13th EWTEC 2019 Proceedings of the 13th European Wave and Tidal Energy Conference 1-6 Sept 2019, Naples, Italy

Market, Investments and deployment scenarios for ocean energy in Europe

Davide Magagna, Wouter Nijs and Pablo Ruiz Castello

Abstract— **Ocean energy is one of few untapped sources for renewable energy. Its potential in the EU is vast, thus it can play a key role in decarbonising energy supply and increasing energy security and fuelling economic growth in coastal regions. The European Commission is supporting the development of the ocean energy sector through the Energy Union, the SET-Plan, and the Blue Growth Strategy policy initiatives. The aim of these activities is to drive the development of ocean energy within the transformation of the European energy system by 2050. Ocean energy technologies must reduce their cost considerably in order to unlock investments in the sector to support the projected market growth.**

In this paper we assess the investments required for the ocean energy sector to meet the SET-Plan targets through an assessment of the potential deployment of wave and tidal energy in an energy-system model. We employ the JRC-EU-TIMES model to assess the deployment of ocean energy converters in the EU with current cost assumptions and under the assumption that SET-Plan cost-reductions. The results obtained from the JRC-EU-TIMES model indicate that achieving the cost-reductions needed to meet the SET-Plan targets will be fundamental for the uptake of tidal and wave energy technologies in Europe.

Keywords—SET-Plan **Times model, ocean energy deployment, market formation, cost-reduction**

I. Introduction and Policy Overview

OCEAN energy is one of few untapped sources for renewable energy. Its potential in the EU is vast, thus it can play a key role in decarbonising energy supply and increasing energy security and fuelling economic growth in coastal regions.

The European Commission is supporting the development of the ocean energy sector through an array of activities: the Energy Union and the SET-Plan and the Blue Growth Strategy. The aim of these activities is to drive the development of ocean energy within the transformation of the European energy system and to exploit is potential to create growth and jobs in the EU.

The EU is at the forefront of ocean energy technology development. The EU hosts 50 % of the world's tidal energy developers, 60 % of wave energy developers and 70 % of the ocean energy research and testing infrastructure[1].

The sector aims to reach 100 GW of ocean energy capacity installed in European waters by 2050[2]. Over 400 000 jobs could be generated if this industrial target is met. The sector is expected to deliver 100 MW of installed capacity by 2020[3].

In order to favour the market uptake of ocean energy technology and stimulate investment in the sector the SET-Plan Declaration of Intent [4] has set cost targets for ocean energy technologies to reach by 2025, 2030 and 2035, as shown in Table I.

TABLE I
LCOE TARGETS FOR WAVE AND TIDAL ENERGY TECHNOLOGIES. SOURCE: [4]

Technology	Year	Target
Tidal energy	2025	15 cEUR/kWh
Tidal energy	2030	10 cEUR/kWh
Wave energy	2025	20 cEUR/kWh
Wave energy	2030	15 cEUR/kWh
Wave energy	2035	10 cEUR/kWh

These targets are ambitious as they indicate that the levelised cost of electricity of ocean energy technologies needs to be reduced of 70-80% from 2015 level[5], [6]. Initial indications from ongoing deployments are showing that this level of cost-reduction is feasible and SET-Plan targets achievable.

The targets of the Ocean Energy SET-Plan Declaration of Intent have been endorsed by the different Member State and, consequently, an Implementation Plan[7] comprising 11 actions to meet these targets has been prepared. Contributions from industry, national and regional governments and European Commission are expected in order for the targets to meet met.

Paper ID 1589 – Track: Economical, social, legal and political aspects of ocean energy.

