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Wave Resources of the Pacific Region for Small-scale Developments

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ABSTRACT

The international focus for development of wave and tidal energy technologies has been principally on large-scale (MW) devices and grid-connected utility-scale arrays. However, the Pacific Islands present many opportunities for smaller-scale (kW) stand-alone developments. Potential sites for deployment can be identified based upon island populations and evaluation of resources at specific sites. The benefits of ocean energy generation being developed at this scale could be significant for many island economies and justifies further research to marry small-scale generation technologies to specific resources and markets.

KEY WORDS:

Wave energy; small-scale developments, electricity generation; energy demand; Pacific Islands.

INTRODUCTION

The Pacific Islands offer potential sites for marine energy project developments, which will differ in scale and scope from projects currently active elsewhere in the world. The Pacific region offers the potential for wave, tidal current and ocean thermal energy conversion (OTEC). This paper focuses on the potential and characteristics for wave energy conversion projects. Pacific Island projects are likely to be smaller, may be stand-alone (as opposed to grid-connected) and may require fewer wave energy converters and/or units of smaller capacity.

Key drivers for successful projects will be device efficiency (wave-to-wire) and economies of scale. Presently isolated island communities must pay very high unit prices for electricity from other forms of electricity generation, particularly stand-alone diesel generation. In part these high prices arise because of the requirement to convert the wave energy to electricity through a series of processes with attendant losses at each energy conversion stage. Greater efficiency may be achieved by using wave power for other purposes, in which there are fewer conversions of energy and thus fewer systemic losses.

Such systems might include:

1. Converting wave energy directly for pumping, rather than electricity generation
2. Using seawater for air conditioning, i.e., seawater-based air conditioning or SWAC (see Lombard *et al.,* 2009; Gautret *et al.,* 2009)
3. Production of potable or mineral water
4. Aquaculture applications

Presently there are no commercially available wave energy technologies and there has certainly not been any convergence to a single design (Falcão, 2009; US DoE, 2011). This arises in part because there are number of different forms of ocean energy (wave, tidal range, tidal and ocean current, ocean thermal energy conversion and osmotic power. Depending on classification there are between three and seven different generic ways of extracting power from waves (Falcão, 2009; EMEC, 2011). It is difficult to quantify the number of devices actively under development but it must exceed 60 different wave device designs.

Most wave energy technology developers are focusing on development of electricity generation units, which will be of utility-scale - 1 MW per unit, e.g., Vlaeminck, 2007. Most are presently testing prototype devices, which are smaller, and few large-scale devices have been tested to date. Still others are focusing on devices, which are smaller (e.g., SwellFuel, www.swellfuel.com) or which can convert wave energy for pumping, rather than electricity generation (e.g., CETO, www.carnegiecorp.com.au). These devices - smaller generation/pumping units – may be most appropriate in island settings. To provide projects of sufficient scale, the number of generation/pumping units required in an array may still be high (20 – 50) but this should provide redundancy. Projects located off island coasts remote from servicing facilities will benefit from such redundancy since an array can maintain supply at a required level without major incremental losses. Furthermore, larger numbers of small units may provide better quality electricity in stand-alone applications or when supplying into island networks. Smaller systems may also be preferable from the perspective of issues relating to competition for space, particularly traditional fishing grounds, and managing environmental effects.

Some Pacific Islands governments have recognized the potential of such renewable energy. For instance, the government of Hawaii has established targets for electricity generation from renewable energy sources (Hawaii: 20% by 2020; Kaya et al., 2009). Other islands have set electricity self-sufficiency targets with electricity generation to come entirely from renewable sources, e.g., such as Reunion in the Indian Ocean by 2030 (Gautret *et al.*, 2009).

However, most Pacific island nations usually comprise a number of isolated islands with few, if any, inter-island grid connections (e.g., Hawaii; Kaya et al., 2009). Consequently, each island may require a stand-alone generation system – of limited capacity – to service each island.

Even though they may be rich in renewable energy resources including geothermal energy (Ásmundsson, 2008) and marine energy (Binger, 2004), many Pacific Islands also have historically high dependence on expensive imported fossil fuels combined with hot climates. With the exception of Papua New Guinea, no Pacific Islands have indigenous petroleum resources and few have hydropower potential of a scale relevant to their populations (PIFS, 2010). Energy supply security is threatened by international oil and gas price fluctuations due to limited bulk storage facilities.

