy plays a key part in the Commission's long-term strategy as outlined in its "Energy Roadmap 2050" (COM(2011) 0885). The decarbonisation scenarios for the energy sector proposed in the roadmap point to a renewable energy share of at least 30% by 2030. However, the roadmap also suggests that the growth of renewable energy will slacken after 2020 unless there is further intervention. On 30 November 2016, the Commission published a legislative package entitled "Clean energy for all Europeans" (COM(2016) 0860) as part of the broader Energy Union strategy (COM(2015) 0080). It includes a revised Renewable Energy Directive to make Europe a global leader in renewable energy and to ensure that the target of at least a 27% share of renewables in the total amount of energy consumed in Europe by 2030 is met.

Throughout the recent years a number of policies have been introduced, which are considered as supporting policies also for ocean energy. Making electricity infrastructure fit for the large-scale deployment of renewables is among the primary goals of the Energy Union strategy (Fact Sheets 2017, 5.7.1-Energy Policy), and is further supported in the "Energy Roadmap 2050" and the "Energy Infrastructure Package" (5.7.2-Internal Energy Market). The promotion and development of new-generation renewable technologies is also one of the key elements of the Strategic Energy Technology Plan or SET-Plan (5.7.1-Energy Policy [13]). On 20 January 2014, the Commission set out an action plan to support the development of ocean energy, including that generated by waves, tidal power, thermal energy conversion and salinity gradient power (in its communication entitled "Blue Energy: Action needed to deliver on the potential of ocean energy in European seas and oceans by 2020 and beyond" (COM(2014) 0008) [14]). This "Blue Energy" action plan guides further development of the ocean energy sector, and has been reflected in priorities and strategies in the sector as set in the strategic roadmaps by TPOcean [7], Ocean Energy Forum [8], etc. Its completion in the period 2014–2017 aimed at helping the industrialisation of the sector, so that it can provide cost-effective, low-carbon electricity as well as new jobs and economic growth for the European economy. The wave energy sector indeed advanced by 2017, with pilot and demonstration projects found in the waters of several countries, including China, Spain, and Sweden [1]. This shows that the "Blue Energy" action plan set a step forward, but, given that wave energy technologies are still emerging, further focus on this sector is needed. At the regional level, several regions have included marine technology as a policy priority aligned with the "Blue Growth" European priority and the sub-priority of "Blue Renewable Energy". "Blue Growth" is the long-term strategy defined by the European Union in 2012 to support sustainable growth in the marine and maritime sectors. It is the maritime contribution to achieve the goals of the Europe 2020 strategy for smart, sustainable and inclusive growth, whereby seas and oceans are identified as key drivers for the European economy with potential for innovation and growth. Common goals are best served through a coordinated and inclusive approach. Although today the ocean energy sector is relatively small, it could expand to contribute to economic growth and job creation in Europe. The sector could also contribute to the EU's 2050 greenhouse gas reduction ambitions if the right conditions are put in place now. Ocean energy should, in the medium- to long-term, be able to achieve the necessary critical mass for its commercialisation and become another European industrial success story.

Necessary cooperation mechanisms: The Renewable Energy Directive promotes cooperation amongst EU Member States to help them meet their renewable energy targets, through joint renewable energy projects and joint renewable energy support schemes. This WECANet COST Action is then built upon all the above-mentioned EU targets.

4. Objectives of WECANet

4.1. Research Coordination Objectives

A strong networking platform that focuses on the current challenges, bottlenecks and barriers, as identified previously, will accelerate the current development of wave energy research and of the wave energy industry. This is the main drive for creating this WECANet COST Action. The primary research coordination objectives (i–v) of this COST Action are presented below:

i. To offer the necessary focus on wave energy: One of the main objectives of this COST Action is to facilitate the necessary integrated interdisciplinary approach for wave energy in Europe through intensive and effective networking based on a strong techno-economic focus, and on collaboration between the participating stakeholders. Additionally, a target of this COST Action is the exchange of existing knowledge in Europe, regarding not only research but also practical or field experience by, for example, closing the gap in between researchers, policy makers and industrial partners. This is a critical time for the wave energy sector, and today this COST Action is more necessary than ever, as illustrated in Section 1.

