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The technological state of the art of wave energy converters

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Abstract. While global demand for energy increases annually, at the same time the demand for carbon-free, sulphur-free and NO_x-free energy sources grows considerably. This state poses a challenge in the research for newer sources like biomass and shale gas as well as renewable energy resources such as solar, wind, geothermal and hydraulic energy.
Although wave energy also is a form of renewable energy it has not fully been exploited technically and economically so far. This study tries to explain those reasons in which it is beyond doubt that the demand for wave energy will soon increase as fossil energy resources are depleted and environmental concerns gain more importance.
The electrical energy supplied to the grid shall be produced from wave energy whose conversion devices can basically work according to three different systems.
i. Systems that exploit the motions or shape deformations of their mechanisms involved, being driven by the energy of passing waves.
ii. Systems that exploit the weight of the seawater stored in a reservoir or the changes of water pressure by the oscillations of wave height,
iii. Systems that convert the wave motions into air flow.
One of the aims of this study is to present the classification deficits of the wave energy converters (WECs) of the "wave developers" prepared by the European Marine Energy Center, which were to be reclassified. Furthermore, a new classification of all WECs listed by the European Marine Energy Center was arranged independently. The other aim of the study is to assess the technological state of the art of these WECs designed and/or produced, to obtain an overview on them.

Keywords: wave energy; wave converter; classification of converter; assessment of converter

1. Introduction

1.1 Wave energy characteristics

Global demand for energy increases annually, whilst the demand for carbon-free, sulphur-free and NOx-free energy resources also grows considerably. Nowadays there is a great need to research for newer sources like biomass and shale gas as well as renewable energy resources like

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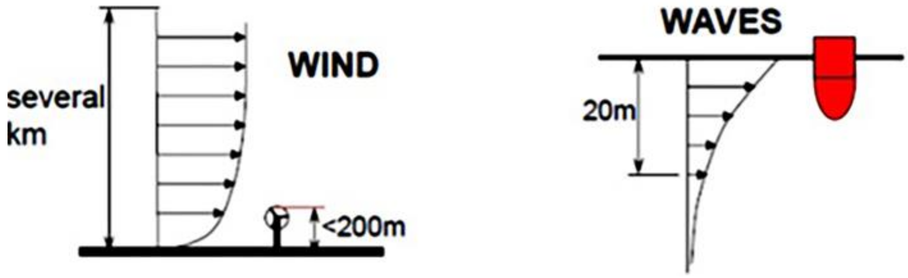


Fig. 1 Comparison of the velocity profiles of the wave and wind (Falcão 2010)

solar, wind, geothermal and hydraulic energy. Scientists and engineers as well as leaders in renewable energy sector have thought that wave energy is also a form of renewable energy which has not fully been exploited technically and economically (Drew *et al.* 2009, Falcão 2010, Duckers 2004). This can be realized if benefits and challenges as well as the characteristics of the wave energy and sea environment are analyzed elaborately (Khan and Bhuyan 2009, CIS Galicia 2010, Vicinanza *et al.* 2012, Huckerby, 2012, Kofoed *et al.* 2006, Joubert *et al.* 2013, Waveplam 2016a, b, Sağlam *et al.* 2010, Pelamis 2016, Wavedragon 2012, Andreas and Wang 2007, Dalton *et al.* 2010). The wave energy is extremely attractive for the reasons as follows:

i. The wind being generated by solar energy creates so-called wind-waves consisting of the highest energy density (Andersen and Frigaard 2011). Solar energy with an average intensity of typically 0.1–0.3 kW/m^2 of horizontal surface is converted to wind energy with an average intensity of 0.4-0.6 kW/m^2 which in turn generates wave energy with an average power flow intensity of 2–3 kW/m^2 of a vertical plane perpendicular to the direction of wave propagation under the water surface (Folley *et al.* 2005). The total theoretical wave power resource in the oceans is estimated between 1-10 TW, whilst the average electrical power consumption of the world accounts for approx. 2.11 TW and 3 TW according to Gunn and Williams (2017) and López *et al.* (2013), respectively.

ii. The wind velocity profile expands over several kilometers on the ground level as seen in Fig. 1, thus a wind turbine and/or farm exploits only a tiny sublayer of that. In contradiction to wind, most of the wave energy flux is concentrated near the sea surface; hence a wave farm at the sea surface can absorb a large part of the wave energy flux as seen in Fig. 1 (Falcão 2013).

iii. Waves are formed by winds changing surface pressure and sea level by blowing over the sea and ocean surface, which make the water particles adopt circular motions. Wave energy occurs due to the movements of these water particles near the surface of the sea. This motion carries kinetic energy, the amount of which depends on the speed, duration and unchanged direction of the wind, the length of sea, over which it blows (fetch), the water depth, sea bed conditions and interactions with the tides. The stronger the wind and the longer the distance over which it blows, the larger the waves and the more energy they carry. This energy can be harvested from waves in terms of the following characteristics:

- The waves possess the potential energy due to gravity, and so the movements of the water from a higher to a lower potential energy position yield its share.

-Additionally, they have the kinetic energy being generated by the actual movement of the waves and create the other share in wave energy.

Here it should be added in terms of tides, since the entire water body moves from the surface to

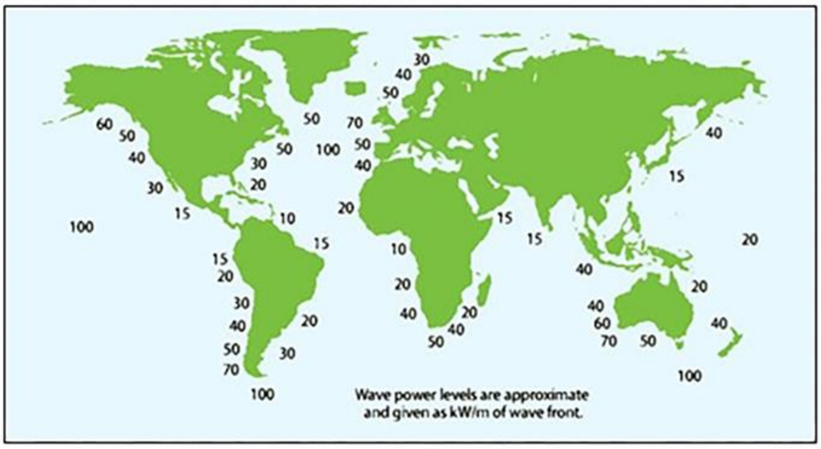


Fig. 2 Average wave power levels in the costs of continents (Thorpe 1999)

the sea bed, the energy occurs due to a net movement of water mass, but in waves, the water acts as a carrier for energy, moving it in some directions, but it does not undergo a net movement itself.

iv. Waves can cover very large distances of thousands of kilometers with little energy loss.

v. Natural seasonal variability of wave energy agrees the electricity demand in temperate climates (Andersen and Frigaard 2011).

vi. Since the oceans and seas have multiple locations, waves are a widely available energy source and there exists a good correlation between resource and demand, since around 37% of the population of the world lives within 90 km of the coasts (EMEC 2015).

In exploiting wave energy, the aim always is to extract energy from the ocean and/or sea waves as efficiently and safely as possible with the cheapest investment and operating costs as well as producing maximum economic return through so-called wave energy converters (WECs) of different types. However, it is technically and economically an uncontroversial problem to meet the expectations to design and produce a commercially viable WEC, because the following principle design and managing challenges for WECs should be overcome:

i. Ocean renewable energy technologies tend to be very intermittent in their power output if the electric energy obtained by these technologies are transmitted and synchronized in consumer locations on land. The WECs can extract significant amounts of energy when the waves encounter them directly and continuously, however is usually not always the case. As a result, the traditional wave energy techniques do not produce energy continuously. Further, since waves vary in height and period, their respective power levels vary accordingly (Zieger *et al.* 2009, Queffeulou and Croize-Fillon 2007, Queffeulou and Croize-Fillon 2016).

In offshore locations, wave direction very often varies, and therefore, in order to capture as much energy as possible, the devices have to align themselves on compliant moorings with the direction of the waves which can sited near the shore in advance, owing to the natural phenomena of refraction and reflection.

ii. Wave energy technology produces electricity at a very low frequency which does not match transmission conditions on sea and high voltage grid connection properties on land.

Thus a significant challenge is the conversion of the slow and oscillatory motion of waves with ~0.1-1.0 Hz into useful motion to drive a generator with electric output quality. In this case, the output has low voltage, and to provide the energy transmission from the sea to the land and further

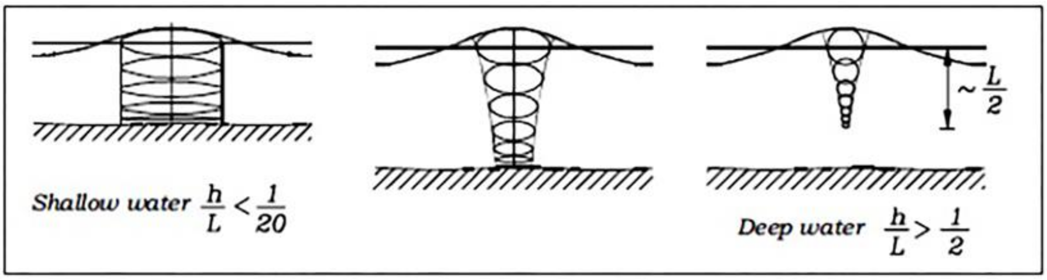


Fig. 3 Movement of water molecules according to the water depth (Andersen and Frigaard 2011)

to connect to the grid, WECs generated voltage levels must be risen to an acceptable level by costly offshore/onshore substations.

iii. It is still unable to economically store wave power in large amounts.

iv. Survivability of the WECs in storm conditions has been a key obstacle of ocean technologies in the past, present and near future which leads to difficult structural engineering challenges; further the maintenance operations become extremely difficult.