Markets are small, very thin and individually variable. Fully 70% of the regional population has no electricity supply, although access ranges from 10% to 100%. A high proportion of the islands only produce electricity from diesel generation, although some have potential for, but not currently generation from, bioenergy, solar energy, geothermal energy, as well as wave energy, tidal current energy and OTEC.

Island economies often pay very high prices for electricity, compared with mainland economies. For example, the unit cost of mainland New Zealand retail electricity is about NZ$ 0.25-0.30/kWh, whilst on the Chatham Islands (800 km east of the South Island), the cost is approximately 3-4 times higher (MED, 2010). This problem is characteristic of the Pacific Islands, where there are few operational alternatives to diesel generation.

The nature of electricity use in these markets can also be a problem. Air conditioning can consume up to 40% of electricity demand (Lombard et al., 2009). These factors could be potentially offset and managed by judicious use of wave energy.

Whilst this paper focuses on wave energy resources, the authors also recognize that tidal current energy and OTEC will, in time, become economic energy conversion options for Pacific Island nations (see Nihous, 2009; Nihous *et al.*, 2009).

BACKGROUND

Most Pacific Islands, with rare exceptions, have small land areas, often with limited natural resources and limited space for onshore renewable energy projects, such as location of wind turbine generators. Access to land and customary uses can be problematic for onshore projects. However, Pacific Island nations frequently control very large marine exclusive economic zones (EEZs), which have provided sustaining industries in fishing and aquaculture (Table 1). The relative size of these EEZs thus justifies consideration of the opportunities for harnessing, even the nearshore energy in these zones.

In this study we have concentrated on three different island groups: the Fiji Islands, French Polynesia and the Chatham Islands east of New Zealand to demonstrate different aspects of the resource and thus the energy supply options.

Table 1. Land and Exclusive Economic Zones.

Island	Land Area (km^2)	Exclusive Economic Zone (km^2)
Fiji	18,274	1,300,000
French Polynesia	3,827	4,767,242
Chatham Islands	970	Part of NZ's EEZ (4,400,000)

*Sources: Fiji (CIA, 2011); French Polynesia (Sea Around Us, 2011); Chatham Islands (CIC, 2011); New Zealand (MfE, 2011).

Many islands are volcanic-centred atolls, which have very deep water immediately offshore. Wave energy projects, unless fully floating, are thus likely to be located near to the shore, as electricity export cable costs and mooring costs would rise steeply with increasing water depth. To date almost all proposed wave energy converters are expected to require some form of seabed mooring for station-keeping, even if their converters are floating. As a result, there is likely to be a much more limited offshore opportunity than might at first appear.

WAVE RESOURCES & BATHYMETRY

Most South Pacific Islands have very good wave resources. Wave energy generated in high latitudes propagates toward the equatorial regions with relatively low losses from friction or topographical sheltering by landmasses. Accordingly, the best wave resources are typically found on the southern or southwestern margins of the islands groups. Because of the long fetch, the wave regime tends to be quite consistent, albeit with a strong seasonal modulation. The highest energy occurs during the austral winter (see Table 2).

Table 2. Wave climate statistics for exposed sites offshore of the three island groups.

Hs (m)	Fiji (177 E, 19 S)		Tahiti (210 E, 19 S)		Chatham (183 E, 44.5 S)	
	Mean	P95	Mean	P95	Mean	P95
Jan	1.72	2.55	1.77	2.51	2.54	4.54
Feb	1.80	2.68	1.92	2.69	3.08	5.17
Mar	2.09	3.13	2.06	2.97	2.98	5.05
Apr	2.42	3.54	2.57	4.02	3.89	7.90
May	2.18	3.33	2.61	4.19	3.62	6.75
Jun	2.63	4.11	2.65	4.22	3.77	6.88
Jul	2.54	3.86	2.52	3.81	3.52	6.50
Aug	2.42	3.70	2.31	3.69	3.52	5.75
Sep	2.24	3.37	2.41	3.96	3.36	5.61
Oct	2.05	3.16	2.18	3.63	3.17	5.52
Nov	1.97	2.91	1.93	2.88	2.93	5.07
Dec	1.87	2.63	2.07	3.14	2.68	4.81

Note: The monthly mean significant wave height (Hs) is provided, along with the 95th percentile non-exceedence level (P95). Source: MetOcean Solutions Ltd.