ii. To enable technology and pave the way for a positive economic perspective: Installation practices and procedures are currently sub-optimal in terms of safety, practicality and cost [15,16]. In line with the supply chain, the array development is a key factor for both reaching optimal size of installation and attracting the energy sector. Optimization of O&M (Operations & Maintenance) is also necessary. In addition, and in order to achieve the sector engagement, it is essential to achieve a grade of commonality that will enable the supply chain, allowing companies to improve their R&D results in a subsequent stage. Consequently, research needs to re-focus onto a techno-economic perspective, where the economics considers the full life cycle costs of the technology [5]. This COST Action aims to bring together stakeholders and increase their understanding of the economic perspective, to contribute to achieving this goal.

iii. To focus on niche European markets for wave energy technology. The need for reaching the quoted grade of commonality will lead to a design consensus required at this stage of the wave energy market. However, in a future mature market, the transition from commonality to freedom of design has the ability to promote the mature market by supporting the generation of tailor-made solutions for each application or site suitable for niche markets in Europe. This COST Action acknowledges that if wave energy can be demonstrated for small niche technologies then this can progress to the development and deployment of larger and more powerful devices suitable for large-scale energy production.

iv. To improve risk management practices and to establish (environmental) impact mitigation measures in order to increase confidence for potential investors. This can be achieved through exploring and supporting, for example, new business models for facilitating risk-sharing under the appropriate political framework, and through adopting a holistic approach for wave energy. This pathway will allow setting up the next generation of systems capable of reducing the ratio cost–performance [17]. Moreover, more realistic and flexible environmental legislation [15] in accordance with the level of wave energy development will contribute to the sector progress. This COST Action will tackle these issues, as a large number of the participants investigate the possible (environmental) impact of WEC arrays/farms, from a technical (e.g., hydrodynamics), but also from an environmental, a legislative, political and socio-economic point of view. Another pathway for reducing uncertainties has directly to do with the numerical and experimental modelling at the design level of WECs or WEC arrays. As currently there are no full-scale and very limited small-scale data available for WEC arrays, the hydrodynamic numerical models currently employed in the sector are lacking validation. WECANet focuses on improving risk management practices, establishing impact mitigation measures and increasing the reliability of wave energy models through core Action activities.

In Section 6 a number of secondary objectives of WECANet are defined within the work plan description of WECANet and how these secondary objectives will be organised in order to achieve the primary research coordination and capacity-building objectives, presented in Section 4.1 and Section 4.2, respectively.

4.2. Capacity-Building Objectives

WECANet provides the necessary opportunities for researchers and other professionals involved in the wave energy sector to meet and cooperate. The primary capacity-building objectives (a–g) of this COST Action are fully aligned with the COST Mission [10] and are presented below:

a. To provide a platform and forum for efficient networking, exchange of information and identification of strategic research needed to deal with challenges and knowledge gaps for promoting deployment and commercialization of WEC arrays and advancing the sector. It is of great importance that the participants share feedback from completed or running research and demonstration projects and experiences from the "lessons learnt", but also that European researchers of all ages and gender can present new research plans and ideas. Through networking between researchers, industrial partners, policy and decision makers and other wave energy stakeholders, the necessary communication, interdisciplinary approach and flow of information between the involved stakeholders is targeted. These networking activities also have the aim to open up to new participants and extend WECANet in order to include as many wave energy stakeholders as possible.
b. To support interdisciplinary education and involvement of ECIs (engineers, environmental scientists, economists, etc.) that will better reflect the interconnection of the large number of different issues (and thus project layers) faced from design to implementation of wave energy deployment. This is achieved through short-term scientific missions (STSMs) and training schools that, for example, bring ECIs and many WECANet participants who have no access to research facilities in contact with state-of-the-art infrastructures owned by several other COST Action participants. A large number of early career investigators (50%) are participating in this Action, as well as many testing infrastructure owners, such as those from the MaRINET2 and HYDRALAB+ Programmes for Transnational Access to research infrastructure, and from the recent MARINERG-i project for the creation of a European network of infrastructures dedicated to Ocean Renewable Energy.
c. To promote and enhance cooperation amongst the participating research institutes and organisations involved in the follow-up of completed and existing, as well as the set-up of new European and (inter)national collaborative projects (e.g., within European programmes open to all researchers: HORIZON2020, HYDRALAB+, MaRINET2, etc.). These collaborations often include joint doctoral research where international experts are directly involved, commercial projects with a strong open-access research aspect, etc. This objective aims to open the gates for future collaboration opportunities with strategic international partners and in strong project consortia, which is of great importance for ECIs and young professionals in terms of research and innovation valorisation.
d. To provide support to the participants for achieving national and European funding through research support to ECIs, PhD students and young professionals (e.g., by organising STSMs). This objective aims to overcome inequalities between countries that are leaders and non-leaders in wave energy, or even for inclusiveness target countries (ITCs, which have already a strong representation in WECANet (50%)) and countries deeply affected by the economic crisis, and; thus, offer equal opportunities to the involved researchers in terms of applying for and obtaining national and EU funding.
e. To carefully balance the gender representation. WECANet has already organised strong participation of women (29%), given the existing inequalities in the sector. In order to

