Article

Marine Renewable Energy Research and Development in New Zealand in the Pre-Offshore Wind Era

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Over the last two decades there have been a range of efforts to develop a marine renewable energy sector in Aotearoa New Zealand. There have been a modest number of successes along with the inevitable stalled ideas and lost effort. With the rapid growth of offshore wind in New Zealand being foreshadowed, it is a suitable time to record some of these early initiatives. The various projects, researchers and ideas all sought to improve the nation's energy emissions profile before climate mitigation options became limited.

Introduction

Marine renewable energy is the extraction of energy from the ocean. The ocean acts as an enormous collector of energy from the sun and moon. Solar heating injects energy into the ocean both directly and via wind and waves. The energy in the tides is primarily due to the gravitational attraction of the moon on the oceans. Internationally, there have been around five decades of development of various technological approaches to capturing this energy (Lewis et al., 2011; Wilberforce et al., 2019).

The Aotearoa New Zealand energy sector has historically been dominated by strong renewable supply for the electricity component from hydroelectricity and geothermal. The non-electricity side of the market remains underpinned by coal and other fossil fuels to the extent that "modern renewables" make up just over one quarter of total energy supply (including for transport). While the share of renewable energy in New Zealand's total energy consumption was at an all-time high (~87%) in 2022, this peak was only slightly higher than the 1994 share (MBIE, 2022*b*).

Aotearoa New Zealand has committed to reaching net-zero carbon emissions by 2050 and, enroute, to reducing emissions to 50% below 2005 levels by 2030. While the "net-zero" due to carbon sequestration and purchase of offshore credits provides some uncertainty in terms of the true contribution needed to avert climate-driven disasters (Ho, 2023), with only 28% of present energy usage nationally coming from modern renewables there is significant opportunity to reduce the current dependence on fossil fuels.

Marine renewable energy resources are mainly from ocean swell waves (Jin and Greaves, 2021) and tidal currents. However, there are other types of resource including tidal barrage power generation technologies such as one operating in La Rance, France since 1966, as well as techniques that utilise gradients of heat and salt in the ocean as a form of pump. These resources could provide affordable renewable power with different variability than wind and solar, thereby reducing the need for fossil fuel baseload supply.

Internationally, there has been a steady growth in offshore wind capacity over the past two decades. There is a disconnect in that this is not considered by some to be strictly a form of "marine renewable energy". However, there are similarities with wave energy systems in terms of variability of resource, operational challenges and environmental impact. There is some evidence that tidal energy systems are more predictable so can provide improved outcomes over wind or wave energy (Lamy and Azevedo, 2018). However, present economics and risk profile makes offshore wind more favourable. As a consequence, in late 2022 the Ministry of Business Innovation and Employment (MBIE) set the domestic scene for a rapid growth in offshore wind developments by announcing a roadmap for development (MBIE, 2022*a*).

Presently, there is no operational marine energy sector in Aotearoa. That's not to say there have not been achievements (Figure 1 provides a context of local vs. international developments). After 16 years the advocacy group AWATEA (Aotearoa Wave and Tidal Energy Association) is considering ways to re-focus their research community. Thus, this paper is a timely record of the activities, achievements, ideas, developments, challenges and lessons learnt.

AWATEA

The Association was formed in 2006 with a mission statement to "promote, aid and foster a vibrant and viable marine energy sector in New Zealand" and a number of objectives.

(i) Promotion of the marine energy industry in New Zealand, including research, energy generation, marine fabrication and marine services.

(ii) Increased recognition and utilization of marine energy.

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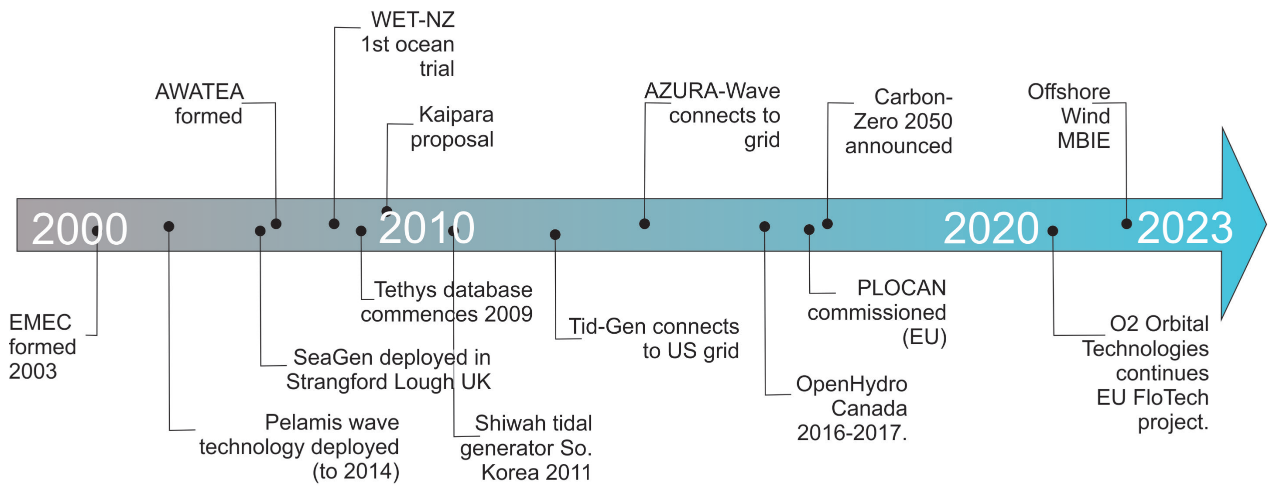