A comparison of the bathymetry of the three island groups (Fiji, French Polynesia and the Chatham Islands) demonstrates the differences of the potential supply options. The low-latitude island groups (i.e., Fiji and Tahiti) are atolls, characterized by an abrupt ascent of the landmass from the abyssal depths, while the Chatham Islands example is underlain by a continental shelf. The geological setting has an important effect on both the wave climate and the manner in which the wave energy resources can be harnessed. The bathymetry for each of the island groups is presented in Figures 1-3.

The atoll morphology allows wave energy from deepwater to approach the shore (or reef edge) with relatively little transformation or attenuation. This is beneficial in terms of the energy flux, but also means that often only a narrow section of the island margin can be utilized. Indeed, the steep sides of some atolls will not provide a suitable environment for the mooring wave energy converters. However, the proximity of the reef edge to the abyssal depths does allow other opportunities to be developed that use wave energy, such as pumping cold saline water to the surface for salt-water air conditioning applications or OTEC.

An island setting within the continental shelf morphology typically allows more options for energy conversion, as the area of seabed within accessible depths is much greater. However, the wave energy flux is significantly attenuated across the shelf, and for a shore-attached device the wave resource is ultimately constrained by the adjacent offshore bathymetry.

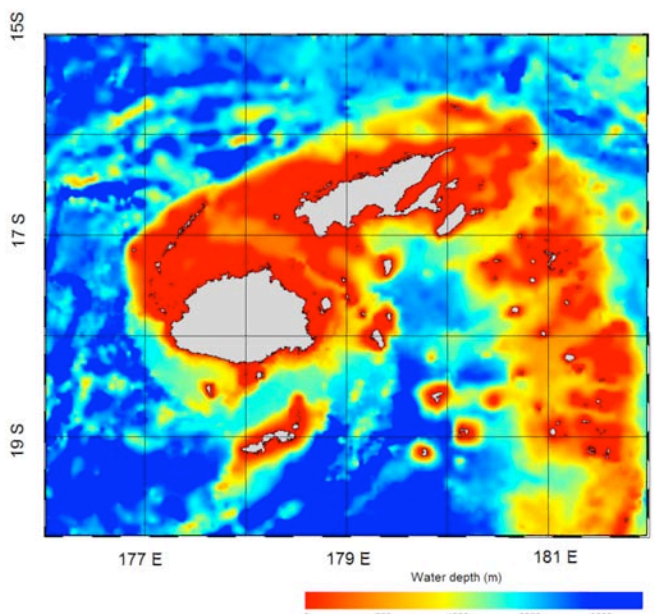

Figure 1. Bathymetry of the Fiji Islands

The energy resources for these three South Pacific island groups are contrasted in the following sections. The wave energy resource has been defined from various multi-year high-resolution numerical wave hindcasts (see www.metocean.co.nz/hindcast for details).