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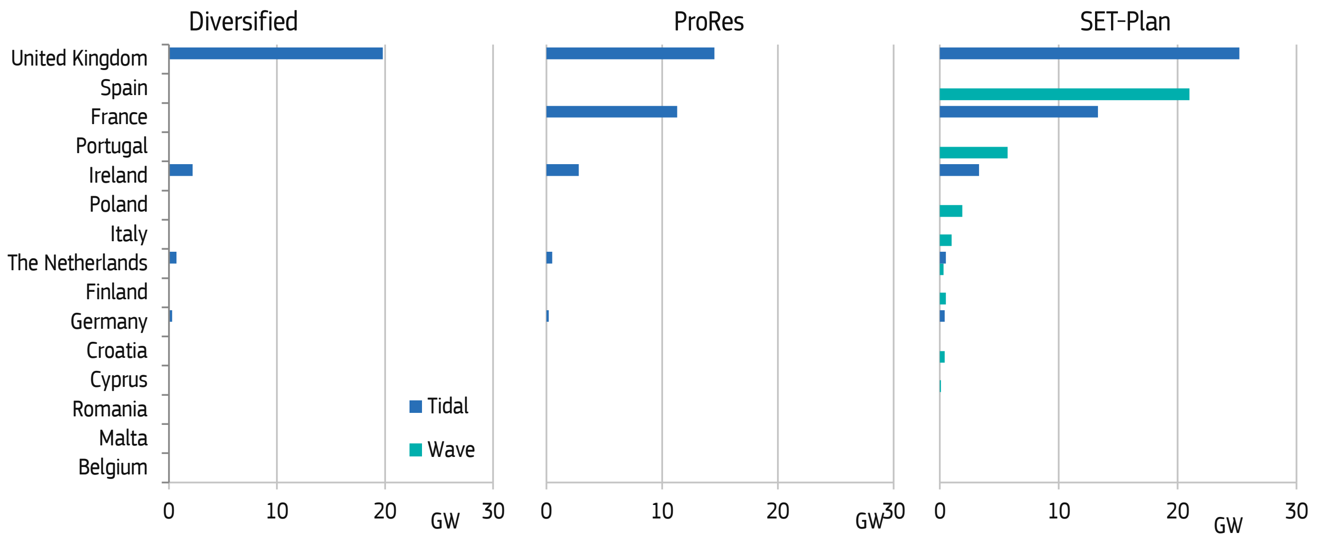

Fig. 1. Installed capacity in GW of wave and tidal energy according to different JRC-EU-TIMES scenarios. The baseline scenario is excluded since it indicates no wave energy capacity by 2050.

In this paper, we assess the investments required for the ocean energy sector to meet the SET-Plan targets through an assessment of the potential deployment of wave and tidal energy in an energy-system model. We employ the JRC-EU-TIMES model we assess the deployment of ocean energy converters in the EU with current cost assumptions and under the assumption that SET-Plan cost-reductions are met.

II. The JRC-EU-Times Model

The JRC-EU-TIMES model is a linear optimisation, bottom-up technology rich model, providing as results the stock and activity of energy supply and demand technologies for each country and period as described in[8], [9] . A detailed description of the application of the JRC –EU-TIMES model for marine energy and deployment based on 2015 data can be found in [10].

For this work, the deployment of ocean energy technology is assessed under three main global scenarios as described in [8]. The three main global scenarios are developed under different policy assumption in terms of decarbonisation of the EU Energy system and uptake of renewable energy sources as follow:

1) Baseline – basic uptake of renewable energy sources.
2) Diversified – higher decarbonisation but includes nuclear energy and CCUS in the system.
3) Pro-RES – higher uptake of renewable energy sources and lower technology costs.

These scenarios are based on a set of inputs and assumptions and it has to be noted that uncertainties are considerable when looking at longer time frames (i.e. up to 2050). The most relevant model outputs are: the annual stock and activity of energy supply and demand technologies for each region and period; the associated energy and material flows, including emissions to air and fuel consumption for each energy carrier; operation and maintenance costs, investment costs, energy and materials commodities prices [10] .

The modelling inputs for ocean energy technology based on current cost are the results of a wide literature review of cost of ocean energy technology as carried out by [11]. In order to better understand the potential evolution of ocean energy technology, a SET-Plan technology learning scenario has been included in the modelling. The SET scenario is based on the assumption that technology innovations allows to meet the targets of the SET-Plan declarations, not only for ocean but for all technology families.

It shall be noted that the JRC-EU-TIMES model does not account for support mechanisms, and that therefore the competition between energy sources and technology is based on technology costs and potential in the different member states based on current costs and future cost estimate. Nevertheless, one should keep in mind that the current limited deployment of wave and tidal technologies is due to the current high technological costs. The required cost-reduction and commercialisation will not happen without further public support. Investors and developers need visibility and certainty in public policy, for instance through the National Energy and Climate Plans and support schemes that will eventually offer revenue and a business perspective for private investors and the industry.