encourage further female participation, the Action has established dedicated teams both from the academic and the private engineering sector, with expertise in gender inclusiveness policies, female entrepreneurship and leadership, and active in women engineering associations. This objective will also focus on actively encouraging female participants to take on leadership roles within funding applications for (inter)national research and innovation projects.

f. To focus on the dissemination of the WECANet COST Action (net)working activities through events, training schools for both expert and non-expert audiences, and through creating a website for this COST Action to act as an information gate for many different stakeholders.

g. To encourage decision/policy makers to take up new interdisciplinary knowledge that addresses the correlation between multi-layer uncertainties and large-scale WEC array deployment, and to raise awareness of energy users and end-users of wave energy R&D and to gain their direct support.

Finally, there is a continuous need for dealing with the challenges which the wave energy sector faces throughout both the European countries and beyond and this is a target for the WECANet network of researchers and stakeholders.

5. Progress beyond the State-Of-The-Art and Innovation Potential

Early estimations of the global wave energy resources [18] have indicated the great potential of wave energy, which is today estimated (Figure 2) at about 3.7 TW [2,19]. From Figure 2 it is clear that Europe includes both high- and low-energetic seas.

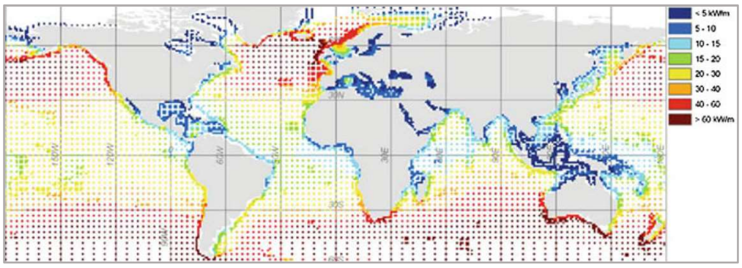

Figure 2. Annual global gross theoretical wave power for all World Waves grid points. Figure from [19].

The efficient exploitation of wave energy will require deployment of large numbers of WECs at specific sea sites, arranged in WEC arrays which will then be grouped together in larger WEC farms. As development continues in WEC technology there is an increasing interest in investigating how WECs interact with one another, and with the environment. The understanding of interactions between WECs is vital to support WEC array and farm design as commercialisation of WEC technologies progresses. Nowadays, many researchers investigate the performance of WEC arrays/farm [20] and WEC interaction [21], but also the possible impact of marine renewables (e.g., environmental, socio-economic and on marine ecosystems) [22,23].

Key findings for the EU and its member states (recent report by EEA (European Environment Agency), 2017 [9]) show that today, renewable energy sources (RESs) have become a major contributor to the energy transition occurring in Europe. In 2015, renewable energy accounted for the majority (77%) of new European-generating capacity for the eighth consecutive year, which has already resulted in greenhouse gas emission reductions in the European electricity sector. Key findings for RESs in a global perspective illustrate that global investments in renewables have shown steady growth for more than a decade. This led to a doubling of global renewable electricity capacity between 2005 and 2015. During this time, RES capacity increased across most parts of the world. According to the IEA Renewable Power Generation 2015 scenario [24], ocean energy technologies, including those based on wave energy, will be part of the energy mix in 2025. According to the IRENA (International Renewable Energy Agency) 2014 report [25], global installed wave power capacity could reach ~500 GWe; however, based on Bloomberg findings and expectations by Ocean Energy Europe (OEE), development targets for WECs have reduced in the past years, while the IEA 2015 report [24] also states that the technology development and projects are not on track compared to what was initially foreseen, and that the wave energy sector is lagging compared to tidal and offshore wind.

