Pearson BTEC Level 3 Nationals Extended Diploma

Supervised Window:
25 November 2021 – 13 January 2022

Time 6 hours

Paper reference **31629H**

Applied Science

UNIT 7: Contemporary Issues in Science

Part A

You do not need any other materials.

Instructions

- **Part A** contains material for the completion of the preparatory work for the set task.
- **Part A** is given to learners during the supervised window before **Part B** is scheduled. Learners are advised to spend no more than 6 hours on **Part A**.
- **Part A** must be given to learners on the specified date so that learners can prepare in the way specified.
- **Part A** is specific to each series and this material must only be issued to learners who have been entered to undertake the task in the relevant series.
- **Part B** materials must be issued to learners on the date specified by Pearson.

Turn over ▶

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Instructions to Teachers/Tutors

This paper must be read in conjunction with the unit information in the specification and the *BTEC Nationals Instructions for Conducting External Assessments (ICEA)* document. See the Pearson website for details.

This set task has a preparatory period. **Part A** sets out how learners should prepare for the completion of the **Part B** task under supervised conditions.

Part A is given to learners during the specified window before **Part B** is scheduled. Learners are advised to spend no more than six hours on **Part A**.

Learners should undertake independent research on the case study given in this **Part A** booklet.

Centres must issue this booklet at the appropriate time and advise learners of the timetabled sessions during which they can prepare. It is expected that scheduled lessons or other timetabled slots will be used for the preparation.

Learners should familiarise themselves with the specific concepts and terminology used in the articles.

Learners may prepare summary notes on the articles. Learners may take up to four sides of A4 notes, which may be handwritten or word processed, into the supervised assessment (**Part B** booklet).

These notes should only include information about scientific terminology, quantities and concepts used in the articles and a summary of the scientific issue discussed. This will enable learners to interpret, analyse and evaluate the articles in **Part B**. Other content is not permitted.

Part B must be completed under supervision in a single 2 hours and 30 minute session timetabled by Pearson. A supervised rest break is permitted.

The supervised assessment should be completed in the **Part B** Task and Answer booklet. Teachers/tutors should note that:

- learners should not be given any direct guidance or prepared materials
- learners should not be given any support in writing or editing notes
- all work must be completed independently by the learner
- learner notes will be retained securely by the centre after **Part B** and may be requested by Pearson if there is suspected malpractice.

Refer carefully to the instructions in this taskbook and the *BTEC Nationals Instructions for Conducting External Assessments (ICEA)* document to ensure that the preparatory period is conducted correctly and that learners have the opportunity to carry out the required activities independently.

Instructions for Learners

Read the set task information carefully.

This is **Part A** of the set task and gives information you need to use to prepare for **Part B** of the set task.

In **Part B** you will be asked to carry out specific activities using the information in this **Part A** booklet and your preparatory notes.

In your preparation for **Part B**, using this **Part A** booklet, you may prepare short notes to refer to when completing the set task. Your notes may be up to four sides of A4 and may be handwritten or typed. Your notes should only include information about scientific terminology, quantities and concepts used in the articles and a summary of the scientific issue discussed. This will enable you to interpret, analyse and evaluate the articles in **Part B**. Other content is not permitted.

You will complete **Part B** under supervised conditions.

You must work independently throughout the supervised assessment period and must not share your work with other learners.

Your teacher/tutor may give guidance on when you can complete the preparation. Your teacher/tutor cannot give you feedback during the preparation period.

You must not take your preparatory notes out of the classroom at any time and you must hand the notes in to your teacher/tutor on completion.

Your notes will be made available to you at the beginning of the supervised assessment.

Set Task Brief

You are provided with the following articles:

Article 1: UK wave power far too costly, warns energy research body
https://www.theguardian.com/environment/2017/jan/16/uk-wave-power-far-too-costly-warns-energy-research-body

Article 2: UK missing opportunity as it swims against tidal energy
https://www.imeche.org/news/news-article/feature-uk-missing-opportunity-as-it-swims-against-tidal-energy

Article 3: Wave and tidal current energy – A review of the current state of research beyond technology
https://www.sciencedirect.com/science/article/pii/S1364032115016676

Your notes should only include information about scientific terminology, quantities and concepts used in the articles and a summary of the scientific issue discussed.

You should spend up to a maximum of six hours to complete your preparatory notes. You may take up to four sides of A4 notes into the supervised assessment.

Part A Set Task Information

Article 1

UK wave power far too costly, warns energy research body

Energy Technologies Institute (ETI) says technology is 10 times dearer than other low carbon power sources and UK should prioritise tidal stream.

This is an edited version of an article that appeared in 'The Guardian' newspaper in January 2017. The article was written by Adam Vaughan.

A tidal power turbine made for the test site off Orkney.

© Jeff J Mitchell/Staff/Getty Images

An embryonic industry trying to harness the UK's waves to generate clean electricity has been dealt a significant blow by a warning that the technology is too costly.

Wave power devices being tested in Cornwall and at Orkney are 10 times more expensive than other sources of low carbon power and need a radical rethink, the ETI said.

The ETI added that even if costs were cut aggressively, wave power would be unlikely to make a significant contribution to the UK's energy demands in coming decades.

The institute, which has a mission to accelerate low carbon technologies, said the UK's marine energy strategy should instead prioritise support for tidal stream power, such as a project being tested in the Pentland Firth, which resembles underwater wind turbines. The ETI urged the government to agree a subsidy deal for Atlantis Resources' MeyGen scheme, which is the world's first large-scale tidal power project.

Atlantis Resources hopes to ultimately expand the tidal array's first four turbines to 269, which would generate even more power than the Swansea Bay tidal lagoon backed by an independent review last week. Such lagoon projects are further advanced than wave energy projects but they are some way behind tidal stream power development, and require large levels of investment, the ETI said.

An artist's impression of the Swansea Bay tidal lagoon scheme
(Photograph: Tidal Lagoon Power/PA)

Experts have previously described the UK's wave power potential as huge and said it could generate a tenth of electricity needs.

But despite being heralded six years ago by Scotland's then first minister Alex Salmond as on the verge of commercial deployment, the fledgling sector has been dogged by delays and bankruptcies, such as the collapse of Scotland's Pelamis Wave Power in 2014 and Aquamarine Power in 2015.

The ETI, which is funded by government and companies including Rolls-Royce, EDF and BP, called for a "radical rethink" if the technology is to provide affordable renewable electricity.

Developers, which include Australia's Carnegie Clean Energy, Finland's Fortum and the UK's Seatricity, need to reconsider their approaches to "drastically" cut costs, the ETI said. Grid connections were another concern, it added.

"On wave energy our view is that even with aggressive cost reduction and innovation activities, current attenuator wave energy technologies are highly unlikely to meet the ETI/UK Energy Research Centre marine energy roadmap targets, and are therefore unlikely to make a significant contribution to the UK energy system in the coming decades," a spokesman said.

However, people in the industry disputed the analysis, saying they would not be testing and developing the technology if they thought it was not commercially viable.

Andy Bristow, managing director at Seatricity said it was "nonsense" to suggest wave power was 10 times as expensive as the alternatives.

"We're confident in our technology but we're less confident in the UK government's commitment to renewables. We're finding it difficult at the moment because of a malaise that seems to have infected the marine renewables sector," Bristow said.

"We think it's a shame, because ultimately it's a no-brainer: it's clean, it's green, it has potential to be very cost effective."

Bristow added that he was surprised the ETI had not consulted the company.

In a statement, Fortum said: "Wave power is still under research, development and piloting phase throughout the world compared to for example solar and wind technologies which are rapidly maturing and becoming more market-based. It is important to understand that the development of new competitive energy technologies takes time."

Tim Sawyer, CEO of Carnegie, said he believed the report was based on out of date data.

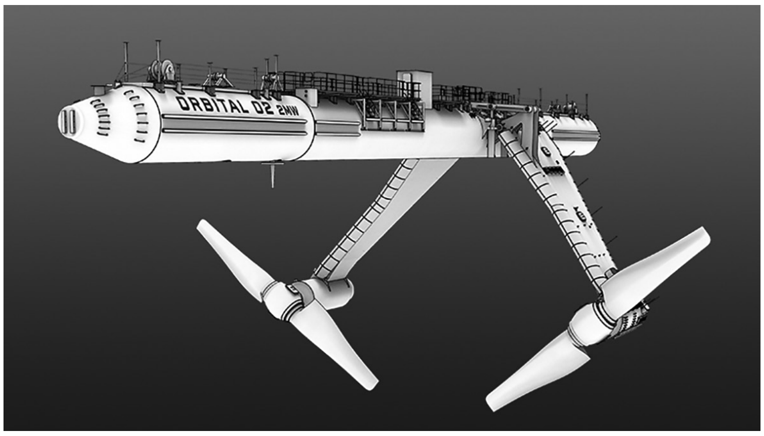
RenewableUK's deputy chief executive, Maf Smith, said: "The UK is right at the forefront of a global race to develop wave power on a commercial scale. It's vital that we don't lose our lead to other countries, who stand to benefit from the years of investment and progress we've made. The more we deploy, the cheaper the technology will become."

The ETI's views on marine energy come after a global renewable energy body said developments in energy storage could be a "game-changer" for clean power. The Abu Dhabi-based Irena said battery storage capacity for electricity could increase from 1GW today to 250GW by 2030, helping alleviate renewable energy's intermittent nature.

Article 2

UK missing opportunity as it swims against tidal energy

This is an edited version of an article published by the Institution of Mechanical Engineers (IME) in February 2019. The article was written by Joseph Flaig.



The Orbital O2 is designed for powerful tidal generation in isolated locations and 'mega-farms' alike

(Composite credit: Orbital Marine Power/ Professional Engineering)

Andrew Scott, chief executive at Orbital Marine Power, said it was "a new benchmark for the tidal industry".

In 12 months, a single SR2000 floating turbine off the coast of Orkney generated over 3GWh – more than the whole Scottish wave and tidal sector managed in the 12 years up to 2016. It supplied energy for the equivalent of 830 households, weathering the worst winter storms for years in the process.

The announcement last August was a celebration for Orbital, which changed its name from Scotrenewables Tidal Power shortly afterwards in a reflection of the company's global ambitions. There was also positive news elsewhere in the UK tidal sector – MeyGen, for example, recently generated 8GWh from four tidal turbines in the Pentland Firth between Orkney and the mainland.

The sector's success painted a picture of a rosy future for a sea-bound UK. A government-cited estimate put the country's share of European tidal resources at 50% – and, after years of dedicated R&D, British technology existed to tap it. But there were stormy seas ahead.

Fast-flowing environment

The number of technologies in development for installation in fast tidal channels reflects the vast size of the potential resource. Devices include underwater 'kites' from Minesto that swim in figures-of-eight to power their under-wing turbines, and vertical-axis turbines with blades pushed around a vertical pole. Other concepts highlighted by the European Marine Energy Centre (EMEC), where Orbital is based, include oscillating hydrofoils to drive hydraulic systems, and Venturi-effect devices, which concentrate tidal flow through narrow tunnels towards turbines.

The most recognisable technology is the horizontal-axis turbine, nearly identical to offshore wind turbines but smaller, with blades beneath the water. Marine engineers immediately saw an analogy with wind when creating tidal devices, says Scott.

"That familiarity – to a large degree – was taken too far," he claims. "Most of them set about 'marinising' drivetrains to be installed on wind-turbine towers at the bottom of the sea. And I would argue that that betrays a very real lack of understanding of the working environment."

That environment is one of the most challenging in which engineers operate. In depths of 30–40 m, the water speed might be 16km/h, with only a few minutes of slack per day. The water's high density and resulting increased power relative to air – an appealing aspect for energy generation – is a challenge. Installing turbine casings that might weigh more than 100 tonnes is no easy task, requiring huge marine construction vehicles.

Sites are also very difficult to reach. Promising tidal streams are normally found between funnelling geographical features, frequently in rocky areas around remote islands or craggy headlands. This can also make maintenance difficult and very expensive. If underwater turbines are analogous to wind turbines, Scott says, operators can expect between six and 12 maintenance interventions per year. If the operators need heavy-lifting machines to remove turbines from the seabed, they could spend more than £100,000 a day.

Enter Orbital's SR2000. "A boat is a far better solution to be able to manufacture, install cost effectively and – crucially – access for maintenance through life, than an underwater wind turbine," says the CEO and mechanical engineer.

The record-breaking prototype – and its commercial successor under development, the O2 – is a UK-built floating generator with two 1MW turbines that extend from port and starboard beneath the hull once tugged into place. The tube-like body contains the drives, transformers, switchgear, oil filtration, power electronics and control systems, which work with the current to rotate the structure between facing flood and ebb tides. The SR2000 worked autonomously after just half a year of operation, with fibre-optic cables, wi-fi, radio and 4G signals allowing managers to take over using a smartphone application if needed.

Mooring lines monitor the loads on the device, and controls can reduce generation to manage loads or balance thrust between the two turbine-rotors. A dynamic electrical connection uses a wet mate connector and turret-mounted slip ring, allowing continuous exporting of electricity to the land, even when turning.