To operate efficiently, the devices and corresponding systems have to be rated for the most common wave power levels which vary 15-200 kW/m as seen in Fig. 2 (Duckers 2004). However, the device must also be able to withstand extreme wave conditions that occur very rarely. The capital cost of the device construction is driven by a need to withstand the high power level of the extreme waves (Duckers 2004).

v. Many WEC developers must produce their prototypes working at maximum efficiency for waves within a certain range of periods and heights. Thus, the WEC behavior and efficiency are high only within this range, but efficiency decreases outside of this range extremely (López *et al.* 2013, Zieger *et al.* 2009, Queffeulou and Croize-Fillon 2007, 2016).

vi. The funding is another serious obstacle (EMEC 2015). Ocean and sea waves are an enormous energy source with great potential and with a number of advantages above-mentioned. However, it has to compete against more mature technologies which have already aquired investment. In this situation, investors need to absolutely realize the significant advantages of investing large amounts of money in these WEC plants.

Nevertheless, for accelerating investments, first the following concrete problems of the available wave energy converter technologies are primarily to be solved:

• Low energy conversion rates of the WECs,

• Special materials and construction are needed for the vast sea environment causing enormous forces and movement, which is highly unsuitable for structural, mechanical and electrical equipment.

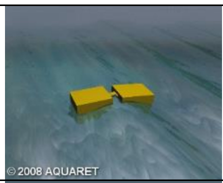
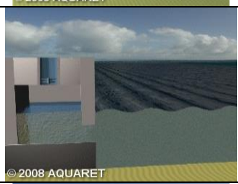
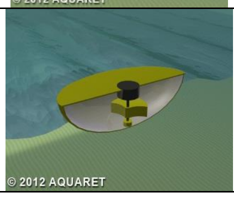
• Associated with those, the high costs of delivering electricity.

Furthermore, the environment at sea and submarine ground levels creates additional difficulties and/or obstacles such as:

• Saltwater is a very corrosive medium for constructions made of metals.

• The ocean floor is a difficult and expensive location for the mounting of equipment foundations, particularly since the constructions must withstand overturning moments due to high horizontal loads occurring at sea level (Fig. 1-3). Therefore the WECs should preferably be installed on existing, stable structures such as breakwaters, peers and fixed platforms.

Table 1 Technological models and/or classification of WECs presented by the EMEC's website (EMEC 2015)

WEC Type	Working Principle	WEC Model
A	Attenuator	
B	Point Absorbers	
C	Oscillating Wave Surge Converter	
D	Oscillating Water Column System	
E	Overtopping and Terminator Converter	
F	Submerged Pressure Differential Device	
G	Bulge	
H	Rotating Mass Device	
I	Others	--

• In offshore WECs, the costs of their maintenance and repair as well as the transmitting costs of generated electric energy to the grid-connection on land are very high. The WECs should at best be protected in sheltered seas and shallow waters as fish farms are in the foreshore. However, this concept is a contradiction allowing for the fact that these seas and shallow waters involve much less wave energy than oceans and/or open seas. Worldwide, very few countries have extensive shallow and protected seas available for wind, thus, wave development.

Further, most sea-based energy generating technologies are hampered by several factors such as design-based weaknesses and/or construction-based shortcomings (Fig. 2-4; Table 1,2). As a result, many of the WECs including their power-take-off-systems (PTO) have been very expensive to manufacture and maintain.

These problems can be eliminated at some WECs by keeping most of the costly electrical components on-shore where they are protected from the marine environment and can be easily serviced. This technique is an alternative to those with grid connection by undersea cabling (Falcão, 2010).

Another measure for improving continuous power supply, certain types of the WECs (Table 1, 2) can also supply energy by pumping seawater into a coastal reservoir at a suitable height above the calm water level, running through a channel into a hydropower turbine therefore solving the general problem of fluctuating output in wave energy (Falcão 2010).

Since the seas and oceans are open to the wind, they are richer in wave energy than the closed seas; further the west coasts of continents have a higher wave energy value compared to their east coasts because of the Coriolis forces (Thorpe 1999) (Fig. 2). The most energy-rich zones are between the latitudes of 40° and 60° in both hemispheres. But, since seasonal variations are much lower in the Southern Hemisphere (SH) than the Northern Hemisphere (NH), the highest mean annual wave power is obtained in SH (NTUA 2004). However, it appears that setting up WEC plants in the open seas and oceans contain important problems regarding the economic and technical aspects as mentioned above. In conclusion despite any drawbacks, one reaches suitable results if the WEC plants are deployed in coastal and/or foreshore areas in shallow waters. Furthermore, zones with moderate but steady wave energy flux are more appropriate than sites where the source is more energetic but inconsistent, and therefore less reliable (Dunnett and Wallace 2009).

Moreover, there is an advantageous combined system whereas some types of the WECs which share infrastructure with offshore/ onshore wind turbines maximize grid electricity production for a given sea area considerably. They should be integrated into the design of the next generation offshore wind foundations. This technique reduces capital costs by sharing offshore infrastructure such as foundations, cabling and grid connection. The intermittency of the output power from the co-located wind-wave farm is considerably reduced by combining wave energy generation with offshore/onshore wind devices.

Nevertheless, the following problem for offshore wind turbines should also be overcome: The leaders in wind energy sector of Europe should soon invest beyond the shallow seas, such as the southern part of the North Sea because the few seas with good wind properties are already overfilled. The other seas with good wind characteristics are either deeper, which cause increasing costs due to fixed foundations, or possess wave features that require special design measures which are an immense cost driver for such wind energy systems. However, the increased revenue from more energetic wave climates could countervail the additional costs of investing, installing and operating of these systems in more challenging seas (Tridentenergy 2015).

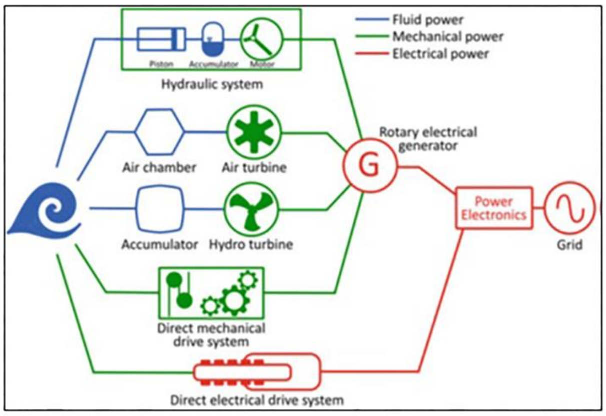


Fig. 4 Different paths for electricity conversion from wave energy (Pecher and Kofoed 2016)

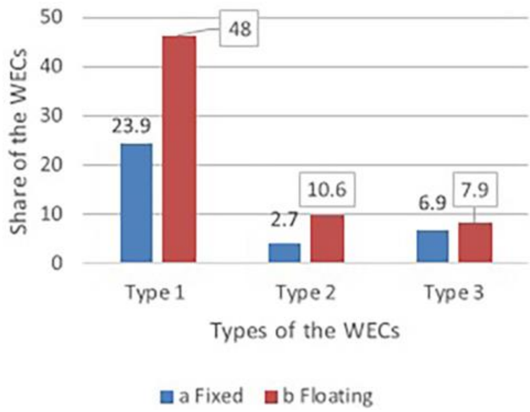


Fig. 5 New classification of the WECs given by the EMEC in Table 2

1.2 Overview and re-classification of the WECs of the European Marine Energy Centre Ltd.

To exploit wind energy, wind turbines are deployed worldwide, whereas major changes and/or differences in the design and manufacturing of wind turbines aren't visible worldwide. However as to the technological state of the art and types, wave energy systems are very different, since many various wave energy converters (WECs) were designed and manufactured as prototypes due to complex interactions between waves and devices in coastal, near shore and offshore zones (Drew *et al.* 2009, Falcão 2010, Duckers 2004, Khan and Bhuyan 2009, CIS Galicia 2010, Vicinanza *et al.* 2012, Huckerby 2012, Kofoed *et al.* 2006, Joubert *et al.* 2013, Falcão 2013, EMEC 2015, Bernhoff *et al.* 2006).

Wave energy devices convert wave energy into electricity through a power take-off (PTO) system that consists usually of power electronics, a rotary electrical generator and a turbine such as Pelton, Kaplan and Wells/ HydroAir/ Denniss–Auld turbines driven by pressurized oil, water and air respectively, and/or of only direct electrical drive system (or direct mechanical drive systems with rotary electrical generator) as given in Fig. 4 (López 2013, Pecher and Kofoed 2016). Wave energy converters can be divided into different types of classifications, e.g., The European Marine

Energy Centre classifies them into nine classes ; attenuators (A; 19%), point absorbers (B; 39%), oscillating wave surge converters (C; 8%), oscillating water column systems (D; 15%), overtopping and terminator converters (E; 11%), submerged pressure differential devices (F; 1.6%), bulges (G; 2%) and rotating mass (H; 4%) as well as the group “others” (I; 0%[†]) (Table 1, 2). The information on the WECs investigated in this study was obtained from original websites of each corresponding companies and the reports on their tank and/or sea tests according to the company list given by the EMEC’s website as to 25th March 2015. The data in Table 2 refer to the last development stages of the systems to respective time.

If all of the various concepts of the WECs registered by the EMEC were investigated elaborately, a conclusion could be reached that the technological modelling of the EMEC is both inappropriate and non-systematic. This argument is proven through non- and misclassification as well as classification of the devices under the group “others” by the EMEC (EMEC 2015).