Fig. 1 present the uptake of wave and tidal energy technologies in terms of cumulative capacity (GW) for the year 2050 for different scenarios modelled. As it can be seen from Fig. 1, meeting the SET-Plan targets is fundamental for the uptake of wave, and to a lesser extent, tidal energy.

In fact, whilst tidal energy would be deployed in UK, France and Ireland under the ProRES scenario and in UK and Ireland only for the Diversified scenario, wave energy uptake can be expected only if a significant reduction of the technology cost is achieved.

III. DEPLOYMENT OF TIDAL ENERGY

The projected cumulative deployment of tidal energy technology under the ProRes and SET-Plan scenario is presented in Fig. 2. Under the Pro-RES Scenario Tidal energy is expected to reach 10.69 GW of installed capacity in 2040, and 28.6 GW in 2050. Under the SET-Plan scenario, tidal energy enters the energy system in 2030 due the considerable cost-reduction forced in the model.

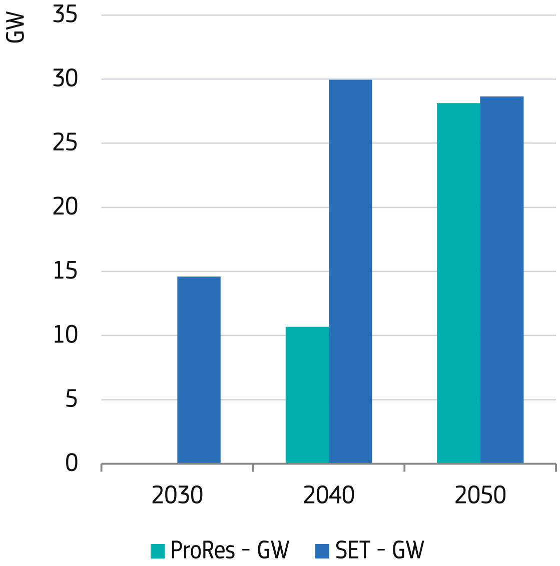

Fig. 2. Projected tidal energy deployment under the ProRes (Green) and SET-Plan Scenario.

Under the SET-Plan scenario 14.6 GW of tidal energy could be needed by the energy system in 2030, with cumulative tidal capacity of 29.9 GW in 2040 and of 28.64 GW in 2050. It shall be noted that this decrease in capacity does not affect the total power generated by tidal energy of 108 TWh/year, that represents the technical potential available in Europe[12].

The uptake of tidal technologies in the energy market is based on the technologies becoming cost-competitive. Fig. 3 presents the evolution of tidal energy Capex under the different scenarios and compares it with the market entry Capex. The Entry Capex is defined as the threshold Capex which would limit the entry of tidal energy in the market. Once the Capex of the technology is equal or below the Entry Capex, it can be expected that tidal energy technologies are taken up in the energy system.

As Fig. 3 highlights the projected Capex reduction in the ProRes, Diversified and SET-Plan scenario will by 2050 reach levels lower than the required Entry Capex. However, under the conditions of the SET-Plan scenario (high learning rate), the CAPEX of tidal energy technology will be below the entry Capex already in 2030, those facilitating market uptake of tidal technologies.

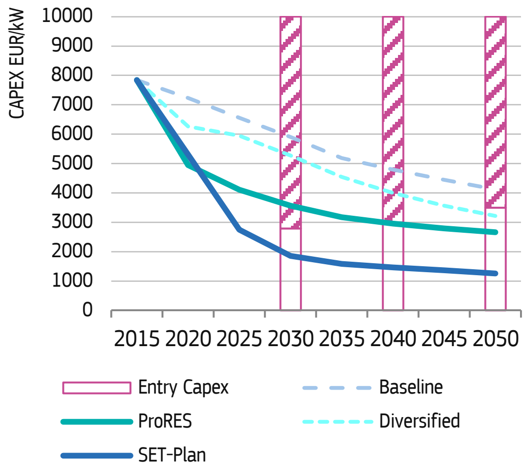

Fig. 3. Capex evolution of tidal energy under different JRC-EU-Times scenarios and market entry-capex for tidal technologies.