The flexibility and reliability offered by floating tidal power makes it suited for a range of installations, says Scott – single units for remote coastal communities all the way up to mega-farms with hundreds of turbines. And although many tidal pioneers are based in or have projects in the UK – Orbital, Atlantis's MeyGen, Nova Innovation, and Minesto with its kite generators – there are large potential sites off the coasts of other countries, some of which might have more amenable governments with considerable pull of their own.

'A very unfortunate situation'

"The UK is very lucky in that we are blessed with tidal resources," says Barnaby Wharton, head of policy at trade association RenewableUK. "It seems like a very sensible course for us to be pursuing."

Sensible, perhaps – simple, no. "We are in a very unfortunate situation," says Orbital's Scott. "Ten or 15 years ago we had infrastructure, we had engineering know-how, we had supply-chain solutions – it was a jigsaw puzzle with all the pieces, we just had to put it together. I think unfortunately what has happened is that we were all maybe a little bit wet behind the ears and overly optimistic."

Some projects failed, such as Tidal Energy's 400 kW DeltaStream project using 12 m tall turbines off the coast of Pembrokeshire in Wales. The £18 m installation stopped working within months thanks to a faulty sonar system and a subsequent mechanical issue.

The UK's most high-profile tidal concept, the Swansea Lagoon, failed to progress altogether after persistent arguments and an insistent PR campaign left government ministers ambivalent and concerned about the projected £1.3bn price tag – although the lagoon technology, which would have used 16 turbines embedded in a 9 km sea wall, is a "very different proposition" from multiple units in a tidal stream, says Scott (since this magazine feature went to print, Tidal Power has announced plans to go ahead with the project).

Even with small-scale projects there would always be issues, he says. "This was never going to be like the dotcom boom, where you lock half a dozen intelligent students, computer programmers, in a garage and give them a million pounds, and three years later you've got a billion-pound business. It is marine engineering, it's going to cost money and it's going to take time."

All that time has given other technologies such as wind turbines, solar panels and biomass generators a head start, bringing prices down and delivering major change to the UK energy mix. Those steps forward have made it harder for tidal-energy companies to justify their requirements.

A recent government policy change has made it even harder – until 2016, about 100MW of energy capacity was ring-fenced for slightly more expensive but less developed sources, such as tidal or wave. That policy ended, however, and the government now only awards contracts for the lowest-cost sources.

"That really is a shame," says Scott. "Ultimately the majority of the heavy lifting, risk-taking has been done by the private sector and done under confidence that at the end of the day there will be a commercial market."

A spokesman for the Department for Business, Energy and Industrial Strategy says: "We are absolutely committed to ensuring our renewables sector continues to thrive through our Clean Growth Strategy, and by 2021 we'll have invested over £2.5bn in low-carbon innovations. We recognise the potential of marine technologies, and £90m has been made available to develop these since 2010."

Any proposals, however, must demonstrate value for money for consumers and taxpayers, he adds. Tidal energy cannot yet compete with the roughly £100/MWh cost of offshore wind, let alone the projected £63/MWh for onshore wind by 2020, a bargain price that is reportedly encouraging growing political support for the long-shunned energy source.

Yet the energy mix needs to be exactly that – a mix. The wind does not always blow, so tidal energy could provide much-needed regularity in future. Decarbonising the energy system and transport requires long-term strategies, and mature tidal energy could pay dividends as the UK tries to meet its goals set in the Paris agreement and legally binding low-carbon targets under the Climate Change Act.

"Long-term strategic initiatives," says Scott, "will require huge investments from supply-chain private-sector companies, and in that context consistency of signal from government and regulators is very, very important."

He adds: "At this stage, before we have got capacity and learning and all those things that onshore and offshore wind have got in spades, we are simply unable to be cost-competitive against them, so effectively there is no market here for us."

'It will slip through our fingers'

Despite the geographical opportunities, promising companies with quickly developing technology, a rich engineering heritage from oil and gas, marine infrastructure and climate-change requirements, tidal energy has almost no market in the UK. That threatens not only a promising and reliable future energy source, but wider industrial and economic benefits from potential global dominance in manufacturing turbines.

For some in the sector, the parallels with another energy source are clear. In the 1970s, say Scott and Wharton, the UK missed a chance to take a lead in onshore wind. As a result, says Wharton, Germany and Denmark "stole the march on us". When the first large-scale wind turbine was installed in Orkney in 1981, it came from Denmark, and by 1983 the UK was a net importer of onshore wind technology, according to a 2016 report for the Marine Alliance for Science and Technology for Scotland. "I don't want to see that happen again in this sector," says Wharton.

That could be exactly what happens, however, as more countries actively pursue large-scale projects. Last autumn, for example, Atlantis – the principally UK-based company behind MeyGen – announced plans for the largest tidal project in Europe, a potentially 2GW array off Normandy.

Firms might also be tempted by growing tidal ambitions in Canada and elsewhere. “They are deliberately targeting this sector now because they see the UK government slipping,” claims Minesto chief executive Martin Edlund, who says the Swedish firm is “basically Welsh” thanks to its major investment in its Holyhead Deep installation. “What happened with wind is happening again. With the lack of political patience and determination, it will slip through our fingers again.”

‘You have to be optimistic’

In the raging waters of the UK energy sector, Edlund and Scott still cling to hope. They hold faith that good news stories from far-flung installations will filter through to politicians, showing a clear “line of sight” to low-cost, low-risk electricity.

“You have to be optimistic in this space,” says Scott. “If you look at the history of tidal energy over the last 10 years, a number of large-scale drivetrains have generated gigawatt hours. That is far more than in the analogous stage of wind turbines onshore back in the 1970s.”

While Westminster only wants the cheapest energy, devolved governments are more forward thinking. Minesto hopes to build a commercial tidal array with a total capacity of 80MW at Holyhead Deep thanks to the Welsh government’s commitment to marine renewable energy. Although the capacity is much smaller than that of the largest windfarm, which offers 659MW, it could be a welcome boost.

Minesto’s ‘kite’ turbine moves in figures-of-eight as it generates electricity
(Credit: Minesto)

“I’m convinced that Westminster will realise that, with hard facts on the table, they can no longer ignore the sector,” says Edlund, but the clock is ticking. “Will the timing be right for enough developers to remain in the UK?”

Some are already looking overseas – Orbital’s announcement of the SR2000’s success last year was a celebration tinged with disappointment, as Scott claims there was a “total lack” of market support. The company, he says, had “no option” but to focus the business on overseas opportunities.

So, despite the UK’s ideal geography, decades of marine engineering experience and wealth of advanced technology, new tides might sweep companies to foreign shores.

Article 3

Wave and tidal current energy – A review of the current state of research beyond technology

This is an edited version of an article that was published in Renewable and Sustainable Energy Reviews in May 2016. The article was written by Andreas Uihlein and Davide Magagna. Some sections have been removed from this article for clarity.

1. Introduction

The oceans of the earth represent a vast source of renewable energy. In general, ocean energy can be divided into six types of different origin and characteristics: ocean wave, tidal range, tidal current, ocean current, ocean thermal energy, and salinity gradient [1], [2], [3].

Currently, all ocean energy technologies except tidal range can be considered at an early stage of development from conceptual up to demonstration stage [2]. Ocean wave and tidal current energy are the two types of ocean energy which are most advanced and are expected to contribute significantly to the supply of energy in the future [2]. Thus, the authors will focus on those two types of ocean energy in this paper.

The ocean energy industry has made significant progress in recent years but is still at a very early stage with some advanced prototypes that are currently being tested [4]. Existing challenges include further development of the technology to prove reliability and robustness and to reduce costs but also deployment and risk reduction. This is reflected in the current research themes funded for example by the EU with 68% of the funds being directed to technology development. However, other not technology-related knowledge gaps and barriers exist [4].

The aim of this review is to provide an overview of the current state of research in the field of wave and tidal current energy. Further research and innovation in the area of technology is the prerequisite to tap the full potential of ocean energy. According to the authors [5], technological barriers represent the most important issue that the ocean energy sector needs to address in the short-medium term. Priority topics include technology advancement, reliability demonstration, sub-system development and optimisation, pre-commercial array sea trial and demonstration, predictive maintenance systems, and array electrical systems [4].

This article will focus on research beyond technology or technological improvements and identify areas where research gaps exist and where future research efforts should be directed. Areas that will be covered in greater detail have been identified according to references [2], [7], [9].

2. Resource assessment and forecasting

The assessment of wave energy resources, which includes the identification of areas with high wave energy, the quantification of average energy resources (e.g. total annual wave energy) and the description of the resource using parameters such as significant wave height, wave energy period and mean wave direction, are needed for proper planning and the optimisation of the design of ocean energy converters [10]. This will help to optimise device performance in terms of power produced. For example, the power output of an Oscillating Water Column device at a certain location has been studied [13]. The current state of technology development will determine how much of the resource can be exploited, with the main technical parameters to be improved being device efficiency and capacity factor [10], [14]. Reducing uncertainties concerning the available resources will also increase the confidence of investors as it allows a better determination of the value of investments and minimises risks [15], [16].

2.1. Ocean wave

2.1.1. Resource assessment

During the last few years, ocean wave energy resources have been assessed for various regions in the world. The first wave energy resource assessments have been made using buoy data limited to local conditions [12]. The second generation of assessments included buoy data in combination with deep water numerical models, which can assess offshore wave resources which helped overcoming the limitations of first generation assessments, namely the limited time period of the buoy measurements and the uncertainties of extrapolating local data to other locations [12]. Recent tools incorporate radar measurements and allow modelling wave generation and propagation also in coastal regions [11], [17]. Usually, wind and bathymetry data are used as an input for such models. Typical output parameters are: significant wave height, mean wave period, peak wave period, and mean wave direction.

2.2.2. Forecast

The German Federal Maritime and Hydrographic Agency provides current predictions of up to 3 days [29]. The model used is a 3D model that takes into account meteorological forecasts for the North Sea and Baltic Sea provided by the German Weather Service (DWD) [30], tides and external surges entering the North Sea from the Atlantic, as well as river runoff from the major rivers. The forecasts for the sea computed by the operational circulation model cover 48 hours.

3. Environmental impacts

Ocean energy – as all other renewable sources of energy – can contribute to a more sustainable energy supply but it is not environmentally friendly per se. The activities involved in manufacturing, operation, maintenance and decommissioning of ocean energy devices will have various effects on the environment. Governments and society need a robust understanding of the environmental implications of ocean energy systems before ocean energy deployment takes place, and also to mitigate or adjust impacts to acceptable levels. While Environmental Impact Assessments (EIA) are performed to ensure that environmental implications of decisions are taken, Life Cycle Assessments (LCA) are used to identify and quantify the impact of industrial products on the environment.

The main direct expected environmental impacts of ocean wave and tidal current technology include impact on the sea bed community (due to alterations in flow patterns, wave structures, sediment dynamics), species-specific response to habitat change, and the entanglement of marine mammals, turtles, larger fish and seabirds [33]. However, due to limited observations, the significance of environmental impacts of commercial deployment projects cannot fully be determined. Future research in the area of environmental impacts should be focused on localised environmental impacts including electromagnetic field effects of subsea cables, flow alteration, sedimentation and habitat change of near generation devices. Examples of such efforts include reference [34], [35] that model the impact on beach morphology exerted by wave energy farms. Furthermore, it was stated that "comprehensive assessment, including both impacts and costs should be performed, applying the well-known LCA methodology to ocean energy generation" [9]. A new range of technologies, devices and sub-systems need in-depth analysis [9]. In addition, competing pressures and uses, for example climate change, fishing, marine transport should be considered when looking at environmental impacts [9].

3.2. Environmental impact assessment and strategic environmental assessment

Until now, there are still gaps concerning the scientific evidence on the environmental effects of ocean energy technologies [2], [33]. Existing data are very much dispersed amongst countries, researchers and developers [42], [43]. Since wave energy and tidal energy technologies are at an early development stage, no data on environmental effects from arrays are available.

Environmental impact assessments (EIA) and strategic environmental assessments (SEA) have been undertaken so far, with a focus on Europe and North America. Reviews on the state of research have been published by several institutions. The International Energy Agency-Ocean Energy Systems (IEA-OES) has summarised available knowledge on environmental impacts of ocean energy devices in three areas: physical interactions between animals and tidal turbines; acoustic impact on marine animals; and effects of energy removal on physical systems [44], [45]. Similarly, the Streamlining of Ocean Wave Farm Impacts Assessment project (SOWFIA) is aimed at sharing and consolidating experience of consenting processes and environmental and socio-economic impact assessment best practices for wave energy [46].

3.2.1. Tidal current

In general, ocean bed habitats will be affected by tidal current energy converters and arrays due to the change of water flows, composition of substrate and sediment dynamics [33]. Potential other effects include mortality of fish passing through turbines (blade-strike) and the collision risk of marine mammals with tidal stream farms [33], [47]. A study showed that change in sediment dynamics will most likely be observed following the installation of tidal arrays, impacting on bed morphology and sea bed ecosystems [48]. This, in turn, could impact on floral and faunal species. Species of marine mammals and fish could experience distress and discomfort.