One of the aims of this study is to present the classification failures of the WECs of the “wave developers” prepared by the EMEC in a web-site list, which are to be reclassified and further a new classification of all WECs was arranged as seen in Table 2 and in Fig. 5-11. The other aim of the study is to assess the technological state of the art of the wave energy converters designed and/or produced, based on their types, functionality and effectiveness, to obtain an overview on them as given in Fig. 12.

2. Analysis of the wave energy converters

As the previous section mentioned, wave energy, unlike wind energy far above the ground level, increases concentration at the free water surface as seen in Fig. 1 and 3. In the depth of one-half of the wave length in deep water the movement of water molecules does not exist. Whereas in transitional water (1/2 > Depth/Wave length (h/L) >1/20) the movement of water molecules decreases partially to the depth, it remains unchanged in horizontal direction in shallow water (Fig. 3). Thus, all WECs must principally be deployed floating at or directly under the free sea surface in both deep and transitional waters; nevertheless, they can be arranged at the free sea surface as well as on the seabed in shallow waters.

From the 80s up to the mid 90s, large offshore WECs were designed and their prototypes were produced in order to reduce energy unit costs, since "most" of all devices had been very expensive in manufacturing and maintaining (Graw, 1995). Although low costs were reached in energy production using these systems which had a very big advantage, these costs increased significantly due to the offshore deployments of the WECs raising the costs of power transmission to the land and the ones of maintenance as well as repairs. Furthermore, it was also very difficult to protect these systems against severe storms. Therefore, they began to design and test versions of the small onshore/near shore WECs after 2000-2010. Some of those reached pre-commercialization stage. If Table 2 is analyzed, it is seen that the projects and works have progressed in this direction. 21 of WECs were commercialized, whereas 34 of those are still in the full scaled prototype testing stage. 107 WECs have undergone a small scaled prototype testing stage whilst 32 devices are still in design stage.

After an examination of all the WECs listed by the EMEC, the following information was

[†] The revised classification in Table 2 was used.

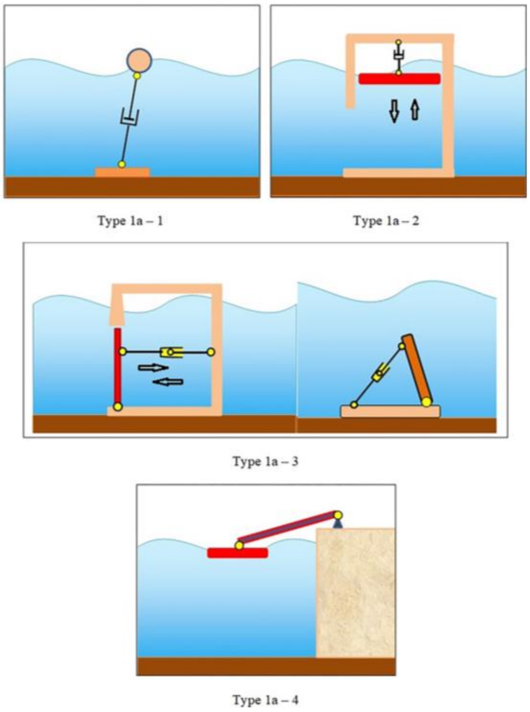


Fig. 6 Tethered WECs of the Type 1

obtained:

i. 17 % of the devices could not be classified (31).

ii. 28 % of the converters were misclassified (51).

iii. 13 % of the devices were arranged under "unknowns or not-classified" (24), which should never have been a classification.

This structuring needs a more systematic order that should contain all the various types of the WECs presented and not presented in the list of the EMEC. As an initial recommendation, all the WECs designed and/or produced should principally be classified as follows in Fig. 5 and 6-11 (Graw, 1995):

Type 1 of the WECs consisting of point absorbers, attenuators and wave surge converters as well as submerged pressure differential devices, define systems generating solid body motions and/or solid body deformations using wave energy, which drive mostly Pelton turbines by a special hydraulic mechanism or direct mechanical drive systems and/or direct electrical drive systems, the last without gearbox and rotary electrical generator as seen in Fig. 4-7.

Type 2 being composed of overtopping devices indicates systems creating seawater storage in a reservoir above the calm water level which drives low head (Kaplan) turbines driving a generator (Fig. 4,5,8,9).

Type 3 of the WECs consisting of oscillating water column (OWC) converters, specifies systems exploiting oscillation of water columns in one or more chambers in which air columns are pressurized for driving Wells/ HydroAir /Dennis Auld turbines driving a generator (Fig. 4,5,10,11).

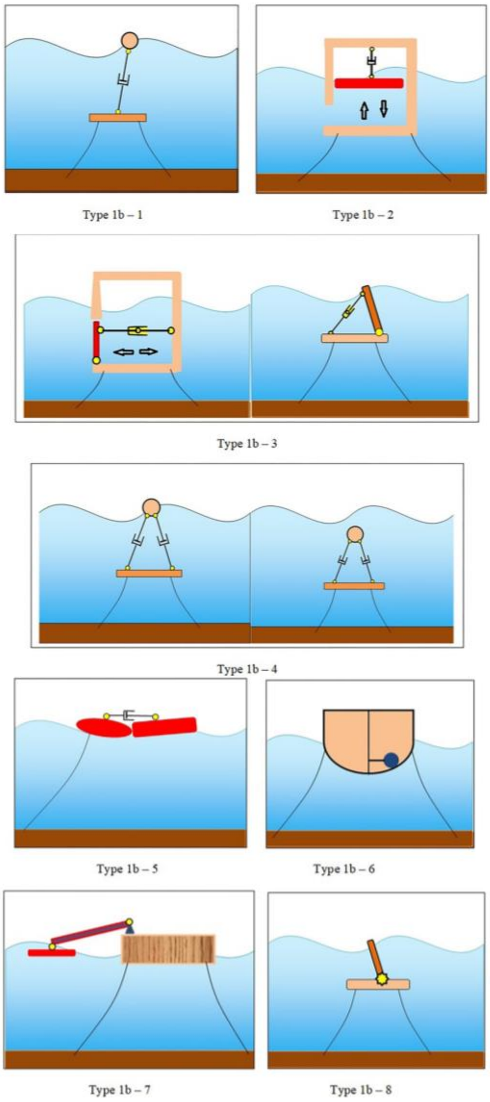


Fig. 7 Floating WECs of the Type 1

In this study, these types are categorized into two subsystems: a) Systems tethered on the seafloor, b) Systems floating with the reference point of the motion, which are slack and/or taut moored to the seafloor as seen in Fig. 5 and 6-11.

The modeling should be arranged elaborately in great number as shown in Fig. 6-11, since the WECs possess many various features and/or functionality. It is expected that a WEC device should be reliable, robust and cost-efficient with high-energy efficiency in the long term. Thus, with regard to these parameters, an assessment matrix for the devices investigated was completed as seen in Table 2.

In assessment matrix, the following economic and technical factors were selected as the basic criteria as well weighted according to each other, since many different types of the WECs in

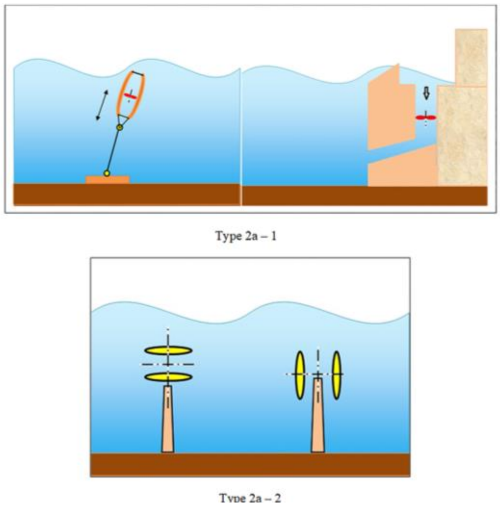


Fig. 8 Tethered WECs of the Type 2

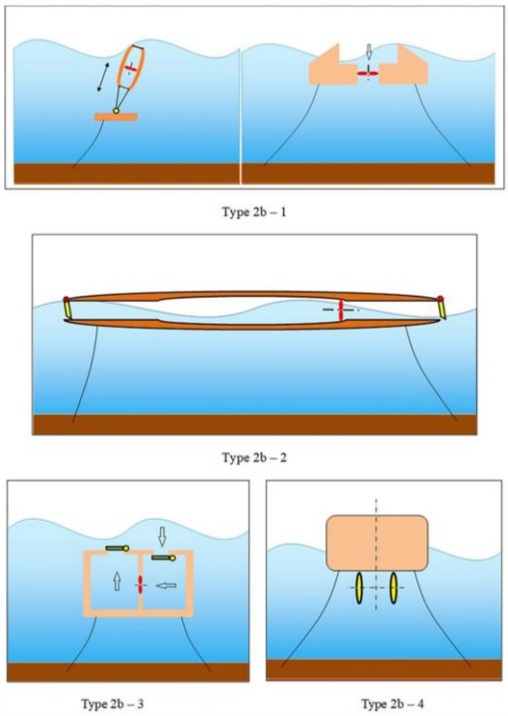
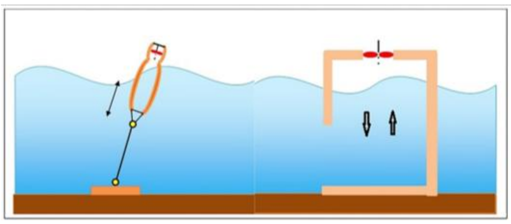


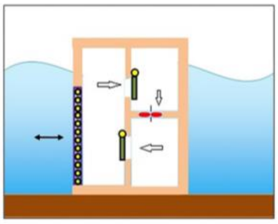
Fig. 9 Floating WECs of the Type 2

various designs with different functioning principles and features are present. Costs of construction/manufacturing, installation, maintenance/repair; reliability, survivability, effectiveness, robustness/durability of the devices were taken into account objectively in the evaluation of each system.