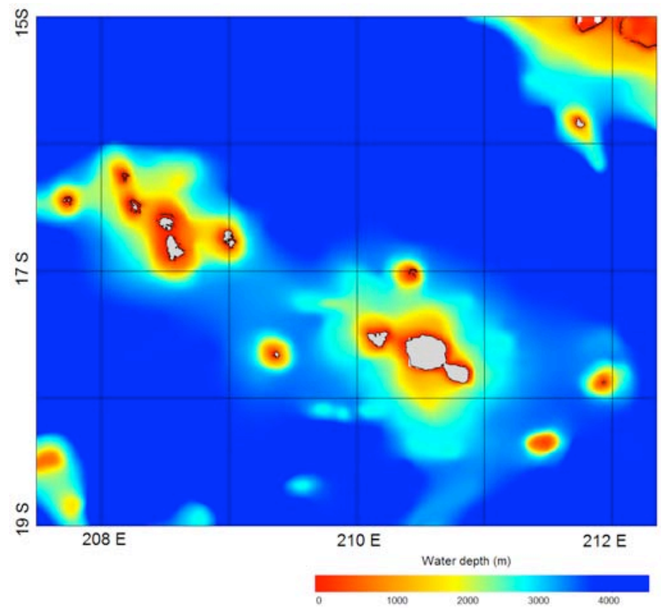

Figure 2. Bathymetry of French Polynesia

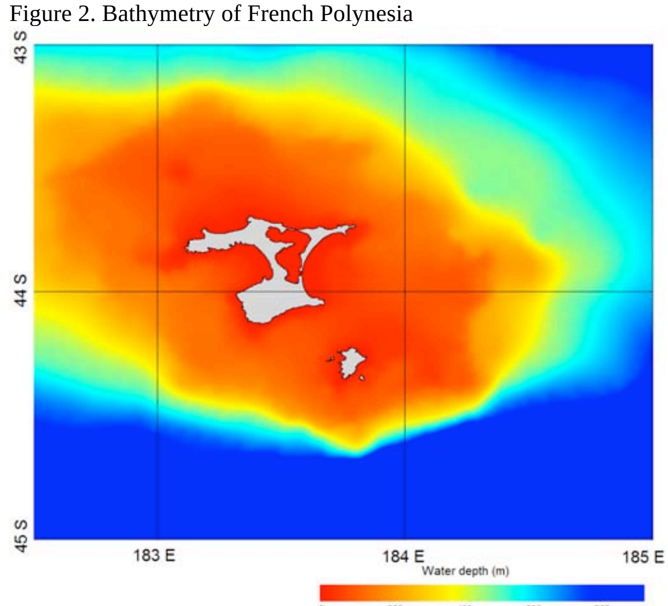

Figure 3. Bathymetry of the Chatham Islands

Note: Figures 1 – 3 are not to the same horizontal or depth scales

Fiji Islands

A summary map of the mean annual significant wave height for the Fiji islands is provided in Figure 4. The wave height map indicates the southern coast receives slightly larger waves than the northern aspects, but the northern coast is exposed to locally generated sea and storm conditions.

However, when the wave energy flux is examined, it is evident that the southern coast receives considerably more energy, typically far-field swells generated in the high latitudes (Figure 5). The hindcast indicates a mean annual wave power resource of 18-27 kW/m is available at discrete locations in the southern regions.

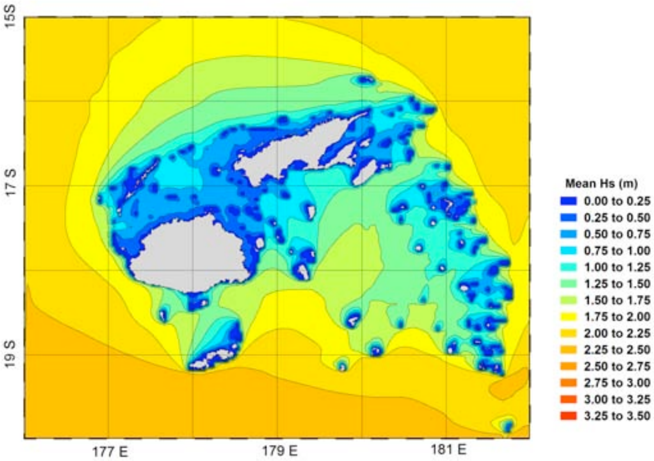

Figure 4. Fiji Islands – Mean Significant Wave Height (H_s)

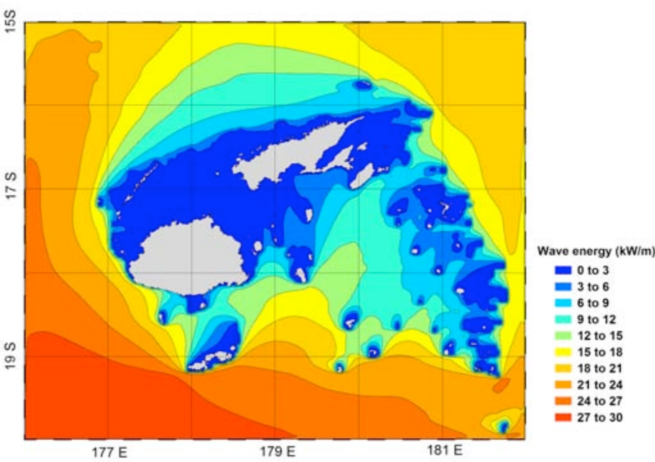

Figure 5. Fiji Islands – Wave Energy Flux (in kW/m)