Regarding utilization of wave energy for electricity production, the current state is that the technologies are not yet mature [2], which emphasizes the importance of this COST Action dedicated to the wave energy sector. A number of full-scale demonstration projects exists [26], but these are generally still in the R&D phase (in which Europe is a world leader), with some of them expected to become operational by 2020. Currently there were 21 active wave energy projects installed in the seas worldwide (European Commission Joint Research Centre (JRC), 2016) [27], while a number of array projects are moving forward (in Australia, in Scotland and in Portugal). CAPEX (CAPital EXpenditures), O&M, and LCoE (Levelized Cost of Energy) figures for WECs are still estimations [27]; however, efforts to reduce costs through optimization of structures, operation, control, economic approach, etc. are expected to reduce the "cost of energy" to a level which at least is comparable with other more mature RES technologies (such as tidal and offshore wind).

5.1. Progress beyond the State-Of-The-Art

In the context of efforts to reduce the "cost of energy", this WECANet COST Action aims to advance the field of wave energy utilization in order to overcome the main barriers and needs the sector is facing (see Section 1 and [15]).

WECANet aims at dealing, in detail, with these challenges. In Figure 2 the inequalities in wave energy potential across Europe are depicted, which reveals the necessity for developing WECs, and research and project practices suitable for niche European markets, yet respecting a degree of consensus in the whole process which is also necessary for achieving large-scale commercialisation. Figure 1 shows that many European countries border open high-energetic oceans, and/or smaller low(er)-energetic seas. Specifically, the different European study cases and sites in WECANet target the Atlantic Ocean, the North Sea, the Baltic Sea, the Black Sea, the Norwegian Sea, the Mediterranean Sea and its main sub basins (the Aegean Sea the Adriatic Sea, the Tyrrhenian Sea), while for the USA more oceans/sea areas are involved. These sites do not only differentiate in terms of wave conditions, but also in terms of bathymetry (e.g., underwater cliffs should be avoided which create constraints for WEC installation, moorings and cable laying); in terms of ecosystems and environmental permissions (e.g., exclusion zones for rare seabed life, migration routes, archaeology, abandoned munitions); and in terms of country economic policy and renewable energy targets, etc. All these different factors affecting wave energy progress will be tackled in WECANet based also on the specific study cases and characteristics for each country.

All WECANet "working groups" are based on innovative interdisciplinary approaches. An example refers to numerical and experimental modelling techniques, for which this Action has dedicated working groups to deal with core issues and knowledge gaps. For instance, a large number of researchers develop numerical models, yet there is a need for an understanding of the pros and cons of each method and their ranges of applicability. Significant improvements in modelling will lead to reducing part of the uncertainties related to wave energy projects, which is currently one of the important barriers.

More than 120 experts have joined forces and initiated this COST Action, all of them being very familiar with the local wave and coastal conditions of their countries, as well as with the local environmental, policy, legal and financial situation, which are all crucial for the design and deployment of wave energy projects. WECANet is unique as it is open to as many as possible stakeholders, it adopts an interdisciplinary approach and it ensures a strong research base.