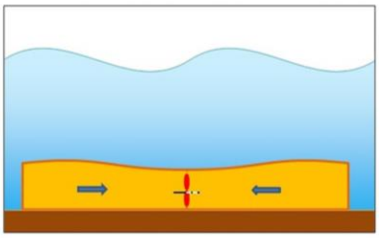
As well known, the WECs commonly are subjected to a harsh sea environment. Therefore, they



Type 3a – 1

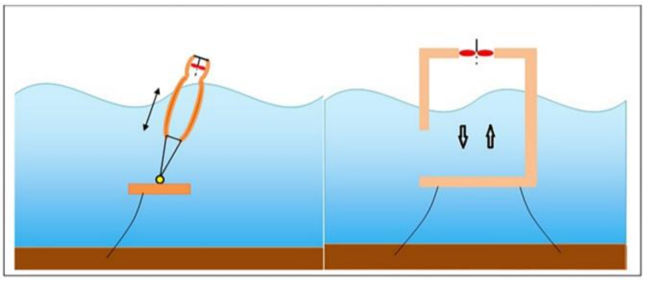


Type 3a – 2

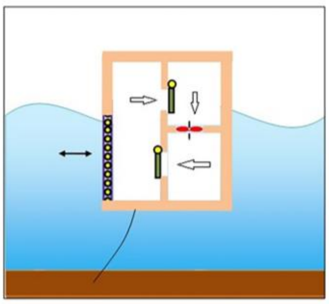


Type 3a – 3

Fig. 10 Tethered WECs of the Type 3



Type 3b – 1



Type 3b – 2

Fig. 11 Floating WECs of the Type 3

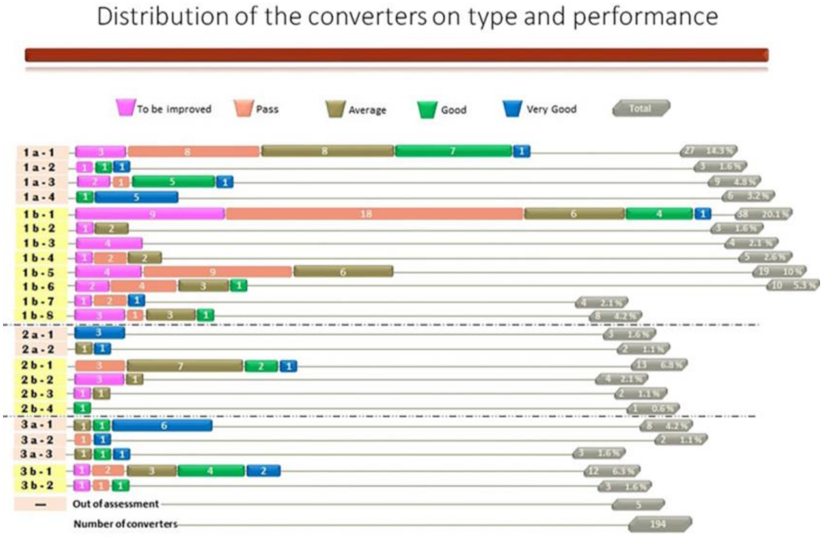


Fig. 12 Distribution of the converters on type and performance according to EMEC as to 25 March 2015

must be constructed with high quality failure free materials. Thus, the cost of materials and manufacturing rises considerably. So the prices / costs of the WECs are generally determined by the costs of materials and manufacturing types and methods, but also with the need for maintenance and repair. The properties "reliability, robustness and survivability" set their price at the end. It is possible that the most important characteristic of a WEC "effectiveness" can be overlooked. Thus the weighting factor for effectiveness in assessment matrix was set to be as 4.0 in terms of costs, functionality and assertiveness of the WECs. By reason of the huge environment on the high seas, survivability, robustness and reliability were decided as criteria with weighting factor of 4.0, 3.5 and 3.5, respectively.

The reason for the demand for high quality materials showed that the weighting factor for construction and manufacturing including materials was determined to be 3.0, while the weighting coefficients for inevitable maintenance as well as repair and installation costs were set as 2.0 and 1.0, respectively, in terms of the widely developed robotic systems.

Unlike in the case of well-engineered and standardized wind turbines, if Table 2 is examined, a wide range of wave energy devices are present at different development stages, which are partly designed, being constructed or being tested as prototypes as well as in pre-commercialization phases. The reason for having a higher score for some systems is that they have been designed merely in combination with onshore/nearshore /offshore wind energy plants. The systems receiving points about 60.0 from 100 indicate that they are prevailingly devices of the Types 1-3 tethered on the seafloor and/or on land as seen in Fig. 12.

The largest type of the device systems consists of simple "floating buoys" of Type 1b-1 in share of 20.1 %, while 14.3 % of all converters are "tethered ones" of Type 1a-1 (Fig. 6,7,12). The third largest type of the converters belongs to the systems with articulated sections (Type 1b-5) known as Pelamis-devices whose share of 10 %. In the wave energy sector, the floating overtopping devices (Type 2b-1) and the floating OWC systems (Type 3b-1) found an application share of 6.9 % and 6.3 %, respectively (Fig. 9,11,12). Also the floating moveable mass devices fall into the group 1b-6 with the use of 5.3 % (Fig. 7,12).

Finally, the tethered Type 1a and floating Type 1b systems comprise 71.9 % of the all converters, while both types of overtopping devices (Type 2a and b) come to 13.3 % and both types of OWC systems (Type 3a and b) mount up to 14.8 % (Fig. 12). Thus it can be determined that, nowadays, first floating devices (48.0 %) and then tethered ones (23.9 %) of the Type 1 (generating solid body motion) definitely dominate the wave energy sector. In the next decade, it is pointed out which types will gain full recognition and thus prevail. Therefore, the following types are more likely:

Since the “fixed” systems (Type 1a, 2a and 3a) are "tethered on the seafloor or onshore” generally, they have a higher capacity for survivalability than those of "floating systems" (Type 1b, 2b and 3b). For some devices in the both systems, some additional measures have been developed "under storm conditions" such as pulling-down / up or lifting and fixing the mechanisms. However, the costs of production, installation, maintenance and repair of these devices are higher than those not having these mechanisms. Furthermore, the taut mooring for floating systems also has the advantage of taking up less space in the sea per buoy, as opposed to slack moored buoys, and provides more energy to be harvested per square kilometer of sea.

Although the “fixed” devices functioning according to the oscillating water column principle (OWC) (Type 3a) are costly in terms of construction and installation, they are cost-efficient regarding maintenance and repair expenditure and can better withstand heavy storms. The floating OWC devices (Type 3b) are operating somewhere between the fixed OWC ones (Type 3a) and the floating devices functioning with water weight or its pressure (Type 2b) in terms of the properties above-mentioned. The Type 1a and 1b are systems which have been applied mostly because managerial directors and engineers have thought that they appear to be cost- and energy-efficient as seen in Table 2 (Figs. 5-12).

In the technologies of most WECs, the capacity factor is similar to the wind energy systems between 0.3-0.40, which amounts to be possibly larger in the southern hemisphere especially between 20° and 40° latitude due to smaller seasonal variations. At the present stage of the technology development, the unit cost of electricity from waves ranges on average between wind and large photovoltaics (Falcão 2013).

Even in oceans where wave potential is significantly better than in open seas, the net present value of wave energy converters is still negative under current market conditions (Dalton, 2012). The reason for this is that the wave energy is still in its research and development phase with few technologies at the pre-commercial and commercial phase as seen in Table 2 (Bahaj, 2011). It can be stated that there are over 1000 wave energy conversion techniques patented in Japan, North America and Europe (Drew *et al.* 2009). High capital costs coupled with low wave resources currently make wave energy conversion in the offshore and at deeper water locations of 100 m depth still unfeasible.

Nevertheless generally WEC plants being deployed in near-shore sites reduce both the costs and power losses in the cable transmitting power to shore, as well as providing considerable reductions in installation and maintenance costs (Folley *et al.* 2005).

A unique system in which existing offshore wind and wave technologies are combined into a single modular structure, can deliver cost-effective and competitive renewable energy systems with minimal impact on the natural environment. They should be integrated into the design of next-generation offshore wind foundations. This technique reduces capital costs by sharing offshore infrastructure such as foundations, cabling and grid connection. Combining wave energy generation with offshore/onshore wind devices reduces the intermittency of the output power from the co-located wind-wave farm. Since this technique enables long term, sustainable cost reduction,

Table 2a WECs and company names presented by the EMEC's website as to 25th March 2015