Fig. 4 presents the expected annual deployment required to meet the forecasted capacity. In particular, in order to reach 14.6 GW installed by 2030, annual capacity should be of 1.4 GW/y from 2020. The installation rates of the ProRes scenario are slower for the period 2030-2040 (1.07 GW/y) and of 1.86 GW/y for the period 2040-2050

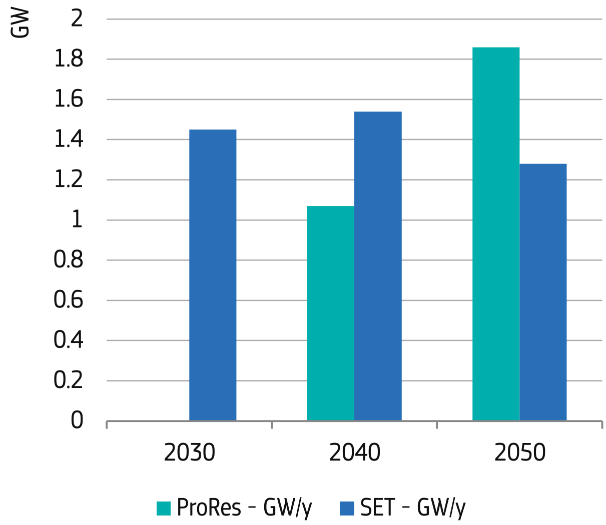

Fig. 4. Annual capacity deployment under the ProRes (Green) and SET-Plan (Blue) scenario for tidal energy.

Fig. 5 presents the total investments required to meet tidal energy growth under the ProRes and SET-Plan Scenario. In total 91 billion EUR of investments would be required under the SET-Plan scenario, whilst the ProRes scenario would require investments of 103 billion EUR. The higher investments in the ProRes correspond to the higher cost of tidal technology compared to the SET-Plan scenario.

Fig. 6 shows the deployed capacity of tidal energy technologies per country according to the ProRes and SET-Plan scenario.

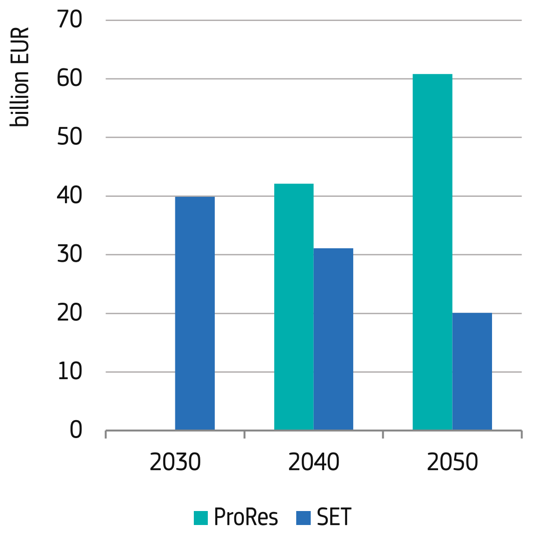

Fig. 5. Total investments needed to meet the cumulative tidal energy capacity under the under the ProRes (Green) and SET-Plan (Blue) scenario.

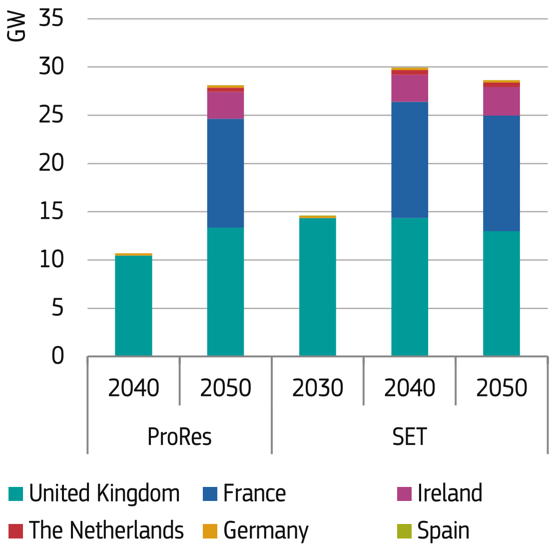

Fig. 6. Deployed tidal energy capacity in different EU countries under the ProRes and the SET-Scenario.

From Fig. 6 it can be seen that both scenarios the UK is the country whose energy system will pick up tidal energy the first, in both cases reaching 13 GW of capacity in 2050. France could also become a significant market for tidal energy, with up to 12 GW deployed by 2050. Tidal uptake in France is dependent on the renewal of nuclear energy. Other countries who can be expected to see tidal energy deployed are Ireland, the Netherlands, Spain and Germany.