However, in their review, Frid et al. concludes that "there is little scientific literature to suggest that operation of underwater tidal stream energy devices will cause elevated levels of mortality to pelagic organisms such as fish and marine mammals" [33]. Also Lewis et al. mention that, "while current technologies have moving parts (rotating rotor blades or flapping hydrofoils) that may harm marine life, there is no evidence to date of harm from tidal current devices to marine life, such as whales, dolphins, seals and sharks" [2]. A critical issue related to tidal energy converters relates to the noise disruption in turbulent waters, affecting in particular marine mammals, who may be severely affected by such instance [49].

3.2.2. Ocean wave

For some devices, an EIA has been carried out, including AquaBuoy and Wave Dragon [50]. Wave energy converters can potentially "alter water column and sea bed habitats locally and by changes in the wave environment" [33]. A modelling exercise showed that the installation of wave energy converter arrays can lead to significant changes in the inter-array and surrounding wave field [51].

According to Lewis et al., environmental impact from ocean wave energy devices might include "competition for space, noise and vibration, electromagnetic fields, disruption to biota and habitats, water quality changes and possible pollution" [2]. As for tidal devices, the environmental impacts are considered comparably small [52], [53]. Wave devices will represent a much lower collision risk compared to offshore wind devices but there could be the risk of underwater collisions for diving birds [54].

3.3. Future research

According to Lewis et al., "information on the environmental and social impacts is limited mainly due to the lack of experience in deploying and operating ocean technologies, although adverse environment effects are foreseen to be relatively low" [2]. In general, environmental impacts will very much depend on size of installation and the location selected [50]. Potential positive effects such as the creation of roosting sites and habitat enhancement for marine birds might occur as well [54].

The majority of the studies recommend that the first commercial scale installations of ocean energy technology should be accompanied by research studies on the local environmental impacts and for most installations, this will be covered by the EIA that is legally required.

Comprehensive LCA of ocean energy arrays are missing and an integration of aspects such as fluctuation of power output, storage, or grid integration would be very helpful. LCA of a number of major wave energy device types are still missing.

4. Socio-economic impacts

Socio-economic impact assessment addresses how a proposed development might affect society as a whole or the local population. Various issues can be addressed ranging from well-being and quality of life to employment, income and economic power. For ocean energy, specific topics are negative effects due to visual impacts and the reduction of access to space for other users of the marine environment. Similar to the assessment of environmental impacts, both positive and negative impacts of ocean energy deployment on society and the economy need to be studied in order to support evidence-based policy making.

4.1. Costs

An economic assessment of ocean energy has been performed by B. Teillant & R. Costello, et al [60]. They highlight the lack of operational experience which means that operational costs have to be estimated. They provide a simulation model for operational costs and device availability to overcome these challenges. For the grid connection of an ocean energy array, Lopez et al. provide a preliminary cost estimate including a comparison of AV and DC transmission [61]. Cost components considered are offshore substation costs, cable costs, maintenance costs, and the costs for energy losses.

4.2. Social impacts

A main social impact that is usually addressed in studies on ocean energy is job creation. On national, European and global levels, several estimates on the future potential for employment in the sector are available [64], [65].

Other social impacts that have been addressed so far include CO_2 reductions [64], positive as well as negative impacts on other marine users [66] and local communities [67]; also the co-existence of fisheries and offshore renewable energy in the UK has been investigated [68]. It seems that other effects are difficult to quantify, including improvements to existing infrastructure; increased knowledge as a result of research and development in wave and tidal, improvements to energy security, health and quality of life.

4.4. Future research

Many studies address economic aspects of ocean energy including predictions of future costs of ocean energy. Still, there are improvements needed, especially in terms of operation and maintenance costs. Clearly, cost-benefit analyses including aspects such as grid integration, energy security, and ecosystem services are missing. Social impacts are not well understood, when it comes to impacts beyond job creation such as welfare [70]. In particular, studies on the effects on national and EU levels as well as coastal communities are needed [67], [71].

5. Grid integration

The integration of ocean energy in the electricity grid poses various challenges. Firstly, ocean energy arrays have to be connected to the grid which can be very expensive since several components such as an array and subsea electrical system and a submarine cable connection to the shore are needed. Of course, grid availability in proximity to ocean energy arrays is a prerequisite for future developments [4]. Often, however, areas that offer good ocean energy resources are remote and often not connected with existing grid installation, thus requiring either grid upgrades or new-built capacity [5]. Grid integration is thus first of all an issue of electricity distribution and transmission and has also to be seen in the context of renewables integration at large [72].

Secondly, variability of electricity production from ocean energy devices might lead to issues such as grid congestion, weak grids, and voltage stability problems which is also related to technological development. Possible solutions and strategies to solve these problems are currently being researched and will be presented in the following sections.

5.1. Variability of resources

Ocean energy is a variable resource. Tidal current energy is periodic, and thus, resource forecasts are possible with a high reliability over long time horizons. Ocean wave energy can be considered an intermittent resource like wind energy [73]. For tidal currents, variability is very high on an hourly basis but limited for longer time horizons (e.g. monthly, yearly variation). On the contrary, variability for ocean wave energy is relatively low for short time scales (hours) but can be great for longer periods of time, for example on a seasonal or annual basis [2].

Reikard states that the forecast for wave energy is more precise than forecasts for wind and solar energy [20]. Still, the grid integration of ocean energy is of course influenced by the variability of resource availability. Several measures exist to accommodate for resource variability according to reference [74], including resource forecasting, intra- and inter-site smoothing, generation and load mix, and storage (e.g. pumped hydro, battery storage).

5.2. Grid connection and grid codes

In many cases, areas with great potential for ocean energy are located at regions with low population density with weak electricity networks. This may lead to a limitation of the electricity delivered to the grid due to quality of supply [75], [76]. A reinforcement of transmission and distribution networks will most probably be necessary which implies high additional costs.

Currently, no European standard grid code exists but the various national system operators issue their respective grid codes and usually, the requirements differ between countries [77]. At the moment, a range of countries are updating grid codes or developing new grid codes dedicated to the accommodation of a growing share of renewable electricity [78]. The MARINET project, funded by FP7 of the European Union produced a report on grid integration and power quality testing and reviewed the national grid codes [79], [80]. The project highlighted that employing state-of-the-art technology from wind energy, such as frequency converters, will likely allow for grid-compliant installations of ocean energy farms [80].

5.3. Power quality and control

In the future, renewable energy producers will face increasing demands on power quality to contribute to system reliability and stability. A number of requirements will have to be met including for example voltage control and regulation, fault ride-through capabilities, active power control, and frequency regulation [78].

Demands on the control ocean energy converters and arrays will be of high importance [76]. This includes voltage and power factor control as well as power conditioning [75]. Hong et al. present an overview of control strategies for ocean energy devices including oscillating water columns, attenuators, and overtopping devices [84]. They argue that further research on control strategies are needed since they also offer the “potential to dramatically affect the absorbed energy and hence the economy of the devices”, which is also highlighted by reference [85]. Also Bacelli and Ringwood studied available control strategies for arrays of wave energy converters with respect to maximisation of energy absorption and conclude that performance can be increased by applying optimised control strategies [86]. The DTOcean project has a work package to identify, adapt and develop methods to optimise operational aspects of arrays of wave and tidal devices in terms of system control and operation [87].

Ongoing research tries to model impacts of ocean energy arrays on the grid by means of power flows and dynamic simulations. It was shown that the integration of the wave energy farm would not pose any significant problems to the grid. Tedeschi and Santos-Mugica simulated the impacts of a wave farm (multi-MW point absorber) using the Spanish offshore testing facility Bimep as a real test case and studied different control options [89]. The model showed the importance of both wave and grid side energy wave energy converter control. In addition, centralised real-time control of the whole wave energy array reduced power variability and in consequence impacts on the grid.

5.4. Future research

Grid connection of ocean energy faces challenges due to weak electricity grids in rural areas. Reinforcement of grids will be needed which comes at high costs. The synergies with offshore wind farms need to be explored. At the moment, no single European standard grid code exists. Instead, the ocean energy sector – as other electricity producers – has to comply with the respective national or regional grid code. We will see increasing demands on power quality of renewable energy to contribute to system reliability and stability (e.g. voltage control and regulation, fault ride-through capabilities, active power control, and frequency regulation).

Most probably, the quality of power output from ocean energy arrays will meet the grid code requirements. However, adequate control systems for ocean energy converters and arrays have to be developed. Further research in the area of control strategies is needed since it offers a great potential for cost reduction due to increased absorbed energy while allowing meeting grid code requirements.

6. Installation, operation and maintenance

The installation, operation and maintenance of ocean energy devices are relatively expensive. It is estimated that annual operation and maintenance costs of ocean energy devices can be as high as about 3.4–5.8% of capital expenditure compared to 2.3–3.7% for offshore wind [90]. One way to reduce those costs is to standardise equipment and procedures by industrial cooperation [4], [6], [91]. Other promising improvement options include the use of modelling tools to improve array layout and design which will lead to increased device and array efficiency and a reduction of costs.

6.2. Installation

So far, only a few full-scale devices have been installed and thus practical experience is limited [75]. However, the ocean energy sector can build on technology and know-how from other offshore energy technologies [69], [75]. Installation equipment from the oil and gas industry might be used but it could be too expensive since for ocean energy projects, the installation costs are responsible for a high share of investment costs [62], [98]. Installation of ocean energy devices has to be easy and fast in order to reduce costs for the installation process [69]. In the case of tidal devices, this is also an important prerequisite because installation has to be performed during slack tide which means a limited time period.

The installation process and costs for wave and tidal devices will significantly depend on the location. For example, shore based wave energy converters might need solid foundations and heavy infrastructure. The same is the case for bottom-mounted tidal devices which demand substantial foundations. The mooring of floating devices with drag-anchors seems to be a very economical solution while in some cases the sea-bed characteristics will demand other and more expensive mooring types such as pin piled moorings [98]. Only a few papers have tried to establish models or tools to assess resource needs for installation requirements in terms of time and cost.

6.3. Operation and maintenance

Ocean energy devices will operate in harsh environments. Demands on survivability and reliability are high since the economic impacts due to failures can be significant. Maintenance costs for ocean energy devices will be as high as for any other offshore technology and have a high share of lifetime costs [58].

The most common issues ocean energy devices will face are bio-fouling (moorings, floating or submerged parts of the device) and corrosion [75], [99]. Research needs to develop special coatings that prevent bio-fouling and corrosion but also sealing materials and electric insulation materials for saline environments [75], [100]. Developers aim at reducing maintenance intervals by creating very robust devices and designing devices for ease-of-maintenance.

Current research tries to model the reliability and possible failure rates of ocean energy devices. For example, Thies et al. developed a methodology to simulate component reliability and failure rates under defined operational conditions [101]. Device testing in environments that can produce the same conditions as in real waters is a prerequisite for assessing device and component reliability [69]. Also array design parameters (e.g. device spacing) impacts on maintenance activities and costs and this is not very well understood so far.

An important aspect that has to be taken into account when designing ocean energy devices and developing ocean energy projects is that maintenance and repair activities can only be carried out in favourable weather conditions. Weather window analyses study the levels of access in terms of a number of weather characteristics for example wave heights or wind speed. Inaccessibility of ocean energy devices for maintenance and repair might require other maintenance strategies such as onshore.

Conclusions

This study has reviewed the state-of-research in ocean energy, focusing on wave and tidal current, not directly associated with improvement to ocean energy technology and identified areas where future research efforts should be directed to.

Modelling approaches for resource assessment and forecasting are already very advanced and have been performed for many regions of the world. However, this should be widened to accommodate conflicting or competing use of the marine environment such as fishing, shipping, offshore wind, habitat protection and also technical limitations for example grid connection.

Comprehensive LCAs of ocean energy arrays that would also include areas like fluctuation of power output, storage, or grid integration are still missing and for a number of individual WEC types, no LCAs are available so far. Another area which merits further research is the field of regulatory and legal affairs to define an adequate and optimal legal framework for ocean energy.

In terms of grid integration, the impacts of increasing demands on power quality of renewable energy to contribute to system reliability and stability should be discussed. Further research in the area of control strategies is needed since it offers a great potential for cost reduction due to increased absorbed energy while allowing meeting grid code requirements. No long-term experience with devices is available concerning commercial operation and maintenance and few articles try to assess the resource needs for installation, for example time and cost. Array design parameters such as device spacing might have an impact on operation and maintenance activities and costs: this is not very well understood so far and should be addressed.

The most important areas, however, which future research should be focussing on are the economic and social impacts of ocean energy. A broad cost benefit analysis of ocean energy incorporating aspects such as grid integration and energy security could be very important. Economic aspects of ocean energy including predictions of future costs of ocean energy have been addressed but improvements are needed, especially in the area of operation and maintenance costs. Cost–benefit analyses that include aspects such as grid integration, energy security, and ecosystem services are missing. Social impacts are not well understood, when it comes to impacts beyond job creation. In particular, studies on the effects on national and EU levels are needed.