Weight for assessment criteria (1 - 4)									3.0	1.0	2.0	3.5	4.0	4.0	3.5		
Company[1]	Device name	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in	Cost of construction / Manufacturing	Installation	Maintenance/ Repair	Reliability	Survivability	Effectiveness/ Exploitation	Robustness/ Durability	Raw score	Relative score
IHC Tidal Energy	Wave Rotor (Breakwater)	2a-2	E!	I		2012			4.0	4.0	3.0	3.0	4.0	3.0	4.0	74.5	0.89
Hann-Ocean	Drakoo B	2a-1	E	B				2012	4.0	4.0	4.0	4.0	3.0	3.0	3.5	74.3	0.88
Voith Hydro Wavegen	Limpet	3a-1	D	D				2000	1.5	3.5	3.5	4.0	4.0	3.5	4.0	73.0	0.87
Wave Energy Cenre (WavEC)	Pico Plant	3a-1	D	D			2008		1.5	3.5	3.5	4.0	4.0	3.5	4.0	73.0	0.87
M3 Wave LLC	DMP Device	3a-3	F!	F		2014			4.0	3.0	4.0	3.0	4.0	2.0	4.0	71.5	0.85
Wave Energy AS	Seawave Slot-Cone Generator	2a-1	E	E		2007			1.0	3.5	3.5	4.0	4.0	3.5	4.0	71.5	0.85
WavElectric Inc	WE 10 / WE 50 / WE 125	1b-1	B/H!	H		2012			4.0	3.0	3.5	3.0	1.0	3.0	2.5	57.3	0.68
Mururan Institute of Technology	Pendulor	1a-3	C	I				For years	3.0	3.0	3.0	3.0	4.0	3.0	4.0	70.5	0.84
Eco Wave Power	Power Wing	1a-4	A!	I				2014	3.0	4.0	3.0	3.5	3.5	3.5	3.0	69.8	0.83
NEMOS GmbH	NEMOS	1a-1	B	I		2014			4.0	4.0	3.5	3.0	3.0	3.0	3.0	68.0	0.81
OWC Power AS	OWC Power	3a-1	D	D			2014		3.0	3.0	3.0	3.0	3.5	3.0	3.5	66.8	0.79
JAMSTEC	Mighty Whale	3b-1	D	E				2003	3.0	3.0	3.0	4.0	3.0	3.0	3.0	66.5	0.79
Wave Star Energy ApS	Wave Star	1a-4	A/B!	B		2013			1.0	1.5	2.0	4.0	4.0	3.5	4.0	66.5	0.79
Oceanlinx	greenWAVE	3a-1	D	D				2011	3.0	4.0	3.0	3.0	3.5	3.0	3.0	66.0	0.79
GasNatural Fenosa	OWC	3a-1	D	D	None				1.0	2.5	3.0	3.5	4.0	3.0	4.0	65.8	0.78
SDK Marine	SDK Marine Wave Turbine	2a-1	E	D		2014			3.0	3.5	3.0	3.0	3.5	3.0	3.0	65.5	0.78
Eco Wave Power	Wave Clapper	1b-7	A!	I				2014	3.0	4.0	2.5	3.0	3.0	4.0	2.5	65.3	0.78
RTI Ocean Wave Energy	RTI Ocean WEC	3a-2	D	None		2013			3.5	3.5	3.0	3.0	3.0	3.0	3.0	65.0	0.77
SDE	SDE	1a-4	C	C				2010	3.5	3.5	3.0	3.0	3.0	3.0	3.0	65.0	0.77
Coppe/UFRJ and Tractebel Energia	Clean Energy from Waves	1a-4	A/B	None			2012		2.0	3.0	3.5	3.5	3.0	3.0	3.5	64.5	0.77
Korean Ins. of Ocean Science and Tech.	KIOST	2b-1	E	None		2010			3.0	3.0	3.0	4.0	2.5	3.0	3.0	64.5	0.77
SeaNergy	Turbo Outburst Power/Top Desalination System	1a-2	F	F				2012	3.5	3.0	3.0	3.5	2.5	3.0	3.0	64.3	0.76

Table 2b WECs and company names presented by the EMEC's website as to 25th March 2015

Company (Continued)[2]	Device name (Continued)	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in	Cost of construction / Manufacturing	Installation	Maintenance/ Repair	Reliability	Survivability	Effectiveness/ Exploitation	Robustness/ Durability	Raw score	Relative score
Weight for assessment criteria (1 - 4)									3.0	1.0	2.0	3.5	4.0	4.0	3.5		
Daedalus Informatics Ltd.	Wave Energy Conversion Activator	3a-1	D	C	2013				2.0	2.0	3.5	3.0	3.0	3.0	4.0	63.5	0.76
eze - Sea Power Generator		1a-4	A/C	-		2013			3.0	3.5	3.0	3.0	3.0	3.0	3.0	63.5	0.76
Float Inc	Rho Cee	3b-1	D	B	-	2009	-	-	1.0	3.0	3.5	3.5	3.0	3.0	4.0	63.3	0.75
Trident Energy Ltd.	PowerPod Linear Generator Power	1b-1	B	B	2013				3.0	3.0	3.5	3.0	2.5	3.0	3.0	62.0	0.74
Aquamarine Power	Oyster 800	1a-3	C	C			2015		2.5	2.5	3.0	3.0	3.0	3.0	3.0	61.0	0.73
Hydrocap Energy SAS	Seacap	1a-1	B	B		2013			3.0	3.0	3.0	3.0	2.5	3.0	3.0	61.0	0.73
Marine Power Tech. Pty Ltd.	Energy Island	3b-1	D	None		2014			3.0	3.0	3.0	3.0	2.5	3.0	3.0	61.0	0.73
Resolute Marine Energy Inc	SurgeWEC	1a-3	C	C			2013		2.0	3.0	3.0	3.5	2.5	3.0	3.0	59.8	0.71
Aker Solutions ASA		1a-4	A/C	None		2014			3.5	3.5	3.0	3.0	2.5	3.0	2.0	59.5	0.71
Calvin College	Wave Powered Water Pump	1a-1	B	No data			2005		4.0	4.0	3.0	3.0	2.0	3.0	2.0	59.5	0.71
Resen Energy	Resen Waves LOPF buoys	1b-8	B/I	B/I				2013	3.5	3.5	3.0	3.0	2.0	3.5	2.0	59.5	0.71
IHC Tidal Energy	Wave Rotor (Floating)	2b-4	E!	I		2012			3.0	3.0	3.0	3.0	2.0	3.0	3.0	59.0	0.70
Marine Hydroelectric Company		1a-2	B	None		2006			2.0	2.0	3.0	3.0	3.0	3.0	3.0	59.0	0.70
Oceanlinx	ogWAVE (Remote control app.)	3b-1	D	D				2014	3.0	3.0	2.5	2.5	3.0	3.0	2.5	58.5	0.70
Lancaster University	WRASPA	1a-3	C	None		2006			3.0	3.0	3.0	3.0	2.0	3.0	2.5	57.3	0.68
Grays Harbor Ocean Energy Comp.	Titan Platform	3a-1	D	D	2009				3.0	3.0	3.0	3.0	2.0	2.5	3.0	57.0	0.68
Portsmounth Innovation Ltd.	WAVESTORE	2b-1	E	E		2012			3.0	3.0	3.0	3.0	1.5	3.0	3.0	57.0	0.68
BioPower Systems Pty Ltd	bioWave	1a-3	C	C/E			2015		1.5	3.0	3.0	2.5	3.0	2.5	3.5	56.5	0.67
Able Technologies LLC	Electric Generating Wave Pipe	1b-1	B	B		2009			3.0	2.0	3.0	3.0	2.0	3.0	2.5	56.3	0.67
Purenco AS	The Fisherman WEC	1a-1	B	B		2011			4.0	3.0	3.0	3.0	2.0	2.0	2.5	56.3	0.67
FOBOX AS	FO3	1b-1	B	D	-	2004	-	-	2.0	3.0	2.0	3.0	2.5	3.0	3.0	56.0	0.67
Ocean Motion International	OMI Combined Energy System	1b-1	B	B		2013			2.0	3.0	3.0	3.0	2.0	3.0	3.0	56.0	0.67
Euro Wave Energy		1a-1	B	B	2008	-	-	-	4.0	4.0	3.0	3.0	1.0	3.0	2.0	55.5	0.66

offshore/onshore wind development can move into deeper waters, further offshore.

All types of utilizing renewable energies in particularly combining offshore/onshore wind energy turbines with convenient wave energy converters protrude as an ideal solution which should be playing an increasingly important part in the energy landscape of industrialized nations

Table 2c WECs and company names presented by the EMEC's website as to 25th March 2015

Company (Continued)[3]	Device name (Continued)	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in	Cost of construction / Manufacturing	Installation	Maintenance/ Repair	Reliability	Survivability	Effectiveness/ Exploitation	Robustness/ Durability	Raw score	Relative score
Weight for assessment criteria (1 - 4)									3.0	1.0	2.0	3.5	4.0	4.0	3.5		
Group Captain SM Ghouse	FreeFloatingWEC	3a-3	D	A	2010				3.0	3.0	3.0	2.0	3.0	2.0	3.0	55.5	0.66
Ocean Wave and Wind Energy	OWWE Rig	2b-1	E	E	2005				2.5	3.0	3.0	3.0	1.5	3.0	3.0	55.5	0.66
Oceanlinx	blueWAVE	3b-1	D	D				2013	3.0	3.0	3.0	3.0	2.0	3.0	2.0	55.5	0.66
RTI Ocean Wave Energy	RTI Ocean WEC	3b-2	D	None		2013			3.0	3.0	3.0	3.0	1.5	3.5	2.0	55.5	0.66
AeroVironment Inc.	Eel Grass	1a-1	B	B	2013				3.0	3.0	3.0	3.5	1.5	3.0	2.0	55.3	0.66
AW Energy	WaveRoller	1a-3	C	C			2012		1.0	3.0	3.0	2.5	3.0	2.5	3.5	55.0	0.65
Ocean Energy Ltd.	Ocean Energy Buoy	3b-1	D	D		2010			3.0	3.0	3.0	3.0	1.0	3.0	3.0	55.0	0.65
Independent Natural Resources	SEADOG	1a-1	B	B			2007		3.5	3.0	3.0	2.5	2.0	2.0	3.0	54.8	0.65
Lancaster University	PS Frog	1b-6	H	B		2005			4.0	3.0	3.0	3.0	1.0	3.0	2.0	54.5	0.65
Wave Energy Tech. Inc.	WET EnGen	1a-1	B	B		2010			3.0	3.0	3.5	3.0	1.5	3.0	2.0	54.5	0.65
40 South Energy	R115	1b-4	B/F!	None				2013	2.5	3.0	3.0	3.5	2.5	2.5	1.5	54.0	0.64
Floating Power Plant	Poseidon-Wave wind hybrid	1b-5	A	A	-	2012	-	-	1.0	2.0	3.0	3.0	2.5	3.0	3.0	54.0	0.64
Pelagic Power AS	W2Power	1b-2	B	B		2009			2.0	3.0	2.5	3.0	2.0	3.5	2.0	53.5	0.64
Protean Energy Ltd.	Protean	1a-1	B	B		2013			3.0	3.0	3.0	3.5	1.0	3.5	1.5	53.5	0.64
WET-NZ New Zealand	WET-NZ Device	1b-8	A/B	B		2013			3.0	3.0	3.0	3.0	1.5	3.0	2.0	53.5	0.64
Limerick Wave Ltd.	Seapower Platform	1b-5	A	None		2013			3.0	3.0	3.0	3.0	1.0	3.0	2.5	53.3	0.63
Offshore Wave Energy Ltd (OWEL)	OWEL WEC	3b-1	D	C		2012			1.5	3.0	3.5	3.0	1.0	3.0	3.5	53.3	0.63
WavePlane Production	WavePlane	2b-1	E	E		2010			2.0	3.0	3.5	3.5	1.0	3.5	2.0	53.3	0.63
Atargis Energy Corporation	Cycloidal WEC (CycWEC)	2a-2	I	I		2012			2.5	2.0	3.0	3.0	1.0	3.0	3.0	52.5	0.63
Fred Olsen Co. Ghent U.	SEEWEC	1b-1	B	B	-	-	2009	-	4.0	3.0	3.0	3.0	1.0	2.5	2.0	52.5	0.63
OWC Power AS	OWC Power	3a-3	D	D			2014		3.0	3.0	2.5	3.0	1.5	3.0	2.0	52.5	0.63
SDK Marine	SDK Marine Wave Turbine	2b-1	E	D		2014			3.0	3.0	2.5	3.0	1.0	3.5	2.0	52.5	0.63
Norvento	Wavecat	2b-1	E	None	2008				3.0	3.0	2.5	3.0	1.0	3.0	2.5	52.3	0.62