IV. DEPLOYMENT OF WAVE ENERGY

The projected cumulative deployment of wave energy technology under the ProRes and SET-Plan scenario is presented in Fig. 7. Under the Pro-RES Scenario wave energy is expected to reach 0.04 GW of installed capacity in 2050. Under the SET-Plan scenario 0.04 GW of wave energy could be needed by the energy system in 2040, with cumulative wave capacity of 30.9 GW in 2050.

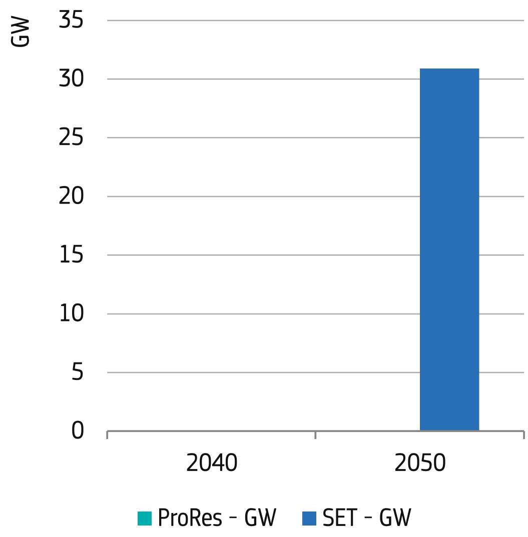

Fig. 7. Projected wave energy deployment under the ProRes (Green) and SET-Plan Scenario.

The slow uptake of wave technologies in the energy market is due of the technology being too costly in many of the scenarios. Fig. 8 presents the evolution of wave energy Capex under the different scenarios and compares it with the market entry Capex.

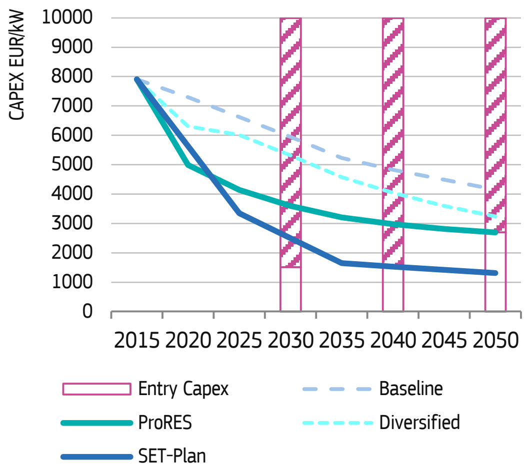

Fig. 8. Capex evolution of wave energy under different JRC-EU-Times scenarios and market entry-capex for wave energy technologies.

As Fig. 8highlights the projected Capex reduction in SET-Plan scenario favours the uptake of wave energy in 2050. The high-cost reductions needs required to meet the SET-Plan targets bring the technology cost below the Entry Capex target in 2040 and 2050, thus driving the deployment of wave energy technology. In the ProRes scenario, the expected Capex of wave energy technology reaches the Entry Capex target in 2050, with thus minimal capacity deployed by then.

Fig. 9 presents the expected annual deployment required to meet the forecasted capacity. In particular, in order to reach 30.9 GW installed by 2050, annual capacity should be of 3 GW/y from 2040. This indicates a fast growth of the wave energy markets once costs reduce significantly. The installation rate of the ProRes scenario is considerably slower given the small capacity forecasted by 2050.

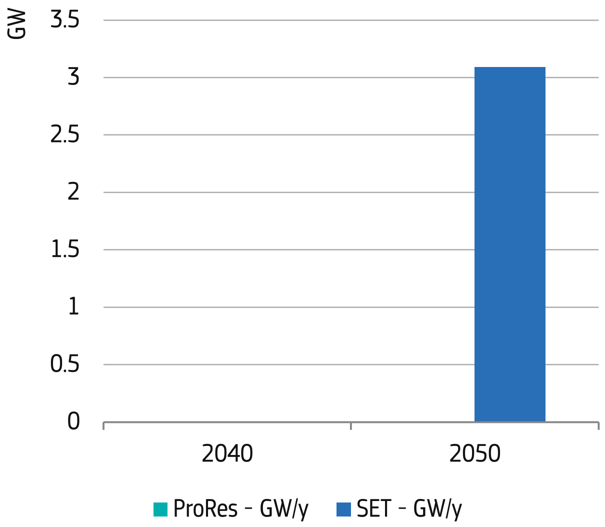

Fig. 9. Annual capacity deployment under the ProRes (Green) and SET-Plan (Blue) scenario for tidal energy.