French Polynesia

The summary maps of mean annual significant wave height, mean annual spectral wave energy flux and mean peak wave period are provided for a section of French Polynesia in Figures 6-8. The French Polynesian islands show a very clear gradient in wave height and wave energy, with the dominant energy source from the Southern Ocean regions. On an annual basis, very little energy is received from the northern sectors. The southern coasts of Tahiti and Moorea – lower centre right of Figure 6 - have the highest exposure, with ~18 - 22 kW/m.

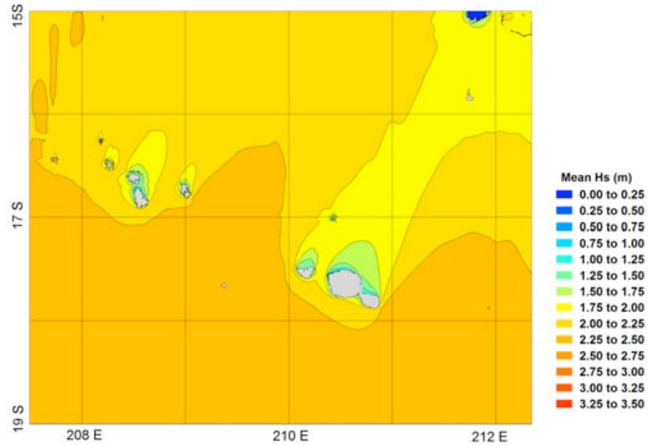

Figure 6. French Polynesia – Mean Significant Wave Height (H_s)

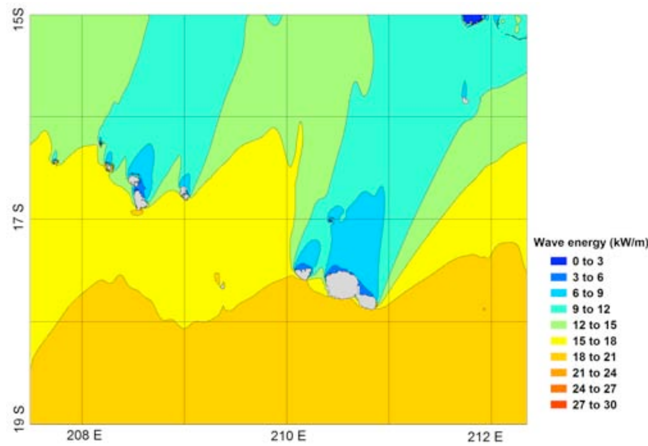

Figure 7. French Polynesia – Wave Energy Flux (in kW/m)

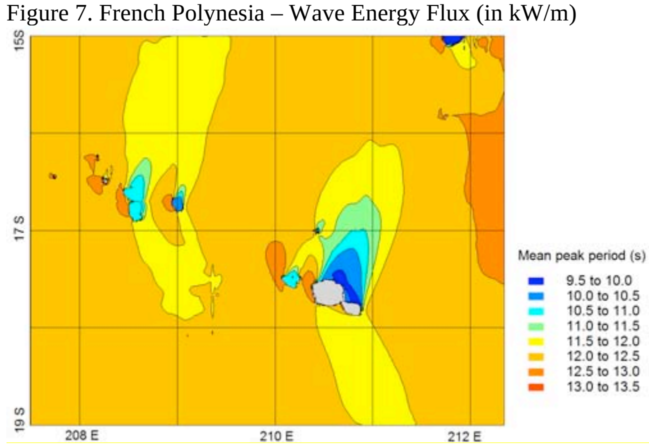

Figure 8. French Polynesia – Mean Peak Wave Period (in s)

Chatham Islands

This island group lies directly adjacent to the Southern Ocean and squarely within an active wave generation zone. The mean annual significant wave height offshore of the group is ~3 m, with the main source of energy coming from the southwest (Figure 9). The mean annual spectral wave energy flux exceeds 100 kW/m at some locations within only 5 km of the southwestern shores (Figure 10). However, closer to the shore in approximately 10 m depth, breaking and attenuation reduces the wave energy to around 30 kW/m.