and developing economies alike. However, delivering reliable and consistent electricity of renewable energy that can compete with conventionally-generated electricity is still the real

Table 2d WECs and company names presented by the EMEC's website as to 25th March 2015

Company (Continued)[4]	Device name (Continued)	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in	Cost of construction / Manufacturing	Installation	Maintenance/ Repair	Reliability	Survivability	Effectiveness/ Exploitation	Robustness/ Durability	Raw score	Relative score
Weight for assessment criteria (1 - 4)									3.0	1.0	2.0	3.5	4.0	4.0	3.5		
Wave Dragon	Wave Dragon	2b-1	E	E			2011		2.0	3.0	3.0	3.5	1.0	3.5	2.0	52.3	0.62
Aquagen Technologies	Surge Drive	1a-1	B	B	2011				3.0	3.0	3.0	3.0	2.0	3.0	1.0	52.0	0.62
ELGEN Wave	Horizon Platform	1b-1	B	B	2013	-	-	-	2.0	3.0	3.0	3.0	1.0	3.0	3.0	52.0	0.62
Etymol Ocean Power SpA	Etymol WEC Alpha Series	2b-2	G	I	-	-	2014	2022	2.0	3.0	2.0	3.0	2.0	2.5	3.0	52.0	0.62
Ocean Harvesting Techn. AB	Collector Hub System	1a-1	B	B	2013				2.5	3.0	3.0	3.0	1.5	3.0	2.0	52.0	0.62
Ocean Power Technologies	Autonomous Power Buoy	1b-1	B	B			2013		2.5	3.0	3.0	3.0	1.5	3.0	2.0	52.0	0.62
Wavetube		2b-3	E/B!	None		2013			3.0	3.0	3.5	3.0	1.0	2.0	3.0	52.0	0.62
Marine Power System	WaveSub	1b-4	B	B		2014			3.0	3.0	3.0	2.5	2.0	2.5	2.0	51.8	0.62
Seabased AB Wave Power Tech.	Linear Generator	1a-1	B	B			2015		3.0	3.0	3.0	3.0	1.5	3.0	1.5	51.8	0.62
Colombia Power Technologies	StingRAY	1b-8	A/B	A/B		2012		2016!	3.0	3.0	3.0	3.0	1.0	3.0	2.0	51.5	0.61
Hann-Ocean	Drakoo R	2b-1	E	B				2012	3.0	3.0	3.0	3.0	1.0	3.0	2.0	51.5	0.61
Sea Energies Ltd.		3b-1	D	None		2014			3.0	3.0	3.0	3.0	1.0	3.0	2.0	51.5	0.61
Snapper Consortium	Snapper	1a-1	B	B		2011			3.0	3.0	3.0	3.0	1.0	3.0	2.0	51.5	0.61
University of Edinburgh	Salter's Duck	1b-8	A/C	A		1980			3.0	3.0	3.0	3.0	1.0	3.0	2.0	51.5	0.61
Embley Energy Ltd	Sperboy	3b-1	D	B/D	-	2001	-	-	1.5	2.0	3.0	3.0	1.0	3.0	3.5	51.3	0.61
Havkraft	Evolver (Havkraft WEC)	3a-1	D	D	2013				1.5	2.0	3.0	3.0	1.0	3.0	3.5	51.3	0.61
Marine Energy Corporation	Wave Catcher Barge	1b-2	B/I	B/I	2013				3.0	3.0	3.0	2.5	1.0	2.5	3.0	51.3	0.61
Seawood Designs Inc.	SurfPower	1a-1	B	B		2012			3.5	3.0	3.0	3.0	1.5	2.5	1.5	51.3	0.61
Caley Ocean Systems	Wave Plane	2b-1	E	I			2013		3.0	3.0	3.0	3.0	1.0	2.0	3.0	51.0	0.61
Gyrodynamics Co Ltd.		1b-6	H	None		2008			3.0	3.0	3.0	3.0	1.0	2.0	3.0	51.0	0.61
GyroWaveGen	GyroWaveGen	1b-6	H	I		2013			3.0	3.0	3.0	3.0	1.0	2.0	3.0	51.0	0.61
Motor Wave	Motor Wave	1b-5	A	B		2006			4.0	4.0	2.5	2.5	1.0	2.5	2.0	50.8	0.60
Wello OY	Penguin	1b-6	H	H			2014		1.0	3.0	3.0	3.0	1.5	2.5	3.5	50.8	0.60

challenge.

Up to now, no system of wave energy technology appears to be dominant unlike the wind energy turbines. From the technological state of the art, development and applications as well as economic trends, the conditions are similar to wind energy technologies in the 1980s (EMEC, 2015). Except for in a small number of cases, there is no experience of maintenance, reliability and survivability under extreme conditions in open-seas for more than one year. The most advanced technologies are still before the pre-commercial stage, because the design and development of a wave energy system is too complex and detailed. Only through a staged project development approach, where actual performance and operation of a device is measured and observed experimentally in a sufficiently large scale and in a sufficiently long term as well as where complete system designs are developed, built and tested, both the device and its actual costs of energy obtained can be assessed much more precisely.

Table 2e WECs and company names presented by the EMEC's website as to 25th March 2015

Weight for assessment criteria (1 - 4)									3.0	1.0	2.0	3.5	4.0	4.0	3.5		
Company (Continued)[5]	Device name (Continued)	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in	Cost of construction / Manufacturing	Installation	Maintenance/ Repair	Reliability	Survivability	Effectiveness/ Exploitation	Robustness/ Durability	Raw score	Relative score
Aqua-Magnetics Inc.	Electric Buoy	1b-1	B	B		2012			4.0	3.0	3.0	3.0	1.0	2.0	2.0	50.5	0.60
Del Buoy	D. B. Wave Powered Desalination	1b-1	B	B	-	-	-	1989	4.0	3.0	2.0	3.0	1.0	2.5	2.0	50.5	0.60
DEXAWAVE A/S	DEXAWAVE Convertor	1b-5	A	A	-	2011	-	-	3.0	4.0	3.0	3.0	1.0	2.5	2.0	50.5	0.60
Ecotricity	Searaser	1a-1	B	B		2014			2.0	3.0	3.0	3.5	1.0	3.5	1.5	50.5	0.60
G Edward Cook	Syphon Wave Genertator	2b-1	E	A		2008			4.0	3.0	3.0	3.0	1.0	2.0	2.0	50.5	0.60
G Edward Cook	Floating Wave Genertator	1b-5	A	F		2007			4.0	3.0	3.0	3.0	1.0	2.0	2.0	50.5	0.60
Greencat Renewables	Wave Turbine	1b-5	A	A		2013			4.0	3.0	2.0	3.0	1.0	2.5	2.0	50.5	0.60
Ocean Electric Inc.	Wave Platform	1b-1	B	B	2014				2.0	3.0	2.0	2.5	2.0	2.5	3.0	50.3	0.60
Seatricity		1a-1	B	B			2015		3.0	3.0	3.0	3.0	1.5	3.0	1.0	50.0	0.60
Chinese Academy of Science (GIEC)	Floating Duck	1b-4	A	A			2012		3.0	3.0	2.0	2.5	1.5	3.0	2.0	49.8	0.59
PerpetuWave Power Pty Ltd.	Hybrid Float	1b-4	A	A		2013			3.0	3.0	3.0	2.5	1.5	2.5	2.0	49.8	0.59
Sea Carpet		1a-2	F	No data		2014			2.5	2.5	3.0	3.0	1.5	3.0	1.5	49.8	0.59
Waveberg Development	Waveberg	1b-5	A	A			2012		3.0	3.0	3.0	3.0	1.0	3.0	1.5	49.8	0.59
Atmocean Wave Energy	Atmocean	1b-1	None	None				2016	3.0	3.0	2.0	3.0	1.0	3.0	2.0	49.5	0.59