5.2. Innovation in Tackling the Challenge

WECANet's innovation potential lies in three major areas situated within its key objectives:

1. The forging of a new open pan-European network for marine renewable energy with a focus on wave energy: Recent questions focus on how to best integrate the different study and design layers involved in wave energy technologies. In part, the challenge lies in the differences of the distribution of the wave energy potential (Figure 2) in space but also in time. Thus, the primary innovation capability—apart from its scientific impetus—can be found in how the network itself has been assembled, combining researchers and wider stakeholders that work on significant wave energy design phases from many countries around the shores of Europe.
2. The advancement of inter- and multidisciplinary concepts and methodologies for research, with particular attention paid to, for example, numerical and experimental modelling using experiences and practices from different engineering disciplines (e.g., combining the knowledge of naval architects on floating body motions with the knowledge of coastal engineers on coastal processes, electrical and mechanical engineers on Power-Take-Off (PTO) systems, structural, chemical and material engineers on structural aspects of the WECs and mathematicians on mathematical models). Moreover, this COST Action combines different sciences (e.g., engineering with economics, environmental sciences, biology and ecology, policy, law and social sciences) as wave energy research has suffered from a lack of conceptual integration with necessary considerations, at different project levels.
3. Increased actor involvement: To establish a forum for discussion and communication between stakeholders and researchers active in wave energy. Most large seas in Europe border on several countries and; therefore, require concept practices that can be applied for groups of countries. To achieve this, scholars from different countries must be able to collaborate. Among these countries, not only are institutional contexts different but also economic circumstances. Networking will serve to develop approaches for wave energy that are applicable for Europe (and beyond). Practical experiences of stakeholders involved will support contextual issues in the debate.

5.3. In Relation to Existing Efforts at the European and/or International Level

This is the first COST Action on marine renewable energy with a focus on wave energy. Projects on wave energy, funded through other programmes (i.e., not COST), which have been completed include WAVEPLAM, with the main objective of introducing wave energy sources into the European renewable energy market, from a marketing point of view, and SOWFIA, which collected data on environmental, social and economic impact assessments.

Regarding the wider "ocean renewable energy" topic, there are already several efforts. DTOcean, an FP7 European collaborative project, as well as the follow-up project (DTOcean+), aimed at the industrial development of ocean energy power generation, and that provided design tools for deploying the first generation of wave and tidal arrays. EquiMar (completed in 2011) allowed testing of ocean energy technologies in terms of performance, cost and environmental impact. The FP6 CA-OE project (completed in 2007) aimed at developing a common knowledge base necessary for coherent development of policies in European, dissemination of this knowledge base and promotion of ocean energy technologies. The MERMAID project took into account socio-economic and environmental pressures on the oceans and marine ecosystems; however, it focused on offshore platforms.

With regard to transnational efforts, "ocean renewable energy" topics are treated by Ocean Energy Europe (OEE), which is an association of professionals from the entire ocean energy sector, which focuses on ocean energy policy and the industry. OEE deals with five different renewable energy technologies and coordinates the SI (Strategic Initiative) Ocean project (completed) as well as TP Ocean (European Technology and Innovation Platform for Ocean Energy), which is an advisory body to the Commission and defines technology priorities for research programmes such as Horizon 2020. The European Energy Research Alliance (EERA) includes public research centres and universities. It has a very wide scope as it deals with all energy-related research topics (not only marine renewables). Internationally, the International Energy Agency (IEA) Ocean Energy Systems is an intergovernmental collaboration programme between countries, which operates under a framework established by the International

Energy Agency (IEA) in Paris, and deals with ocean energy technologies. INORE (International Network on Offshore Renewable Energy) is a network of postgraduate young researchers working on issues related to offshore renewable energy. FORESEA, MaRINET2 and HYDRALAB+ aim at supporting the development of marine energy technologies and coastal structures by providing access to test facilities and sites through programmes of competitive calls. OCEANERA-NET launches transnational competitive joint calls for funding collaborative R&D in ocean energy.

However, all the above efforts do not combine WECANet's pillars: inclusiveness (geographical balance, age, gender, researchers' background), open network and thus without any membership fees, techno-economic and research focus, interdisciplinary and multi-layer approach, etc. This WECANet COST Action addresses the wave energy sector with a strong emphasis on inclusiveness and achieving excellence by adopting multidisciplinary approaches. It gathers together perspectives from the fields of engineering, socio-economics, law and environmental sciences that have not extensively been included in the previously mentioned projects. Furthermore, it focuses on the active role of stakeholders in all planned activities.