Fig. 10 presents the total investments required to meet tidal energy growth under the ProRes and SET-Plan Scenario. In total 50 billion EUR of investments would be required under the SET-Plan scenario to see wave energy reach 30 GW of installed capacity by 2050.

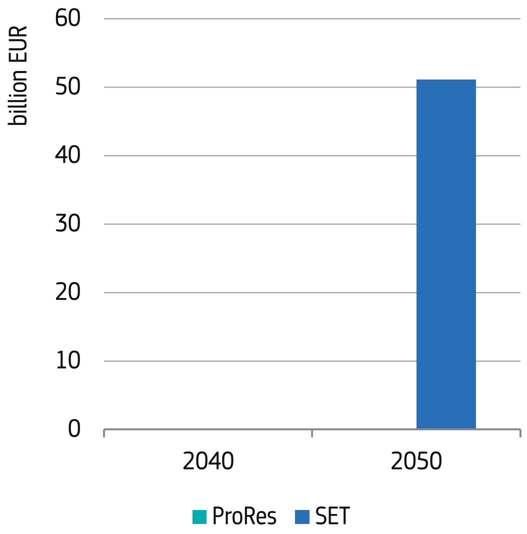

Fig. 10. Total investments needed to meet the cumulative tidal energy capacity under the under the ProRes (Green) and SET-Plan (Blue) scenario.

Fig. 11shows the deployed capacity of wave energy technologies per country according to the ProRes and SET-Plan scenario. It can be seen that wave energy will play a significant role in the energy system of Spain and Portugal by 2050 if cost-reductions targets are met, with installed capacity across the whole of the EU.

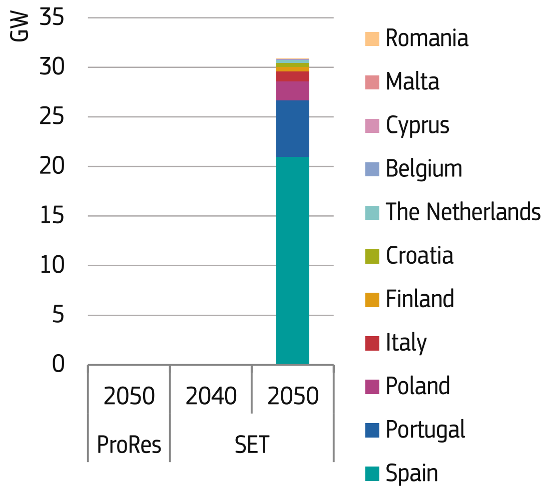

Fig. 11. Deployed wave energy capacity in different EU countries under the ProRes and the SET-Scenario.

V. Role of Ocean Energy in Other Scenarios

Ocean energy deployment in the EU energy system as modelled in JRC-EU-TIMES depends not only on the assumptions made for tidal and wave energy cost and performances but also on the assumptions made for the other energy technologies modelled, and their uptake, and consequent completion in the energy system.

For example under the SET-Plan scenario, it can be seen countries with a significant share of tidal energy technologies (UK, France and Ireland) have no uptake of wave energy technologies. The only country where wave and tidal energy technologies are part of the energy system is The Netherlands.

Fig. 12 shows the contribution of ocean energy to the energy system of each MS under different scenario. Competition with other energy sources, such as wind is minimal. In fact, the share of wind energy in countries such as Ireland and UK is only partly affected by a bigger deployment of ocean energy under the SET-Plan scenario. Furthermore in countries such as Spain and Portugal, both ocean and wind energy increases under the SET-Plan scenario.

A more in-depth look at the deployment of offshore renewable energies foreseen under different JRC-EU-Times scenario is show in Fig. 13. One can see that in the three scenario the uptake of tidal energy is similar, with capacity of about 25-28 GW. The uptake of offshore wind energy increases significantly between the diversified and ProRes scenario. However, In the SET-Plan scenario, it can be seen that when wave energy enters the market (30 GW in 2050) offshore wind capacity would be reduced by about 34 GW, indicating that wave energy and offshore wind technology may in the long term be competing for market place.