Table 2e Continued

Company (Continued)[5]	Device name (Continued)	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in	Cost of construction / Manufacturing	Installation	Maintenance/ Repair	Reliability	Survivability	Effectiveness/ Exploitation	Robustness/ Durability	Raw score	Relative score
Weight for assessment criteria (1 - 4)									3.0	1.0	2.0	3.5	4.0	4.0	3.5		
Blue Power Energy		1a-1	B	B		2014			3.5	3.0	3.0	3.0	1.0	3.0	1.0	49.5	0.59
FlanSea	Wave Pioneer	1a-1	B	B	-	2013	-	-	3.0	3.0	3.0	3.0	1.0	2.5	2.0	49.5	0.59
Sea Power Ltd.	Sea Power Platform	1b-5	A	A		2014			3.5	3.0	3.0	3.0	1.0	3.0	1.0	49.5	0.59
Sea Wave Energy Ltd (SWEL)	Waveline Magnet	1b-5	A	I		2014			3.5	3.0	3.0	3.0	1.0	3.0	1.0	49.5	0.59
Seavolt	Wave Rider	1a-1	B	No data	2007				3.5	3.0	3.0	3.0	1.0	3.0	1.0	49.5	0.59
VERT Labs		1b-1	B	None		2012			3.0	3.0	3.0	3.0	1.0	2.5	2.0	49.5	0.59
SARA Inc.	MHD WE Conversion	1a-1	B	I		2008			3.5	3.0	3.0	3.0	1.0	2.5	1.5	49.3	0.59
Applied Technologies Company	Float Wave Electric Power Station	1b-1	B	B		2011			3.5	3.0	3.0	3.0	1.0	2.0	2.0	49.0	0.58
AWS Ocean Energy	AWS III	3b-2	D	E		2011			2.5	3.0	3.5	3.0	1.0	2.5	2.0	49.0	0.58

Table 2f WECs and company names presented by the EMEC's website as to 25th March 2015

Company (Continued)[6]	Device name (Continued)	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in	Cost of construction / Manufacturing	Installation	Maintenance/ Repair	Reliability	Survivability	Effectiveness/ Exploitation	Robustness/ Durability	Raw score	Relative score
Weight for assessment criteria (1 - 4)									3.0	1.0	2.0	3.5	4.0	4.0	3.5		
Brandl Motor	Brandl Generator	1b-1	B	B	2007				3.5	3.0	3.0	3.0	1.0	2.0	2.0	49.0	0.58
Fred Olsen Ltd	The B1 Buoy	1b-1	B	A	-	2008	-	-	4.0	3.0	3.0	2.0	1.0	2.5	2.0	49.0	0.58
Fred Olsen Ltd	Wavehub	1b-1	B	None	-		2014	-	4.0	3.0	3.0	2.0	1.0	2.5	2.0	49.0	0.58
Pure Marine	DUO WEC	1b-1	B	None		2012			3.0	3.0	2.5	3.0	1.0	3.5	1.0	49.0	0.58
Spindrift Energy	Spindrift Energy Device	2b-1	B	B		2011			3.5	3.0	3.0	3.0	1.0	2.0	2.0	49.0	0.58
Bombora Wave Power	Bombora	3a-2	D!	F		2015			2.5	2.5	2.5	2.5	2.0	2.5	2.0	48.8	0.58

Table 2f Continued

Company (Continued)[6]	Device name (Continued)	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in	Cost of construction / Manufacturing	Installation	Maintenance/ Repair	Reliability	Survivability	Effectiveness/ Exploitation	Robustness/ Durability	Raw score	Relative score
Weight for assessment criteria (1 - 4)									3.0	1.0	2.0	3.5	4.0	4.0	3.5		
Laminaria	Laminaria	1a-3	C	None		2012			3.0	3.0	2.5	2.5	2.0	2.0	2.0	48.8	0.58
Chinese Academy of Science (GIEC)	Eagle	1b-5	A	A			2014		3.0	3.0	2.5	2.5	1.5	2.5	2.0	48.8	0.58
Avium AS	Yeti Cluster System	1b-6	I/H	I			2014		2.0	3.0	3.0	3.0	1.0	3.0	2.0	48.5	0.58
Fred Olsen Ltd	BOLT Lifesaver	1b-1	B	None	-		2012		2.0	3.0	3.0	3.0	1.0	3.0	2.0	48.5	0.58
KN Ocean Energy Science&Development	KNSWING	3b-1	D	None		2013			2.0	3.0	3.0	3.0	1.0	3.0	2.0	48.5	0.58
OWEC Ocean Wave Energy Company	OWEC Ocean WEC	1a-1	B	B		2013			2.5	3.0	3.0	2.0	1.5	3.0	2.0	48.5	0.58
Orecon Ltd.	MRC Orecon	3b-1	D!	No data			2011		1.0	2.0	3.0	3.5	1.0	3.5	2.0	48.3	0.57
Aker Solutions ASA		1b-7	A/C	None		2014			3.0	3.0	3.0	3.0	1.0	3.0	1.0	48.0	0.57
CorPower Ocean AB	CPO2	1b-1	B	B	2012				3.0	3.0	3.0	3.0	1.0	3.0	1.0	48.0	0.57
M4 Wave Power	M4	1b-5	A	None		2014			3.0	3.0	3.0	3.0	1.0	3.0	1.0	48.0	0.57
Ocean Wave and Wind Energy	Wave Pump Rig	1b-1	B	B		2001			2.5	3.0	3.0	3.0	1.0	2.5	2.0	48.0	0.57
Seamax Energy	Triton	1a-1	B	I		2012			3.0	3.0	3.0	3.0	1.0	3.0	1.0	48.0	0.57
The CyanWave WEC	CyanWave4	2b-1	E	None		2013			2.0	2.5	3.0	3.0	1.0	3.0	2.0	48.0	0.57
Martifer Energia	FLOW FutureLife in OceanWaves	1b-5	A	A		2010			3.0	3.0	2.0	2.5	1.0	3.0	2.0	47.8	0.57
Renewable Energy Pumps		1a-1	B	B	2013				3.0	3.0	3.0	3.0	1.0	2.5	1.5	47.8	0.57
Tecnalia	PSE-MAR	1b-6	A	A		2011		2013!	3.0	3.0	3.0	3.0	1.0	2.5	1.5	47.8	0.57
Balkee Tide and Wave Electricity Generator	TWPEG	1b-1	B	C/E	2010				3.0	3.0	3.0	3.0	1.0	2.0	2.0	47.5	0.57

Table 2g WECs and company names presented by the EMEC's website as to 25th March 2015

Company (Continued)[7]	Device name (Continued)	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in	Cost of construction / Manufacturing	Installation	Maintenance/ Repair	Reliability	Survivability	Effectiveness/ Exploitation	Robustness/ Durability	Raw score	Relative score
Weight for assessment criteria (1 - 4)									3.0	1.0	2.0	3.5	4.0	4.0	3.5		
eze - Offshore Sea Power Generator		1b-7	A/C	-	2010				2.5	3.0	2.5	3.0	1.0	3.5	1.0	47.5	0.57
Joules Energy Efficiency Services Ltd.	Wave Train	1b-1	B	D		2013			3.0	2.5	3.0	3.0	1.0	3.0	1.0	47.5	0.57
Ocean Rus Energy	Ocean 3 / 160 7 640	1b-6	H	H				2013	4.0	4.0	3.0	3.0	1.0	1.0	2.0	47.5	0.57
Tremont Electric	nPower WEC	1b-1	B	B	2011				3.0	3.0	3.0	3.0	1.0	2.0	2.0	47.5	0.57
Alba TERN	Squid	1b-1	B	A		2014			2.5	3.0	2.5	3.0	1.0	3.0	1.5	47.3	0.56
Ecle Centarle de Nantes	SEA REV	1b-6	H	D	-	-	2010	-	3.0	4.0	2.0	2.0	2.0	2.0	2.0	47.0	0.56
Ecomerit technologies Centipod		1b-5	A	A	2010	-	-	-	3.0	4.0	3.0	3.0	1.0	2.5	1.0	47.0	0.56
Indian Wave Energy Device	IWAVE	1b-1	B	B	2007				3.0	2.5	3.0	2.5	1.0	2.0	2.5	47.0	0.56
Pelamis Wave Power	Pelamis	1b-5	A	A				2008!	1.0	3.0	2.0	3.5	1.0	3.0	2.5	47.0	0.56
Navatek Ltd.	Navatek WEC	1b-5	A	A		2007			3.0	3.0	2.5	2.5	1.0	2.5	2.0	46.8	0.56
WaveBob Ltd.	WaveBob	1b-1	B	B			2012		2.0	3.0	3.0	3.0	1.0	3.0	1.5	46.8	0.56
Langlee Wave Power	Langlee System	1b-8	C	C			2013		2.0	3.0	2.0	3.0	1.0	3.0	2.0	46.5	0.55
SRI International	Electroactive polymer artificial muscle tech.	1b-1	B	I		2007			3.0	3.0	3.5	3.0	1.0	1.5	2.0	46.5	0.55
Ocean Harvesting Technologies AB	Ocean Harvester	1a-1	B	B		2010		2016	4.0	4.0	3.0	2.0	1.0	2.0	1.5	46.3	0.55
Kinetic Wave Power	PowerGin	2b-1	E	E		2008			3.0	3.0	3.0	2.0	1.0	2.5	2.0	46.0	0.55
Waves 4 Power	WaveEL-Buoy	1b-1	B	B			2012		3.0	3.0	3.0	2.5	1.0	2.5	1.5	46.0	0.55
HidroFlot SA	Hidroflot	1b-1	B	B		2007			2.0	3.0	2.5	2.5	1.0	3.0	2.0	45.8	0.54
Korean Ins. of Ocean Science and Tech.	KIOST	1b-3	C	None		2013			3.0	3.0	2.0	2.5	1.0	2.5	2.0	45.8	0.54
Oceantec Energias Marinas SL	Oceantec Energy Convertor	1b-6	A	H		2008			3.0	3.0	3.0	2.5	1.0	2.0	2.0	45.8	0.54
PolyGen Ltd.	Volta WaveFlex	1b-3	C	C		2014			3.0	3.0	3.0	2.5	1.0	2.0	2.0	45.8	0.54
Carnegie Wave Energy Ltd.	CETO 5	1a-1	B	B			2014		1.5	3.0	3.0	3.0	1.0	3.0	1.5	45.3	0.54
Waveenergyfyn	Crestwing	1b-5	A	A		2009			3.0	3.0	2.5	2.5	1.0	3.0	1.0	45.3	0.54
Pontoon Power	Pontoon Power Converter	1b-1	B	A		2012			3.0	3.0	1.5	2.0	1.5	2.5	2.0	45.0	0.54