Figure 1: NZ marine renewables timeline in context of selected international developments

(iii) Acting as a centre for advocacy of marine energy, including lobbying, drafting and making submissions to the Government and representing the views of the marine energy industry.

(iv) Assisting in the exchange of information about the marine energy sector and providing and publish statistics and informed commentary on issues affecting the uptake of marine energy in New Zealand.

(v) Being a meeting place for marine energy industry participants.

(vi) Representing the New Zealand marine energy industry national bodies, including government agencies, non-governmental organisations and other industry bodies.

The primary instigator who initially formed the Association was John Huckerby, an engineer with a background in geoscience and who operated a consultancy company "Power Projects" which commissioned several early ocean energy resource assessment studies. Four other chairpersons (Table 1) filled the executive office/chair role (including the author). Their expertise and perspective followed a trajectory from exploration, research, policy, operations and engagement.

The Association ran annual conferences from 2007-2016 with good attendances demonstrating a growing interest in the new concepts of ocean energy (Table 2). The themes evolved from ones around getting a new idea off the ground through to promoting international achievements in marine energy at times when local developments had stalled. The organisation was funded primarily via membership subscriptions with external support including from EECA (Energy Efficiency and Conservation Authority) and Genesis Power. Lack of diversity of those involved in the Association remained an issue through the entire period of activity reflecting the community it served. On a more positive note, the 2023 Offshore Renewable Energy Forum held in New Plymouth had much improved demographics.

Executive/Chair	
John Huckerby	2006 – 2013
Craig Stevens	2013 – 2016
Gareth Gretton	2016 – 2018
Nick Inskip	2018 – 2019
Martin Knoche/Vladislav Sorokin	2019 – 2023

Table 1: AWATEA Executive Office/Chair

Year	**Theme**	**Attendees**
2007	Blue Energy: taking the plunge	90
2008	Blue energy: let's get wet!	75
2009	Blue Energy: making waves	82
2010	Blue energy: New Zealand's place in the world	120
2011	The business of marine energy	65
2012	Blue energy: from international vision to reality	73
2013	Blue energy in the Pacific: powering innovation	58
2014	The business of developing marine energy	unknown
2015	Innovative oceans	39
2016	Global advances	unknown

Table 2: AWATEA Conferences

EECA was a strong supporter of marine energy in the early phase of the Association and was represented on the board level as well as supporting events and products. Most notably, it commissioned a resource assessment (MetOcean Solutions, 2008) that provided a basic guide to the available wave and tidal resources (Figure 2). Another strong supporter of the Association was HERA (Heavy Engineering