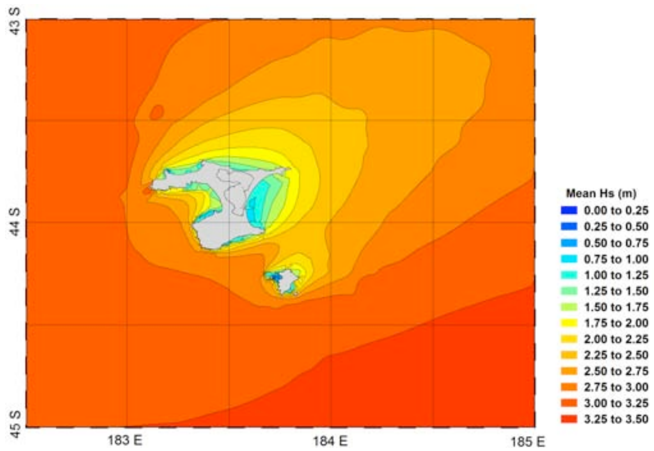

Figure 9. Chatham Islands – Mean Significant Wave Height (H_s)

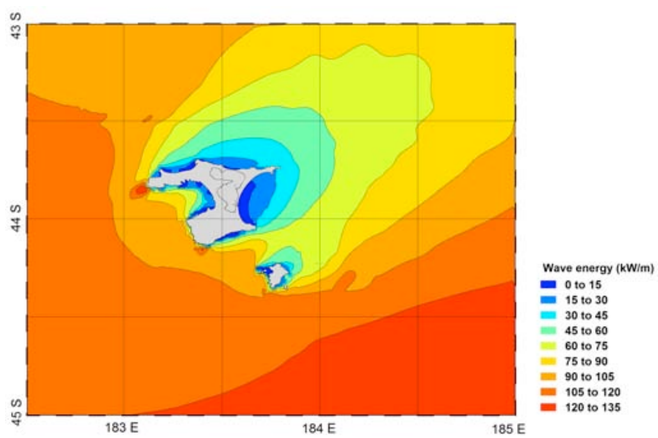

Figure 10. Chatham Islands – Wave Energy Flux (in kW/m)

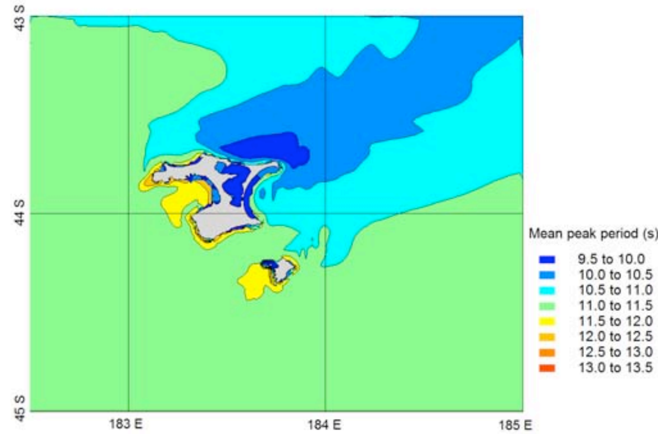

Figure 11. Chatham Islands – Mean Peak Wave Period (in s)

Wave energy flux increases dramatically away from the Equator and energy attenuation by even small islands has a significant effect (>50% attenuation) on the leeward side of islands.

WAVE ENERGY PROJECT CONSIDERATIONS

Introduction

As noted by Hammar *et al.*, 2009 with respect to rural Africa, those energy projects in developing countries, which use new renewable energy technologies, such as wave energy converters, face many of the challenges of conventional energy projects with additional problems:

1. Availability of measured resource data (for validation)
2. Complexity, arising from the range of operational skills required (see Lombard et al., 2009)
3. Lack of trained personnel for operations and maintenance, which could be particularly problematic for new wave energy technologies
4. Travel and transport issues to remote island locations
5. Lack of other infrastructure, including vessels for deployment, operations and maintenance
6. Social acceptance

It is therefore critical to identify appropriate technologies, which can minimize the technical risk in a project. In this paper we focus on wave energy conversion. There are three principal types of devices for harnessing wave energy (Falcão, 2009):

1. Oscillating water column devices
2. Oscillating body devices
3. Overtopping devices

The features of these device types will fit them for specific purposes and locations. For instance some types of OWC devices are built into cliffs and developments require significant permanent modification of the coastal morphology, due to excavation. Such devices may be better suited to installation in existing or new breakwater applications (see Torre-Enciso *et al.*, 2009). These devices have the considerable benefit that the generators are usually directly accessible from onshore. Still other OWC devices are fully floating and would be well suited to offshore deployment.