6. Implementation of the WECANet Work Plan

Description of Working Groups

This Action consists of working groups (WGs), whose interaction is regulated by the Management committee (MC) through the COD (COST Action coordination and dissemination) activities. Each WG and the COD have a specific function and focus as described in the following:

COD—COST Action coordination and dissemination: Coordination activities are undertaken by the core group of this Action throughout its entire duration (e.g., web-site development, training schools, STSMs, newsletter production, annual report development, MC meetings organisation and the organisation of conferences). Important tasks of COD are also to ensure an easy flow of information between the different WGs, and to identify and discuss funding and collaboration opportunities on wave energy projects. Dissemination of information and knowledge gathered during the Action will be addressed to wave energy communities, public authorities, developers and industry. The COD ensures coordination, management and communication (internal and external communication of WECANet). Communication and interaction between the WGs will ensure the targeted integrated techno-economical approach of wave energy in Europe (interaction between hydrodynamics, array optimization, concept and PTO optimization, economics, policy, legislation, etc.).

WG1—Numerical hydrodynamic modelling for WECs, WEC arrays/farms and wave energy resources (accuracy, uncertainty, coupling, applicability, usability): For evaluation of wave energy resources and site characterization, and for studying far-field effects of WEC arrays/farms, typically wave propagation models are employed (e.g., in [28–30]), while for studying WECs and their near-field effects, wave-WEC interaction solvers (e.g., in [31,32]) are used (e.g., based on boundary element methods (BEM), computational fluid dynamics (CFD), etc.). Nowadays, coupling techniques are also used between wave propagation models and wave-WEC interaction solvers [33,34]. During the past five years the sector has witnessed the rapid development of numerical tools which can model multi-body interactions to the second order or higher accuracy, such as non-linear BEM, CFD [35], and particle-following (Lagrangian) models [36,37]. Within WECANet, a large number of researchers use such models and thus WG1 aims to increase the understanding of the pros and cons of each method and their ranges of applicability.

WG2—Experimental hydrodynamic modelling and testing of WECs, WEC arrays/farms, PTO systems, and field data (accuracy, uncertainty, testing facility suitability, measurement techniques): During the past five years the sector has witnessed the rapid development of numerical tools used for wave energy projects; however, there is at present an acute need for data that can be used for their validation and thus for the assessment of the related uncertainties. The experimental facilities typically employed to model WECs, WEC arrays or WEC components are wave basins/flumes and towing tanks for hydrodynamic testing, wave emulators to perform dry tests for PTO systems, and sea test sites.

Nevertheless, no public experimental studies concerning both near- and far-field effects of large WEC farms, and which cover the validation needs of all the above mentioned (recent) numerical models, are reported in the literature. Only two previous experiments have looked at large WEC farms until today: the "PerAWaT" [38] and the "WECwakes" [21,39] projects. WG2 aims at a better understanding of physical modelling aspects: scale, laboratory effects, etc.

WG3—Technology of WECs and WEC arrays: The activities of WECANet aim to reduce costs and risks of wave energy technologies, and to contribute to the advancement of the sector by dealing with a number of identified issues related to the developing wave energy technologies [40]. Those include: improvement of the performance of WECs (optimal design, control and electrical aspects); WEC survivability, structural loads, loading and moorings of WEC arrays; deployment, installation, operation, cabling, WEC interconnections and connection to the grid, maintenance; feasibility for co-located wind and wave farms; WEC system design and sub-system integration; tools addressing industry-wide questions, multi-parameter problems and efficient optimisation techniques. WG3 aims at a better understanding of the techno-economic aspects of wave energy.

WG4—Impacts and economics of wave energy and how they affect decision- and policy-making: Economic mechanisms and impacts of ocean and wave energy [41–43] and how these affect decision- and policy making are subject of WG4. The activities of WECANet aim to reduce uncertainties when deciding on wave energy investments, and to contribute to increasing confidence of potential investors by dealing with: probabilistic lifetime design and O&M strategies; evaluation of tools which target key decision-investment barriers; the creation of a set of industry guidelines to be used for project development; incorporating the feedback on the needs of industry; multi-parameter problems and optimisation techniques; life cycle assessment, technology economics, legislation, policy, risk management; the introduction of systematic approaches to improve investor confidence; the way in which non-technological barriers such as regulatory frameworks, public acceptance and socio-economic and environmental impacts (e.g., on marine ecosystems, fisheries) affect the development of the wave energy sector. WG4 aims at a better understanding of the non-technological aspects affecting the sector.