Table 2h WECs and company names presented by the EMEC's website as to 25th March 2015

Company (Continued)[8]	Device name (Continued)	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in	Cost of construction / Manufacturing	Installation	Maintenance/ Repair	Reliability	Survivability	Effectiveness/ Exploitation	Robustness/ Durability	Raw score	Relative score
Weight for assessment criteria (1 - 4)									3.0	1.0	2.0	3.5	4.0	4.0	3.5		
Waves Ruiz		1b-7	C	None		2014			3.0	3.0	2.5	2.5	1.0	2.5	1.5	45.0	0.54
Innova Foundation	Penwest	1b-6	H	None		2013			3.5	3.0	2.5	3.0	1.0	2.0	1.0	44.5	0.53
Colombia Power Technologies	Direct Drive Rotary WEC	1b-8	A/B	None		2011			2.0	2.5	2.0	3.0	1.0	3.0	1.5	44.3	0.53
Intentium AS	Intentium Offshore WEC	1b-1	B	I			2012		3.0	3.0	2.0	2.5	1.0	3.0	1.0	44.3	0.53
Wave Energy Technology New Zealand		1b-8	A/B	B		2013			2.5	3.0	3.0	2.5	1.0	2.0	2.0	44.3	0.53
Norwegian University of Science and Technology	CONWEC	1a-1	B	B		2000			3.0	3.0	2.0	3.0	1.0	2.5	1.0	44.0	0.52
PIPO Systems	APC-PISYS	1a-1	B	None		2012			2.0	3.5	2.5	2.0	1.0	3.5	1.0	43.0	0.51
Vigor Wave Energy AB	Vigor WEC	2b-2	G	A		2014			2.5	3.0	3.0	2.5	1.0	2.0	1.5	42.5	0.51
Ocean Energy Indusries Inc.	WaveSurfer	1b-1	B	B			2012		3.0	3.0	2.0	2.5	1.0	2.5	1.0	42.3	0.50
Joules Energy Efficiency Services Ltd.	TETRON	1b-1	B	B		2007			4.0	3.0	2.0	2.0	1.0	2.0	1.0	41.5	0.49
Lancaster University	Seaweaver	1a-3	C	None		2010			3.0	2.5	2.0	2.0	1.0	2.0	2.0	41.5	0.49
Nualgi Nanobiotech	Rock n Roll WE Device	1b-4	A/B	A/B	2013				3.0	3.0	2.5	2.0	1.0	2.5	1.0	41.5	0.49
Weptos	WEPTOS WEC	1b-8	C/I	I			2015		2.0	3.0	2.0	2.5	1.0	3.0	1.0	41.3	0.49
Leancon Wave Energy	Multi Absorbing WEC	3b-1	D	D		2008			2.0	3.0	2.0	2.5	1.0	2.5	1.5	41.0	0.49
Grey Island Energy Inc.	SeaWeed	1b-5	A	None		2014			2.0	3.0	2.0	2.5	1.0	2.0	2.0	40.8	0.49
Oscilla Power Inc.	Magnetostrictive WE Harvester	1b-1	B	B			2014		2.5	3.0	3.0	2.5	1.0	2.0	1.0	40.8	0.49
Checkmate Seaenergy UK Ltd.	Anaconda	2b-2	G	G		2012			3.0	3.5	3.0	2.5	1.0	1.0	1.5	40.5	0.48
Marine Energy Corporation	Wave Catcher with round pontons	1b-2	B/I	B/I	2012				3.0	3.0	2.0	2.0	1.0	2.5	1.0	40.5	0.48
Yu Energy Corp.	Yu Oscillatting Generator (YOG)	1a-3	C	C	2009				3.0	3.0	2.0	2.0	1.5	2.0	1.0	40.5	0.48
Sigma Energy	MD wave power converting device	1b-1	B	None		2013			3.0	3.0	2.0	2.5	1.0	2.0	1.0	40.3	0.48
Jospa Ltd.	Irish Tube Compressor	2b-2	G/D	I		2010			4.0	3.0	3.0	2.0	1.0	1.0	1.0	39.5	0.47
WavePiston	WavePiston	1b-3	A!	A		2013			3.0	3.0	2.5	2.0	1.0	1.5	1.5	39.3	0.47
Kneider Innovations	Wave Energy Propulsion	1b-5	A	A		2005			4.0	4.0	2.0	2.0	1.0	1.0	1.0	38.5	0.46

Table 2i WECs and company names presented by the EMEC's website as to 25th March 2015

Weight for assessment criteria (1 - 4)									3.0	1.0	2.0	3.5	4.0	4.0	3.5		
Company (Continued)[9]	Device name (Continued)	New Classification	Revised Classification of EMEC	Classification of EMEC	In design stage since	At small scaled model testing stage in	At full scaled prototype testing stage in	At commercializing stage in	Cost of construction / Manufacturing	Installation	Maintenance/ Repair	Reliability	Survivability	Exnloitation Effectiveness/	Robustness/ Durability	Raw score	Relative score
Ocean Hyropower Systems Ltd.	OHS Wave Energy Array	1b-1	B	B			2014		3.0	3.0	2.0	2.0	1.0	2.0	1.0	38.5	0.46
Wind Waves and Sun	WaveBlanket	3b-2	D!	I	2007				3.0	3.0	3.0	2.0	1.0	1.5	1.0	38.5	0.46
Phil Pauley Innovation	Solar Marine Cells	1b-1	B	I	2011				2.0	3.0	2.0	2.0	1.0	2.5	1.0	37.5	0.45
Costas Wave	Costas Wave	2b-3	E!	E	2013				2.0	3.0	2.0	2.0	1.5	1.5	1.5	37.3	0.44
Yu Energy Corp.	Yu Oscillatting Generator (YOG)	1b-3	C	C	2009				3.0	3.0	1.0	1.5	1.0	2.0	1.0	34.8	0.41
Greenheat Systems Ltd.	Gentech WaTS	1b-5	D	I	2014				1.0	1.0	2.0	1.5	1.0	1.0	2.0	28.3	0.34
Abengoa Seapower		None	None	None					No data	0.00							
Acubens	REWAB	None	None	None					No data	0.00							
Alistair McCaskill		3b-1&2	None	None	2014				No data	0.00							
College of the North Atlantic	SARAH Pump	1b-1	B	F		2006			No data	0.00							
Vortex Oscillation Technology Ltd.	Vortex Oscillation Technology	2a!	!	A	2005				Unintelligible	0.00							

3. Conclusions

Hitherto, wave energy is the only renewable energy source that is not commercially exploited. In terms of converters and their PTO systems, numerous designs and concepts exist and most are in the early development stage with limited knowledge concerning the actual costs and expenses and/or ability to operate and survive in the harsh environment of oceans and seas.

Furthermore, the systems of the WECs can be very complex in design, non-linear in performance and include numerous costs and/or legal uncertainties such as grid integration and legal processes as well as permissions. In real sea conditions, the predictions of numerical energy analyses on capacity factors of the WECs can be out by over 40%. Until prototypes have been designed, built and tested for a sufficiently long time, one does not know the true cost of energy obtained nor able to reliably forecast methods of cost reduction.

Investments are going prevailingly in the direction of the Type 1b-1 and 1a-1, the floating and tethered buoys, as well as the floating articulated systems of the Type 1b-5 and secondly to the floating overtopping devices 2b-1 and floating OWC devices 3b-1. In the short term, the following recommendations should be mentioned:

• Point absorbers and attenuators as well as wave surge converters (Type 1a-1~4 and 1b-1~8), which should be designed and produced as simple and as cost-efficient as possible, should be deployed in onshore/foreshore locations by keeping most of the costly electrical components on land.

• Marine structures such as caisson breakwaters and other similar costal and harbor protection consructions can be combined with energy production systems from waves using the technology of solid body motion (Type 1a-1~4) and the oscillating water column with air turbines (Type 3a-1~3). This is to be carried out in coastal areas of low wave energy content.

• The WECs above-mentioned can be utilized by pumping the seawater into a coastal reservoir at a suitable height above the calm water level, running through a channel into a hydropower turbine (Type 1a-1~4, Type 1b-1~8 and Type 2a-1~2).

• Furthermore it would be appropriate to build and install sufficiently large overtopping devices with low pressure turbines and oscillating water column converters with air turbines at coastal areas (Type 2a-1~2, and 3a-1~3) or to deploy near shore (Type 2b-1~4 and 3b-1~2); they are especially applicable where the population density and industrialization level is low, e.g in SH.

• For providing extensive exploitation of wave energy, large farms of the WECs should be planned as is the case in other energy systems like wind energy, in other words considering "economy-of-scale effect".

• Combining the WECs as much as possible with onshore/offshore wind power plants should be carried out intensively.

The traditional wave power companies are still challenged with obtaining a continuous power supply, and it seems that existing technology does not have the ability to reach high energy conversion rates and therefore cannot become competitive with burning fossil fuels yet especially at these current low oil prices.

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