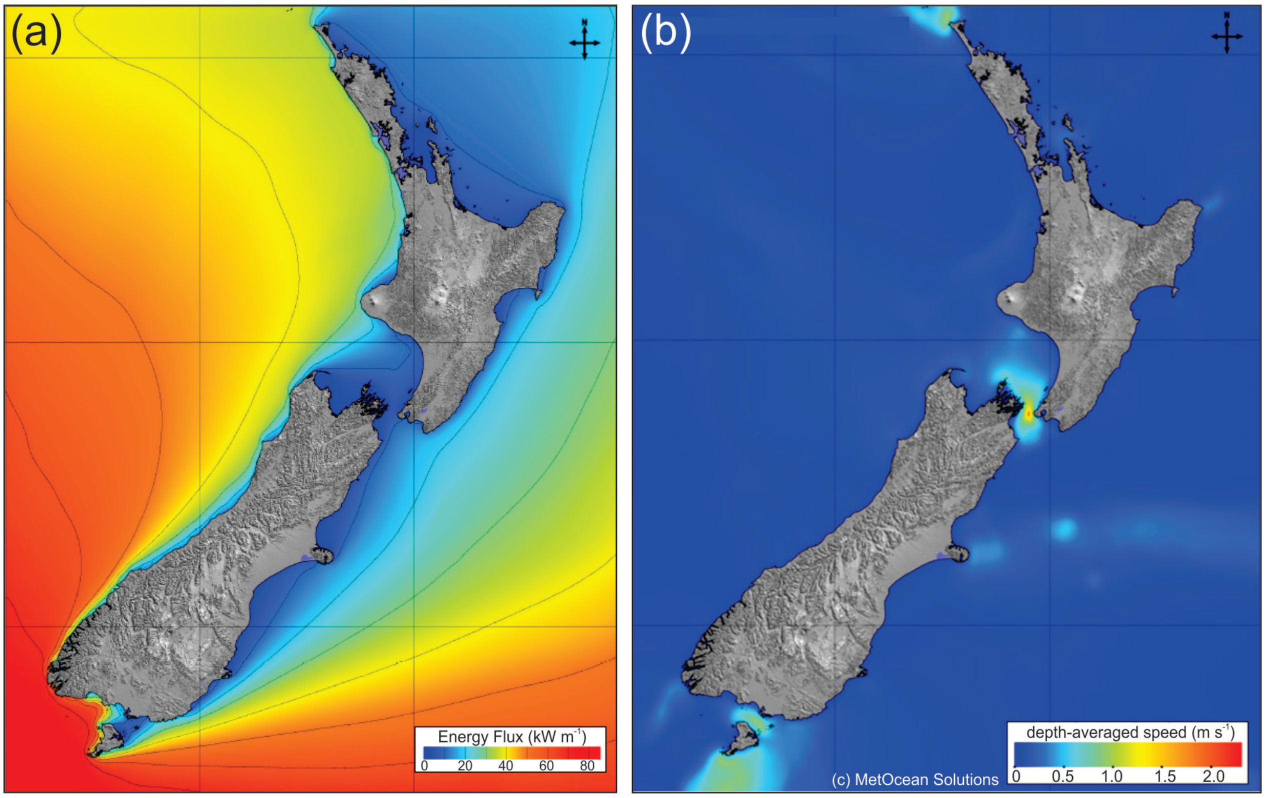

Figure 2: (left) wave energy flux and (right) tidal current from EECA (2008) – with permission from EECA and MetOcean Solutions.

Research Association) including a period with HERA's Nick Inskip in the role of AWATEA chair.

AWATEA took a leading role in developing the Marine Energy Deployment Fund, a government initiative that offered matching funding to prospective developers to accelerate trials of various technologies. This fund was established in 2007 as part of the New Zealand Energy Strategy. Financial support for a project was subject to a number of conditions such as the project receiving a resource consent and providing power to the electricity grid. Several project developers applied but ultimately none were able to fulfil the conditions of the fund.

At its very first meeting, AWATEA had an agenda item on establishing an "Aotearoa Marine Energy Centre". The association carried this discussion through for many years, ultimately developing a business case for a centre in Wellington. This was in conjunction with development of the Aquantis Turbine technology suitable for deepwater deployment (Fleming, 2014). The centre concept struggled to find a balance between a research and education facility and a commercial operation although similar hybrid operations are now relatively commonplace globally. For example, the EMEC (European Marine Energy Centre) facility in Orkney (Norris, 2009) laid a template for such initiatives and was involved as a partner in the AWATEA proposal. Since that time, several successful centres have emerged internationally including PLOCAN in the Canary Islands, Spain (González et al., 2015), WERC in Albany, Western Australia (Gaudin et al., 2018) and FORCE in the Bay of Fundy, Canada (Keefe and Kozak, 2011).

Tidal Currents

New Zealand is not an obvious location for tidal energy as tidal elevation ranges around the coast are not large compared with some places where tidal energy is a focus (Brittany, Bay of Fundy, South Korea (Neill et al., 2018)). Tidal currents are more promising due to interactions with the coast and topography meaning that there are regions with substantial flows. At the same time technology is evolving to extract energy from slower flows. The EECA (2008) report indicated that "there are three locations in New Zealand with an open-coast tidal resource namely Cook Strait, Cape Reinga and the waters surrounding Stewart Island" (Figure 2). This review didn't focus on some of the details relevant to inlets such as Kaipara and Tory Channel. Tidal barrages, conceptually possible for harbours along the west coast of the North Island including Kaipara, Manukau and Hokianga, have never gained support as the likely environmental impacts would be unacceptable.

In 2008 the Foundation for Research, Science and Technology (FRST) of the Ministry for Science and Innovation funded a four-year project led by NIWA (National Institute of Water and Atmospheric Research) to examine Optimising Renewable Energy from Tidal Streams. Notably the Request for Proposals specifically excluded resource assessment. A similar situation seems to have arisen in the land-based wind sector (Poletti and Staffell, 2021). The project focused on the tidal streams in Cook Strait and how aspects of this high energy environment would need to be managed. Despite the lack of directive around resource assessment, basic measurements were made in order to quantify the variability in the system (Stevens et al., 2012). The work identified the strong flows around and just north of Cape Terawhiti (Figure 3) as being energetic but reasonably protected from southerly storms and hence suited to arrays with a capacity of around 40 MW. Flow data are available for this location (Stevens et al., 2010).

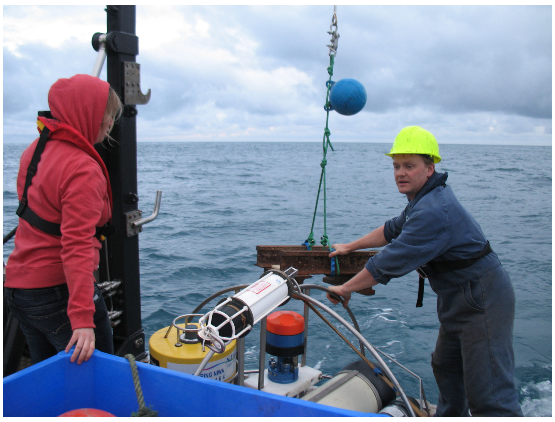

Figure 3: An acoustic Doppler current profiler being deployed off Cape Terawhiti in 2008 (Fiona Elliott left, Craig Stewart right, image T. Divett).