References

This article has been edited and some references have been removed from the list.

[1] Huckerby J, Jeffrey H, Jay B. An international vision for ocean energy. Ocean energy systems implementing agreement; 2011.

[2] A. Lewis, S. Estefen, J. Huckerby, W. Musial, T. Pontes, J. Torres-Martinez. Ocean Energy et al. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner (Eds.), IPCC special report on renewable energy sources and climate change mitigation, Cambridge University Press, Cambridge (New York) (2011), pp. 497–533.

[3] Brito E Melo A, Villate JL, editors. Annual report 2014. Implementing Agreement on ocean energy systems. IEA-OES; 2015.

[4] Magagna D, MacGillivray A, Jeffrey H, Hanmer C, Raventos A, Badcock-Broe A, et al. Wave and tidal energy strategic technology agenda. Strategic initiative for ocean energy (SI ocean); 2014.

[5] D. Magagna, A. Uihlein; JRC ocean energy status report; Publications Office of the European Union, Luxembourg (2014).

[6] MacGillivray A, Jeffrey H, Hanmer C, Magagna D, Raventos A, Badcock-Broe A. Ocean energy technology: gaps and barriers. Strategic initiative for ocean energy (SI ocean); 2013.

[7] EERA and ERA-NET joint workshop on wave and tidal energy within the European Union. European Energy Research Alliance; 2014.

[9] G. Sannino, C. Cavicchioli; Overcoming research challenges for ocean renewable energy; European Union, Luxembourg (2013).

[10] G. Iglesias, R. Carballo; Choosing the site for the first wave farm in a region: a case study in the Galician Southwest (Spain) Energy, 36 (2011), pp. 5525–5531.

[11] R.A. Arinaga, K.F. Cheung; Atlas of global wave energy from 10 years of reanalysis and hindcast data; Renew Energy, 39 (2012), pp. 49–64.

[12] M. Gonçalves, P. Martinho, C. Guedes Soares; Wave energy conditions in the western French coast; Renew Energy, 62 (2014), pp. 155–163.

[13] R. Carballo, G. Iglesias; A methodology to determine the power performance of wave energy converters at a particular coastal location; Energy Convers Manag, 61 (2012).

[14] F. O'Rourke, F. Boyle, A. Reynolds; Tidal current energy resource assessment in Ireland: Current status and future update; Renew Sustain Energy Rev, 14 (2010), pp. 3206–3212.

[15] K. Gunn, C. Stock-Williams; Quantifying the global wave power resource; Renew Energy, 44 (2012), pp. 296–304.

[16] Strategic Research Agenda/Market Deployment Strategy. European wind energy technology platform; 2014.

[17] Cornett AM. A global wave energy resource assessment. In: Proceedings of the eighteenth international offshore polar engineering conference. Vancouver: The International Society of Offshore and Polar Engineers (ISOPE); 2008, p. 318–27.

[20] G. Reikard; Integrating wave energy into the power grid: simulation and forecasting; Ocean Eng, 73 (2013), pp. 168–178, 10.1016/j.oceaneng.2013.08.005 (2013).

[29] Prediction models. ⟨http://www.bsh.de/en/Marine_data/Forecasts/Prediction_models/index.jsp⟩; 2015 [accessed 07.07.15].

[30] Weather and Climate – Deutscher Wetterdienst – Seewetter. http://www.dwd.de/bvbw/appmanager/bvbw/dwdwwwDesktop?_nfpb=true&_pageLabel=_dwdwww_spezielle_nutzer_schiffffahrt_seewetter&T18605718401151909352281gsbDocumentPath=Navigation%2FSchifffahrt%2FSeewetter%2FHome__NO__node.html%3F__nnn%3Dtrue⟩; 2015 [accessed 07.07.15].

[33] C. Frid, E. Andonegi, J. Depestele, A. Judd, D. Rihan, S.I. Rogers, et al.; The environmental interactions of tidal and wave energy generation devices; Environ Impact Assess Rev, 32 (2012), pp. 133–139.

[34] J. Abanades, D. Greaves, G. Iglesias; Wave farm impact on beach modal state; Mar Geol, 361 (2015), pp. 126–135.

[35] J. Abanades, D. Greaves, G. Iglesias; Wave farm impact on the beach profile: a case study; Coast Eng, 86 (2014), pp. 36–44.

[42] Brito E Melo A, Huckerby J, editors. Annual report 2012. Implementing agreement on ocean energy systems. Lisboa: IEA-OES; 2012.

[43] Brito E Melo A, Villate JL, editors. Annual report 2013. Implementing agreement on ocean energy systems. Lisboa: IEA-OES; 2013.

[44] A. Copping, H. Battey, J. Brown-Saracino, M. Massaua, C. Smith; An international assessment of the environmental effects of marine energy development; Ocean Coast Manag, 99 (2014), pp. 3–13.

[45] Copping A, Hanna L, Whiting J, Geerlofs S, Grear M, Coffey A, et al. Environmental effects of marine energy development around the world. Annex IV final report. IEA-OES; 2013.

[46] Conley D, Magagna D, Greaves D, Aires E, Leitao JC, Witt M, et al. Work package 3 final report. Deliverable 3.5. 2013.

[47] G. Boehlert, A. Gill; Environmental and ecological effects of ocean renewable energy development – a current synthesis; Oceanography, 23 (2010), pp. 68–81.

[48] D. Fallon, M. Hartnett, A. Olbert, S. Nash; The effects of array configuration on the hydro-environmental impacts of tidal turbines; Renew Energy, 64 (2014), pp. 10–25.

[49] Polagye B, Cleve B Van, Kirkendall K, Copping A. Environmental effects of tidal energy development. In: Proceedings of a scientific workshop. Seattle: National Oceanic and Atmospheric Administration (NOAA); 2011.

[50] L. Margheritini, A.M. Hansen, P. Frigaard; A method for EIA scoping of wave energy converters—based on classification of the used technology; Environ Impact Assess Rev, 32 (2012), pp. 33–44.

[51] A.J. Posner, K. O' Sullivan, J. Murphy; Economic and environmental impact appraisal of commercial scale offshore renewable energy installations on the west coast of Ireland; J Coast Res, 29 (2013), pp. 1639–1644.

[52] A. Clément, P. McCullen, A. Falcão, A. Fiorentino, F. Gardner, K. Hammarlund, et al.; Wave energy in Europe: current status and perspectives; Renew Sustain Energy Rev, 6 (2002), pp. 405–431.

[53] M. Fadaeenejad, R. Shamsipour, S.D. Rokni, C. Gomes; New approaches in harnessing wave energy: With special attention to small islands; Renew Sustain Energy Rev, 29 (2014), pp. 345–354.

[54] W.J. Grecian, R. Inger, M.J. Attrill, S. Bearhop, B.J. Godley, M.J. Witt, et al.; Potential impacts of wave-powered marine renewable energy installations on marine birds; Ibis, 1859 (152) (2010), pp. 683–697.

[58] Ocean energy: cost of energy and cost reduction opportunities. Strategic initiative for ocean energy (SI ocean); 2013.

[60] B. Teillant, R. Costello, J. Weber, J. Ringwood; Productivity and economic assessment of wave energy projects through operational simulations; Renew Energy, 48 (2012), pp. 220–230.

[61] Lopez J, Ricci P, Villate JL, Bahaj AS, Myers LE, Retzler C, et al. Preliminary economic assessment and analysis of grid connection schemes for ocean energy arrays. In: Proceedings of the 3rd international conference on ocean energy, Bilbao; 2010.

[62] M. Morandeau, R.T. Walker, R. Argall, R.F. Nicholls-Lee; Optimisation of marine energy installation operations; Int J Mar Energy, 3–4 (2013), pp. 14–26.

[64] Impact Assessment. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Ocean Energy. Action needed to deliver on the potential of ocean energy by 2020. Brussels: European Commission; 2014.

[65] Industry Vision Paper 2013. Brussels: European Ocean Energy Association; 2013.

[66] A socio-economic methodology and baseline for Pentland Firth and Orkney waters wave and tidal developments. The Crown Estate; 2012.

[67] S.K. Henkel, F.D.L. Conway, G.W. Boehlert; Environmental and human dimensions of ocean renewable energy development; Proc IEEE, 101 (2013), pp. 991–998.

[68] J. De Groot, M. Campbell, M. Ashley, L. Rodwell; Investigating the co-existence of fisheries and offshore renewable energy in the UK: identification of a mitigation agenda for fishing effort displacement; Ocean Coast Manag, 102 (2014), pp. 7–18.

[69] J. Houde, Cost-Benefit; Analysis of tidal energy generation in Nova Scotia: a scenario for a tidal farm with 300 MW of installed capacity in the Minas Passage in 2020; Dalhousie University (2012)

[70] J.P. Deane, G. Dalton, B.P. Ó Gallachóir; Modelling the economic impacts of 500 MW of wave power in Ireland; Energy Policy, 45 (2012), pp. 614–627.

[71] S. Kerr, L. Watts, J. Colton, F. Conway, A. Hull, K. Johnson, et al.; Establishing an agenda for social studies research in marine renewable energy; Energy Policy, 67 (2014), pp. 694–702.

[72] ENTSOE. Ten-year network development plan 2014. ⟨https://www.entsoe.eu/major-projects/ten-year-network-development-plan/Pages/default.aspx⟩; 2014 [accessed 11.11.14].

[73] A.S. Iyer, S.J. Couch, G.P. Harrison, A.R. Wallace; Variability and phasing of tidal current energy around the United Kingdom; Renew Energy, 51 (2013), pp. 343–357.

[74] M. Santos Múgica, F. Salcedo Fernandez, D. Ben Haim, J. Lopez Mendia, P. Ricci, J.L. Villate Martínez, et al.; Integrating wave and tidal current power: case studies through modelling and simulation; Tecnalia, Powertech Labs, HMRC (2011)

[75] M. Mueller, R. Wallace; Enabling science and technology for marine renewable energy; Energy Policy, 36 (2008), pp. 4376–4382.

[76] A.E. Kiprakis, A.R. Wallace; Maximising energy capture from distributed generators in weak networks; IEE Proc – Gener Transm Distrib, 151 (2004), p. 611.

[77] R. Llorente Iglesias, R. Lacal Arantegui, M. Aguado Alonso; Power electronics evolution in wind turbines—a market-based analysis; Renew Sustain Energy Rev, 15 (2011), pp. 4982–4993.

[78] Grid integration of large-capacity renewable energy sources and use of large-capacity electrical energy storage. Geneva: International Electrotechnical Commission; 2012.

[79] Santos-Mugica M, Robles E, Endegnanew AG, Tedeschi E, Giebhardt J. Grid integration and power quality testing of marine energy converters: research activities in the MARINET project. In: Proceedings of the 2014 ninth international conference on ecological vehicles and renewable energies, Monte Carlo; 2014, p. 9.

[80] Giebhardt J, Kracht P, Dick C, Salcedo F. Report on grid integration and power quality testing. Deliverable 4.3 final. MARINET; 2014.

[84] Y. Hong, R. Waters, C. Boström, M. Eriksson, J. Engström, M. Leijon; Review on electrical control strategies for wave energy converting systems; Renew Sustain Energy Rev, 31 (2014), pp. 329–342.

[85] E.V. Sanchez, R.H. Hansen, M.M. Kramer; Control performance assessment and design of optimal control to harvest ocean energy; IEEE J Ocean Eng (2014), pp. 1–12.

[86] G. Bacelli, J. Ringwood; Constrained control of arrays of wave energy devices; Int J Mar Energy, 3–4 (2013), pp. e53–e69.

[87] System Control & Operation. ⟨http://www.dtocean.eu/Work-Packages/System-Control-Operation⟩; n.d. [accessed 09.07.15].

[89] E. Tedeschi, M. Santos-Mugica; Modeling and control of a wave energy farm including energy storage for power quality enhancement: the bimep case study; IEEE Trans Power Syst, 29 (2014), pp. 1489–1497.

[90] R. Lacal-Arantegui, A. Jäger-Waldau, M. Vellei, B. Sigfusson, D. Magagna, M. Jakubcionis, et al.; DRAFT 2014 energy technology reference indicator (ETRI) projections for 2010–2050; Publications Office of the European Union, Luxembourg (2014)

[91] Badcock-Broe A, Flynn R, George S, Gruet R, Medic N. Wave and tidal energy market deployment strategy for Europe. Strategic initiative for ocean energy (SI ocean); 2014.

[98] Ocean energy: state of the art. Strategic initiative for ocean energy (SI ocean); 2012.

[99] J.M. Walker, K.A. Flack, E.E. Lust, M.P. Schultz, L. Luznik; Experimental and numerical studies of blade roughness and fouling on marine current turbine performance; Renew Energy, 66 (2014), pp. 257–267.

[100] A. Boisseau, P. Davies, F. Thiebaud; Sea water ageing of composites for ocean energy conversion systems: Influence of glass fibre type on static behavior; Appl Compos Mater, 19 (2012), pp. 459–473.