Fig. 12. Role of ocean energy technology in the energy system under different scenarios

It follows that the long term viability of wave energy is connected to the cost of the technology being in line with those of offshore wind to grant entry in the market.

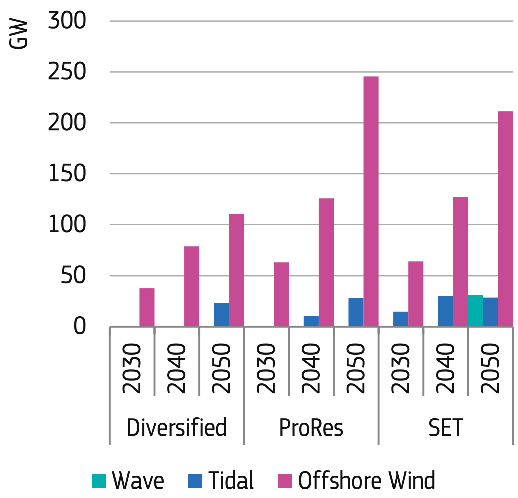

Fig. 13. Deployment of Marine renewable energies under the diversified, ProRes and SET scenarios.

VI. Comparison with other Market studies

In 2018 two key market studies were released: one by DG Mare (contracted to COGEA and Wavec), one by Ademe in France These studies are here compared with the results of the JRC-EU-TIMES modelling. These study have been developed with different purposes compared to the modelling of the JRC-EU-TIMES presented before, with a focus on understanding the deployment of wave and tidal energy technologies in the EU based on current costs, on project announced and not necessarily from an energy system perspective.

At technical level the studies are very different, driven by different assumptions and calculations behind.

1) ADEME [13]– The study addresses tidal energy development in UK, FR, CA, JP and Indonesia, looking at 1) large tidal turbines (>1.5 MW), using cost data from turbines manufacturers (Including Atlantis, Openhydro, Alstom), including those who have stopped operations. The starting point of the study is a LCOE of about 365 EUR/MWh with the expectations that LCOE could reach a reference value of 165 EUR/MWh in 2030. In the optimal case, LCOE could reach 120 EUR/MWh .

   The study presents 3 scenarios: pessimistic, optimistic and reference. It's not clear how installed capacity and market uptake of the technology is modelled, but it is highly likely that this is done on costs only. The total potential taken in account is 120 GW globally, and 18 GW in Europe (9 UK, 5 FR, and 4 between Italy, Greece and Spain). No information is provided with regards to floating technology, and tidal kites.
2) DG Mare[14] – The study is based on a steady technological progression from low TRL to TRL9 for wave and tidal technology, with deployment increasing thanks to technology progression. The study considers that grants form a considerable part of the funds to ensure projects go ahead (capital support). 3 scenario are presented: pessimistic, medium and optimistic.

The results of the ADEME and DG Mare studies are compared with those obtained by the JRC-EU-TIMES modeling. In order to compare the different studies the results of the ProRES scenario are compared to the pessimistic and central scenarios of the ADEME and DG Mare. The SET-Plan scenario is used for comparison with the optimistic and disruptive scenarios from ADEME and DG Mare. A comparison between the different market forecasts of tidal energy up to 2030 is shown in Table II.

TABLE II
COMPARISON OF MARKET FORECASTS PROVIDED BY ADEME, DG MARE AND JRC – SOURCE [13], [14]

Pessimistic	2025	2030
Ademe	11	14
DG Mare	200	949
JRC-EU Times	0	0
Central		
Ademe	35	83
DG Mare	550	1440
JRC-EU Times	0	0
Disruptive		
Ademe	307	888
DG Mare	800	2232
JRC-EU Times	5000	14500

A. *Pessimistic Scenario*

In the pessimistic scenario, ADEME [13] foresees a maximum of 14 MW installed in Europe by 2030 (FR and UK only), meaning that no new capacity is installed from now to 2030.

The forecasts from DG Mare [14] indicate that up to 950 MW of tidal energy installed capacity could take place. No uptake of tidal energy capacity is expected by JRC Times model, indicating that costs are too high for the energy system.

B. *Central Reference Scenario*

In the reference scenario, tidal energy capacity could reach 83 MW according to ADEME [13], and 1440 MW according to DG Mare [14]. The JRC-EU-Times models foresees no installed capacity for tidal energy.