Around the same time, the Marsden Fund supported research led by Ross Vennell (University of Otago) to examine the implications and efficiencies for large arrays of tidal stream turbines. The project examined the degree to which the drag effect from an array of tidal turbines affects the local resource. The study confirmed the hypothesis that this challenge is greater for tidal turbine arrays than wind farms. This approach was extended in a sequence of studies on large interactions and feedbacks were synthesized in a review article (Vennell et al., 2015). It estimated the total resource potential of Cook Strait could be as much as 14 GW, with individual arrays rated up to 90 MW being viable (Vennell et al., 2020).

Associated with both the Vennell tidal project and the FRST Cook Strait study, a PhD project by Tim Divett and part-funded by Todd Energy looked at how an adaptive mesh computational fluid dynamics model could be used to simulate the flow affect due to large farms (Divett et al., 2016). This provided a method to combine the details of flow around individual turbines with the wider tidal flow mechanics. Typically, models represent the drag of an array of turbines as evenly spread over a given area (Plew and Stevens, 2013). The "Sustainable Seas" National Science Challenge funded a further modelling project in 2017 that developed an approach to rapidly assess the potential for large arrays of turbines (Vennell et al., 2020).

As well as the exposed waters of Cook Strait, a number of tidal stream project developers have considered the fast flows of French Pass and the entrance to Tory Channel on the margins of the strait. Despite the presence of ferry activity, the Tory Channel provides a viable setting for an array of turbines (Plew and Stevens, 2013). The developer Energy Pacifica proposed deploying turbines in this location, although this was several years before a suitable technology becoming available, and so the project did not proceed.

Wave energy

As a result of its location in the southwest Pacific, Aotearoa New Zealand is subject to substantial wave energy fluxes – primarily on the southern and western margins (Figure 2). As a result of limited direct data, but sufficiently mature and validated modelling results, there is a reasonable level of confidence in present assessments (Gorman et al., 2003). However, there is uncertainty around possible changes in wave patterns with the evolving climate. A resource assessment commissioned by EECA found "there is a mean annual wave power resource of at least 30 $kW{\cdot}m^{-1}$ available within about 15 km of the shoreline along most of the west coast of New Zealand, except the western Cook Strait region and the North Taranaki Bight" (MetOcean Solutions, 2008). More recently, Bertram et al. (2020) reviewed the state of wave energy projects in Aotearoa in the context of a range of factors beyond energy resources and including type of technology, location, shared usage and social factors. The study produced a spatial assessment of ideal wave energy deployment scenarios.

The Azura Ocean Wave Technology development is the longest coherent project operating nationally and is continuing a successful development pathway. It is the result of process that started with a Request for Proposals from FRST in 2004 that specifically excluded resource assessment and instead requested a focus on technology development. The initial successful proposal (WET-NZ) was a four-year programme of work that merged initially separate proposals from researchers from two Crown Research Institutes, Industrial Research Limited (IRL, now Callaghan Innovation) and NIWA, partnering with Power Projects Limited. As such, WET-NZ proved to be a central pillar for AWATEA. The project, led by Alister Gardiner and Lan Le-Ngoc (IRL), Murray Smith (NIWA) and John Huckerby (Power Projects Limited - PPL), developed a concept around a hinged spar buoy that responds to pitch and heave. Initial laboratory developments at the University of Auckland (Kelly, 2007) were followed by test deployments in Evans Bay (Figure 4) and Moa Point on the Wellington south coast. A plan to install a power take-off to connect to the local energy grid at the Moa Point test site did not eventuate. At the end of four-years, IRL and PPL began another government-supported extension project and ultimately the WET-NZ project passed to EHL, an engineering developer based in New Plymouth. This subsequently evolved into the Azura Wave range of products (Ling et al., 2019) and now includes support from international developers. In 2015, EHL installed the first grid-connected wave resource in Hawaii. This successful project is an indicator of the timescales required where available investment is limited.