[101] P.R. Thies, L. Johanning, G.H. Smith; Towards component reliability testing for marine energy converters; Ocean Eng, 38 (2011), pp. 360–370.

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Pearson BTEC Level 3 Nationals Extended Diploma

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Time 2 hours 30 minutes

Paper reference **31629H**

Applied Science

UNIT 7: Contemporary Issues in Science

Part B

You will need:
Up to four sides of A4 notes from **Part A**

Total Marks

Instructions

- Use **black** ink or ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and learner registration number.
- Answer **all** questions.
- Answer the questions in the spaces provided – *there may be more space than you need.*
- **Part A** will need to have been used in preparation for completion of **Part B**.
- **Part B** must be undertaken in a single session of 2 hours and 30 minutes in the assessment session timetabled by Pearson.
- **Part B** materials must be issued to learners for the specified session.
- **Part B** is specific to each series and this material must only be issued to learners who have been entered to undertake the task in the relevant series.
- **Part B** should be kept securely until the start of the 2 hour and 30 minute supervised assessment.

Information

- The total mark for this paper is 50.
- The marks for each question are shown in brackets – *use this as a guide as to how much time to spend on each question.*
- The three articles are at the back of **Part B**.

Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.

Turn over ▶

Pearson

Instructions to Teachers/Tutors

This paper must be read in conjunction with the unit information in the specification and the *BTEC Nationals Instructions for Conducting External Assessments (ICEA)* document. See the Pearson website for details.

Part B set task is undertaken under supervision in a single session of 2 hours and 30 minutes timetabled by Pearson. Centres may schedule a supervised rest break during the session.

Part B set task requires learners to apply understanding gained through familiarisation with the articles. Learners should bring in notes as defined in **Part A**.

Learners must complete the set task using this task and answer booklet.

Maintaining security

- Only permitted materials for the set task can be brought into the supervised environment.
- During any permitted break and at the end of the session materials must be kept securely and no items removed from the supervised environment.
- Learner notes related to **Part A** must be checked to ensure length and contents meet limitations.
- Learner notes from **Part A** will be retained securely by the centre after **Part B** and may be requested by Pearson if there is suspected malpractice.

After the session the teacher/tutor and/or invigilator will confirm that all learner work was completed independently as part of the authentication submitted to Pearson.

Outcomes for submission

This task and answer booklet should be submitted to Pearson.

Instructions for Learners

Read the set task information carefully.

Complete all your work in this task and answer booklet in the spaces provided.

This session is 2 hours and 30 minutes (during the day). Your teacher/tutor and/or invigilator will tell you if there is a supervised break. Plan your time carefully.

You have prepared for the set task given in this **Part B** task and answer booklet. Use your notes prepared during **Part A** if relevant. Attempt all the questions in **Part B**.

Your notes must be your own work and will be retained by your centre until results are issued.

You will complete this set task under supervision and your work will be kept securely during any breaks taken.

You must work independently throughout the supervised assessment period and should not share your work with other learners.

Outcomes for submission

You will need to submit the following document on completion of the supervised assessment period:

- a completed **Part B** task and answer booklet.

Set Task

Answer ALL questions in the spaces provided.

1 Discuss the implications of the scientific issue identified in the articles.

(12)

(Total for Question 1 = 12 marks)

2 Identify the different organisations/individuals mentioned in the articles and suggest how they may have an influence on the scientific issue.

(6)

(Total for Question 2 = 6 marks)

3 Discuss whether Article 3 has made valid judgements.

In your answer you should consider:

- how the article has interpreted and analysed the scientific information to support the conclusions/judgements being made
- the validity and reliability of the data
- references to other sources of information.

(12)

(Total for Question 3 = 12 marks)

4 Suggest potential areas for further development and/or research of the scientific issue from the three articles.

(5)

(Total for Question 4 = 5 marks)

5 You are a researcher working for a general news website.

The website wants to produce an article about the UK Government's tidal renewable energy policy.

Your task is to write an article that evaluates the advantages and disadvantages of possible tidal power projects to generate electricity.

Use information from the three articles provided for this task.

When writing your article, you should consider:

- who is likely to read the article
- what you would like the reader to learn from the article.

(15)

(Total for Question 5 = 15 marks)

TOTAL FOR PAPER = 50 MARKS

Part A Set Task Information

Article 1

UK wave power far too costly, warns energy research body

Energy Technologies Institute (ETI) says technology is 10 times dearer than other low carbon power sources and UK should prioritise tidal stream.

This is an edited version of an article that appeared in 'The Guardian' newspaper in January 2017. The article was written by Adam Vaughan.

A tidal power turbine made for the test site off Orkney.
© Jeff J Mitchell/Staff/Getty Images

An embryonic industry trying to harness the UK's waves to generate clean electricity has been dealt a significant blow by a warning that the technology is too costly.

Wave power devices being tested in Cornwall and at Orkney are 10 times more expensive than other sources of low carbon power and need a radical rethink, the ETI said.

The ETI added that even if costs were cut aggressively, wave power would be unlikely to make a significant contribution to the UK's energy demands in coming decades.

The institute, which has a mission to accelerate low carbon technologies, said the UK's marine energy strategy should instead prioritise support for tidal stream power, such as a project being tested in the Pentland Firth, which resembles underwater wind turbines. The ETI urged the government to agree a subsidy deal for Atlantis Resources' MeyGen scheme, which is the world's first large-scale tidal power project.

Atlantis Resources hopes to ultimately expand the tidal array's first four turbines to 269, which would generate even more power than the Swansea Bay tidal lagoon backed by an independent review last week. Such lagoon projects are further advanced than wave energy projects but they are some way behind tidal stream power development, and require large levels of investment, the ETI said.

An artist's impression of the Swansea Bay tidal lagoon scheme
(Photograph: Tidal Lagoon Power/PA)

Experts have previously described the UK's wave power potential as huge and said it could generate a tenth of electricity needs.

But despite being heralded six years ago by Scotland's then first minister Alex Salmond as on the verge of commercial deployment, the fledgling sector has been dogged by delays and bankruptcies, such as the collapse of Scotland's Pelamis Wave Power in 2014 and Aquamarine Power in 2015.

The ETI, which is funded by government and companies including Rolls-Royce, EDF and BP, called for a "radical rethink" if the technology is to provide affordable renewable electricity.

Developers, which include Australia's Carnegie Clean Energy, Finland's Fortum and the UK's Seatricity, need to reconsider their approaches to "drastically" cut costs, the ETI said. Grid connections were another concern, it added.

"On wave energy our view is that even with aggressive cost reduction and innovation activities, current attenuator wave energy technologies are highly unlikely to meet the ETI/UK Energy Research Centre marine energy roadmap targets, and are therefore unlikely to make a significant contribution to the UK energy system in the coming decades," a spokesman said.

However, people in the industry disputed the analysis, saying they would not be testing and developing the technology if they thought it was not commercially viable.

Andy Bristow, managing director at Seatricity said it was "nonsense" to suggest wave power was 10 times as expensive as the alternatives.

"We're confident in our technology but we're less confident in the UK government's commitment to renewables. We're finding it difficult at the moment because of a malaise that seems to have infected the marine renewables sector," Bristow said.

"We think it's a shame, because ultimately it's a no-brainer: it's clean, it's green, it has potential to be very cost effective."

Bristow added that he was surprised the ETI had not consulted the company.

In a statement, Fortum said: "Wave power is still under research, development and piloting phase throughout the world compared to, for example, solar and wind technologies which are rapidly maturing and becoming more market-based. It is important to understand that the development of new competitive energy technologies takes time."

Tim Sawyer, CEO of Carnegie, said he believed the report was based on out of date data.

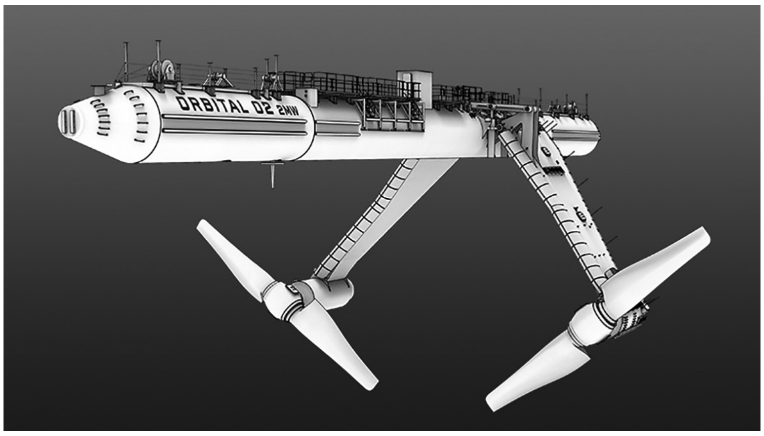
RenewableUK's deputy chief executive, Maf Smith, said: "The UK is right at the forefront of a global race to develop wave power on a commercial scale. It's vital that we don't lose our lead to other countries, who stand to benefit from the years of investment and progress we've made. The more we deploy, the cheaper the technology will become."

The ETI's views on marine energy come after a global renewable energy body said developments in energy storage could be a "game-changer" for clean power. The Abu Dhabi-based Irena said battery storage capacity for electricity could increase from 1GW today to 250GW by 2030, helping alleviate renewable energy's intermittent nature.

Article 2

UK missing opportunity as it swims against tidal energy

This is an edited version of an article published by the Institution of Mechanical Engineers (IME) in February 2019. The article was written by Joseph Flaig.



The Orbital O2 is designed for powerful tidal generation in isolated locations and 'mega-farms' alike

(Composite credit: Orbital Marine Power/ Professional Engineering)

Andrew Scott, chief executive at Orbital Marine Power, said it was "a new benchmark for the tidal industry".

In 12 months, a single SR2000 floating turbine off the coast of Orkney generated over 3GWh – more than the whole Scottish wave and tidal sector managed in the 12 years up to 2016. It supplied energy for the equivalent of 830 households, weathering the worst winter storms for years in the process.

The announcement last August was a celebration for Orbital, which changed its name from Scotrenewables Tidal Power shortly afterwards in a reflection of the company's global ambitions. There was also positive news elsewhere in the UK tidal sector – MeyGen, for example, recently generated 8GWh from four tidal turbines in the Pentland Firth between Orkney and the mainland.

The sector's success painted a picture of a rosy future for a sea-bound UK. A government-cited estimate put the country's share of European tidal resources at 50% – and, after years of dedicated R&D, British technology existed to tap it. But there were stormy seas ahead.

Fast-flowing environment

The number of technologies in development for installation in fast tidal channels reflects the vast size of the potential resource. Devices include underwater 'kites' from Minesto that swim in figures-of-eight to power their under-wing turbines, and vertical-axis turbines with blades pushed around a vertical pole. Other concepts highlighted by the European Marine Energy Centre (EMEC), where Orbital is based, include oscillating hydrofoils to drive hydraulic systems, and Venturi-effect devices, which concentrate tidal flow through narrow tunnels towards turbines.

The most recognisable technology is the horizontal-axis turbine, nearly identical to offshore wind turbines but smaller, with blades beneath the water. Marine engineers immediately saw an analogy with wind when creating tidal devices, says Scott.

"That familiarity – to a large degree – was taken too far," he claims. "Most of them set about 'marinising' drivetrains to be installed on wind-turbine towers at the bottom of the sea. And I would argue that that betrays a very real lack of understanding of the working environment."

That environment is one of the most challenging in which engineers operate. In depths of 30–40 m, the water speed might be 16km/h, with only a few minutes of slack per day. The water's high density and resulting increased power relative to air – an appealing aspect for energy generation – is a challenge. Installing turbine casings that might weigh more than 100 tonnes is no easy task, requiring huge marine construction vehicles.

Sites are also very difficult to reach. Promising tidal streams are normally found between funnelling geographical features, frequently in rocky areas around remote islands or craggy headlands. This can also make maintenance difficult and very expensive. If underwater turbines are analogous to wind turbines, Scott says, operators can expect between six and 12 maintenance interventions per year. If the operators need heavy-lifting machines to remove turbines from the seabed, they could spend more than £100,000 a day.

Enter Orbital's SR2000. "A boat is a far better solution to be able to manufacture, install cost effectively and – crucially – access for maintenance through life, than an underwater wind turbine," says the CEO and mechanical engineer.

The record-breaking prototype – and its commercial successor under development, the O2 – is a UK-built floating generator with two 1MW turbines that extend from port and starboard beneath the hull once tugged into place. The tube-like body contains the drives, transformers, switchgear, oil filtration, power electronics and control systems, which work with the current to rotate the structure between facing flood and ebb tides. The SR2000 worked autonomously after just half a year of operation, with fibre-optic cables, wi-fi, radio and 4G signals allowing managers to take over using a smartphone application if needed.

Mooring lines monitor the loads on the device, and controls can reduce generation to manage loads or balance thrust between the two turbine-rotors. A dynamic electrical connection uses a wet mate connector and turret-mounted slip ring, allowing continuous exporting of electricity to the land, even when turning.