C. *Disruptive – Optimistic Scenario*

In this scenario tidal energy capacity could range between 888 MW foreseen by ADEME [13], 2232 MW by DG Mare [14] and 14500 MW from JRC Times.

The assumptions made by ADEME [13] in this scenario consider that:

1) The Normandie Hydro Farm is deployed (14 MW of OpenHydro/Naval Energies);
2) Meygen is expanded to 80 MW;
3) That offers for Raz Blanchard and Fromvuer are made (not clear if feed-in-tariff).

The projects announced by Atlantis in France are not considered. The JRC-EU-TIMES scenario, which foresees a very high level of penetration of tidal energy by 2030, suggests that cost-reductions of tidal energy technology coupled with foreseeable and reliable generation make the technology competitive in a highly decarbonised EU energy system. The DG Mare study foresees that most of the tidal energy projects announced will go ahead [14].

D. *Key takeaways from market forecasts*

The different market studies show that there is sinifican potential for tidal energy growth in Europe.

The main point from the ADEME study is that cost-reduction can take place, even with limited installed capacity. Further, there are reasons believe that the disruptive scenario could lead the technology costs in close proximity to what the SET-Plan targets are, allowing for the technology to be already competitive in an integrated energy system. This scenario includes the deployment of partly publicly supported project such as Normandie Hydro and Meygen 1 (up to 80 MW) and the potential opening of tenders for Fromvuer and Raz Blanchard in France. The optimistic case presented by DG Mare studies shows that the potential deployment of tidal energy is in line with the current pipeline of projects planned and announced in Europe [14].

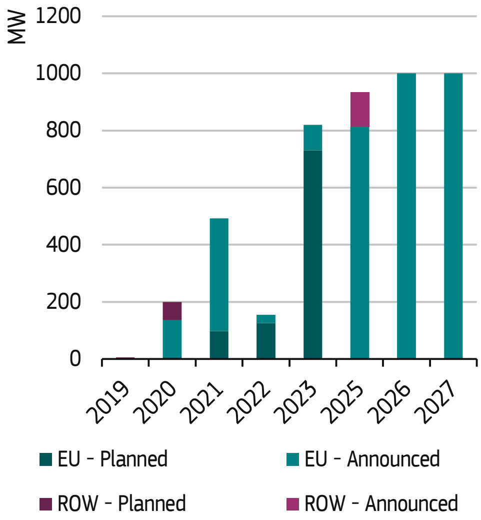

Fig. 14. Tidal energy planned and announced projects worldwide and in the EU. Announced projects are projects were developers have shown intention to deploy but no planning has begun yet. Source JRC.

It is therefore plausible that establishing support mechanisms in EU, in line with what is presented by ADEME and DG Mare optimistic scenario, could bring the cost of tidal energy close to targets for commercialisation. In particular establishing a set of grant and revenue systems to target of 300 MW of installed capacity by 2025, as indicated by ADEME in their optimistic scenario, would be feasible and limited in funds required.

VII. CONCLUSION

The results obtained from the JRC-EU-TIMES model, indicate that achieving the cost-reductions needed to meet the SET-Plan targets will be fundamental for the uptake of tidal and wave energy technology in Europe.

Tidal energy could grow considerably compared to current deployment, and uptake could be significant already by 2030 if cost-reductions continue to take place. On the other hand, deployment for wave energy would be limited under most scenarios and become visible only in 2050.

Under the SET-Plan scenario investments of over 140 million EUR will be needed in order to deploy 30 GW of wave and 30 GW of tidal energy capacity.

The comparison of the JRC-Times scenario with other market studies, highlight the importance of cost-reductions. The optimistic scenario of the ADEME and the DG MARE market studies suggest that by 2030 capacity of tidal energy could be ranging between 880 and 2200 MW, sufficient to achieve significant cost-reductions to the level required by the SET-Plan.

More importantly, these estimates are based on a number of projects announced in the EU. It follows that the deployment of demonstration farms is fundamental to unlock the necessary cost-reductions and the potential market of ocean energy.

ACKNOWLEDGEMENT

The study presented in the paper has been carried out as part of the "Low Carbon Energy Observatory" Project carried out by the JRC for DG RTD. The authors would like to thank colleagues Matthijs Soede, Aliki Georgakaki, Nigel Taylor, Johan Carlsson for their inputs and revisions.

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