Initiatives

Running counter to the success of Azura Ocean Wave Technology, there have been a string of unsuccessful

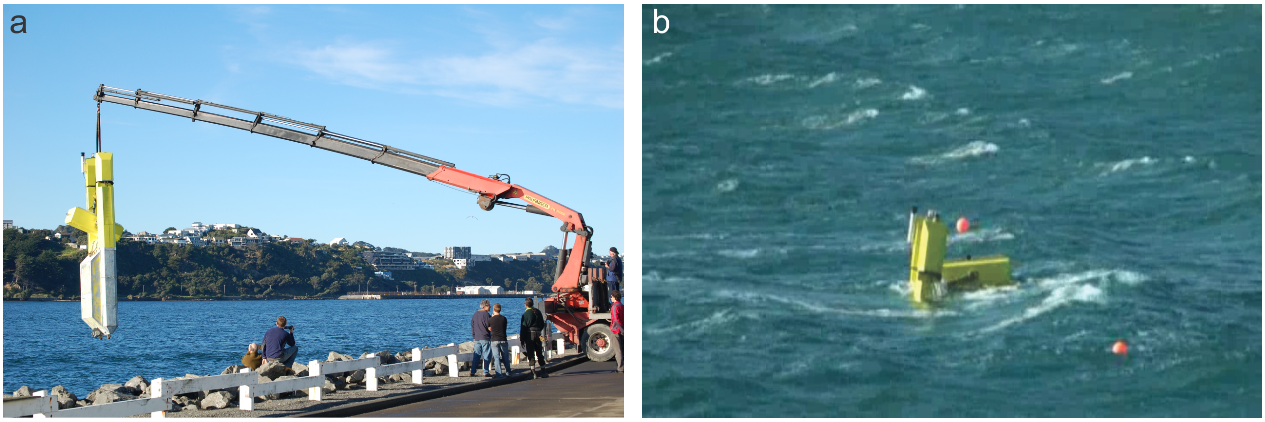

Figure 4: WET-NZ deployment in Evans Bay 2008 (a) deployment (image: N. Robinson), (b) still from operational video recorded from NIWA offices (C. Stewart).

initiatives. One that generated high visibility, and also exposed the need for development that worked with, and for, local communities, was the Crest Energy proposal for a tidal stream generator project at the entrance to Kaipara Harbour, north of Auckland. The development intended to use technology that was not mature. It also proposed as a large-scale array, despite the uncertainties and insufficient positive engagement with Māori groups in the region. This last point was true to the extent that a rāhui (cultural moratorium) was placed on development by a Māori group.

By way of contrast, Māori support was at the heart of arguably the first marine energy study in New Zealand where assessment was made for the potential to support the off-grid community at Waipoua using a range of renewable energy options (Penny, 2005). In addition, the Ruka marine turbine has been in development for over two decades. This run-of-river type device has design elements in common with high profile developments elsewhere such as the Orbital Marine Power Turbine. Despite this, the Māori-led, self-financed initiative has not been able to find funding support in Aotearoa due to a combination of investment conservatism and economics.

A similar scale of outcome to the Kaipara initiative was proposed by Neptune Power in 2008 who promoted a concept for mooring many tidal stream turbines in Cook Strait. Although this project was more about technology development for turbines operating in deep water which remains a legitimate frontier of research, especially in New Zealand where there are not great expanses of tidal streams in shallow water, except in a few locations. The limited shallow-water area increases the chance of shared-use conflict. Specifically, in the case of the Neptune Power initiative, the proposal immediately generated concern from fishers as it would have limited the available area for their activity on an on-going basis. The nature of marine energy development in terms of infrastructure provides additional challenges for marine spatial planning in Aotearoa New Zealand (Peart, 2019). International developments in regard of spatial planning highlight how advanced planning and siting, aspects that differ for tidal, wave and offshore wind, may reduce future conflict (Stelzenmüller et al., 2022).

Over the same period, several smaller developments were proposed to a greater or lesser extent. For example, Chatham Islands Marine Energy Ltd (CHIME) sought to install a shore-based device to capture wave energy in a community largely reliant at the time on diesel generators. The Parnell Baths Marine Energy scheme aimed to deploy three turbines on the Tamaki Drive Bridge in Auckland to harness the tidal flows in and out of Hobson Bay. The electricity generated by the turbines was to be used to pump and re-circulate treated seawater in the nearby Parnell Baths. Also, Tangaroa Energy sought to develop a 20kW wave energy device for the eastern waters of Stewart Island/Rakiura. Such remote communities are well suited to solutions based around a number of energy sources (Majdi Nasab et al., 2021). These were all suitable locations for marine energy systems, but all foundered for reasons ranging from technology readiness through to the inability to find a way to commercial balance with existing energy infrastructure.

The academic research sector maintained a steady level of productivity despite the lack of funding. As well as Vennell's tidal modelling, this includes the development of a hybrid energy-aquaculture technology concept that seeks to form the majority of the mass of a wave device from biological material that potentially has aquaculture value (Hildebrand et al., 2021). In addition, a novel oscillating buoy designed to be integrated into aquaculture farms is being developed at the University of Auckland (Everett et al., 2024).

The reasons for the inability of marine energy projects to gain a significant foothold in New Zealand's mix of renewable energy technologies are many. Certainly, a high degree of conservatism in the energy sector, as well as limited funding, has played a role. But the high share of renewable electricity already present, approaching around 80-90% of electricity, also played a role in making novel approaches to renewable energy generation.

All through the lifecycle of AWATEA, the on-going uncertainty regarding the future of the aluminium smelter at Tiwai Point provided a constant spoiler to development of marine energy proposals. This indirect outcome, combined with systemic conservatism, remains a very disappointing aspect that likely held up growth in the renewables sector. This issue was made all the more frustrating as cheap, renewable, low-impact electricity will always have beneficial applications (Gaston, 2020).