The flexibility and reliability offered by floating tidal power makes it suited for a range of installations, says Scott – single units for remote coastal communities all the way up to mega-farms with hundreds of turbines. And although many tidal pioneers are based in or have projects in the UK – Orbital, Atlantis's MeyGen, Nova Innovation, and Minesto with its kite generators – there are large potential sites off the coasts of other countries, some of which might have more amenable governments with considerable pull of their own.

'A very unfortunate situation'

"The UK is very lucky in that we are blessed with tidal resources," says Barnaby Wharton, head of policy at trade association RenewableUK. "It seems like a very sensible course for us to be pursuing."

Sensible, perhaps – simple, no. "We are in a very unfortunate situation," says Orbital's Scott. "Ten or 15 years ago we had infrastructure, we had engineering know-how, we had supply-chain solutions – it was a jigsaw puzzle with all the pieces, we just had to put it together. I think unfortunately what has happened is that we were all maybe a little bit wet behind the ears and overly optimistic."

Some projects failed, such as Tidal Energy's 400 kW DeltaStream project using 12 m tall turbines off the coast of Pembrokeshire in Wales. The £18 m installation stopped working within months thanks to a faulty sonar system and a subsequent mechanical issue.

The UK's most high-profile tidal concept, the Swansea Lagoon, failed to progress altogether after persistent arguments and an insistent PR campaign left government ministers ambivalent and concerned about the projected £1.3bn price tag – although the lagoon technology, which would have used 16 turbines embedded in a 9 km sea wall, is a "very different proposition" from multiple units in a tidal stream, says Scott (since this magazine feature went to print, Tidal Power has announced plans to go ahead with the project).

Even with small-scale projects there would always be issues, he says. "This was never going to be like the dotcom boom, where you lock half a dozen intelligent students, computer programmers, in a garage and give them a million pounds, and three years later you've got a billion-pound business. It is marine engineering, it's going to cost money and it's going to take time."

All that time has given other technologies such as wind turbines, solar panels and biomass generators a head start, bringing prices down and delivering major change to the UK energy mix. Those steps forward have made it harder for tidal-energy companies to justify their requirements.

A recent government policy change has made it even harder – until 2016, about 100MW of energy capacity was ring-fenced for slightly more expensive but less developed sources, such as tidal or wave. That policy ended, however, and the government now only awards contracts for the lowest-cost sources.

"That really is a shame," says Scott. "Ultimately the majority of the heavy lifting, risk-taking has been done by the private sector and done under confidence that at the end of the day there will be a commercial market."

A spokesman for the Department for Business, Energy and Industrial Strategy says: "We are absolutely committed to ensuring our renewables sector continues to thrive through our Clean Growth Strategy, and by 2021 we'll have invested over £2.5bn in low-carbon innovations. We recognise the potential of marine technologies, and £90m has been made available to develop these since 2010."

Any proposals, however, must demonstrate value for money for consumers and taxpayers, he adds. Tidal energy cannot yet compete with the roughly £100/MWh cost of offshore wind, let alone the projected £63/MWh for onshore wind by 2020, a bargain price that is reportedly encouraging growing political support for the long-shunned energy source.

Yet the energy mix needs to be exactly that – a mix. The wind does not always blow, so tidal energy could provide much-needed regularity in future. Decarbonising the energy system and transport requires long-term strategies, and mature tidal energy could pay dividends as the UK tries to meet its goals set in the Paris agreement and legally binding low-carbon targets under the Climate Change Act.

"Long-term strategic initiatives," says Scott, "will require huge investments from supply-chain private-sector companies, and in that context consistency of signal from government and regulators is very, very important."

He adds: "At this stage, before we have got capacity and learning and all those things that onshore and offshore wind have got in spades, we are simply unable to be cost-competitive against them, so effectively there is no market here for us."

'It will slip through our fingers'

Despite the geographical opportunities, promising companies with quickly developing technology, a rich engineering heritage from oil and gas, marine infrastructure and climate-change requirements, tidal energy has almost no market in the UK. That threatens not only a promising and reliable future energy source, but wider industrial and economic benefits from potential global dominance in manufacturing turbines.

For some in the sector, the parallels with another energy source are clear. In the 1970s, say Scott and Wharton, the UK missed a chance to take a lead in onshore wind. As a result, says Wharton, Germany and Denmark "stole the march on us". When the first large-scale wind turbine was installed in Orkney in 1981, it came from Denmark, and by 1983 the UK was a net importer of onshore wind technology, according to a 2016 report for the Marine Alliance for Science and Technology for Scotland. "I don't want to see that happen again in this sector," says Wharton.

That could be exactly what happens, however, as more countries actively pursue large-scale projects. Last autumn, for example, Atlantis – the principally UK-based company behind MeyGen – announced plans for the largest tidal project in Europe, a potentially 2GW array off Normandy.

Firms might also be tempted by growing tidal ambitions in Canada and elsewhere. “They are deliberately targeting this sector now because they see the UK government slipping,” claims Minesto chief executive Martin Edlund, who says the Swedish firm is “basically Welsh” thanks to its major investment in its Holyhead Deep installation. “What happened with wind is happening again. With the lack of political patience and determination, it will slip through our fingers again.”

‘You have to be optimistic’

In the raging waters of the UK energy sector, Edlund and Scott still cling to hope. They hold faith that good news stories from far-flung installations will filter through to politicians, showing a clear “line of sight” to low-cost, low-risk electricity.

“You have to be optimistic in this space,” says Scott. “If you look at the history of tidal energy over the last 10 years, a number of large-scale drivetrains have generated gigawatt hours. That is far more than in the analogous stage of wind turbines onshore back in the 1970s.”

While Westminster only wants the cheapest energy, devolved governments are more forward thinking. Minesto hopes to build a commercial tidal array with a total capacity of 80MW at Holyhead Deep thanks to the Welsh government’s commitment to marine renewable energy. Although the capacity is much smaller than that of the largest windfarm, which offers 659MW, it could be a welcome boost.

Minesto’s ‘kite’ turbine moves in figures-of-eight as it generates electricity
(Credit: Minesto)

“I’m convinced that Westminster will realise that, with hard facts on the table, they can no longer ignore the sector,” says Edlund, but the clock is ticking. “Will the timing be right for enough developers to remain in the UK?”

Some are already looking overseas – Orbital’s announcement of the SR2000’s success last year was a celebration tinged with disappointment, as Scott claims there was a “total lack” of market support. The company, he says, had “no option” but to focus the business on overseas opportunities.

So, despite the UK’s ideal geography, decades of marine engineering experience and wealth of advanced technology, new tides might sweep companies to foreign shores.

Article 3

Wave and tidal current energy – A review of the current state of research beyond technology

This is an edited version of an article that was published in Renewable and Sustainable Energy Reviews in May 2016. The article was written by Andreas Uihlein and Davide Magagna. Some sections have been removed from this article for clarity.

1. Introduction

The oceans of the earth represent a vast source of renewable energy. In general, ocean energy can be divided into six types of different origin and characteristics: ocean wave, tidal range, tidal current, ocean current, ocean thermal energy, and salinity gradient [1], [2], [3].

Currently, all ocean energy technologies except tidal range can be considered at an early stage of development from conceptual up to demonstration stage [2]. Ocean wave and tidal current energy are the two types of ocean energy which are most advanced and are expected to contribute significantly to the supply of energy in the future [2]. Thus, the authors will focus on those two types of ocean energy in this paper.

The ocean energy industry has made significant progress in recent years but is still at a very early stage with some advanced prototypes that are currently being tested [4]. Existing challenges include further development of the technology to prove reliability and robustness and to reduce costs but also deployment and risk reduction. This is reflected in the current research themes funded for example by the EU with 68% of the funds being directed to technology development. However, other not technology-related knowledge gaps and barriers exist [4].

The aim of this review is to provide an overview of the current state of research in the field of wave and tidal current energy. Further research and innovation in the area of technology is the prerequisite to tap the full potential of ocean energy. According to the authors [5], technological barriers represent the most important issue that the ocean energy sector needs to address in the short-medium term. Priority topics include technology advancement, reliability demonstration, sub-system development and optimisation, pre-commercial array sea trial and demonstration, predictive maintenance systems, and array electrical systems [4].

This article will focus on research beyond technology or technological improvements and identify areas where research gaps exist and where future research efforts should be directed. Areas that will be covered in greater detail have been identified according to references [2], [7], [9].

2. Resource assessment and forecasting

The assessment of wave energy resources, which includes the identification of areas with high wave energy, the quantification of average energy resources (e.g. total annual wave energy) and the description of the resource using parameters such as significant wave height, wave energy period and mean wave direction, are needed for proper planning and the optimisation of the design of ocean energy converters [10]. This will help to optimise device performance in terms of power produced. For example, the power output of an Oscillating Water Column device at a certain location has been studied [13]. The current state of technology development will determine how much of the resource can be exploited, with the main technical parameters to be improved being device efficiency and capacity factor [10], [14]. Reducing uncertainties concerning the available resources will also increase the confidence of investors as it allows a better determination of the value of investments and minimises risks [15], [16].

2.1. Ocean wave

2.1.1. Resource assessment

During the last few years, ocean wave energy resources have been assessed for various regions in the world. The first wave energy resource assessments have been made using buoy data limited to local conditions [12]. The second generation of assessments included buoy data in combination with deep water numerical models, which can assess offshore wave resources which helped overcoming the limitations of first generation assessments, namely the limited time period of the buoy measurements and the uncertainties of extrapolating local data to other locations [12]. Recent tools incorporate radar measurements and allow modelling wave generation and propagation also in coastal regions [11], [17]. Usually, wind and bathymetry data are used as an input for such models. Typical output parameters are: significant wave height, mean wave period, peak wave period, and mean wave direction.

2.2.2. Forecast

The German Federal Maritime and Hydrographic Agency provides current predictions of up to 3 days [29]. The model used is a 3D model that takes into account meteorological forecasts for the North Sea and Baltic Sea provided by the German Weather Service (DWD) [30], tides and external surges entering the North Sea from the Atlantic, as well as river runoff from the major rivers. The forecasts for the sea computed by the operational circulation model cover 48 hours.

3. Environmental impacts

Ocean energy – as all other renewable sources of energy – can contribute to a more sustainable energy supply but it is not environmentally friendly per se. The activities involved in manufacturing, operation, maintenance and decommissioning of ocean energy devices will have various effects on the environment. Governments and society need a robust understanding of the environmental implications of ocean energy systems before ocean energy deployment takes place, and also to mitigate or adjust impacts to acceptable levels. While Environmental Impact Assessments (EIA) are performed to ensure that environmental implications of decisions are taken, Life Cycle Assessments (LCA) are used to identify and quantify the impact of industrial products on the environment.

The main direct expected environmental impacts of ocean wave and tidal current technology include impact on the sea bed community (due to alterations in flow patterns, wave structures, sediment dynamics), species-specific response to habitat change, and the entanglement of marine mammals, turtles, larger fish and seabirds [33]. However, due to limited observations, the significance of environmental impacts of commercial deployment projects cannot fully be determined. Future research in the area of environmental impacts should be focused on localised environmental impacts including electromagnetic field effects of subsea cables, flow alteration, sedimentation and habitat change of near generation devices. Examples of such efforts include reference [34], [35] that model the impact on beach morphology exerted by wave energy farms. Furthermore, it was stated that "comprehensive assessment, including both impacts and costs should be performed, applying the well-known LCA methodology to ocean energy generation" [9]. A new range of technologies, devices and sub-systems need in-depth analysis [9]. In addition, competing pressures and uses, for example climate change, fishing, marine transport should be considered when looking at environmental impacts [9].

3.2. Environmental impact assessment and strategic environmental assessment

Until now, there are still gaps concerning the scientific evidence on the environmental effects of ocean energy technologies [2], [33]. Existing data are very much dispersed amongst countries, researchers and developers [42], [43]. Since wave energy and tidal energy technologies are at an early development stage, no data on environmental effects from arrays are available.

Environmental impact assessments (EIA) and strategic environmental assessments (SEA) have been undertaken so far, with a focus on Europe and North America. Reviews on the state of research have been published by several institutions. The International Energy Agency-Ocean Energy Systems (IEA-OES) has summarised available knowledge on environmental impacts of ocean energy devices in three areas: physical interactions between animals and tidal turbines; acoustic impact on marine animals; and effects of energy removal on physical systems [44], [45]. Similarly, the Streamlining of Ocean Wave Farm Impacts Assessment project (SOWFIA) is aimed at sharing and consolidating experience of consenting processes and environmental and socio-economic impact assessment best practices for wave energy [46].

3.2.1. Tidal current

In general, ocean bed habitats will be affected by tidal current energy converters and arrays due to the change of water flows, composition of substrate and sediment dynamics [33]. Potential other effects include mortality of fish passing through turbines (blade-strike) and the collision risk of marine mammals with tidal stream farms [33], [47]. A study showed that change in sediment dynamics will most likely be observed following the installation of tidal arrays, impacting on bed morphology and sea bed ecosystems [48]. This, in turn, could impact on floral and faunal species. Species of marine mammals and fish could experience distress and discomfort.