Overtopping devices can also be located at the shoreline, in breakwaters or as floating structures.

Lastly there is a wide range of floating, submerged or bottom-sitting oscillating body devices. These may extract the heave, surge or pitch energy of incident waves. Designs are widely different and some devices are being deliberately targeted at smaller-scale applications. These devices are generally intended for deployment in arrays, rather than individually.

Autonomy

Wave energy projects should be stand-alone operations, although energy supply may be integrated with other options. Wave energy could potentially supply low-level base-load power but hybrid systems, e.g., wave and wind systems, may be preferable to deal with austral summer conditions.

Size

Projects are likely to be small, sufficient to supply some but not all of an individual island's requirements but with sufficient equipment redundancy to meet base requirements, since there may be long delays in dealing with unplanned maintenance, due to distance and access. Breakwater projects may require few units, since maintenance access may be from onshore but offshore projects may require arrays of units to provide sufficient size and redundancy.

Location

As noted in atoll situations, proposed projects may occupy only a narrow band of coastline on the windward side of islands. The projects are likely to be preferentially located near population centres or existing infrastructure to minimize transmission, distribution and connection costs.

Distance from shore and size of arrays are critical economic factors, since inter-array cables and export cables to the beach will be a significant component of the overall cost of island-based projects. Distance from shore may not be a serious issue in atoll-based projects, since the accessible resource may be located in shallow-to-moderate water depths relatively close to shore.

DISCUSSION

Vlaeminck (2007) highlighted the lack of existing infrastructure and logistical issues but these issues may be more easily resolved than was possible in 2007:

1. Wave energy device developers are beginning to consider deployment issues more seriously than in the past
2. A number of deployment systems are under development
3. Submarine cable supply problems have eased since the economic crisis in 2008

Wave energy converters are not fully commercial yet and the unit cost of electricity from marine energy generation is still relatively high, although it is cheaper than solar PV arrays (Vlaeminck, 2007).

The complexity of energy projects in developing economies makes finance difficult to secure. Such projects have high initial capital cost, which can be offset by long project lives, lower maintenance costs and the absence of any fuel costs.

Addressing the environmental concerns will be critical, particularly for tourism, which is often the principal income source in some Pacific islands. Some tourism operators are increasingly interested in environmental projects (see Lombard *et al.*, 2009).

Wave energy could be used to displace more expensive energy uses, providing some indirect benefits, such as:

1. Pumping systems for SWAC projects
2. Production of freshwater in desalination projects or production of lower quality water to offset natural high quality uses, e.g., irrigation
3. Mineral water production
4. Aquaculture applications, e.g., production of algae for biofuels (see Yosa, 2009).

CONCLUSIONS

Wave energy generation could help to meet the energy and/or electricity needs of many small Pacific Islands. Small-scale wave energy converters deployed in arrays could supply sustainable, clean, available, reliable and emission-free generation. This could be in new applications, where no electricity supply currently exists, or as support to existing generation. Wave energy converters could also be used for pumping water for other end-uses, such as SWAC or desalination.

Since wave resources are variable, it is likely that electricity generation will be used to supplement other forms of generation in larger networked systems. In stand-alone systems, wave energy may provide baseload generation.

Pacific Islands offer some unusual niche applications for wave energy conversion, different from the utility-scale investments being planned in other parts of the world. The sea space available for wave energy projects around Pacific Islands may be smaller than at first glance. Pacific Island governments may need to consider establishing space/resource allocation regimes to ensure optimal use of the limited space available. As wave energy conversion technologies mature, the potential for wave energy to become a viable energy supply option for Pacific Island nations becomes more viable. The potential has already been recognized by a number of device and project developers.

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