The development of offshore renewable electricity generation typically focuses on large infrastructure. However, there remains a place for small-scale developments. Certainly, the N.Z. Ministry for Foreign Affairs and Trade has sought to enhance the ability of Pacific Island states to secure their own renewable energy resources. For example, Ocean Thermal Energy Conversion (OTEC) is one approach that requires a large vertical temperature gradient as occurs in some areas of the Pacific Ocean (Petterson and Kim, 2020). This approach, however, is not suited to the cool and well-mixed waters around Aotearoa.

From around 2019, there appeared to be renewed support in Aotearoa for marine renewables, but in the form of offshore wind. This was due to the rapid expansion of the offshore wind sector in Europe as well as more recent advances in development in Australia. In 2022 it was announced that a zone of operations in southern Taranaki was being assessed for development for offshore wind turbines that would result in a significant shift in perspective of the value and use of the coastal ocean. Unlike some other uses of the marine space, the underpinning need for mitigation efforts in terms of greenhouse gas emissions from fossil fuel combustion is fundamentally required.

Strategically, the Aotearoa New Zealand research system has been in a state of uncertainty for a number of years with the cancelled Te Ara Paerangi Future Pathways process (New Zealand Association of Scientists, 2022), an ignored National Research Priorities report, and most recently, the Science System Advisory Group initiative looking at ways to prioritise what science should get done and how. One can contemplate where the growing effort in offshore renewables involving billions of dollars of investment would be if there had been a marine energy centre set up in 2014. There could be perhaps four or five active researchers and academics and maybe 10 to 20 PhD and MSc graduates in this area. While these numbers are small, these people would have entered various organisations, taking with them awareness of technologies and a likely propensity to inject marine energy pathways for emissions mitigation into related discussions. In addition, there could have been at least one installed cable and trials of several devices with associated partnerships and services. Instead, with offshore wind development facing effectively a blank canvas, the seascape is dominated by large international developers. In the case of marine renewable energy, an opportunity to have home-grown impact and benefit has been lost.

Environmental Impacts

With New Zealand's commitment to supporting high environmental standards, the *Tethys* (Copping et al., 2015) database proved timely. It is a growing synthesis of projects and activities from around the world that relate to *Tethys* goal to "progress industry in an environmentally responsible manner". It includes a searchable database including a map viewer and a set of tools for things like risk retirement, risk management, regulatory frameworks and a wind energy monitoring and mitigation tool. Copping et al. (2015) reviewed potential environmental impacts of marine renewable activity, however, these are very site and region specific, as is the regulatory seascape (Hale et al., 2024). With the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012 covering the ocean beyond 12 nautical miles offshore and the Resource Management Act (currently under review) covering the inner 12 nautical miles. Primary aspects that control the narrative include marine mammals, habitat, seabirds as well as multiple users of marine space. In addition, with large installations some other factors also become relevant such as enhanced mixing and sediment in the water column and downstream effects on biological productivity and ecosystem function (Dorrell et al., 2022).

Future Opportunities

Overarching the last two decades of efforts to develop marine renewable energy concepts against the headwinds of contemporary policy and strategy (Figure 1) is the point that we now, more than ever, need extra renewable capacity and resilience - as well as cost effective structures that make this accessible to consumers in a way that also supports greenhouse gas emissions reductions.

A theme championed by Alex Malahoff (Chief Executive at Geological and Nuclear Sciences) during his time on the AWATEA board was the lack of marine engineering studies in the NZ University sector (Stevens and O'Callaghan, 2015). This limits domestic development of ideas and capacity and reduces the knowledge transfer into other sectors, (i.e. not everyone who trains in one topic ends up in a career doing exactly that thing). It was concluded that growth in the sector required a critical mass of teaching and research activities rather than relying on just a couple of isolated academics. With homegrown development of capability and capacity would come wider engagement with the oceans surrounding Aotearoa. Such a commitment to capacity building would also build improved connections with community and the ability to effectively address hurdles related to resource management. In addition, the transition away from fossil fuels has brought the need to support climate-impacted communities. The marine renewable energy development and testing centre concept would work well in this regard. Consideration of the impact of such centres in places like Strangford and the Canary Islands provides evidence for such initiatives in Northland or Taranaki. With the import of offshore wind technology over the next decade there will be opportunities to evolve our perspective on ocean energy in order to diversify the security of supply vital for a resilient economy and society with the growing climate challenges. At the same time there is the potential for a greater engagement with the marine environment that envelopes and supports Aotearoa.