However, in their review, Frid et al. concludes that “there is little scientific literature to suggest that operation of underwater tidal stream energy devices will cause elevated levels of mortality to pelagic organisms such as fish and marine mammals” [33]. Also Lewis et al. mention that, “while current technologies have moving parts (rotating rotor blades or flapping hydrofoils) that may harm marine life, there is no evidence to date of harm from tidal current devices to marine life, such as whales, dolphins, seals and sharks” [2]. A critical issue related to tidal energy converters relates to the noise disruption in turbulent waters, affecting in particular marine mammals, who may be severely affected by such instance [49].

3.2.2. Ocean wave

For some devices, an EIA has been carried out, including AquaBuoy and Wave Dragon [50]. Wave energy converters can potentially “alter water column and sea bed habitats locally and by changes in the wave environment” [33]. A modelling exercise showed that the installation of wave energy converter arrays can lead to significant changes in the inter-array and surrounding wave field [51].

According to Lewis et al., environmental impact from ocean wave energy devices might include “competition for space, noise and vibration, electromagnetic fields, disruption to biota and habitats, water quality changes and possible pollution” [2]. As for tidal devices, the environmental impacts are considered comparably small [52], [53]. Wave devices will represent a much lower collision risk compared to offshore wind devices but there could be the risk of underwater collisions for diving birds [54].

3.3. Future research

According to Lewis et al., “information on the environmental and social impacts is limited mainly due to the lack of experience in deploying and operating ocean technologies, although adverse environment effects are foreseen to be relatively low” [2]. In general, environmental impacts will very much depend on size of installation and the location selected [50]. Potential positive effects such as the creation of roosting sites and habitat enhancement for marine birds might occur as well [54].

The majority of the studies recommend that the first commercial scale installations of ocean energy technology should be accompanied by research studies on the local environmental impacts and for most installations, this will be covered by the EIA that is legally required.

Comprehensive LCA of ocean energy arrays are missing and an integration of aspects such as fluctuation of power output, storage, or grid integration would be very helpful. LCA of a number of major wave energy device types are still missing.

4. Socio-economic impacts

Socio-economic impact assessment addresses how a proposed development might affect society as a whole or the local population. Various issues can be addressed ranging from well-being and quality of life to employment, income and economic power. For ocean energy, specific topics are negative effects due to visual impacts and the reduction of access to space for other users of the marine environment. Similar to the assessment of environmental impacts, both positive and negative impacts of ocean energy deployment on society and the economy need to be studied in order to support evidence-based policy making.

4.1. Costs

An economic assessment of ocean energy has been performed by B. Teillant & R. Costello, et al [60]. They highlight the lack of operational experience which means that operational costs have to be estimated. They provide a simulation model for operational costs and device availability to overcome these challenges. For the grid connection of an ocean energy array, Lopez et al. provide a preliminary cost estimate including a comparison of AV and DC transmission [61]. Cost components considered are offshore substation costs, cable costs, maintenance costs, and the costs for energy losses.

4.2. Social impacts

A main social impact that is usually addressed in studies on ocean energy is job creation. On national, European and global levels, several estimates on the future potential for employment in the sector are available [64], [65].

Other social impacts that have been addressed so far include CO_2 reductions [64], positive as well as negative impacts on other marine users [66] and local communities [67]; also the co-existence of fisheries and offshore renewable energy in the UK has been investigated [68]. It seems that other effects are difficult to quantify, including improvements to existing infrastructure; increased knowledge as a result of research and development in wave and tidal, improvements to energy security, health and quality of life.

4.4. Future research

Many studies address economic aspects of ocean energy including predictions of future costs of ocean energy. Still, there are improvements needed, especially in terms of operation and maintenance costs. Clearly, cost-benefit analyses including aspects such as grid integration, energy security, and ecosystem services are missing. Social impacts are not well understood, when it comes to impacts beyond job creation such as welfare [70]. In particular, studies on the effects on national and EU levels as well as coastal communities are needed [67], [71].

5. Grid integration

The integration of ocean energy in the electricity grid poses various challenges. Firstly, ocean energy arrays have to be connected to the grid which can be very expensive since several components such as an array and subsea electrical system and a submarine cable connection to the shore are needed. Of course, grid availability in proximity to ocean energy arrays is a prerequisite for future developments [4]. Often, however, areas that offer good ocean energy resources are remote and often not connected with existing grid installation, thus requiring either grid upgrades or new-built capacity [5]. Grid integration is thus first of all an issue of electricity distribution and transmission and has also to be seen in the context of renewables integration at large [72].

Secondly, variability of electricity production from ocean energy devices might lead to issues such as grid congestion, weak grids, and voltage stability problems which is also related to technological development. Possible solutions and strategies to solve these problems are currently being researched and will be presented in the following sections.

5.1. Variability of resources

Ocean energy is a variable resource. Tidal current energy is periodic, and thus, resource forecasts are possible with a high reliability over long time horizons. Ocean wave energy can be considered an intermittent resource like wind energy [73]. For tidal currents, variability is very high on an hourly basis but limited for longer time horizons (e.g. monthly, yearly variation). On the contrary, variability for ocean wave energy is relatively low for short time scales (hours) but can be great for longer periods of time, for example on a seasonal or annual basis [2].

Reikard states that the forecast for wave energy is more precise than forecasts for wind and solar energy [20]. Still, the grid integration of ocean energy is of course influenced by the variability of resource availability. Several measures exist to accommodate for resource variability according to reference [74], including resource forecasting, intra- and inter-site smoothing, generation and load mix, and storage (e.g. pumped hydro, battery storage).

5.2. Grid connection and grid codes

In many cases, areas with great potential for ocean energy are located at regions with low population density with weak electricity networks. This may lead to a limitation of the electricity delivered to the grid due to quality of supply [75], [76]. A reinforcement of transmission and distribution networks will most probably be necessary which implies high additional costs.

Currently, no European standard grid code exists but the various national system operators issue their respective grid codes and usually, the requirements differ between countries [77]. At the moment, a range of countries are updating grid codes or developing new grid codes dedicated to the accommodation of a growing share of renewable electricity [78]. The MARINET project, funded by FP7 of the European Union produced a report on grid integration and power quality testing and reviewed the national grid codes [79], [80]. The project highlighted that employing state-of-the-art technology from wind energy, such as frequency converters, will likely allow for grid-compliant installations of ocean energy farms [80].

5.3. Power quality and control

In the future, renewable energy producers will face increasing demands on power quality to contribute to system reliability and stability. A number of requirements will have to be met including for example voltage control and regulation, fault ride-through capabilities, active power control, and frequency regulation [78].

Demands on the control ocean energy converters and arrays will be of high importance [76]. This includes voltage and power factor control as well as power conditioning [75]. Hong et al. present an overview of control strategies for ocean energy devices including oscillating water columns, attenuators, and overtopping devices [84]. They argue that further research on control strategies are needed since they also offer the “potential to dramatically affect the absorbed energy and hence the economy of the devices”, which is also highlighted by reference [85]. Also Bacelli and Ringwood studied available control strategies for arrays of wave energy converters with respect to maximisation of energy absorption and conclude that performance can be increased by applying optimised control strategies [86]. The DTOcean project has a work package to identify, adapt and develop methods to optimise operational aspects of arrays of wave and tidal devices in terms of system control and operation [87].

Ongoing research tries to model impacts of ocean energy arrays on the grid by means of power flows and dynamic simulations. It was shown that the integration of the wave energy farm would not pose any significant problems to the grid. Tedeschi and Santos-Mugica simulated the impacts of a wave farm (multi-MW point absorber) using the Spanish offshore testing facility Bimep as a real test case and studied different control options [89]. The model showed the importance of both wave and grid side energy wave energy converter control. In addition, centralised real-time control of the whole wave energy array reduced power variability and in consequence impacts on the grid.

5.4. Future research

Grid connection of ocean energy faces challenges due to weak electricity grids in rural areas. Reinforcement of grids will be needed which comes at high costs. The synergies with offshore wind farms need to be explored. At the moment, no single European standard grid code exists. Instead, the ocean energy sector – as other electricity producers – has to comply with the respective national or regional grid code. We will see increasing demands on power quality of renewable energy to contribute to system reliability and stability (e.g. voltage control and regulation, fault ride-through capabilities, active power control, and frequency regulation).

Most probably, the quality of power output from ocean energy arrays will meet the grid code requirements. However, adequate control systems for ocean energy converters and arrays have to be developed. Further research in the area of control strategies is needed since it offers a great potential for cost reduction due to increased absorbed energy while allowing meeting grid code requirements.

6. Installation, operation and maintenance

The installation, operation and maintenance of ocean energy devices are relatively expensive. It is estimated that annual operation and maintenance costs of ocean energy devices can be as high as about 3.4–5.8% of capital expenditure compared to 2.3–3.7% for offshore wind [90]. One way to reduce those costs is to standardise equipment and procedures by industrial cooperation [4], [6], [91]. Other promising improvement options include the use of modelling tools to improve array layout and design which will lead to increased device and array efficiency and a reduction of costs.

6.2. Installation

So far, only a few full-scale devices have been installed and thus practical experience is limited [75]. However, the ocean energy sector can build on technology and know-how from other offshore energy technologies [69], [75]. Installation equipment from the oil and gas industry might be used but it could be too expensive since for ocean energy projects, the installation costs are responsible for a high share of investment costs [62], [98]. Installation of ocean energy devices has to be easy and fast in order to reduce costs for the installation process [69]. In the case of tidal devices, this is also an important prerequisite because installation has to be performed during slack tide which means a limited time period.

The installation process and costs for wave and tidal devices will significantly depend on the location. For example, shore based wave energy converters might need solid foundations and heavy infrastructure. The same is the case for bottom-mounted tidal devices which demand substantial foundations. The mooring of floating devices with drag-anchors seems to be a very economical solution while in some cases the sea-bed characteristics will demand other and more expensive mooring types such as pin piled moorings [98]. Only a few papers have tried to establish models or tools to assess resource needs for installation requirements in terms of time and cost.

6.3. Operation and maintenance

Ocean energy devices will operate in harsh environments. Demands on survivability and reliability are high since the economic impacts due to failures can be significant. Maintenance costs for ocean energy devices will be as high as for any other offshore technology and have a high share of lifetime costs [58].

The most common issues ocean energy devices will face are bio-fouling (moorings, floating or submerged parts of the device) and corrosion [75], [99]. Research needs to develop special coatings that prevent bio-fouling and corrosion but also sealing materials and electric insulation materials for saline environments [75], [100]. Developers aim at reducing maintenance intervals by creating very robust devices and designing devices for ease-of-maintenance.

Current research tries to model the reliability and possible failure rates of ocean energy devices. For example, Thies et al. developed a methodology to simulate component reliability and failure rates under defined operational conditions [101]. Device testing in environments that can produce the same conditions as in real waters is a prerequisite for assessing device and component reliability [69]. Also array design parameters (e.g. device spacing) impacts on maintenance activities and costs and this is not very well understood so far.

An important aspect that has to be taken into account when designing ocean energy devices and developing ocean energy projects is that maintenance and repair activities can only be carried out in favourable weather conditions. Weather window analyses study the levels of access in terms of a number of weather characteristics for example wave heights or wind speed. Inaccessibility of ocean energy devices for maintenance and repair might require other maintenance strategies such as onshore.

Conclusions

This study has reviewed the state-of-research in ocean energy, focusing on wave and tidal current, not directly associated with improvement to ocean energy technology and identified areas where future research efforts should be directed to.

Modelling approaches for resource assessment and forecasting are already very advanced and have been performed for many regions of the world. However, this should be widened to accommodate conflicting or competing use of the marine environment such as fishing, shipping, offshore wind, habitat protection and also technical limitations for example grid connection.

Comprehensive LCAs of ocean energy arrays that would also include areas like fluctuation of power output, storage, or grid integration are still missing and for a number of individual WEC types, no LCAs are available so far. Another area which merits further research is the field of regulatory and legal affairs to define an adequate and optimal legal framework for ocean energy.

In terms of grid integration, the impacts of increasing demands on power quality of renewable energy to contribute to system reliability and stability should be discussed. Further research in the area of control strategies is needed since it offers a great potential for cost reduction due to increased absorbed energy while allowing meeting grid code requirements. No long-term experience with devices is available concerning commercial operation and maintenance and few articles try to assess the resource needs for installation, for example time and cost. Array design parameters such as device spacing might have an impact on operation and maintenance activities and costs: this is not very well understood so far and should be addressed.

The most important areas, however, which future research should be focussing on are the economic and social impacts of ocean energy. A broad cost benefit analysis of ocean energy incorporating aspects such as grid integration and energy security could be very important. Economic aspects of ocean energy including predictions of future costs of ocean energy have been addressed but improvements are needed, especially in the area of operation and maintenance costs. Cost–benefit analyses that include aspects such as grid integration, energy security, and ecosystem services are missing. Social impacts are not well understood, when it comes to impacts beyond job creation. In particular, studies on the effects on national and EU levels are needed.