7. Conclusions and Summary

Wave energy is currently based on emerging technologies and; therefore, the sector needs to increase confidence of potential investors by reducing technological and non-technological risks. This can be achieved through an interdisciplinary approach by involving engineers, economists, environmental scientists, lawyers, regulators and policy experts. The formation of the first open pan-European Network with an interdisciplinary approach will contribute to large-scale WEC Array deployment by dealing with the current bottlenecks. The WECANet European COST Action, introduced in September 2018, aims at an interdisciplinary, collaborative and inclusive approach for wave energy. WECANet's main target is the equal research, training, networking, collaboration and funding opportunities for all researchers and professionals, regardless of age, gender and country in order to obtain understanding of the main challenges governing the development of the wave energy sector.

The expected short-term and long-term impacts of WECANet are distinguished in impact related to scientific and technological, and to socio-economic factors. The expected short-term impacts in the wave energy challenge part related to science and technology are: to put attention on the urgent needs of the wave energy sector and contribute in its progress; the advancement of multi-layer scientific approaches to wave energy sector with regard to technological, environmental, socio-economic viability, etc.; deriving integrative concepts and tools for wave energy applications to increase investors' confidence; and to develop a common research agenda—the synergies between disciplines leads to more effective and efficient research and finally better practical implementation of its results. The first steps towards such a common research agenda are guidelines to be prepared for modelling and designing WEC arrays, as well as collaboration within projects and national and European funding applications; interdisciplinary knowledge production: by bringing together stakeholders and practitioners, the WECANet COST Action contributes towards the co-creation of scientific and practical knowledge, which may be immediately relevant for developing novel approaches; and the creation of inter- and multidisciplinary research clusters to nurture local and regional research.

With regard to short-term socio-economic impacts these will include: a focus on wave energy and on niche European markets from a techno-economic perspective; access of ECIs and other researchers to state-of-the-art European infrastructure; equal research, collaboration, funding, professional opportunities for all researchers regardless of age, gender and location; advancement of an inter- and multidisciplinary knowledge-based and evidence-led approaches to the implementation of wave energy projects; developing capacities on inclusive multidisciplinary practices for ECIs and mechanisms to involve ITCs, countries non-leaders in wave energy, as well as countries affected by the recent European economic (debt) crisis that has been taking place in the European Union since the end of 2009; strengthening cross-sectoral cooperation between state and non-state actors with regard to strategies supporting Blue Growth and Blue Energy.

With regard to long-term scientific and technological impacts, WECANet's target is to: establish an internationally recognised network for research, publishing, advice and guidelines; sustain a generation of early career investigators and young professionals familiar with approaches to integrated and multi-disciplinary practices for wave energy; and to contribute in the increase of successful wave energy projects. The WECANet focuses on the current challenges and bottlenecks of the wave energy sector and makes an important contribution to solving the main problems.

The expected long-term socio-economic impacts are to: strengthen pathways that promote cross border and multi-disciplinary cooperation on marine renewable energy themes; develop mechanisms to sustain inclusive multidisciplinary practices for ECIs, ITCs, etc.; achieve awareness raising: Wave energy developers, industry, governments, NGOs and engineers will be made aware of the WECANet results, which is vital for the efficient development of the sector.

As such, WECANet has a high potential for socio-economic, scientific and technological breakthroughs. An important breakthrough accomplished by the action will be an increased awareness of the potential to efficiently exploit wave energy through advanced approaches. The WECANet's innovation outcomes primarily comprise scientific findings and technology insights, being in line with current state-of-the-art research. Finally, WECANet is committed to bringing out excellence and inclusiveness in wave energy science Europe-wide and clearing away obstacles by offering a low-barrier entry research network and creating interdisciplinary research cooperation opportunities for researchers. Importantly, WECANet aims at creating strong interaction with other existing networks, running wave energy projects and transnational access programmes (some of them are mentioned in Section 5.3) in order to achieve the highest possible complementarity and benefits for its members and for the scientific community.

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