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References

Bertram, D., Tarighaleslami, A., Walmsley, M., Atkins, M. and Glasgow, G. (2020), 'A systematic approach for selecting suitable wave energy converters for potential wave energy farm sites', *Renewable and Sustainable Energy Reviews* **132**, 110011.
https://doi.org/10.1016/j.rser.2020.110011

Copping, A., Hanna, L., Van Cleve, B., Blake, K. and Anderson, R. M. (2015), 'Environmental risk evaluation system—an approach to ranking risk of ocean energy development on coastal and estuarine environments', *Estuaries and coasts* **38**, 287–302.
https://doi.org/10.1007/s12237-014-9816-3

Divett, T., Vennell, R. and Stevens, C. (2016), 'Channel-scale optimisation and tuning of large tidal turbine arrays using LES with adaptive mesh', *Renewable energy* **86**, 1394–1405.
https://doi.org/10.1016/j.renene.2015.09.048

Dorrell, R. M., Lloyd, C. J., Lincoln, B. J., Rippeth, T. P., Taylor, J. R., Caulfield, C.-c. P., Sharples, J., Polton, J. A., Scannell, B. D., Greaves, D. M. et al. (2022), 'Anthropogenic mixing in seasonally stratified shelf seas by offshore wind farm infrastructure', *Frontiers in Marine Science* **9**, 830927.
https://doi.org/10.3389/fmars.2022.830927

Everett, J., Sorokin, V., Whittaker, C. and Aw, K. (2024), 'Numerical and experimental analysis of the power output performance of a point absorber WEC for nearshore wave conditions', *Ocean Engineering* **309**, 118381.
https://doi.org/10.1016/j.oceaneng.2024.118381

Fleming, A. (2014), Aquantis Ocean Current Turbine Development: Innovative Power Generation Technology, Technical report, Dehlsen Associates, LLC, Santa Barbara, CA and U.S. Department of Energy, Washington, DC.

Gaston, N. (2020), 'Five Alternatives to Aluminium at Tiwai'.
https://www.macdiarmid.ac.nz/news-and-events/news/in-the-media/five-alternatives-to-aluminium-at-tiwai/

Gaudin, C., Lowe, R., Draper, S., Hansen, J., Wolgamot, H., O'Loughlin, C., Fievez, J., Taylor, D. and Pichard, A. (2018), A Wave Energy Research Centre in Albany, Australia, *in* '4th Asian Wave and Tidal Energy Conference', p. 371.

González, J., Monagas, V., Remírez, X., Luque, A., Hernández, J. and Llinás, O. (2015), PLOCAN. An offshore test site for ocean energy converters, *in* 'OCEANS 2015 - Genova', pp. 1–4.
https://doi.org/10.1109/OCEANS-Genova.2015.7271245

Gorman, R. M., Bryan, K. R. and Laing, A. K. (2003), 'Wave hindcast for the New Zealand region: nearshore validation and coastal wave climate', *New Zealand Journal of Marine and Freshwater Research* **37**(3), 567–588.
https://doi.org/10.1080/00288330.2003.9517190

Hale, R., Thompson, D., Brough, T., Kregting, L., Hayden, M., Parsons, D., Nodder, S. D., Beaumont, J., Anderson, O. and Stevens, C. (2024), 'Environmental implications of future offshore renewable energy development in Aotearoa New Zealand', *Journal of the Royal Society of New Zealand* . in review.

Hildebrand, T., Fischer, C., Relano, V., Gorman, R. and Stevens, C. (2021), 'Cost-Benefit Analysis of a Hybrid Biophysical Approach to Wave Energy Extraction: Bio-Oscillator', *Frontiers in Marine Science* **8**, 628148.
https://doi.org/10.3389/fmars.2021.628148

Ho, D. T. (2023), 'Carbon dioxide removal is not a current climate solution — we need to change the narrative. World View.', *Nature* **616**, 9.
https://doi.org/10.1038/d41586-023-00953-x

Jin, S. and Greaves, D. (2021), 'Wave energy in the UK: Status review and future perspectives', *Renewable and Sustainable Energy Reviews* **143**, 110932.
https://doi.org/10.1016/j.rser.2021.110932

Keefe, D. J. and Kozak, J. (2011), Tidal Energy in Nova Scotia, Canada: The Fundy Ocean Research Center for Energy (FORCE) Perspective, *in* 'International Conference on Offshore Mechanics and Arctic Engineering', Vol. 44373, pp. 371–376.

Kelly, S. (2007), Hydrodynamic Optimisation of point wave-energy converter using laboratory experiments, Msc, University of Auckland.

Lamy, J. V. and Azevedo, I. L. (2018), 'Do tidal stream energy projects offer more value than offshore wind farms? A case study in the United Kingdom', *Energy Policy* **113**, 28–40.
https://doi.org/10.1016/j.enpol.2017.10.030

Lewis, A., Estefen, S., Huckerby, J., Musial, W., Pontes, T. and Torres-Martinez, J. (2011), *Ocean Energy*, IPCC special report on renewable energy sources and climate change mitigation, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ling, B. A., Bosma, B. and Brekken, T. K. (2019), 'Experimental validation of model predictive control applied to the azura wave energy converter', *IEEE Transactions on Sustainable Energy* **11**(4), 2284–2293.
https://doi.org/10.1109/TSTE.2019.2953868