References

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[1] Huckerby J, Jeffrey H, Jay B. An international vision for ocean energy. Ocean energy systems implementing agreement; 2011.

[2] A. Lewis, S. Estefen, J. Huckerby, W. Musial, T. Pontes, J. Torres-Martinez. Ocean Energy et al. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner (Eds.), IPCC special report on renewable energy sources and climate change mitigation, Cambridge University Press, Cambridge (New York) (2011), pp. 497–533

[3] Brito E Melo A, Villate JL, editors. Annual report 2014. Implementing Agreement on ocean energy systems. IEA-OES; 2015.

[4] Magagna D, MacGillivray A, Jeffrey H, Hanmer C, Raventos A, Badcock-Broe A, et al. Wave and tidal energy strategic technology agenda. Strategic initiative for ocean energy (SI ocean); 2014.

[5] D. Magagna, A. Uihlein; JRC ocean energy status report; Publications Office of the European Union, Luxembourg (2014).

[6] MacGillivray A, Jeffrey H, Hanmer C, Magagna D, Raventos A, Badcock-Broe A. Ocean energy technology: gaps and barriers. Strategic initiative for ocean energy (SI ocean); 2013.

[7] EERA and ERA-NET joint workshop on wave and tidal energy within the European Union. European Energy Research Alliance; 2014.

[9] G. Sannino, C. Cavicchioli; Overcoming research challenges for ocean renewable energy; European Union, Luxembourg (2013).

[10] G. Iglesias, R. Carballo; Choosing the site for the first wave farm in a region: a case study in the Galician Southwest (Spain) Energy, 36 (2011), pp. 5525–5531.

[11] R.A. Arinaga, K.F. Cheung; Atlas of global wave energy from 10 years of reanalysis and hindcast data; Renew Energy, 39 (2012), pp. 49–64.

[12] M. Gonçalves, P. Martinho, C. Guedes Soares; Wave energy conditions in the western French coast; Renew Energy, 62 (2014), pp. 155–163.

[13] R. Carballo, G. Iglesias; A methodology to determine the power performance of wave energy converters at a particular coastal location Energy Convers Manag, 61 (2012), pp. 8–18.

[14] F. O’Rourke, F. Boyle, A. Reynolds; Tidal current energy resource assessment in Ireland: Current status and future update; Renew Sustain Energy Rev, 14 (2010), pp. 3206–3212.

[15] K. Gunn, C. Stock-Williams; Quantifying the global wave power resource; Renew Energy, 44 (2012), pp. 296–304.

[16] Strategic Research Agenda/Market Deployment Strategy. European wind energy technology platform; 2014.

[17] Cornett AM. A global wave energy resource assessment. In: Proceedings of the eighteenth international offshore polar engineering conference. Vancouver: The International Society of Offshore and Polar Engineers (ISOPE); 2008, p. 318–27.

[20] G. Reikard; Integrating wave energy into the power grid: simulation and forecasting; Ocean Eng, 73 (2013), pp. 168–178, 10.1016/j.oceaneng.2013.08.005 (2013).

[29] Prediction models. ⟨http://www.bsh.de/en/Marine_data/Forecasts/Prediction_models/index.jsp⟩; 2015 [accessed 07.07.15].

[30] Weather and Climate – Deutscher Wetterdienst – Seewetter. http://www.dwd.de/bvbw/appmanager/bvbw/dwdwwwDesktop?_nfpb=true&_pageLabel=_dwdwww_spezielle_nutzer_schiffffahrt_seewetter&T18605718401151909352281gsbDocumentPath=Navigation%2FSchifffahrt%2FSeewetter%2FHome__NO__node.html%3F__nnn%3Dtrue⟩; 2015 [accessed 07.07.15].

[33] C. Frid, E. Andonegi, J. Depestele, A. Judd, D. Rihan, S.I. Rogers, et al.; The environmental interactions of tidal and wave energy generation devices; Environ Impact Assess Rev, 32 (2012), pp. 133–139.

[34] J. Abanades, D. Greaves, G. Iglesias; Wave farm impact on beach modal state; Mar Geol, 361 (2015), pp. 126–135.

[35] J. Abanades, D. Greaves, G. Iglesias; Wave farm impact on the beach profile: a case study; Coast Eng, 86 (2014), pp. 36–44.

[42] Brito E Melo A, Huckerby J, editors. Annual report 2012. Implementing agreement on ocean energy systems. Lisboa: IEA-OES; 2012.

[43] Brito E Melo A, Villate JL, editors. Annual report 2013. Implementing agreement on ocean energy systems. Lisboa: IEA-OES; 2013.

[44] A. Copping, H. Battey, J. Brown-Saracino, M. Massaua, C. Smith; An international assessment of the environmental effects of marine energy development; Ocean Coast Manag, 99 (2014), pp. 3–13.

[45] Copping A, Hanna L, Whiting J, Geerlofs S, Grear M, Coffey A, et al. Environmental effects of marine energy development around the world. Annex IV final report. IEA-OES; 2013.

[46] Conley D, Magagna D, Greaves D, Aires E, Leitao JC, Witt M, et al. Work package 3 final report. Deliverable 3.5. 2013.

[47] G. Boehlert, A. Gill; Environmental and ecological effects of ocean renewable energy development – a current synthesis; Oceanography, 23 (2010), pp. 68–81.

[48] D. Fallon, M. Hartnett, A. Olbert, S. Nash; The effects of array configuration on the hydro-environmental impacts of tidal turbines; Renew Energy, 64 (2014), pp. 10–25.

[49] Polagye B, Cleve B Van, Kirkendall K, Copping A. Environmental effects of tidal energy development. In: Proceedings of a scientific workshop. Seattle: National Oceanic and Atmospheric Administration (NOAA); 2011.

[50] L. Margheritini, A.M. Hansen, P. Frigaard; A method for EIA scoping of wave energy converters—based on classification of the used technology; Environ Impact Assess Rev, 32 (2012), pp. 33–44.

[51] A.J. Posner, K. O' Sullivan, J. Murphy; Economic and environmental impact appraisal of commercial scale offshore renewable energy installations on the west coast of Ireland; J Coast Res, 29 (2013), pp. 1639–1644.

[52] A. Clément, P. McCullen, A. Falcão, A. Fiorentino, F. Gardner, K. Hammarlund, et al.; Wave energy in Europe: current status and perspectives; Renew Sustain Energy Rev, 6 (2002), pp. 405–431.

[53] M. Fadaeenejad, R. Shamsipour, S.D. Rokni, C. Gomes; New approaches in harnessing wave energy: With special attention to small islands; Renew Sustain Energy Rev, 29 (2014), pp. 345–354.

[54] W.J. Grecian, R. Inger, M.J. Attrill, S. Bearhop, B.J. Godley, M.J. Witt, et al.; Potential impacts of wave-powered marine renewable energy installations on marine birds; Ibis, 1859 (152) (2010), pp. 683–697.

[58] Ocean energy: cost of energy and cost reduction opportunities. Strategic initiative for ocean energy (SI ocean); 2013.

[60] B. Teillant, R. Costello, J. Weber, J. Ringwood; Productivity and economic assessment of wave energy projects through operational simulations; Renew Energy, 48 (2012), pp. 220–230.

[61] Lopez J, Ricci P, Villate JL, Bahaj AS, Myers LE, Retzler C, et al. Preliminary economic assessment and analysis of grid connection schemes for ocean energy arrays. In: Proceedings of the 3rd international conference on ocean energy, Bilbao; 2010.

[62] M. Morandeau, R.T. Walker, R. Argall, R.F. Nicholls-Lee; Optimisation of marine energy installation operations; Int J Mar Energy, 3–4 (2013), pp. 14–26.

[64] Impact Assessment. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Ocean Energy. Action needed to deliver on the potential of ocean energy by 2020. Brussels: European Commission; 2014.

[65] Industry Vision Paper 2013. Brussels: European Ocean Energy Association; 2013.

[66] A socio-economic methodology and baseline for Pentland Firth and Orkney waters wave and tidal developments. The Crown Estate; 2012.

[67] S.K. Henkel, F.D.L. Conway, G.W. Boehlert; Environmental and human dimensions of ocean renewable energy development; Proc IEEE, 101 (2013), pp. 991–998.

[68] J. De Groot, M. Campbell, M. Ashley, L. Rodwell; Investigating the co-existence of fisheries and offshore renewable energy in the UK: identification of a mitigation agenda for fishing effort displacement; Ocean Coast Manag, 102 (2014), pp. 7–18.

[69] J. Houde, Cost-Benefit; Analysis of tidal energy generation in Nova Scotia: a scenario for a tidal farm with 300 MW of installed capacity in the Minas Passage in 2020; Dalhousie University (2012)

[70] J.P. Deane, G. Dalton, B.P. Ó Gallachóir; Modelling the economic impacts of 500 MW of wave power in Ireland; Energy Policy, 45 (2012), pp. 614–627.

[71] S. Kerr, L. Watts, J. Colton, F. Conway, A. Hull, K. Johnson, et al.; Establishing an agenda for social studies research in marine renewable energy; Energy Policy, 67 (2014), pp. 694–702.

[72] ENTSOE. Ten-year network development plan 2014. ⟨https://www.entsoe.eu/major-projects/ten-year-network-development-plan/Pages/default.aspx⟩; 2014 [accessed 11.11.14].

[73] A.S. Iyer, S.J. Couch, G.P. Harrison, A.R. Wallace; Variability and phasing of tidal current energy around the United Kingdom; Renew Energy, 51 (2013), pp. 343–357.

[74] M. Santos Múgica, F. Salcedo Fernandez, D. Ben Haim, J. Lopez Mendia, P. Ricci, J.L. Villate Martínez, et al.; Integrating wave and tidal current power: case studies through modelling and simulation; Tecnalia, Powertech Labs, HMRC (2011)

[75] M. Mueller, R. Wallace; Enabling science and technology for marine renewable energy; Energy Policy, 36 (2008), pp. 4376–4382.

[76] A.E. Kiprakis, A.R. Wallace; Maximising energy capture from distributed generators in weak networks; IEE Proc – Gener Transm Distrib, 151 (2004), p. 611.

[77] R. Llorente Iglesias, R. Lacal Arantegui, M. Aguado Alonso; Power electronics evolution in wind turbines—a market-based analysis; Renew Sustain Energy Rev, 15 (2011), pp. 4982–4993.

[78] Grid integration of large-capacity renewable energy sources and use of large-capacity electrical energy storage. Geneva: International Electrotechnical Commission; 2012.

[79] Santos-Mugica M, Robles E, Endegnanew AG, Tedeschi E, Giebhardt J. Grid integration and power quality testing of marine energy converters: research activities in the MARINET project. In: Proceedings of the 2014 ninth international conference on ecological vehicles and renewable energies, Monte Carlo; 2014, p. 9.

[80] Giebhardt J, Kracht P, Dick C, Salcedo F. Report on grid integration and power quality testing. Deliverable 4.3 final. MARINET; 2014.

[84] Y. Hong, R. Waters, C. Boström, M. Eriksson, J. Engström, M. Leijon; Review on electrical control strategies for wave energy converting systems; Renew Sustain Energy Rev, 31 (2014), pp. 329–342.

[85] E.V. Sanchez, R.H. Hansen, M.M. Kramer; Control performance assessment and design of optimal control to harvest ocean energy; IEEE J Ocean Eng (2014), pp. 1–12.

[86] G. Bacelli, J. Ringwood; Constrained control of arrays of wave energy devices; Int J Mar Energy, 3–4 (2013), pp. e53–e69.

[87] System Control & Operation. ⟨http://www.dtocean.eu/Work-Packages/System-Control-Operation⟩; n.d. [accessed 09.07.15].

[89] E. Tedeschi, M. Santos-Mugica; Modeling and control of a wave energy farm including energy storage for power quality enhancement: the bimep case study; IEEE Trans Power Syst, 29 (2014), pp. 1489–1497.

[90] R. Lacal-Arantegui, A. Jäger-Waldau, M. Vellei, B. Sigfusson, D. Magagna, M. Jakubcionis, et al.; DRAFT 2014 energy technology reference indicator (ETRI) projections for 2010–2050; Publications Office of the European Union, Luxembourg (2014)

[91] Badcock-Broe A, Flynn R, George S, Gruet R, Medic N. Wave and tidal energy market deployment strategy for Europe. Strategic initiative for ocean energy (SI ocean); 2014.

[98] Ocean energy: state of the art. Strategic initiative for ocean energy (SI ocean); 2012.

[99] J.M. Walker, K.A. Flack, E.E. Lust, M.P. Schultz, L. Luznik; Experimental and numerical studies of blade roughness and fouling on marine current turbine performance; Renew Energy, 66 (2014), pp. 257–267.

[100] A. Boisseau, P. Davies, F. Thiebaud; Sea water ageing of composites for ocean energy conversion systems: Influence of glass fibre type on static behavior; Appl Compos Mater, 19 (2012), pp. 459–473.

[101] P.R. Thies, L. Johanning, G.H. Smith; Towards component reliability testing for marine energy converters; Ocean Eng, 38 (2011), pp. 360–370.

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