Majdi Nasab, N., Kilby, J. and Bakhtiaryfard, L. (2021), ‘Case study of a hybrid wind and tidal turbines system with a microgrid for power supply to a remote off-grid community in New Zealand’, *Energies* **14**(12), 3636. https://doi.org/10.3390/en14123636

MBIE (2022*a*), Enabling Investment in Offshore Renewable Energy: Discussion Document, Technical report, Ministry of Business, Innovation and Employment. https://www.mbie.govt.nz/have-your-say/enabling-investment-in-offshore-renewable-energy/

MBIE (2022*b*), Energy in New Zealand 2022, Technical report, Ministry of Business, Innovation and Employment. https://www.mbie.govt.nz/have-your-say/enabling-investment-in-offshore-renewable-energy/

MetOcean Solutions (2008), Marine energy resources: Ocean wave and tidal current resources in New Zealand, Technical report, Energy Efficiency and Conservation Authority.

Neill, S. P., Angeloudis, A., Robins, P. E., Walkington, I., Ward, S. L., Masters, I., Lewis, M. J., Piano, M., Avdis, A., Piggott, M. D. et al. (2018), ‘Tidal range energy resource and optimization–Past perspectives and future challenges’, *Renewable energy* **127**, 763–778. https://doi.org/10.1016/j.renene.2018.05.007

New Zealand Association of Scientists (2022), ‘Te Ara Paerangi Future Pathways submission’, *New Zealand Science Review* **78**(1-4), 6–11. https://doi.org/10.26686/nzsr.vi.8068

Norris, J. (2009), European Marine Energy Centre: the development of a targeted environmental monitoring strategy and the streamlining of marine renewables consents in Scotland, *in* ‘Proceedings of the 8th European Wave and Tidal Energy Conference, Uppsala, Sweden’, pp. 1057–64.

Peart, R. (2019), ‘Sea Change Tai Timu Tai Pari: addressing catchment and marine issues in an integrated marine spatial planning process’, *Aquatic Conservation: Marine and Freshwater Ecosystems* **29**(9), 1561–1573. https://doi.org/10.1002/aqc.3156

Penny, G. (2005), ‘Energy in rural Māori communities’, *Water & Atmosphere* **13(4)**, 18–19.

Petterson, M. G. and Kim, H. J. (2020), Can Ocean Thermal energy conversion and seawater utilisation assist small island developing states? A Case study of Kiribati, Pacific Islands Region, *in* ‘Ocean Thermal Energy Conversion (OTEC)-Past, Present, and Progress’, IntechOpen, pp. 3–20. https://doi.org/10.5772/intechopen.91945

Plew, D. R. and Stevens, C. L. (2013), ‘Numerical modelling of the effect of turbines on currents in a tidal channel–Tory Channel, New Zealand’, *Renewable Energy* **57**, 269–282. https://doi.org/10.1016/j.renene.2013.02.001

Poletti, S. and Staffell, I. (2021), ‘Understanding New Zealand’s wind resources as a route to 100% renewable electricity’, *Renewable Energy* **170**, 449–461. https://doi.org/10.1016/j.renene.2021.01.053

Stelzenmüller, V., Letschert, J., Gimpel, A., Kraan, C., Probst, W., Degraer, S. and Döring, R. (2022), ‘From plate to plug: the impact of offshore renewables on European fisheries and the role of marine spatial planning’, *Renewable and Sustainable Energy Reviews* **158**, 112108. https://doi.org/10.1016/j.rser.2022.112108

Stevens, C. and O’Callaghan, J. (2015), ‘When the holiday is over: being clever in New Zealand’s marine domain’, *Journal of the Royal Society of New Zealand* **45**(2), 89–94. https://doi.org/10.1080/03036758.2015.1014377

Stevens, C., Smith, M., Grant, B., Stewart, C. and Divett, T. (2012), ‘Tidal energy resource complexity in a large strait: The Karori Rip, Cook Strait’, *Continental Shelf Research* **33**, 100–109. https://doi.org/10.1016/j.csr.2011.11.012

Stevens, C., Stewart, C. and Grant, B. (2010), ‘Cape Terawhiti ADCP Dataset’, *SEANOE* **33**, 100–109. https://doi.org/10.17882/76439

Vennell, R., Funke, S. W., Draper, S., Stevens, C. and Divett, T. (2015), ‘Designing large arrays of tidal turbines: A synthesis and review’, *Renewable and Sustainable Energy Reviews* **41**, 454–472. https://doi.org/10.1016/j.rser.2014.08.022

Vennell, R., Major, R., Zyngfogel, R., Beamsley, B., Smeaton, M., Scheel, M. and Unwin, H. (2020), ‘Rapid initial assessment of the number of turbines required for large-scale power generation by tidal currents’, *Renewable Energy* **162**, 1890–1905. https://doi.org/10.1016/j.renene.2020.09.101

Wilberforce, T., El Hassan, Z., Durrant, A., Thompson, J., Soudan, B. and Olabi, A. G. (2019), ‘Overview of ocean power technology’, *Energy* **175**, 165–181. https://doi.org/10.1016/j.energy.2019.03.068